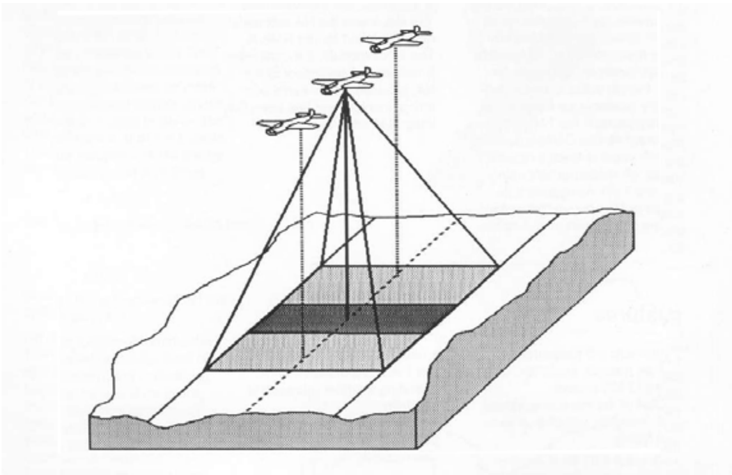
DEUTSCHE GEODÄTISCHE KOMMISSION
bei der Bayerischen Akademie der Wissenschaften

Reihe E Geschichte und Entwicklung der Geodäsie Heft Nr. 30

Dierk Hobbie

The development of photogrammetric instruments and methods at Carl Zeiss in Oberkochen



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1. Introduction

With the formation of the "Deutsche Gesellschaft für Photogrammetrie" in 1909 and of the International Society for Photogrammetry in 1910 both societies, like photogrammetric technology itself, are celebrating a centennial anniversary. All is tightly linked with the development of photogrammetric methods and instruments at CARL ZEISS in Jena, especially because the decision for the foundation of the German Society for Photogrammetry was made during a first "Ferienkurs" (holiday course) at ZEISS in Jena. Although the first metric photographs were taken and evaluated around 1850, formal photogrammetric procedures were introduced by ZEISS at the beginning of the 20th century and since 1909 have been explained and discussed with the user community at the Ferienkurse, later called "Photogrammetric Weeks" (JUNG 1960).

After World War II not only Germany but also CARL ZEISS was divided into two separate entities. As a result of the Yalta Treaty in February 1945 the Americans agreed to deliver the area of Thuringia, where Jena is located, to the Russians in exchange for a sector of Berlin. Before handing over in June they took the brain of ZEISS (the top scientists and the most important documents) to the American zone of occupation in Baden-Württemberg. The Russians, on the other hand, from October 1945 onwards transported the "second level" and most of the production equipment to Russia (HERRMANN 1989). It was not until 1948/49 that the photogrammetric people at ZEISS in the west (later as CARL ZEISS, OBERKOCHEN) and in the east (as nationally owned VEB CARL ZEISS JENA) could resume their work. After the German reunification in 1989 the two ZEISS-groups were reintegrated (SCHREINER et al. 2006). For economic reasons the photogrammetric business units in Jena and Oberkochen were concentrated in Oberkochen (and the geodetic units in Jena) in December 1995, and in April 1999 the photogrammetric business was brought into Z/I IMAGING GMBH, a separate company and a joint venture with INTERGRAPH, Huntsville, AL/USA. Effective September 30, 2002 CARL ZEISS sold its 40%-share to INTERGRAPH and thus ended its engagement in photogrammetry, with the exception of continuing the supply of sophisticated components (e. g. aerial camera lenses) and calibration services.

The pre-war development of photogrammetric equipment at ZEISS in Jena is well documented in (SCHUMANN 1986). SCHÖLER described the respective post-war activities in Jena in publication No. 27 of the DGK E-series (SCHÖLER 2006). In the following the development of photogrammetric methods and instruments at CARL ZEISS in Oberkochen is described.

2. Pre-war history

The first steps into photogrammetry - as well as the foundation of the CARL ZEISS company - date back to around 1850. In France AIMÉ LAUSSEDAT in 1851 developed the stereo-measurement within topographic photographs and called it "Iconométrie", later in 1859 "Métrophotographie". In Germany ALBRECHT MEYDENBAUER independently planned in 1858 to take photographs of churches for photogrammetric use (SCHWIDEFSKY 1963). And also in 1858, the first photographs from a balloon were taken by GASPARD-FELIX TOURNACHON called NADAR, a photographer from Paris, which was the beginning of aerial photography.

The mechanician CARL FRIEDRICH ZEISS (1816-1888) after a thorough technical and scientific education established his own workshop in the spring of 1846, and during the following decades he concentrated on manufacturing and ongoing improvement of microscopes with increasing success (HELLMUTH et al. 1996). It was not before 1888, that he entered into new business segments: PAUL RUDOLF started developing photo lenses for cameras, from which a few later became important for photogrammetry. And from 1890 CARL PULFRICH (1858-1927) headed a new department for optical measurement equipment, where refractors and comparators were developed.

Stimulated by field equipment (binoculars) for stereoscopic viewing and distance measurement PULFRICH in 1901 developed the stereocomparator for the measurement of coordinates and parallaxes in photographs. This resulted in the first photogrammetric instrument from CARL ZEISS. In addition to the continuous improvement of the stereocomparator and the development of related camera equipment such as phototheodolites and fixed-base stereocameras, more fundamental photogrammetric instruments were created. At the 1st Ferienkurs in 1909 the STEREOAUTOGRAPH as proposed by EDUARD VON OREL was introduced as a first stereoplotter and may have stimulated the enthusiasm for founding the German Photogrammetric Society. This Autograph for terrestrial applications was further improved in the following years till the Klein-Autograph C/3 in 1945. For stereoplotting with inclined aerial photographs the development started in 1918 on STEREOPLANIGRAPH C/1 after the ideas of PULFRICH and WALTER BAUERSFELD

(1879-1959), which followed the concept of the phototheodolite. The C/1 was introduced into the market in 1921, and improved over the years until 1937 when it was delivered as model C/6.

From 1911 with the appearance of aeroplanes and airships ZEISS developed several aerial cameras and balloon cameras, resulting in 1922 with the metric "Reihenbildmesskammer" RMK C/1. Many further camera models and accessories including a statoscope, navigation devices and the first wide angle lens designed by ROBERT RICHTER (1886-1956) in 1933, formed a complete family of aerial cameras. The RMK P was a state of the art camera at the beginning of World War II.

Another line of instruments was rectifiers. After the creation of a transforming printer for photogrammetric images in 1921 the development of the autofocussing rectifier C/2 started in 1924. In 1939 the model C/8 was renamed the SEG IV. Other pre-war developments were pocket and mirror stereoscopes (available since 1902), stereometer for plotting and the aerial sketchmaster (both since 1934), the famous MULTIPLEX aeroprojector (1933) and a radial slot cutter for mechanical aerial triangulation. All of these instruments were to become important again during the restart in Oberkochen.

In 1930 OTTO VON GRUBER (1884-1942) became head of the "Bildmessabteilung". This photogrammetry department had been formally established after PULFRICHS death in 1927. VON GRUBER had joined ZEISS in 1922, after 3 years as a consultant, for the development of surveying instruments. He had also stayed in close connection with ZEISS during his professorship in geodesy at Stuttgart University 1926 - 1930.

In 1931 CARL ZEISS became a 50%-shareholder of the newly founded ZEISS-AEROTOPOGRAPH GmbH (ZA) in Jena, which arose from the AEROTOPOGRAPH GmbH in Dresden founded 5 years earlier. This former competitor, which had sold photogrammetric instruments of the HEYDE company developed by REINHARD HUGERSHOFF, had been managed by EDUARD OSKAR MESSTER (1893-1982), who now became responsible for the new ZA as a sales and service unit, where he gained an important influence on the product policy of the Bildmessabteilung at CARL ZEISS (WALTER 2000). The manufacturing of the instruments remained in the ZEISS factory. After the early death of OTTO VON GRUBER IN 1942 KURT SCHWIDEFSKY (1905-1986) became the head of photogrammetric R & D. One of the scientists since 1932 was WALTER BRUCKLACHER (1910-1995).

With the evacuation by the Americans at the end of June 1945 a total of 81 top level employees from ZEISS and 3 from ZEISS-AEROTOPOGRAPH left Jena together with their families, among them were BAUERSFELD, MESSTER, SCHWIDEWSFKY, RICHTER and BRUCKLACHER, the latter just having returned from military service.

3. Restart in Oberkochen

Several potential factory sites in Munich had been considered for housing the deported ZEISS brain (companies DECKEL, STEINBEIL and LINHOFF) and in Stuttgart (the CONTESSA-factory of ZEISS IKON) but these were all too heavily damaged. Therefore the army trucks with the ZEISS families were directed to Heidenheim an der Brenz, a town between Munich and Stuttgart, where they arrived during the night of June the 24th. After staying a few nights in an empty police school the families were distributed to private rooms in the neighbouring villages. MESSTER and BRUCKLACHER of ZEISS-AEROTOPO-GRAPH left Jena at the last minute on June 30th for Munich, where MESSTER had relatives.

After having checked several empty factories in the region (in Esslingen, Schwäbisch Gmünd and Immenstadt), the heads of the "emigrants" decided on an empty and undestroyed factory of the LEITZ company in nearby Oberkochen, where during the war the landing gear of MESSERSCHMIDT-fighters had been produced. The deciding factors for this location were the support offered by the local commune and county, the similarity of the wooded and hilly landscape to that of the Jena region, and there was no need for a further relocation. It took 4 months to get a first work permit from the allied occupation: the license for an "Optical Repair Shop". With machine tools borrowed from the PILTZ company, already a supplier of ZEISS in Jena, the first income was generated by the servicing and repair of manifold optical instruments. On June 14th, 1946 the US military government advised the Ministry of Economics for Württemberg and Baden to assign to the "Firma CARL ZEISS, Werk Oberkochen" the clearance for production.

Fig. 3.1: Oberkochen in 1950

With establishment of the articles of incorporation on October 4th and with the registration on October 30th, 1946, the "OPTON Optische Werke Oberkochen GmbH" was founded and renamed "ZEISS-OPTON" starting from October 31st, 1947. The majority shareholder was the CARL ZEISS STIFTUNG in Heidenheim. Now the future was open to begin with the reconstruction of the first instruments, based on the few documents brought from Jena. In July 1947 the first stereomicroscope was completed. The restart of the more sensitive photogrammetric production could not begin until 1949.

By 1950 the view of Oberkochen had changed a lot with new homes for the ZEISS employees, who had previously lived in private rooms or barracks, and by the building of new factory buildings on ZEISS grounds (Fig. 3.1).

4. Reconstruction

Based on his Liechtenstein passport in 1946 EDUARD OSKAR MESSTER in Munich was allowed to travel to foreign countries, on behalf of ZEISS-AEROTOPOGRAPH. As the only German participant at the International Congress for Photogrammetry 1948 in Scheveningen (BARING 1963) he was able to re-establish the old connections with photogrammetric friends all over the world. After returning from this event he decided to restart the production of photogrammetric instruments, and in the winter of 1948/49 he placed an order with his colleagues in Oberkochen for the "reconstruction and production of the STEREOPLANIGRAPH using the newest technology" (WEIMANN 1952). With the ongoing development KURT SCHWIDEFSKY became "Technischer Leiter Bildmess" (Head of photogrammetric R & D) in Oberkochen in June 1951 a position he held until his appointment as professor at the University in Karlsruhe in 1960. Before 1951 he had been scientific director at the ZEISS owned company HENSOLDT AG in Wetzlar since 1947, where he had already begun pre-development of a new rectifier.

ZEISS-AEROTOPOGRAPH, with staff in Munich and in a barrack near the ZEISS factory in Oberkochen, started with the reconstruction of the non-sophisticated instruments, which were then manufactured by smaller workshops in Munich, Wetzlar and Berlin. These were several types of stereoscopes and radial slot cutters, as well as laboratory equipment for developing and drying of aerial film and for contact printing.

4.1 Stereoscopes and aerial sketchmaster

The TS 4 pocket stereoscope for an image format of up to 6 x 13 cm and with test-figures for stereoscopic viewing became the first and, with 80 000 units sold, the top-selling product from 1950. A similar bridge stereoscope was a flop and was only offered between 1959 and 1971 (Bild 4.1). The OV mirror stereoscope, introduced in 1953 as the first stereoscope for full-size contact prints of aerial images, and the plotting stereometer which was similar to the Jena STEREO-PANTOMETER from 1939 (Bild 4.2) were not very successful. The N 2 mirror stereoscope introduced in 1965 became a great success and was produced like the TS 4 in huge numbers and was often delivered with binoculars for magnification and with the SMM stereomicrometer for parallax measurement (Bild 4.3).

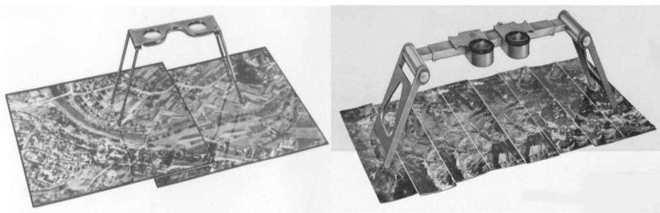


Fig. 4.1: TS 4 pocket stereoscope and bridge stereoscope

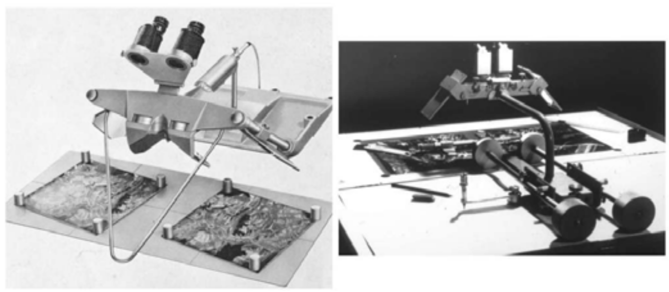


Fig. 4.2: OV mirror stereoscope and plotting stereometer

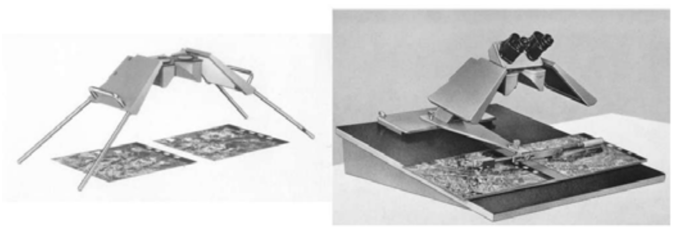


Fig. 4.3: N 2 mirror stereoscope, at right with 3x binocular viewing, SMM stereomicrometer and inclined desk

All these stereoscopes were manufactured by small companies, and the successful models were sold worldwide and nearly unchanged for almost 50 years. Several unique features of these stereoscopes were protected by patents and registered designs (ZEISS-AEROTOPOGRAPH 1954 & SONNBERGER 1954e).

The LUZ aero-sketchmaster for monocular viewing and optical superimposition of an aerial photograph with a map to be revised was introduced in 1953 and was also very popular. About 3 000 were sold before production ceased in the late 1980's (Bild 4.4).

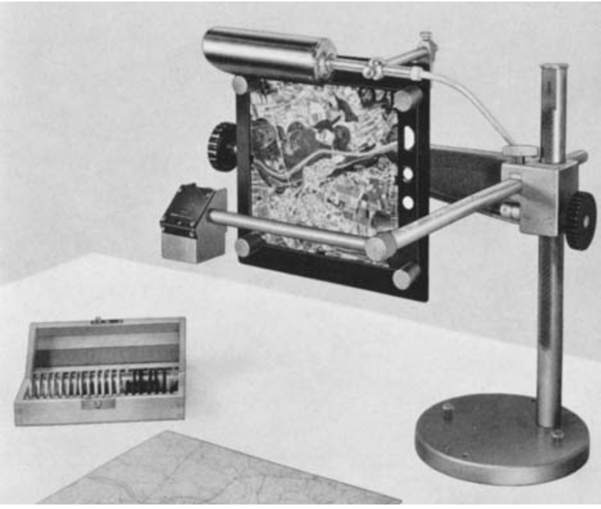


Fig. 4.4: LUZ aero-sketchmaster (1953)

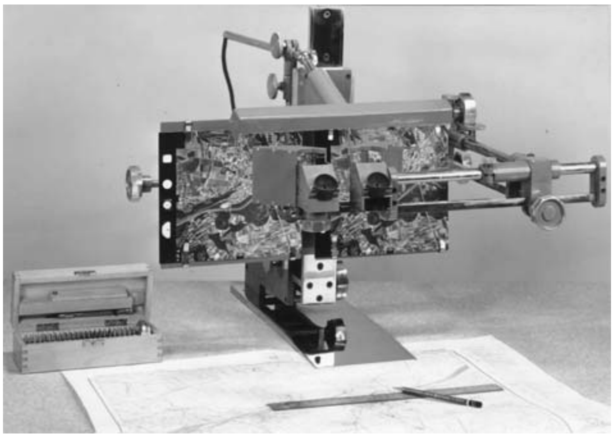


Fig. 4.5: Stereo-LUZ (prototype 1967)

In 1967 the ZEISS Oberkochen photogrammetrists developed a stereo-version of the aerial sketchmaster (Fig. 4.5), but this prototype did not lead to a series production.

4.2 Radial slot cutters

In 1951 the RS I RADIALSECATOR (Fig. 4.6) for analogue triangulation was introduced. It was a remake of the 1945 bi-level slot cutter C/3 from Jena. In this context related patent applications of that time were renewed at the Deutsches Patentamt in 1954 (SCHWIDEFSKY 1954a & 1954b). The aerial contact prints to be triangulated were put into the upper level and the lower level was fed with a templet to be punched, so that the contact prints were not damaged. The scale of the templets could vary from 0.5x to 1.5x (image format 23 cm x 23 cm) or up to 2x (18 cm x 18 cm). For punching the slots direct into the contact prints, the RADIALSECATOR II (Fig. 4.7) was designed in 1955, similar to the Jena slot cutter C/1 of 1941. By the 1970s about 125 and 230 units respectively were sold.

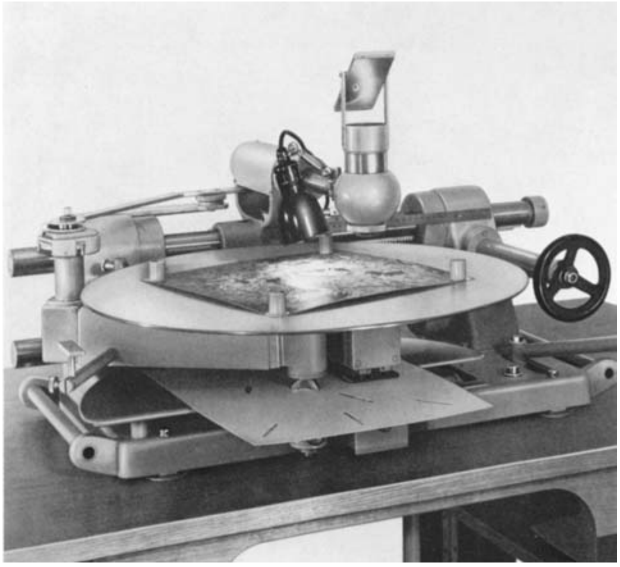


Fig. 4.6: RS I RADIALSECATOR (1951)

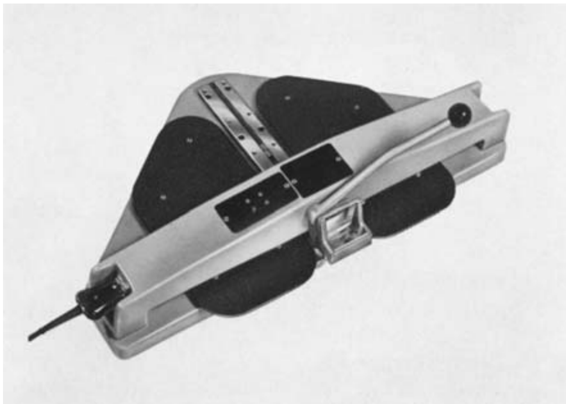


Fig. 4.7: RS II RADIALSECATOR

4.3 Laboratory equipment

Equipment for developing and drying aerial films and a contact printer had already been offered in 1937 by ZEISS-AEROTOPOGRAPH in Jena. Therefore these devices were also included in the post-war catalogue and were manufactured by small subcontractors: from 1953 the redesigned FE 120 film developing outfit (Fig. 4.8), which was protected by three registered designs (ZEISS-AERO-TOPOGRAPH 1953a, 1953b & 1953c), and from 1958 the TG 24 film dryer (Fig. 4.9). By the late 1980s about 750 and 550 units respectively were produced. Although colour films and powerful photographic laboratories began to dominate the workflow of the photo flights, the FE 120 and TG 24 remained valuable equipment because they could be used right after touch down near the air field and in remote areas, thus allowing an immediate check on the quality of the photographs taken.

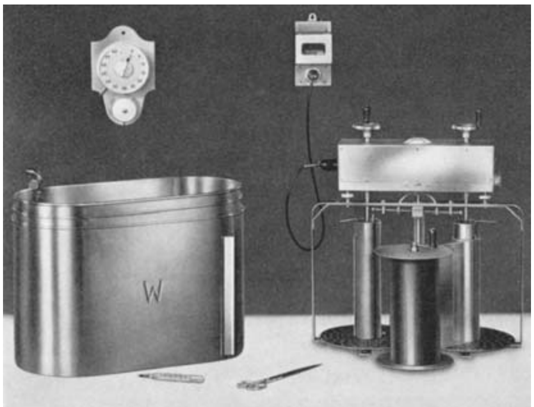


Fig. 4.8: FE 120 film developing outfit

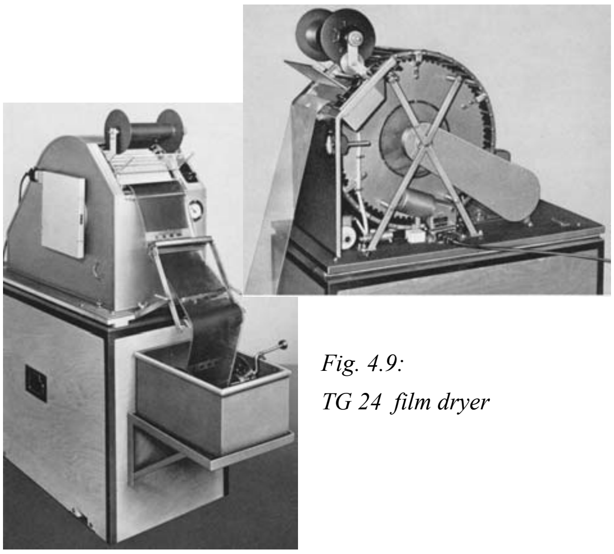


Fig. 4.9: TG 24 film dryer

It should be mentioned, that Oberkochen in 1959 developed a "light pencil" for scribing on the undeveloped film in the photographic laboratory. This invention was registered for design with the patent's office (ZEISS 1959), but not introduced into the market.

The KG 30 contact printer, introduced in 1954, became very successful (Fig. 4.10). It was manufactured in Berlin by a small subcontractor and about 1 000 were sold.

Fig. 4.10: KG 30 contact printer

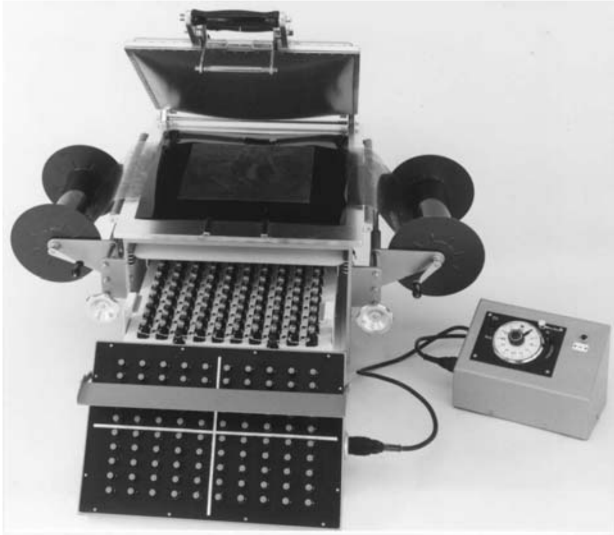


Fig. 4.11: "Kaleda"-light unit for the KG 30 (1971)

For this KG 30 a special light unit was designed in 1971, consisting of 100 small light bulbs arranged in a matrix 10 x 10 (Fig. 4.11). The idea was to compensate for light variations within the photograph by individually adjusting the lamps, thus being a low cost solution for the very expensive but powerful automatic dodging printers of American brand. But this "Kaleda"-unit was not accepted by the market.

Last but not least viewing desks were needed for the inspection of the aerial roll film and for photo interpretation. Initially developed at ZEISS-AEROTOPOGRAPH in Munich and later improved by the Oberkochen staff, these desks were like the stereoscopes manufactured by subcontractors. Fig. 4.12 shows one of the later models. Special versions for the direct comparison of several films and different film types and scales had been developed for the reconnaissance community but cannot be shown here.

Fig. 4.12: L 3 viewing desk (1985)

4.4 STEREOPLANIGRAPH

A much more complex task in Oberkochen was the reconstruction of the Jena STEREOPLANIGRAPH. The concept of this universal 1st order stereoplotter with a rigid solution with the so-called "subjective optical projection" (Fig. 4.13) was already created by PULFRICH

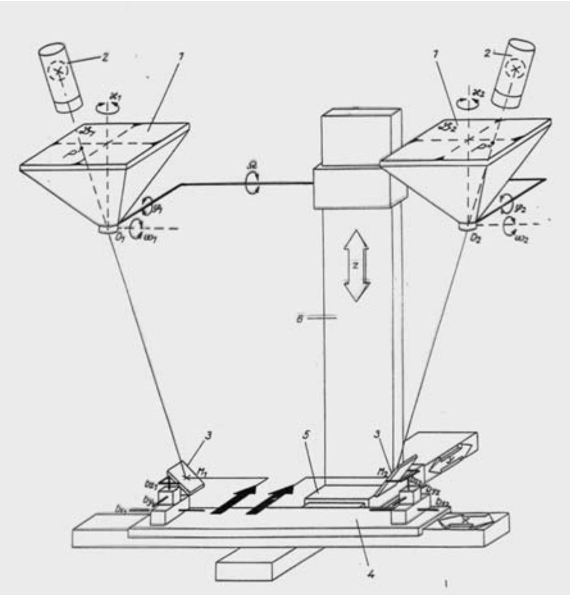


Fig. 4.13: Design scheme of the STEREOPLANIGRAPH: "subjective optical projection"

in 1918 and, after the invention of the optical lens system for automatic focussing by BAUERSFELD in 1920 (Fig. 4.14), was first built in 1921 as the STEREOPLANIGRAPH C/1. During the following years this instrument was improved continuously until model C/5 in 1937 (Fig. 4.15). Model C/6 designed in 1945 was not introduced.

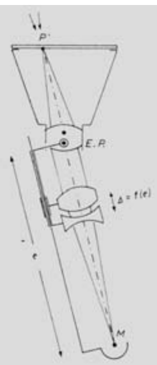


Fig. 4.14: Optical autofocus system after BAUERSFELD

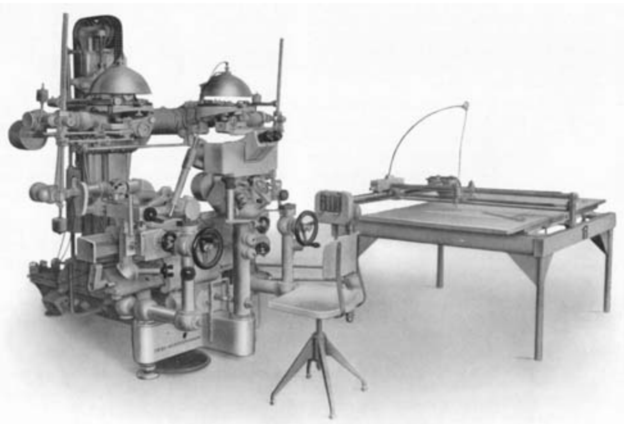


Fig. 4.15: C/5 STEREOPLANIGRAPH with tracing table (1937)

In the winter of 1949/50 ZEISS-AEROTOPOGRAPH placed the first post-war order on ZEISS-OPTON in Oberkochen to redesign and to improve significantly the STEREOPLANIGRAPH. But there were not any drawings and tooling plans in Oberkochen for this sophisticated optical-mechanical instrument with 2 600 different designed parts and in total 5 000 manufactured parts. However, after some time Oberkochen was able to buy back a C/5 for 5 000 US-Dollars. This instrument had been built in Jena in 1944 and was scheduled to be shipped to Japan by a submarine adapted to transport freight but the shipment went to the bottom of the Main river. The packages were well prepared for maritime freight and were recovered in 1945 by a semi-official recycling company (BARING 1963).

The redesign was also very much supported by BAUERSFELD, who had played an important role in the original development and who now was a member of the executive board in Oberkochen. Support also came from the head technician, KURT WOLF, who had joined ZEISS in Jena in 1912 and had worked for Bildmess on the STEREOPLANIGRAPH from 1921 onwards. WOLF came to Oberkochen in 1949 and was by now heading the assembly line for photogrammetric instruments (Montage und Justierei) called "MJ 6" (Fig. 4.16). By making use of user experience, in-house research and new manufacturing methods important improvements were introduced. The resulting C 7 STEREOPLANIGRAPH, already announced at the Geodetic Week in Cologne in 1950 (SCHWIDEFSKY 1950), was first exhibited at the 21st Photogrammetric Week in 1951 in Munich. The improvements were:

- *Image format up to 24 cm x 24 cm (before 18 cm x 24 cm),*
- *optional optical plates for compensating radial distortion,*
- *floating mark illuminated and with selectable shape, colour and intensity (before black & white only),*
- *coated optics,*
- *z-motor drive (for large height differences),*
- *z-reading also in feet,*
- *higher precision of measurements and readings.*

Fig. 4.16: Serial production of the STEREOPLANIGRAPH in the MJ 6 photogrammetric assembly hall (1952)

First customers were critical that the C 7 brochure claimed an accuracy potential of up to 0.02 ‰ of flying height but this was "too bad by a factor of 2" compared to the real accuracy. However, the following year, in September 1952, the improved C 8 STEREOPLANIGRAPH (Fig. 4.17) was introduced at the VII. International Congress for Photogrammetry in Washington D.C. (HOFMANN 1953). Compared to the C 7 there were now photo carriers available for various focal lengths, also improved reading scales for the orientation elements and the "Druckzählwerk", a new patented coordinate recording unit (ZEISS-AEROTOPOGRAPH 1951). This device replaced the cumbersome and error-prone reading and hand-writing of the coordinate values (Fig. 4.18). The printing of x and y was carried out with a resolution of 0,01 mm, and the z-values could be recorded as height values in 13 different scales and in metres and feet by mechanical gears.

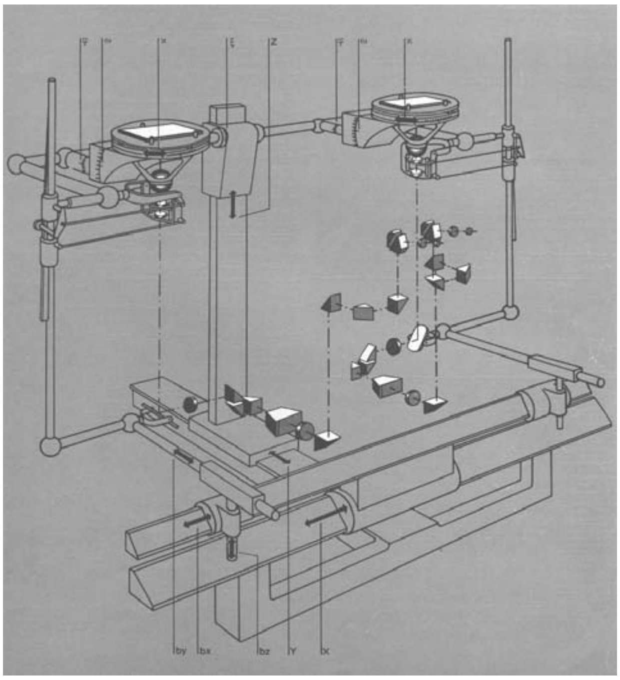


Fig. 4.17: Design scheme of the C 7 and C 8.

The important parameters for the C 8 (Fig. 4.19) were:

- *Focal length / image format in mm: from 100 / 140 x 140 to 610 / 240 x 240,*
- *phi: -20 to +30 gon,*
- *omega: -10 to +10 gon,*
- *kappa: ± 400 gon,*
- *common omega: -20 to +60 gon,*
- *bx: -290 mm to +310 mm,*
- *by: ± 30 mm,*
- *bz: ± 20 mm,*
- *x: ± 275 mm,*
- *y: -425 mm to +275 mm,*
- *z: 170 mm to 605 mm.*

When production ceased in 1974 the C 7 and C 8 STEREOPLANIGRAPH had sold 144 units (MEIER 1986). Together with the 150 units built in Jena (BRUCKLACHER 1952) the total number manufactured was 300 over more than 50 years.

Fig. 4.18: C 8 coordinate recording unit

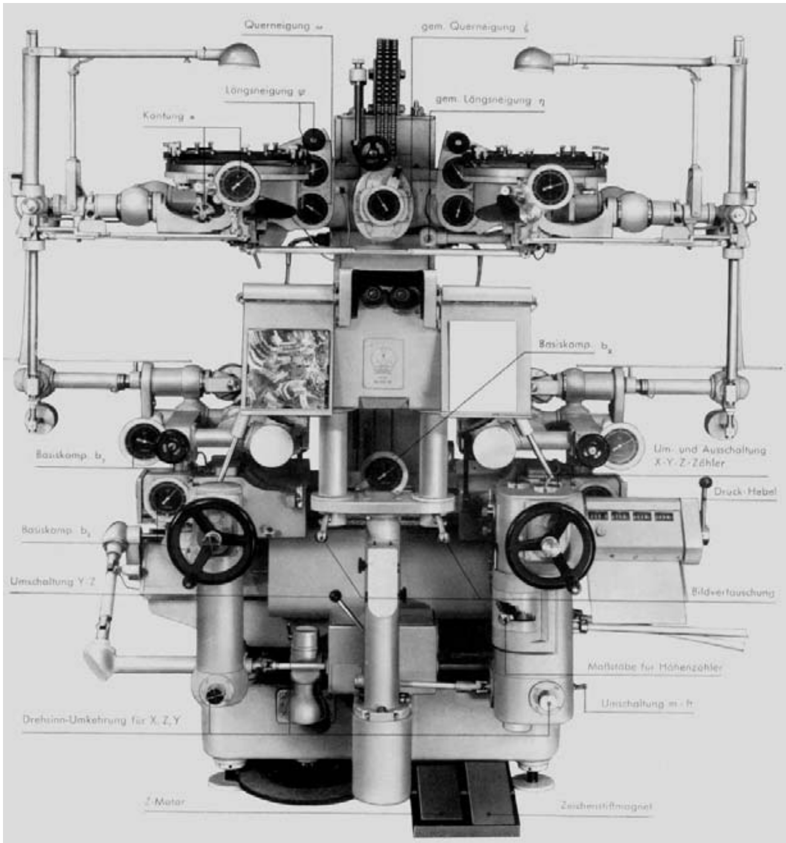


Fig. 4.19: C 8 STEREOPLANIGRAPH (1952)

5. New designs for pre-war ideas

Although started in 1949 as a reconstruction task of the Jena C/5, the STEREOPLANIGRAPH C 7 and soon after the C 8 were significantly enhanced instruments. Together with other improvements the period of new developments began as early as 1950. At the first post-war Photogrammetric Week in Munich in 1951 the SEG V rectifier was introduced together with the C 7 and the earlier described minor devices. At the 7th International Congress for Photogrammetry in 1952, in Washington D.C., the STEREOTOP and a new aerial camera lens were added, and at the 8th FIG International Congress in 1953, in Paris, the respective new metric aerial camera was available.

5.1 STEREOTOP

In addition to a 1st order stereoplotter like the STEREOPLANIGRAPH a worldwide need for a less expensive mapping instrument for medium and small scales (1 : 25 000 to 1 : 100 000) had been identified. In Oberkochen the idea of extending the Stereometer (mirror stereoscope plus plotting tool) with a simple mechanical device for reducing perspective distortions and model deformations resulted in the STEREOTOP (Fig. 5.1),

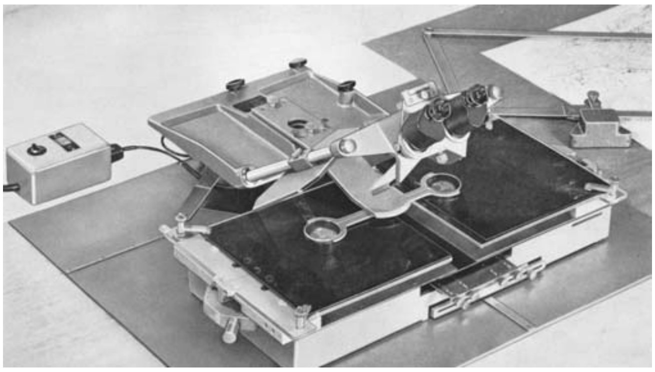


Fig. 5.1: STEREOTOP with SD trans-illumination attachment (1953)

which was first shown as a functional model at the Washington-Congress (HOFMANN 1953 & BRUCKLACHER 1954). Two mechanical computers use slide rulers for executing approximate formulas to reduce the model and height errors (Fig. 5.2). Fig. 5.3 and 5.4 show the setting knobs of the mechanical computers, which were developed by HEINRICH SONNBERGER, a design engineer, who had earlier gained much experience with similar mechanical computers for military aiming devices in Jena (DEKER 1956 & 1959). Later investigations showed, that by special measurement procedures the height accuracy could be further increased (KUPFER 1957a & 1957b). And in 1959 an optional parallax converter (Fig. 5.5) completed this equipment (MONDON 1959a).

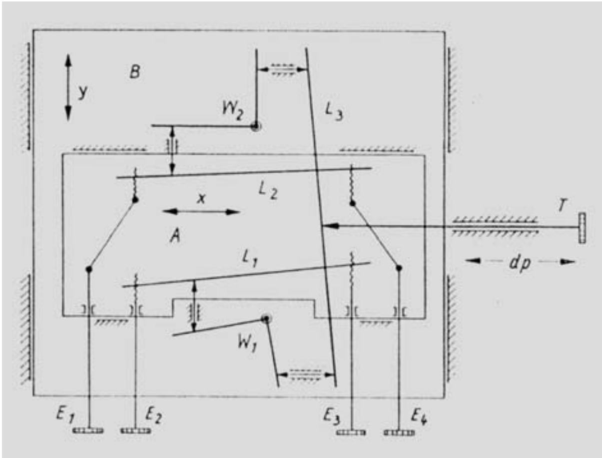


Fig. 5.2: Principle of Computer I of the STEREOTOP with setting knobs E1 to E4 (SCHWIDEFSKY 1963)

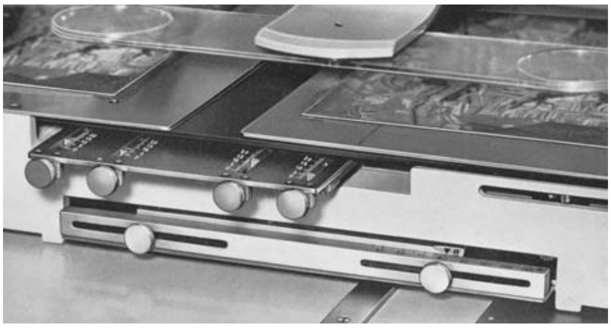


Fig. 5.3: Setting knobs E1 to E4 of Computer I and Computer II a

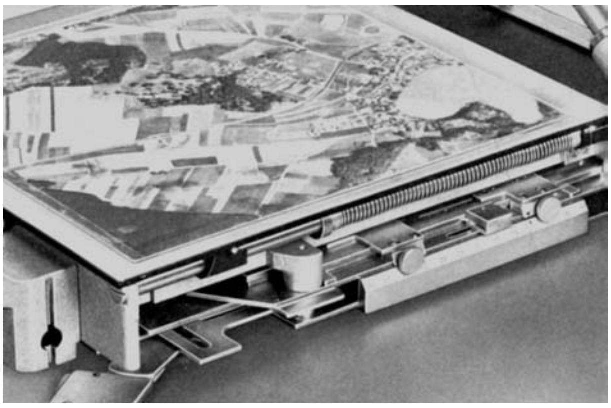


Fig. 5.4: Computer II b at the rear side

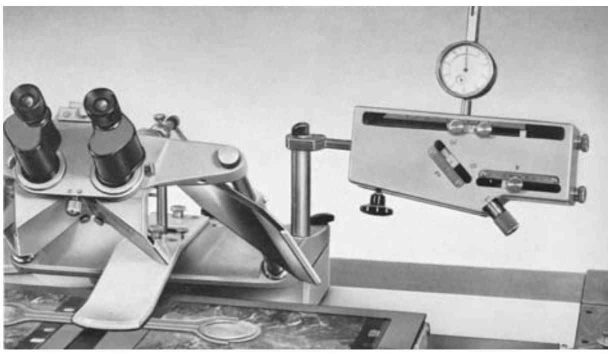


Fig. 5.5: Parallax converter for the STEREOTOP

Patents for a more precise mechanical computer for the STEREOTOP were registered (DEKER 1953 & 1954, SONNBERGER 1954f), but not realised. By the termination of production in 1976 about 840 units of this very popular 3rd order stereoplotter were sold. In 1980 its use for the evaluation of LANDSAT-images was reported in a technical paper (CLERICI et al. 1980).

In 1957 a simplified version for photointerpretation and raw drafting was presented and named STEREOPRET (Fig. 5.6). It had no computers, but was equipped with the parallax converter and a pantograph. It was manufactured by a subcontractor and 600 were sold by 1986.

Fig 5.6: STEREOPRET (1957)

5.2 SEG rectifier

In Jena self-focusing rectifiers were developed and built since 1924 under the name SEG (Selbstfokussierendes Entzerrungs-Gerät). In 1939 the SEG I was the latest full-size version and at the same time there was the SEG IV a stripped down version for easy transportation. However, the SEG V (later SEG 5) announced in 1950 and first exhibited in 1952 was a completely new development and was patented in Oberkochen (HOFMANN 1953), with the first conceptual work by SCHWIDEFSKY during his time in Wetzlar (Fig. 5.7).

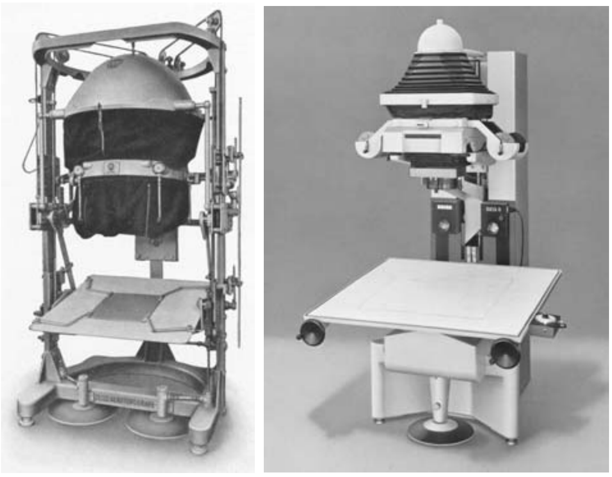


Fig. 5.7: Autofocusing rectifiers SEG I (1937) and SEG 5 (status of 1972)

The improvements were inter alia an extended magnification range, a projection lens with only 50 instead of 200 µm distortion, an innovative illumination, the now always vertical optical axis, and last but not least only 3 instead of 5 degrees of freedom: the setting of the magnification by lifting/lowering of the lens carriage and the tilting of the easel in x and y.

For keeping the rectified projection of inclined images sharp firstly the Newton's lens equation has to be fulfilled in the optical axis (Fig. 5.8), and secondly the SCHEIM-PFLUG condition has to be maintained for the whole area. For the SEG 5 the lens formula is fulfilled by motor (M) driven adjustment of the distance b between the image carrier (B) above the manually moved lens carriage, for which the Δb change is detected from a cam converter (SK) by a patented sensor (SD).

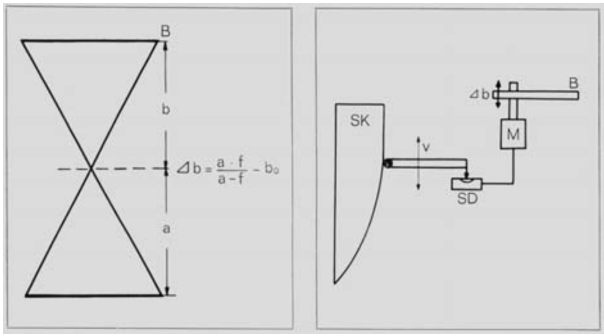


Fig. 5.8: Newton's lens equation and control

The SCHEIMPFLUG condition requires that the image plane, the lens plane and the projection surface all meet in a single straight line (Fig. 5.9). This is controlled by a so-called CARPENTIER-inversor, a stable mechanical rod located in the instrument's column, which by levers causes the required tilt of the image plane and the easel.

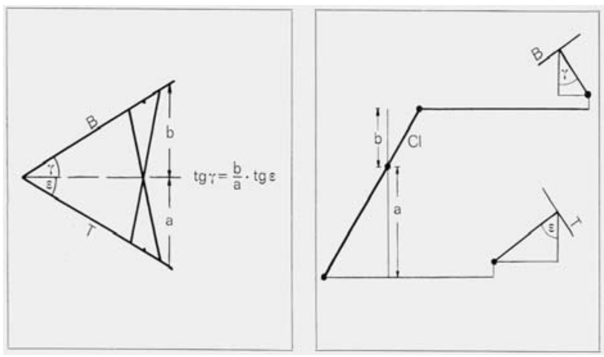


Fig. 5.9: SCHEIMPFLUG condition and control

The geometrically correct rectification finally requires a vanishing point shift for maintaining the projective relation between image and projected image in the map scale (Fig. 5.10). The innovative automatic vanishing point control of the SEG 5 calculates the image shift Δs (EBNER 1966) by analogue electrical means in the foot of the instrument (Fig. 5.11), which then drives the shift motors (Fig. 5.12).

All these control systems as well as the ball-and-socket mounting of the projection surface were protected by registered patents (BAUERSFELD et al. 1953a, SONNBERGER 1953a & 1953b, SONNBERGER et al. 1954).

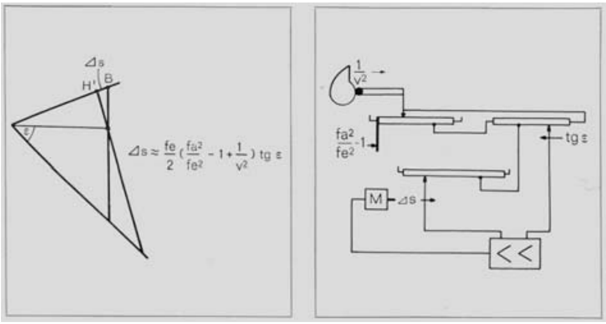


Fig. 5.10: Vanishing point requirement and control

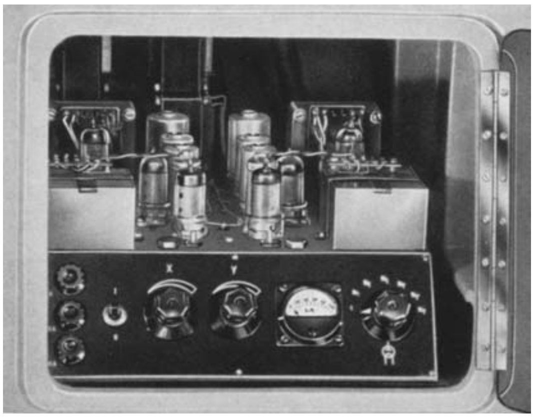


Fig. 5.11: Analogue vanishing point control of the SEG 5

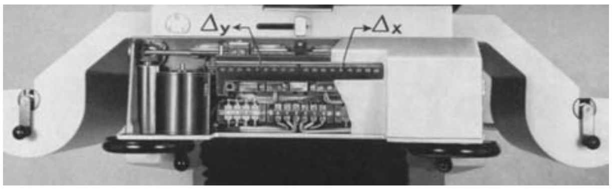


Fig. 5.12: Electrical vanishing point displacement (SEG 5)

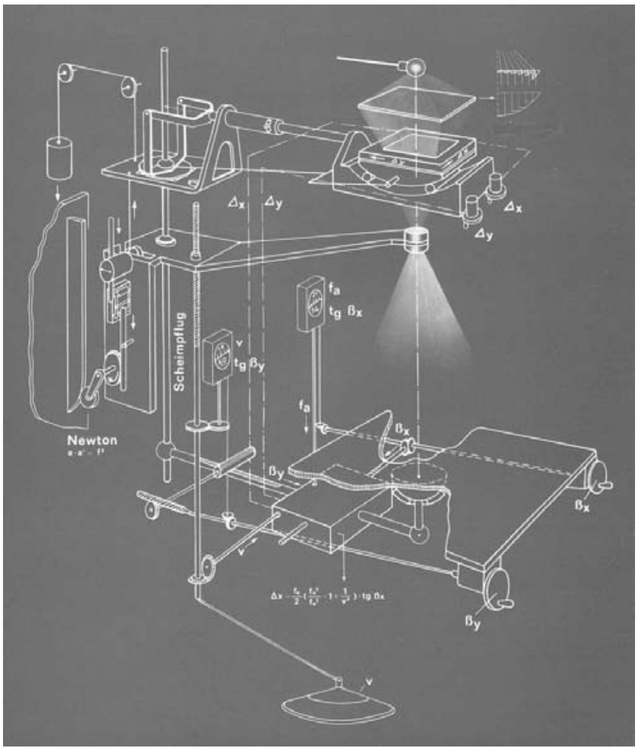


Fig. 5.13: SEG 5 design priciple

The design scheme in Fig. 5.13 does show all these described functions. There one can also see the compact illumination system using a Fresnel lens condensor, a special design with 4 effective surfaces. These were manufactured on an especially developed optical tooling machine by cutting very precise circular grooves into acrylic glass (Fig. 5.14). Later the well-known overhead projectors used similar single-surface lenses, but these had less demanding requirements and were pressed like disc records. The fresnel lens condenser was firmly mounted on top of the image carrier, but this required a controlled move of the lamp housing in relation to the condenser depending on the change of magnification.

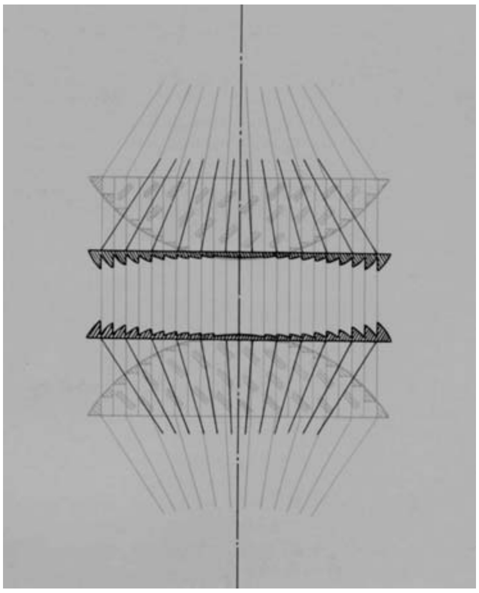


Fig. 5.14: Fresnel lens condensor reduces instrument height and weight (drawing simplified)

The TOPOGON V 6.3/180 projection lens was a new optical design for the extended magnification range of 0.5x to 6.5x, and it was equipped with a built-in red filter and a remote-controlled shutter.

The main SEG 5 parameters were:

- *Magnification range: 0.5x to 6.5x,*
- *negative size: up to 300 mm x 300 mm,*
  projected format: up to 230 mm x 230 mm,
- *table size: 1 m x 1 m,*
- *maximum easel tilt: ± 14 gon in x and in y,*
- *lens TOPOGON V 6.3/180,*
- *lens stops: 6.3 / 9 / 12,5 / 18 / 25 / 36 / 50,*
- *fresnel lens condenser size 400 mm x 400 mm,*
- *high pressure mercury lamp HQA 125 W,*
- *fully automatic focusing,*
- *fully automatic vanishing point control.*

Often chosen SEG accessories were the grid exposure frame (Fig. 5.15) and the vacuum easel for better film flattening (Fig. 5.16).

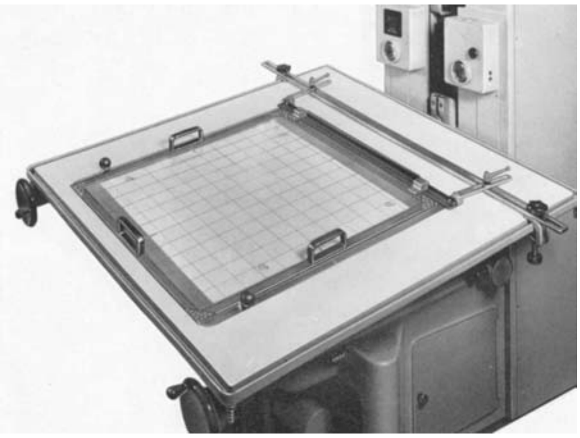


Fig. 5.15: Grid (50 mm x 50 mm) exposure frame for the SEG

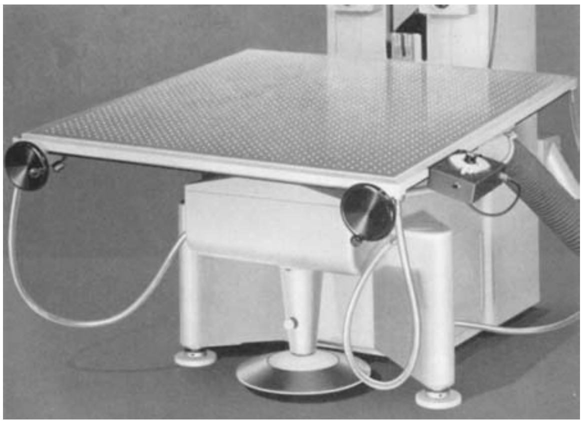


Fig. 5.16: SEG vacuum easel

In 1963 a mobile version of this rectifier was developed for the German Army, the SEG Vb. As the height of the vans was limited, the magnification range had to be constricted to 3.5x, and the illumination unit had to be replaced by a broad-beam lamp system. For better illumination this was later upgraded to a 4 000 watts version which required a powerful cooling system (Fig. 5.17).

In 1972 the improved TOPOGON V2 6.3/180 enabled the greatest aperture for the exposure to be increased from f/12.5 to f/9, and with a further improvement in 1979 the range of lens stops were changed to 5.6 / 8 / 11 / 16. f/5.6 was now the greatest and an excellent stop for exposure.

At the Photogrammetric Week in Stuttgart in 1977 the model SEG 6 was introduced (HOBBIE 1977a). Without changing the design principle and working ranges the redesign of the mechanical and electrical components after 25 years of production led to more cost-effective manufacturing and assembly. Now the electrical unit was centralised in a pack on the back, the lamp control was further improved and the vacuum easel with a white surface for a better view of the projected image was standard (Fig. 5.18). Another new feature was the optional motor driven magnification change, which was initiated by pushing the foot wheel. Fig. 5.18 also shows the OCS 1 orientation control system for computing the orientation parameters which was developed for the SEG 5 in 1976. It consisted of the position measurement with a pointing device connected to spring-loaded wires, the DIREC 1 electronic counting and interface unit, the HP 9815 deskcomputer and the necessary software (HOBBIE 1976a). The coordinates of the projected control points were calculated according to the triangulation

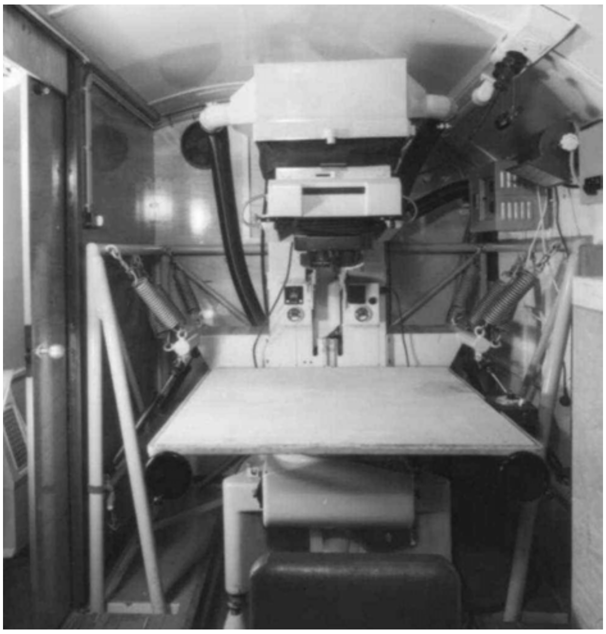


Fig. 5.17: SEG Vb mobile rectifier with 4 000 watts lamp

Fig. 5.18: SEG 6 with electrical backpack and OCS 1 orientation control system

principle, and by comparison to the given ground coordinates the settings for the magnification and easel tilts were computed.

The development of SEG 6 and OCS 1 was supported by the Federal Ministry for Research and Technology under the headline "Automatic Rectification" (HOBBIE 1979a).

By making use of the progress in electronics and computers in 1985 the version OCS 2 with DIREC 2 and HP 85 B was introduced (FAUST 1985). The year before the CLS 2000 colour illumination system of the famous DURST company was presented (Faust 1984). This colour head consisted of a 2 000 watts halogen lamp and a dichroitic filtersystem for continuous colour correction (Fig. 5.19). This SEG 6 C was a powerful variant dedicated for professional colour work.

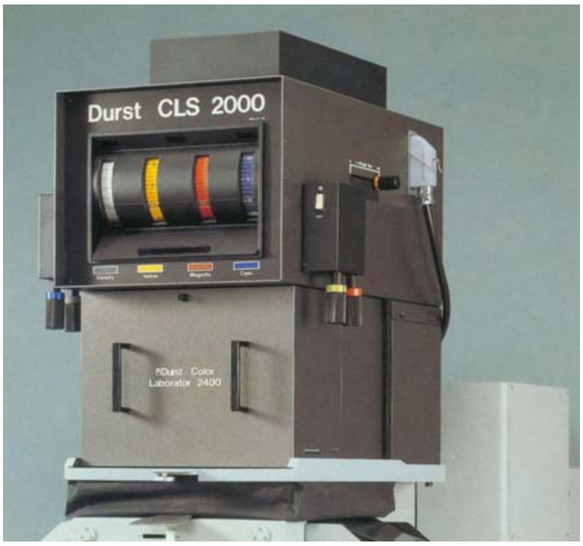


Fig. 5.19: CLS 2000 Colour head (from DURST) at the SEG 6

SEG V or 5 and SEG 6 were most successful and were by far the best selling rectifiers on the photogrammetric market. About 400 instruments were delivered. When sales of the pre-war SEG's were added the combined total was almost 700 units.

5.3 RMK 21/18 with TOPAR 4/210

Before World War II the Jena aerial survey cameras RMK P 21 and the RMK P 10 had been very popular. Since 1932 the RMK P 21 had the normal angle ORTHOMETAR 4.5/210 lens (Fig. 5.20) and since 1936 the RMK P 10 had a wide angle lens (Fig. 5.21). Both had the then dominating image format of 18 cm x 18 cm. In addition the P 20/3030 had a format of 30 cm x 30 cm. A late development in 1938 was the HS 1818 with exchangeable lenses for f = 21 cm and f 10 cm. Whereas the shutter speed of the P 21 with the "Kugellamellenverschluss" (a ball-shaped shutter) was limited to 1/75 sec - 1/150 sec, the wide angle cameras with the TOPOGON 6.3/100 and 6.3/200 lenses and a rotating disc shutter allowed an increased range of 1/25 sec - 1/200 sec. At that time the necessary film flattening was done by pressing the film against a back plane by using air compressed by the aircraft speed or a pump.

Bild 5.20: RMK P 21 normal angle camera (1932)

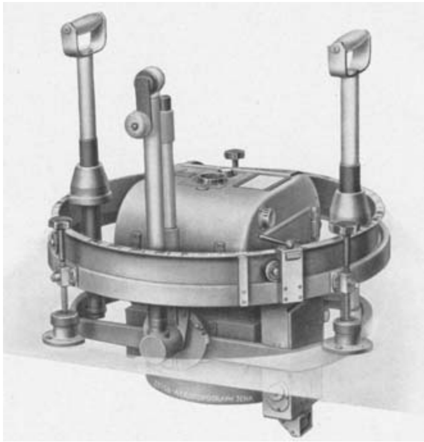


Fig 5.21: RMK P 10 wide angle camera (1936)

After the lost war initially all matters related to aviation were off-limits for the Germans. Only in 1952 was permission given for the first survey flight for cadastral purposes in the state of Hesse. This seemed to be a dawn. In Oberkochen ZEISS had not been dormant and had designed a complete new aerial survey camera. In 1952 the new TOPAR 4/210 wide angle lens (Fig. 5.22) for an image format of 18 cm x 18 cm was announced (RICHTER 1952). The first image results were shown at the Washington-Congress, where the comparison with samples of the former ORTHOMETAR documented the impressive gain in image quality. Now the same ground resolution could be achieved by doubling the flying height resulting in a fourfold footprint.

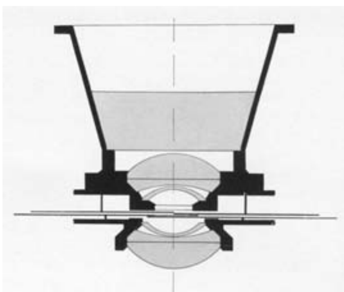


Fig. 5.22:

Scheme of TOPAR 1 : 4, f = 21 cm (1952)

With distortion less than 4 µm the TOPAR at that time was practically distortion-free.

When introducing the complete new camera RMK 21/18 (Fig. 5.23) at the 8th International FIG-Congress in Paris the 10x enlarged, illuminated photo samples attracted the visitors (N.N. 1953). One special feature was the new and patented (SONNBERGER 1954c) rotating disc shutter AEROTOP (Fig. 5.24) with four continuously fast rotating discs, an additional slow rotating disc and an exposure controlling blocker. This innovative device allowed lens stops between 1/100 sec and 1/1000 sec and a light transmission efficiency of almost 90 %.

Bild 5.23: RMK 21/18 with IRU (1953)

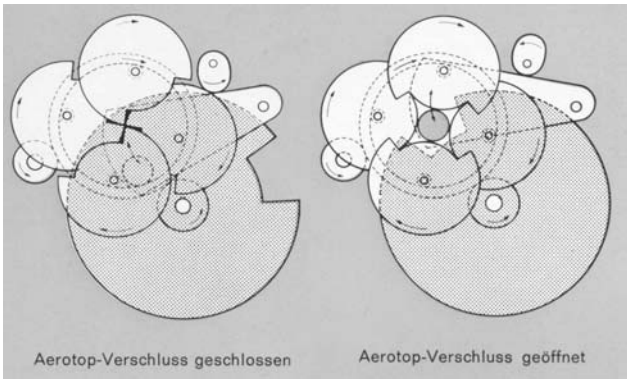


Fig. 5.24: AEROTOP rotating disc shutter (principle)

The new film magazine had several patented features, too (ZEISS 1954a, SONNBERGER 1954b & 1955, SONNBERGER et al. 1954). Now the film was flattened better and more reliably by vacuum, and also the danger of exposed "flashes" caused by friction was reduced. The film capacity was doubled from 60 m to 120 m (BRUCKLACHER 1954). The IRU intervalometer (Fig. 5.25) was patented as well (SONNBERGER 1954d). It supported an overlap range between 20 % and 90 %, and it was designed as a separate unit, allowing it to be used distant from the camera. And last but not least the way of exposing the auxiliary data was protected by a patent (SONNBERGER 1954a).

Fig. 5.25: IRU intervalometer

According to a proposal to use two cameras in a convergent arrangement for increasing the covered model area together with an advantageous base to height ratio (BRUCKLACHER 1956 & ACKERMANN 1956) the RMK 21/18 was offered as a convergent camera "2 x RMK 21/18" in a special mount (Fig. 5.26). However, this concept soon lost its appeal due to the new "American" image fomat of 9" x 9" (23 cm x 23 cm).

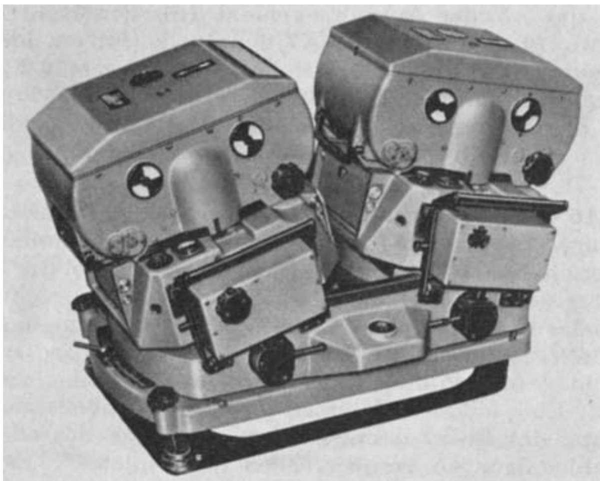


Fig. 5.26: Convergent camera: 2 x RMK 21/18 (1956)

5.4 RMK 15/23 with PLEOGON 5,6/153

While still introducing the RMK 21/18 into the market in 1953, Oberkochen developed a new wide angle lens for this new 9" x 9" format, which was widely used in the USA. The resulting PLEOGON with a largest aperture of 1 : 5.6 was derived from the TOPOGON from 1932 (Fig. 5.27 & 5.28) and presented in 1955. It showed a significant enhancement in image flatness, uniformity of exposure and chromatic correction (RICHTER 1955 & SCHWIDEFSKY 1956a).

Fig. 5.27: TOPOGON wide angle lens (1932)

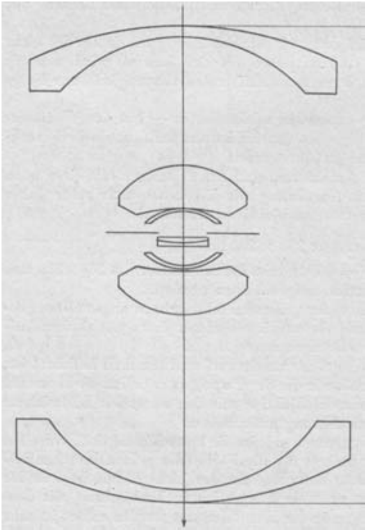


Fig. 5.28: PLEOGON 5.6/153 (1955)

The PLEOGON 5.6/153 with a radial distortion of less than 5 µm (compared to the 50 µm of the TOPOGON 6.3/100 in the wide angle camera RMK HS 1818 from 1938) was assigned for the new RMK 15/23 (Fig. 5.29), which was introduced at the 8th International Congress for Photogrammetry in 1956 in Stockholm. This RMK 15/23 was the first member of a large and successful RMK-family from CARL ZEISS Oberkochen with the image format 23 cm x 23 cm. With identical components and accessories as for the RMK 21/18 at the beginning, the new family was produced over nearly 35 years with continuous improvements and extensions, but unchanged in the basic design. This RMK-line was strictly dedicated to the improved aerial film (BRUCKLACHER et al. 1956 & AHREND 1957), whereas the famous Swiss competitor still marketed an aerial camera using glass plates.

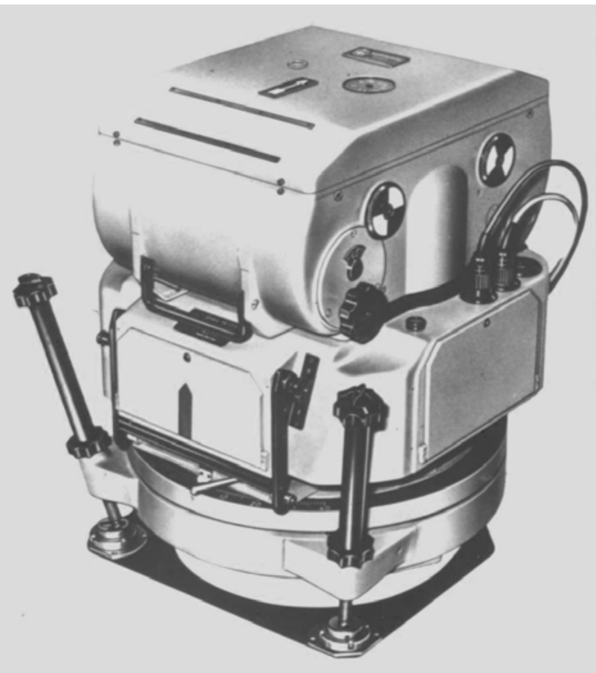


Fig. 5.29: RMK 15/23 aerial camera (1956)

5.5 S 2 c statoscope

In Stockholm in 1956 a new recording statoscope for the barometric measurement of small changes of flying height was presented. This data was valuable additional information for stabilising the aerial triangulation process (MEIER 1956). The S 2c statoscope determined the air pressure change from a liquid manometer with coaxially arranged legs by using electrical capacitance, displayed it to the pilot and recorded it beneath the exposed photograph by imaging a second display. For temperature control the manometer was placed in a thermos bottle filled with ice-water (Fig. 5.30). The in-flight accuracy of the measured height changes was about 1 to 2 m.

Fig. 5.30: S 2c Statoscope of 1956

5.6 REDUKTOR

In 1956 Oberkochen developed the REDUKTOR, a precision transforming printer (Fig. 5.31).

Fig. 5.31: REDUKTOR tansforming printer (1956)

The early variety of aerial cameras with different calibrated focal lengths, various image formats (up to 30 cm x 30 cm) and still not negligible lens distortion often made it necessary, to transform the photographs to get a calibrated focal length and/or reduced image format that would fit into an available stereoplotter, or to reduce or compensate for troublesome distortion. Transforming printers were required before World War II, e. g. for generating the small image format, required for the MULTIPLEX aeroprojektor, with the Jena "Universal-Reduktionsgerät" of 1939.

The image carrier of the REDUKTOR could handle photographs up to 23 cm x 23 cm in the same full size as the film cassette in the lower part of the instrument, the latter being driven in and out by a motor. The overall magnification range was 0.18x to 5.5x. With the distorton-free standard lens TOPAR 8/200 the scale range was 0.65x to 1.55x, which was sufficient in most cases. Other ranges were realised by optional lenses. The reading for positioning of the lens and the film cassette on illuminated glass scales allowed setting as precise as 0.01 mm. For the correction of image distortion individual optical compensation plates could be offered (SCHWIDEFSKY 1956b).

The REDUKTOR became obsolete around 1970 due to the increasing standardisation of the aerial cameras with the dominating 23 cm x 23 cm image format, the convergence on only four different focal lengths 85/88 mm, 153 mm and 305 mm and the now generally negligible lens distortion.

6. New developments after 1956

Within two to three years of the start in Oberkochen stereoscopes, the stereometer, RADIALSECATOR I & II, SEG V rectifier and the C 7 & C 8 STEREOPLANIGRAPH were available (SCHWIDEFSKY 1952a). In the summer of 1956 at the 8th International Congress for Photogrammetry in Stockholm, after 7 years, the photogrammetric poduct line of CARL ZEISS in Oberkochen and ZEISS-AEROTOPOGRAPH in Munich was almost complete. The line included laboratory equipment, the new STEREOTOP, the aerial cameras RMK 21/18 and 15/23, with a wide range of accessories, and the REDUKTOR (HOFMANN 1956). During the following years Oberkochen concentrated on continuous improvement by exploiting new technology and on fresh developments following the market needs.

For a clear representation of the numerous and manifold activities in Oberkochen during the following 45 years between 1957 and 2002 (the year when INTERGAPH assumed full responsibility) its description shall be divided into several chapters. One possible grouping could be according to the (overlapping) technology periods of the following decades:

- *1957 - 1980 mechanical-electrical phase,*
- *1973 - 1987 electronic & computerised phase,*
- *1984 - 2002 digital phase.*

In this case the next chapters would have had to be named according to the technologies, which have dominated the photogrammetic R & D activities in Oberkochen after World War II. Then the overall structure would be as follows:

- *1948 - 1951 reconstruction,*
- *1952 - 1956 update by new designs,*
- *1957 - 1973 new analogue instuments,*
- *1974 - 1987 analytical systems,*
- *1988 - 2002 digital systems.*

In this case instruments for a specific task such as orthophoto generation, but of different technological periods would be described in different chapters. For a better understanding of the influence of technological development on the progress of individual photogrammetric applications the next chapters are structured primarily following the usual photogrammetric tasks as shown in Fig. 6.1.

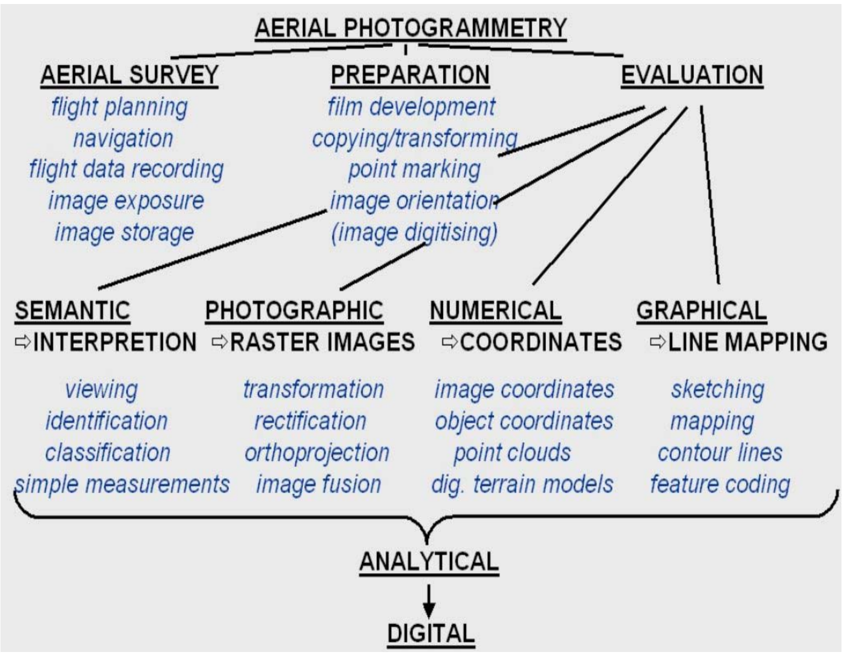


Fig. 6.1: Working procedures in aerial photogrammetry

The use and taking of aerial photographs is by far the dominating application of photogrammetry and is therefore the primary factor regarding the economic success and the variety and quantity of instruments in use (chapter 7 to 12). The other areas are terrestrial or close-range photogrammetry mainly for topographical, architectural and industrial tasks (chapter 13), the non-topographical special applications (chapter 14) and remote sensing for civilian and military use (chapter 15), the latter generally being called reconnaissance. For the photogrammetric community aerial photogrammetry is most interesting and diversified and therefore shall be further divided into the chapters on aerial photography (chapter 7), preparation and evaluation.

For evaluation the obvious structure is according to semantic, photographic (chapter 8), numerical (chapter 9) and the dominating graphical plotting (chapter 10). The analytical stereoplotters and the digital photogrammetric systems require separate chapters (11 and 12), because they distinguish more by software than by hardware design. The development activities of Carl Zeiss Oberkochen with respect to preparation and semantic evaluation have been very limited after 1957 and therefore will be described not in separate chapters but in context with other developments.

7. Aerial photography

The aerial survey is the first step in the working process of aerial photogrammetry, and the aerial cameras are a decisive factor for the overall quality of the following evaluation steps. Therefore Carl Zeiss Oberkochen (CZO) soon resumed the successful pre-war tradition of putting much into the development of the RMK by renewing and further improving the RMK-family from the early 1950s. In the following years the scientists of CZO and ZA did a lot of research into all aspects of the photo flight procedure and image quality, which was reported by presentations at the almost yearly Photogrammetric Weeks in Munich and by published articles (Brucklacher 1957, Meier 1960a, Schwidefsky 1960a & 1960b). This also led to a deeper knowledge of the contrast transfer function and of contrast enhancement, which then resulted in a significantly better colour correction of a new generation of aerial lenses, called "A-characteristics".

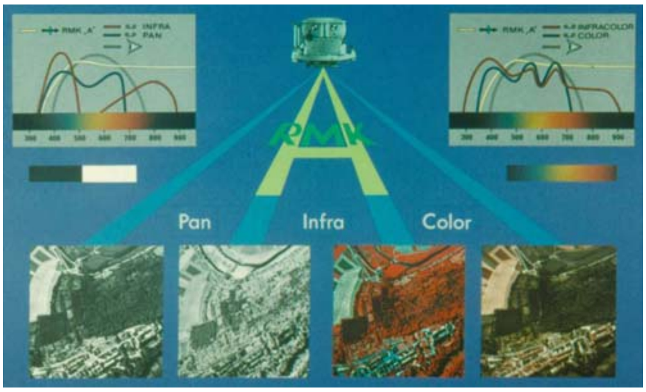


Fig. 7.1 Achromatic corrected aerial lenses improve the image quality when using infrared- and colour film

7.1 RMK-family with A-characteristics

Several research institutions had shown, that the clorophyll of leaves shows a better remission in the infrared range, thus enhancing object contrast and the interpretability of vegetation by using infrared aerial films. Whereas panchromatic films with a sensitivity in the range of 400 nm to 700 nm were used so far, an increased demand for infrared sensitive emulsions (up to 900 nm) had to be expected in future. Therefore Oberkochen improved the lens design of the Pleogon in such way, that the chromatic correction and the focus stability were extended up to 800 nm (Fig. 7.1). This achromatic lens correction was named "A-characteristics". Wolfgang Roos and Rudolf Winzer realised this feature for the first time in 1960 with the Pleogon A 5.6/153, which was introduced into the series production of the RMK A 15/23 (Fig. 7.2) in 1961 (Meier 1962).

Fig. 7.2: RMK A 15/23 in AS II mount together with IRU and the pilot's display for time of next exposure (1961)

After this breakthrough the Topar A 5.6/305 normal angle lens, and later the Toparon A 4/210 intermediate angle lens and the Telikon A 6.3/610 narrow angle lens were also redesigned and equipped with the A-characteristics (Fig. 7.3). The first delivery of the respective camera bodies RMK A 21/23, RMK A30/23 and RMK 60/23 (Fig. 7.4) took place successively in 1964 (Meier 1964b).

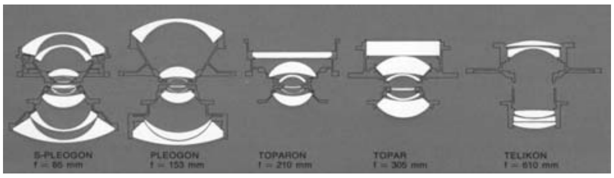


Fig. 7.3: Lens schemes for the RMK A-family, already with the super wide angle S-PLEOGON for RMK A 8.5/23

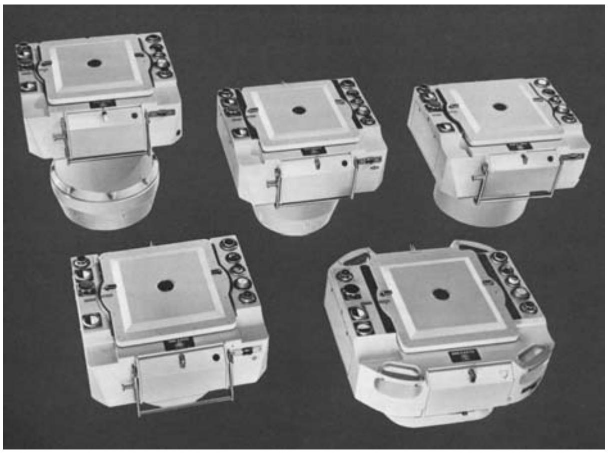


Fig. 7.4: The 5 camera bodies of the RMK A-family, already with the RMK A 8.5/23, introduced in 1968

From 1963 the most popular wide angle and normal angle cameras were offered also as reseau-versions, RMK AR 15/23 und RMK AR 30/23, with a patented configuration of the reseau-grid (MEIER 1964d). The initial demand for reseau-cameras was based on a better accuracy potential, but the increased expenditure of time for measuring the reseau crosses soon led to a loss of interest.

The AS II (Fig. 7.2) mount did accommodate all camera bodies (except the later super wide angle camera). It was vibration-cushioned and allowed levelling as well as rotating for drift compensation. The FK 24/120 film magazine fitted all camera bodies as well and was capable of handling up to 120 m unperforated film. It was equipped with a vacuum back plane (lifted during film transport), a film transport indicator and a device for marking the film. A light-tight closing door allowed the magazine to be exchanged quickly and easily during the photo flight. The electrical motor drive for film transport and lifting of the backplane and the vacuum pump were part of the camera body, so there were no electrics at all within the magazine.

During the development the robustness and stability of the lenses and camera bodies were tested in temperature chambers between -50° and +50° Celsius, accelerated in a centrifuge (until 12 g), vibrated in a frquency range from 4 to 3 000 Hertz (Fig. 7.5), shaken with an acceleration of up to 4 respective 8 g, and dropped into sand from 70 cm height (Fig. 7.6) resulting in a shock of 12 g (MEIER 1964a).

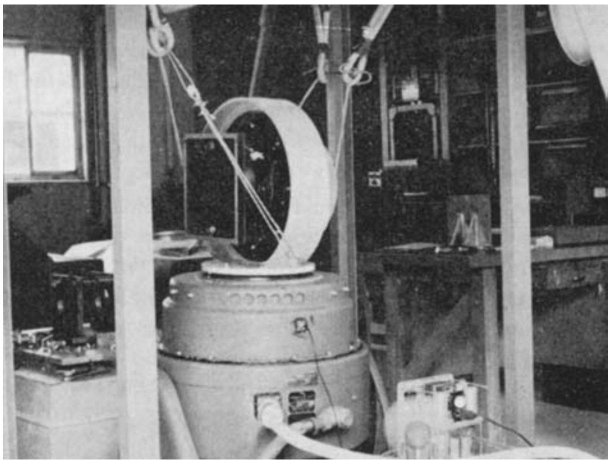


Fig. 7.5: Vibration test with RMK-lens

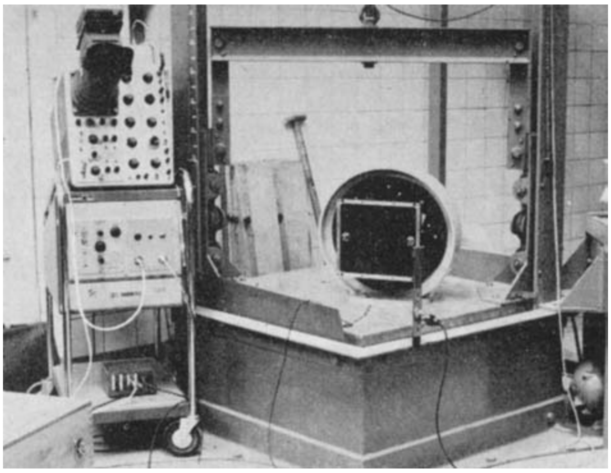


Fig. 7.6: Dropping test with RMK-lens

All camera bodies of the RMK-family were using the identical exposing procedure and arrangement of auxiliary data (Fig. 7.7). Besides the image counter, the statoscope or a barograph display, the circular level, a clock and a small note plate were exposed. The RMK-typical fiducials were exposed with natural object light. On special request additional corner fiducials were installed and calibrated as required for the US-market.

Fig. 7.7: Auxiliary data of the RMK A images

Optical colour filters were available for the RMK-family: a range of about 10 edge filters from filter A (half-value transmission at 440 nm) to filter K (700 nm). The most important ones were filter B (480 nm, "yellow") and D (535 nm, "orange"), which were part of the standard equipment. Further variants could have been manufactured on request.

As mentioned before, improvements of camera bodies and accessories were steadily made and immediately introduced into series production. This also took place with the lens enhancements, based on more powerful software and hardware for lens computations, and for satisfying the increasing demand in quality, e. g. for colour images (Meier 1967). The genealogy of the Pleogon wide angle lens is a typical example:

- *1955: Pleogon 5.6/153,*
- *1960: Pleogon A 5.6/153,*
- *1965: Pleogon A1 5.6/153,*
- *1968: Pleogon A2 5.6/153,*
- *1971: Pleogon A 4/153,*
- *1974: Pleogon A2 4/153,*
- *1988: Pleogon A3 4/153.*

7.2 RMK A 8,5/23 super-wide angle camera

Richter in Jena in 1941 had designed the Pleon 8/7.25 as a super-wide angle lens with an aperture angle of 148°, which for the benefit of a somehow acceptable light loss showed an enormous distortion. This lens was used in the Rb 7/18 aerial camera for covering wide areas in Northern Africa during World War II. The huge distortion was compensated by transforming in a special Pleon-image transformer.

At the Photogrammetric Week in 1962 the potential of such a super-wide angle camera for use in developing countries was discussed. A lens was required that would allow sufficiently small photo scales for the efficient topographic mapping in the required 1 : 25 000 to 1 : 100 000 scale range in spite of the limited ceiling heights of the available aircraft. But at this time the problem of vignetting at large image angles in combination with heavier haze at great flying heights could not be solved. But Zeiss decided to complement the RMK-family with a newly developed super-wide angle camera and in 1967 Roos and Winzer were successful with deriving the S-Pleogon A 4/85 with an aperture angle of 125° from the wide angle Pleogon A. This S-Pleogon with the so far unmatched aperture of 1 : 4 and only 7 µm distortion instead of 30 to 50 µm was extremely powerful.

The usual vignetting according to the $\cos^4$-law would result in only about 6 % of light compared to the center without any additional measures. However, by according to a patent of Roossinov from 1946 the size of the entrance pupil was enlarged with increasing image angle α (Fig. 7.8) and by the resulting $\cos^3 \alpha$ effect the vignetting was reduced to 25 %. With an additional antivignetting filter with 33 % transmission in the center the evenness of illuminance was further improved and an acceptable value achieved. The resulting RMK A 8.5/23 was presented at the Lausanne-Congress in 1968 (Meier 1968).

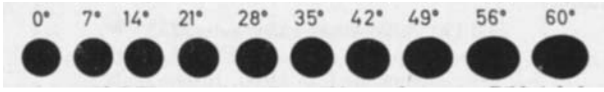


Fig. 7.8: Entrance pupil of the S-Pleogon 4/85 in relation to the viewing angle

Soon after the antivignetting filter was further improved for colour photography using a patented production procedure (Mottweiler et al. 1969).

Finally the light efficiency for the lens stops 1 : 4 and 1 : 8 was increased to 89 % and 92 % by changing the exposure time range for this RMK A 8.5/23 from 1/100 sec - 1/1 000 sec to 1/50 sec - 1/500 sec. Due to the usually greater flying heights and thus smaller image motion this was no disadvantage.

The much larger aperture angle of the super-wide angle camera required a lower installation in the aircraft in order to avoid enlarging the hole in the fuselage. Therefore the special mount AS V (Fig. 7.9) was required. By using an adapter ring this mount could be used for the other camera bodies as well.

Fig. 7.9: RMK A 8.5/23 super wide angle camera in AS V mount (1968)

7.3 Accessories for camera & flight control

Since the introduction of the Zeiss RMK 21/18 and the RMK 15/23 in 1953 and 1956 respectively, the handling of the camera was done at the camera body, and the release of the exposure was controlled by the separate IRU intervalometer. The operator had to switch on the camera, to rotate camera and IRU for drift compensation and then to concentrate on adjusting the speed of the intervalometer for keeping the chain of moving splines synchronised with the terrain. The navigation was the task of the pilot.

Following the experience in different types of aircraft further accessories for navigation and camera operation were required. With having established the RMK-family in 1964 a new navigation telescope and a remote control unit was presented (MEIER 1964a): for allowing the operator to do the fine navigation, and for enabling the camera to be operated from a remote position, e. g. from the copilot's seat. The NT 1 navigation telescope (Fig. 7.10) was equipped with a 90° wide angle lens, of which the optical axis was forward inclined by 40°. By this the field of view ranged from 5° below the forward horizon to 5° behind the nadir point. The telescope could be levelled and rotated 360° (for drift compensation, for backward looking and for checking the sidelap), and the height of the eyepiece was adjustable. The reticle within the field of view showed the nadir point, the flight axis and the side borders for the wide and normal angle cameras.

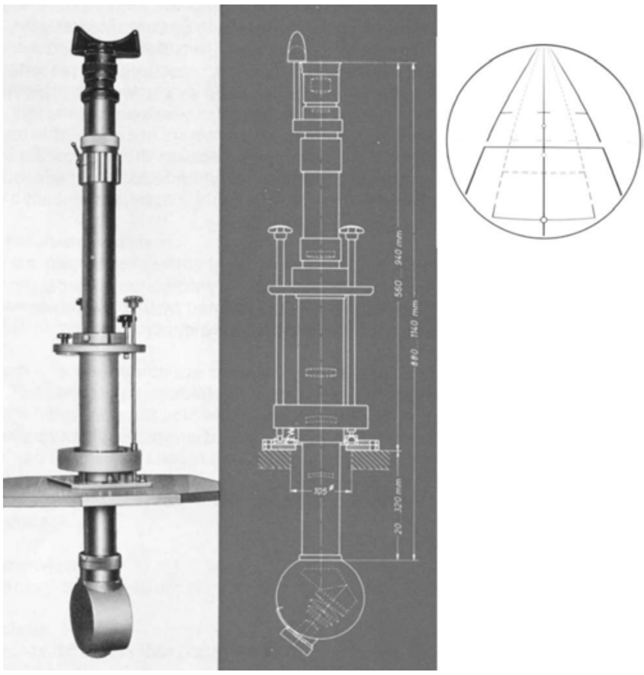


Fig. 7.10: NT 1 navigation telescope (1964)

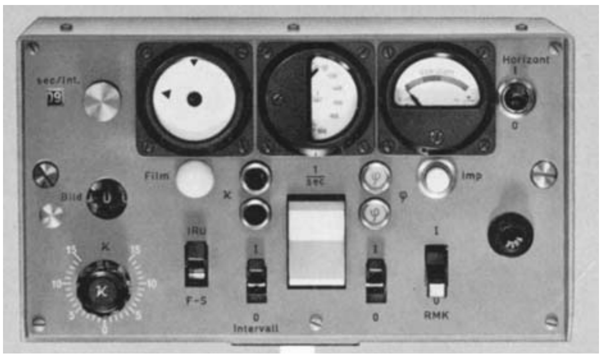


Fig. 7.11: Panel of the FS 2 remote control (1964)

The basic FS 1 remote control had made it possible to transfer the drift value set at the IRU to the camera mount by potentiometers and servomotors, when the operator could not reach the mount. The FS 2 remote control (Fig. 7.11) in addition supported the handling and supervision of all important RMK-functions from any location within the aircraft:

- *Leveling of the camera in flight direction (φ) for the compensation of the aircraft trim in the range ± 5° with 0.5° precision,*
- *Setting of the drift (κ) in the range of ± 15° with 0.3° precision and a speed of 1°/sec maximum,*
- *Setting of the exposure time in the range of 1/100 sec to 1/1 000 sec,*
- *Automatic release of exposures according to the preselected time interval between 2 and 60 sec, or from the parallel working IRU intervalometer, but in addition allowing individual single or serial releases,*
- *Remotely supervising the moment of exposure, the exposure time, the correct functioning of the vacuum for film flattening and the film transport, the exposed photo number, and the settings of drift (κ) and levelling (φ).*

A special feature was the display of the time remaining before the next serial exposure using a white rotating disc (in Fig 7.11 on the left side of the panel). An additional and separate display for the pilot allowed him to foresee the available time for flight corrections.

In 1973 improved versions of the accessories for navigation and camera control were introduced: the NS 1 navigation sensor as an improved IRU intervalometer, and the ICC interval control computer as a separate control box (Fig. 7.12). The latter now generated the release signal for exposure, based on the presetting of focal length and required forward overlap p and the angular rate v/h detected within the NS 1.

The advantage of this configuration was that it allowed the easy replacement of the NS 1 by the also new NT 2 navigation telescope, in which now not only an intervalometer was incorporated and displayed into the field of view, but also the effective values of lens stop and exposure time were shown (Fig. 7.13).

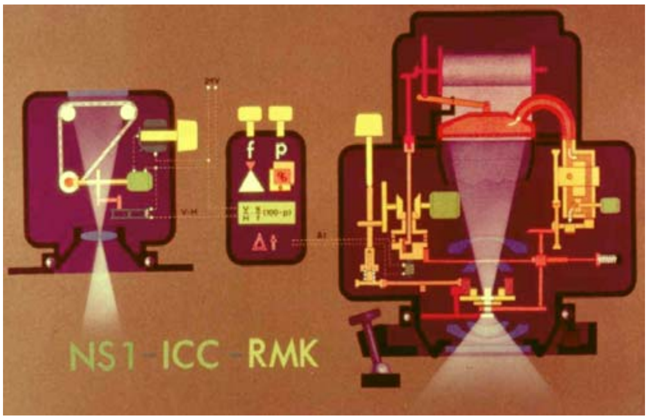


Fig. 7.12: Camera control with ICC interval control-computer nd NS 1 navigation sensor (1973)

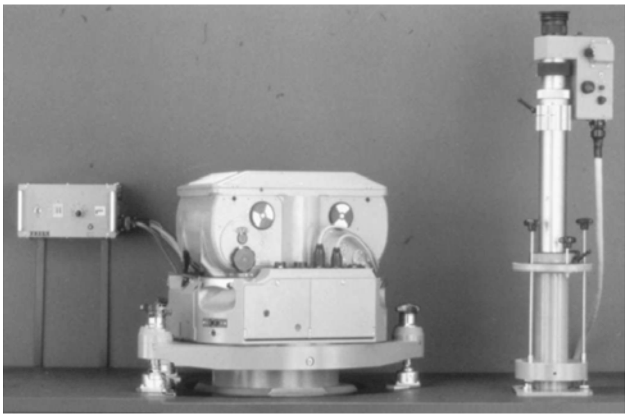


Fig. 7.13: RMK A 8.5/23 with ICC interval control-computer and NT 2 navigation telescope (1973)

Since 1968 ZEISS had offered the EMI 1 (Exposure Meter Integral) for its RMK cameras. This in fact was an off-the-shelf product, of which the photoconductive cell was placed in a small cone at the bottom of the RMK. By comparing the measured value with film speed, filter factor and tolerable exposure time the value for the lens stop was computed and then manually introduced.

The automatic setting of the lens stop based on the detected illumination was realised with the EMI 2 in 1972 (MEIER 1972b). Now the sensor was located adjacent to the front lens in a 70° cone and the film speed and filter factor was introduced directly at the electronic unit at the camera body (Fig. 7.14). Fig. 7.15 shows the functional diagram. The value for the effective exposure time was gained directly from the speed detector of the rotating disc shutter.

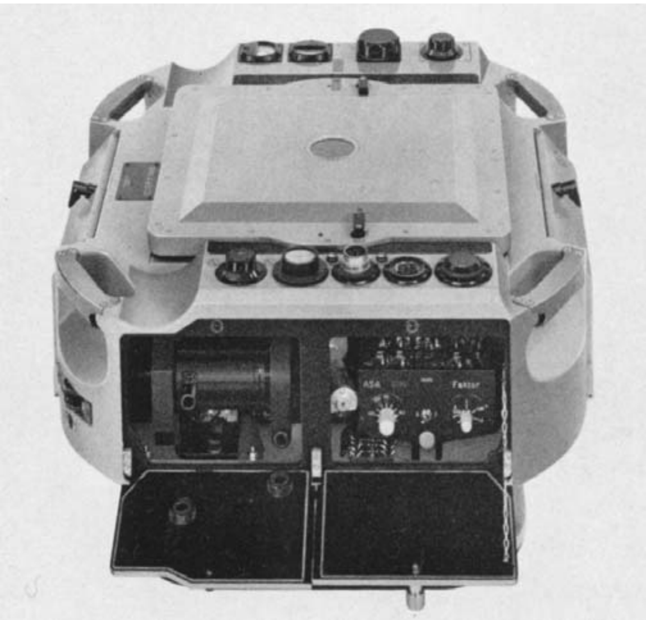


Fig. 7.14: EMI 2 automatic exposure contol in RMK A 15/23 (1972)

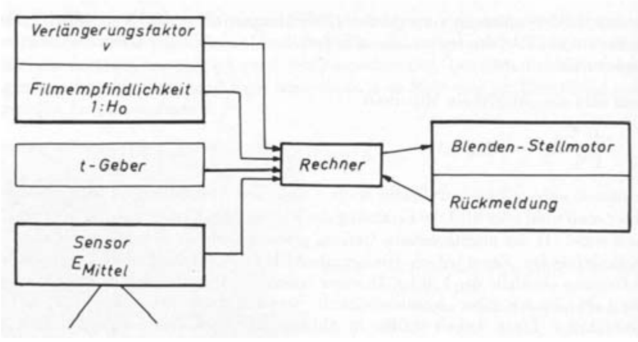


Fig. 7.15: Diagram of the EMI 2 automatic exposure contol

And last but not least ZEISS in 1976 presented the patented EMI 3 exposure automat (FELLE 1974a & 1974b). Compared to the EMI 2 the exposure time was now the primary control parameter, within the range of accepted image motion (LORCH 1976). The parameters had to be set at the EMI-electronics at the camera body as before. In addition to the display of effective lens stop and exposure time at the selected navigation unit (e. g. NT 2) indicator lamps warned of under or overexposure and of exceeding the tolerable image motion (Fig. 7.16).

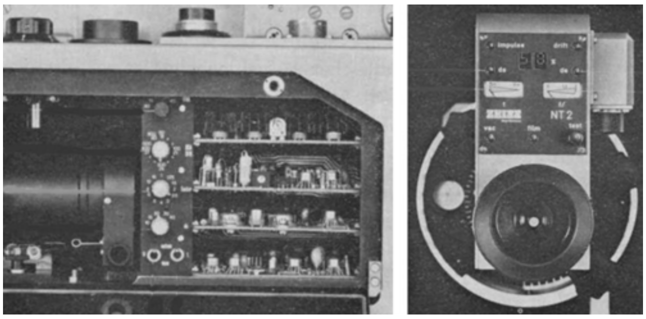


Fig. 7.16: EMI 3 automatic exposure contol and display at the NT 2 navigation telescope (1976)

The EMI 3 control algorithm primarily was adjusting the exposure time at the optimum lens stop, and only when approaching the tolerable image blur, the lens stop range would be used. For a manual control under special conditions the automatic correction could be suspended.

When introducing the EMI 3 at the International Congress in Helsinki in 1976, Oberkochen was already developing the NA automatic navigation meter for automating the control of end lap and drift. Presented in the following year, this new device could be used in combination with the new remote control component CCON/NM, replacing or adding to the NS 1 navigation sensor or the NT 2 navigation telescope (Fig. 7.17). The manual operation and the switching to automatic NA-control was done at the CCON/NM module (Fig. 7.18), which was usually placed close to the NT 2 (LORCH 1977). By this the navigator was able to control the camera, too. Fig. 7.19 shows a typical system configuration, including the motor-driven drift compensation (DCON) determined by the NA and the motor-driven levelling (HCON).

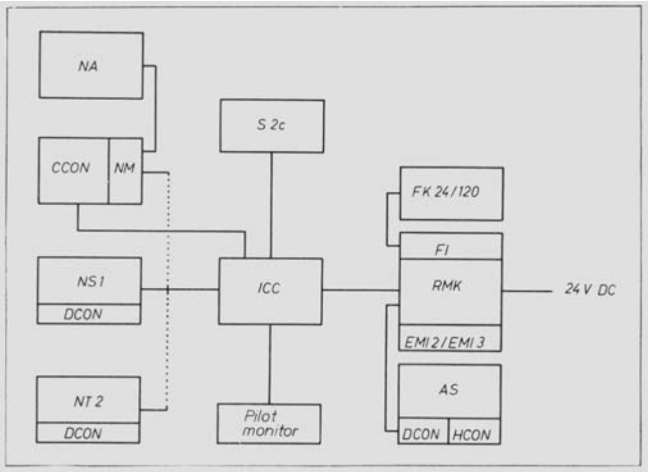


Fig. 7.17: Scheme of the possibilities for camera contol

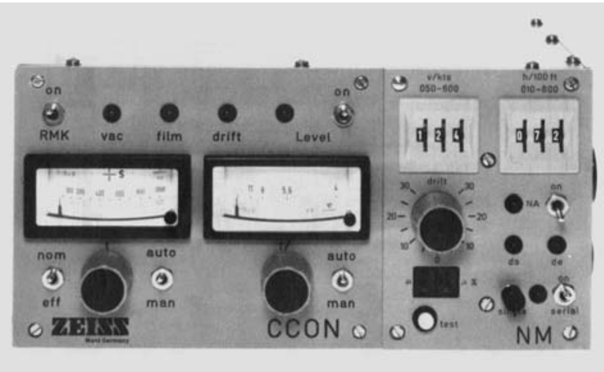


Fig. 7.18: Panel of the CCON camera control unit (1976)

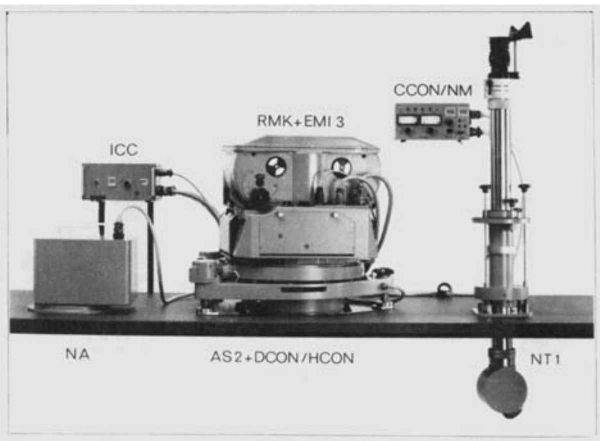


Fig. 7.19: RMK configuration with NA automatic navigation meter and NT 1 telescope (1977)

The information for the HCON automatic levelling was taken from the gyro systems for navigation, which in the meantime became affordable and were increasingly used in practise. The physical dimension of the NA were nearly identical to those of the NS 1 and it therefore fitted into the same place, but, being without any buttons and displays, it could also be installed at an inaccessible location.

The functional principle of the NA was protected by a patent (PRINZ et al. 1976) and consisted of a system of cylindrical lenses, which divided the terrain structures, wandering within the field of view, into two rectangular components. Perpendicular to these components a pair of parallel diode arrays was arranged. The time difference between the appearance of identical image structures at the two parallel arrays resulted in the respective image speed. By having aligned the arrays parallel to the aircraft these values were equivalent to the v/h angular speed and the drift angle and were sent to the CCON and DCON drives. The overall in-flight accuracy of the NA was about ± 2.5 % in the longitudinal overlap and ± 1.5° for the drift angle, which met or even outperformed the manual precision.

The increased use of the gyro systems for navigation raised the demand for direct registration of the derived navigation data (geographical coordinates and aircraft attitudes) on film next to the image. For this task the DAS data annotation system for the RMK-family was presented in 1980 (MEIER 1980). Fig. 7.20 shows a sample of such annotation (exposure position, attitudes and time stamp) from the PICS Inertial navigation system from LITTON, which was based on the LTN-72 and LTN-76 inertial guidance systems for automatic flight navigation (BRULAND 1981).

Fig. 7.20: DAS auxiliary data für the RMK (1980)

7.4 RMK A in space

After the US-launch of LANDSAT as the first civilian satellite for earth exploration in 1972 the Geo-scientists in Germany expressed their interest in establishing a satellite-based remote sensing program. In 1974 the Federal Ministry for Research and Technology promised the funding of such a project and that initiated a proposal for a METRIC CAMERA experiment at the European Space Lab being under development (Fig. 7.21). In 1977 the ESA European Space Agency accepted the recommendation to adapt a ZEISS RMK aerial camera for use in space (SCHROEDER 1977).

Fig. 7.21: METRIC CAMERA-Logo of the SPACELAB 1 - mission

The goal of this Spacelab 1 experiment, scheduled first for 1980 and then for 1982, was to determine the suitability of these space images for mapping at medium and small scales, because these images could be evaluated in any photogrammetric stereoplotter without any special treatment (Lorch 1979). In preparation the DFVLR German Aerospace Center (now DLR) investigated the ideal film/filter-combination with high altitude photo flights using a RMK A 30/23 and a RMK A 60/23 (Schroeder 1979). And Zeiss as a subcontractor of DLR compiled an experiment specification together with MBB Messerschmitt-Bölkow-Blohm. The only necessary modifications to a serial RMK A 30/23 were the adaptation of the electrical interface to the Spacelab and a weight reduction of the camera body. Fig. 7.22 shows the components prepared for the space flight. The integration of the RMK Metric Camera into the Spacelab took place a the Erno-MBB space company (Fig. 7.23).

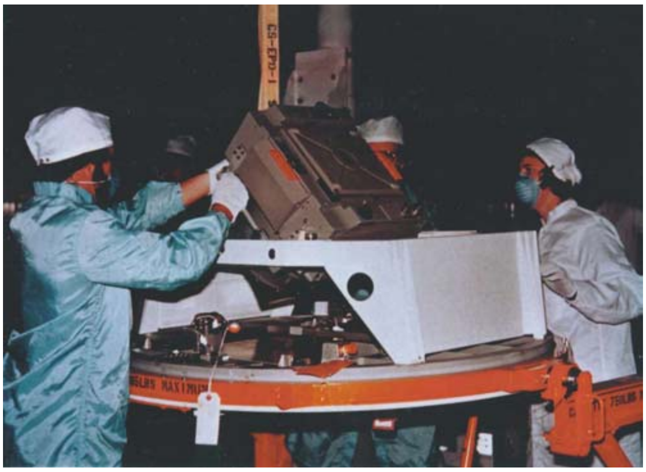


Fig. 7.23: Installing the RMK A 15/23 for the Spacelab-mission

After several delays the flight in space proceeded in 1983 from November 11 to December 8 at a height of 250 km. In spite of very unfavourable conditions due to the winter in the Northern hemisphere almost 1000 images were successfully taken and stored in two FK 24/120 film magazines, one with panchromatic black&white and one with colour-infrared film. These images were evaluated by 100 principal investigators (Konecny 1984). Because it was a well known serial product a handling problem with the camera, which occured during the space flight, could easily be solved by diagnosis and work-around hints over a hot line via DLR to Zeiss.

A beautiful selection of the space images was published in a sought after Zeiss calendar for the year 1985. One of these pictures is shown in Fig. 7.24.

Unfortunately, a scheduled second flight at a better time of the year with the new image motion compensation (see chapter 7.5) had to be cancelled due to the Challenger disaster in January 1986.

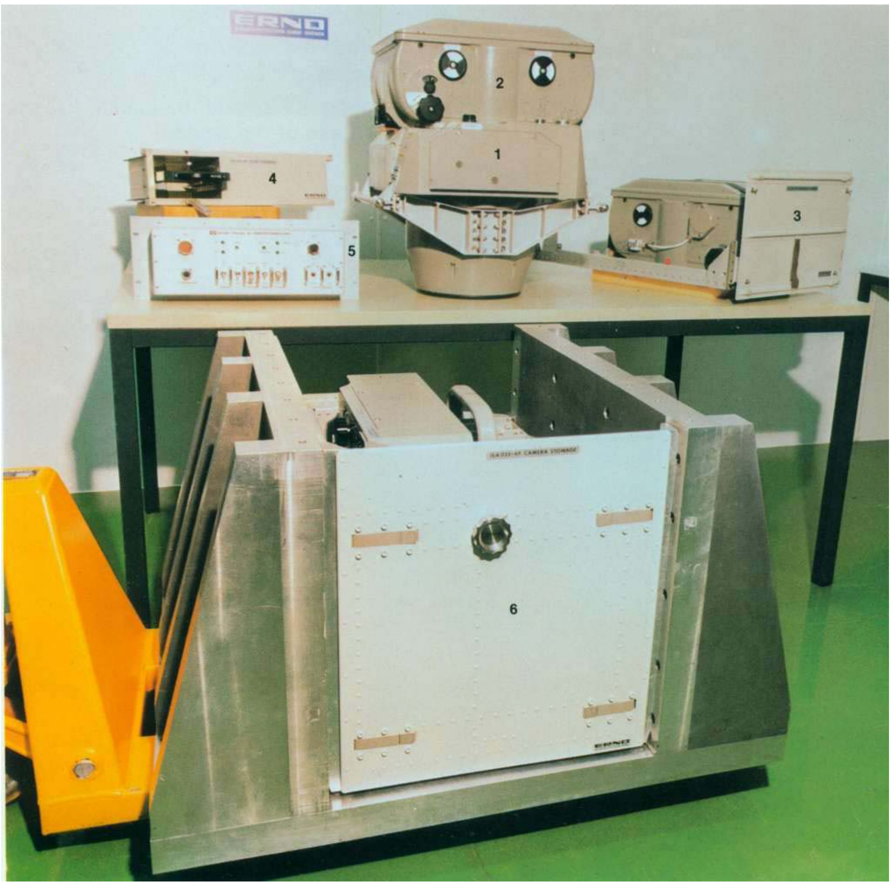


Fig. 7.22: Metric Camera equipment with camera body (1), film magazine (2), additional magazine in drawer (3), camera filter in box (4), remote contol (5) and camera container (6)

Fig. 7.24: "Horn of Africa", taken with ZEISS RMK A 30/23 (METRIC CAMERA) on KODAK infrared colour film during Spacelab flight from November 28 to December 8 ,1983 (photo: ESA/DFVLR)

7.5 Image motion compensation

Although the aerial cameras of the major photogrammetric manufacturers had all reached a high level of accuracy and quality in the mid 1970s (MEIER 1975a, 1975b & 1980), the R&D teams were still looking for further improvement. Image motion was identified as one of the larger remaining causes of image degradation, and the question of how to reduce the resulting blur as much as possible (Fig. 7.25). The benefits of a further significant gain in image quality was motivating (Fig. 7.26).

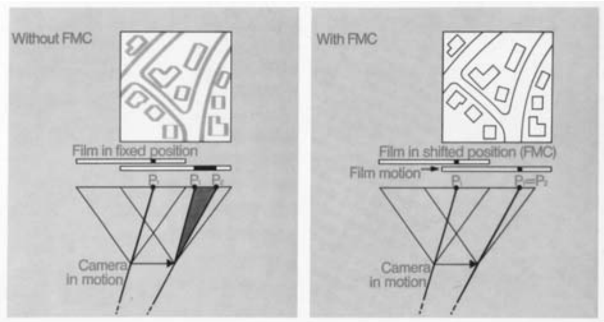


Fig. 7.25: The principle of image motion compensation

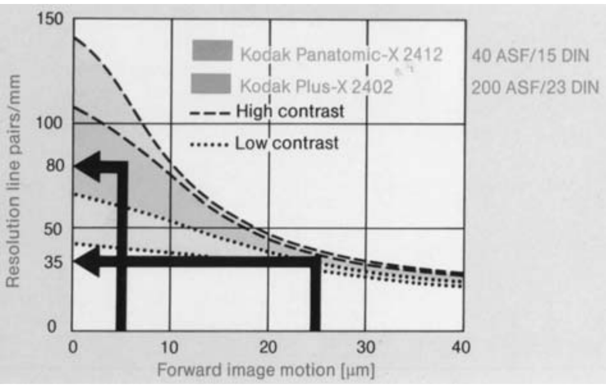


Fig. 7.26: Quality improvement within the aerial image by forward motion compensation

When the VEB CARL ZEISS JENA GmbH in 1982 was the first to introduce FMC (Forward Motion Compensation) in their new LMK aerial camera, CARL ZEISS, Oberkochen accelerated its own activities and presented a RMK film magazine modified for image motion compensation at the International Congress for Photogrammetry and Remote Sensing in Rio de Janeiro in 1984 (HOBBIE 1984b). Previous investigations had shown that image geometry would not be disturbed by the film motion during exposure (MEIER 1985b), and that a precise and stable film movement could be garantueed.

This development resulted in the CC 24 compensation cassette based on the FK 24/120 film magazine. By use of an additional control module CC Con the CC 24 was fully compatible with RMK systems on the market (Fig. 7.27). CC Con was connected to the ICC control unit (Fig. 7.28) and its only control function was the on/off-switch for the FMC and the setting of the focal length.

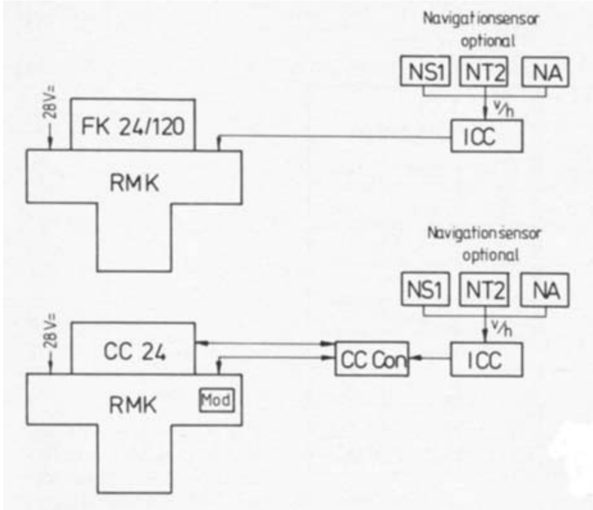


Fig. 7.27: System configuration for FK 24/120 and for CC 24

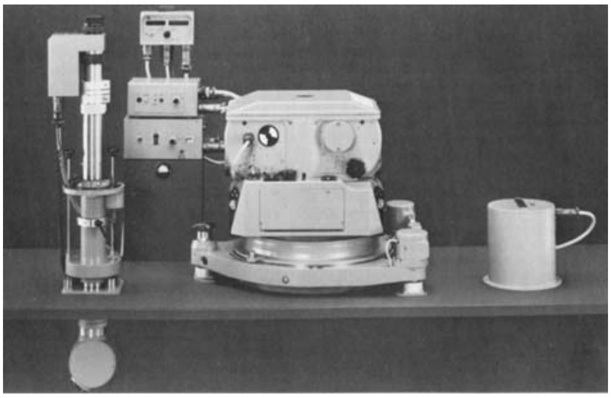


Fig. 7.28: RMK-setup for image motion compensation with CC 24, CC Con, ICC, NA and NT 2

The required movement speed was determined by the focal length and the v/h angular rate taken from the ICC. The highest possible speed of film movement of the CC 24 was 30 mm/sec, which resulted in a shift of 0.3 mm at 1/100 sec shutter speed (MEIER 1984).

Due to the evident quality improvement ecpecially for larger image scales (LORCH 1986), the forward motion compensation soon became a mandatory requirement in most photo flight tenders. From 1987 onwards WILD Heerbrugg as the third vendor of aerial cameras also offered image motion compensation with its RC 20.

7.6 RMK TOP and T-AS

With the many improvements such as new lenses, the NA automatic navigation and the FMC the RMK family had gained a new quality dimension during the past two decades. In spite of this ZEISS Oberkochen continued to look for even more improvements. In 1989 this led to a complete overhaul of the camera design based on new technology and resulted in the presentation of the RMK TOP (ZÜGGE 1989). The basic design and the system configuration remained compatible with the cameras in use, but the electrical modules were redesigned to make use of microprocessors and computer-oriented handling

(TOP for "Terminal OPerated"). As their was no longer any demand for super wide angle (85 mm focal length) and narrow angle cameras (605 mm), only two camera bodies for wide angle (153 mm) and normal angle (305 mm) were designed.

The most important features of the new RMK TOP were:

- *Two significantly improved lenses Pleogon A3 4/153 and Topar A3 5.6/305,*
- *automatic optimisation of image quality by intelligent control of exposure time and lens stop,*
- *shutter now as pulsed rotating disc shutter with 50 msec constant access time,*
- *controllable internal filter revolver,*
- *programmable recording of auxiliary data and "flashed" fiducial marks,*
- *improved T-MC film magazine with extended FMC range,*
- *new gyro-stabilized T-AS mount,*
- *new microprocessor-based T-CU control module,*
- *new alphanumerical user terminal T-TL as main user panel,*
- *T-NT navigation telescope as modified NT 2.*

The RMK TOP system configuration with all components is shown in Fig. 7.29, and a typical in-flight setup in Fig. 7.30. The main T-CU control module contained the microprocessor and most of the control and power-electronics and was therefore especially cost-effective when using two of the now stripped-down camera bodies (e. g. the RMK TOP 15 and RMK TOP 30).

Fig. 7.30: RMK TOP 15 configuration with T-MC film magazine, T-AS stabilised mount, T-CU control unit and T-TL user panel at the T-NT navigation telescope

By thoroughly using BITE-functions (Built-In Test Equipment) the reliability of this computerised camera was ensured, occasional malfunctions or mishandlings were reported on the screen of the T-TL user panel. The centralised handling and supervision of the camera with this T-TL was supported by an alphanumeric key pad, soft keys and a high performance LCD display. There was no longer a need to handle the camera directly, except to exchange the film magazine or camera body. The T-TL terminal was placed near the operator, usually at the T-NT navigation telescope. The T-NT, which was developed by modifying the previous NT 2, now also made error messages visible by blinking of the moving splines of the intervalometer. Previous navigation equipment such as NS 1, NT 1, NT 2 and NA could be used with the RMK TOP, too. The NA was later replaced by an integrated T-NA module. Fig. 7.29 also shows the interface for importing external data such as positional data (e. g. from GPS or gyro systems) for navigation purposes and /or for recording in the terminal for later evaluation.

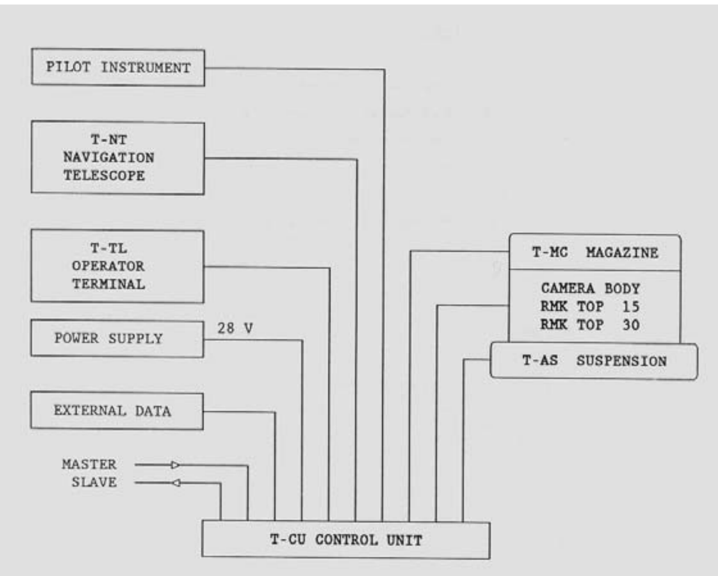


Fig. 7.29: RMK TOP system configuration (1989)

The stripped down camera bodies RMK TOP 15 and RMK TOP 30 were now smaller, and the previous wear and tear parts such as friction wheel and carbon brushes were replaced by wearless components. The sensor of the T-NA was placed close to the front lens as before (Fig. 7.31). And the compatibility between the new camera bodies and the previous mounts AS 2 and AS 5 was maintained, as well as with the previous film magazines CC 24 and FK 24.

Fig. 7.31: Sensor head of the NA automatic navigation near RMK TOP lens

Although the imaging performance of the RMK lenses PLEOGON A2 4/152 and TOPAR A1 5.6/305 had an outstanding reputation, the performance of the PLEOGON A3 and TOPAR A3 could be further increased (Fig. 7.32). The lift of the area weighted average modulation (AWAM) especially for high spatial frequencies is important for exploiting the potential of high resolution aerial films. The RMK TOP 15 as delivered confirmed a significantly improved image quality even in the image corner. By using the KODAK PANATOMIC-X film an area weighted average resolution (AWAR) of 100 line pairs/mm was achieved with the large apertures. A 100+ resolution was also regularly certified by the rigid testing at the US Geological Survey (LORCH 1991 & 1992).

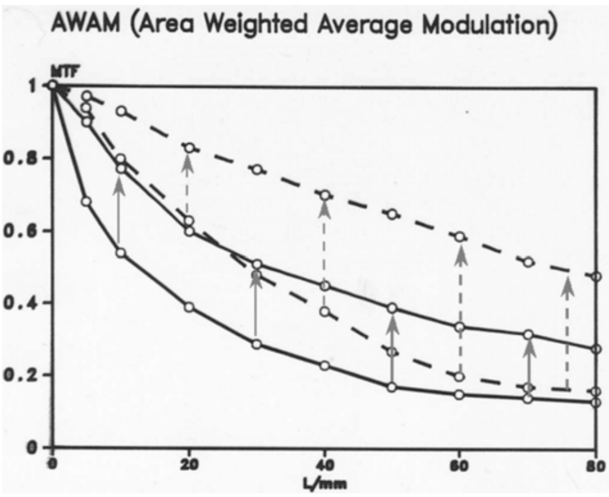


Fig. 7.32: Quality improvement of the PLEOGON A3 versus A2 at lens stops 4 and 5.6 (dashed)

A new feature of the RMK TOP lenses was the internal, terminal controlled revolving filter disc in the center of the lens close to the motorised diaphragm (Fig. 7.33).

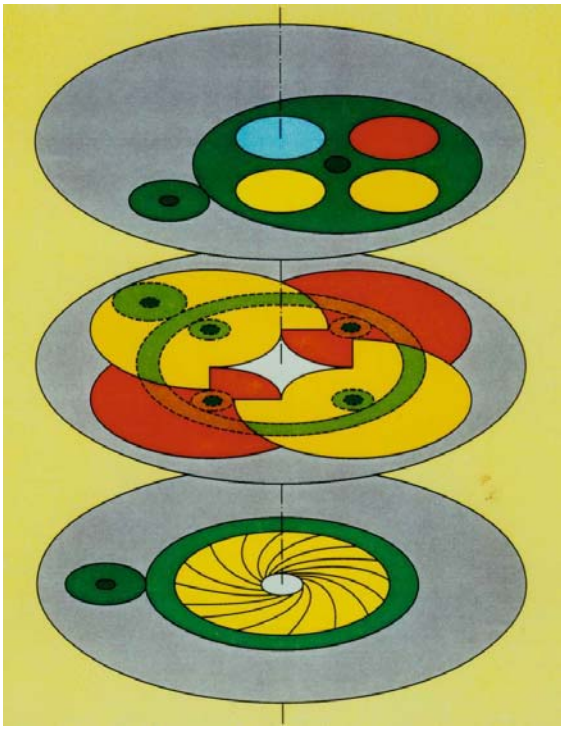


Fig. 7.33: Arrangement of internal filters, rotary disc shutter and diaphragm

The revolving filter disc contained up to four filters, usually the filters KL (clear), A2 (haze), B (yellow) and C (orange). The rotary disc shutter for the RMK TOP was modified into a "pulsed" shutter and patented (FELLE et al. 1988). The advantage of the start/stop mode was the constant access time of 50 msec between the release-signal and the real mid-point of exposure. This was especially important for pin-point photography (e. g. over the center of map sheets). With the earlier constantly rotating discs the access time varied with the rotation speed (being equivalent to the selected exposure time), and could last up to 1 sec. At the mid-point of the exposure a signal was generated, which was not only used for recording, and later referencing with the GPS and navigational data, but also for flash exposing the 8 numbered fiducial marks. Fig. 7.34 explains the arrangement of these fiducials and the auxiliary data. In addition to the 4-digit photo number in the image corner the ZEISS logo and the serial number of the magazine back plane were recorded. When using the new T-MC magazine a line the length of which represented the FMC movement was also recorded. A new programmable 2 x 48-digit matrix-display replaced the previous analogue auxiliary data such as altimeter, level, time, camera data and manual notes. This digital recording could be used for any kind of data about the system status or the project (Fig. 7.35). This sample photo shows the factory premises of CARL ZEISS in Oberkochen on a Saturday (October 26, 1996 at 1:40 p.m.), which explains the empty parking site.

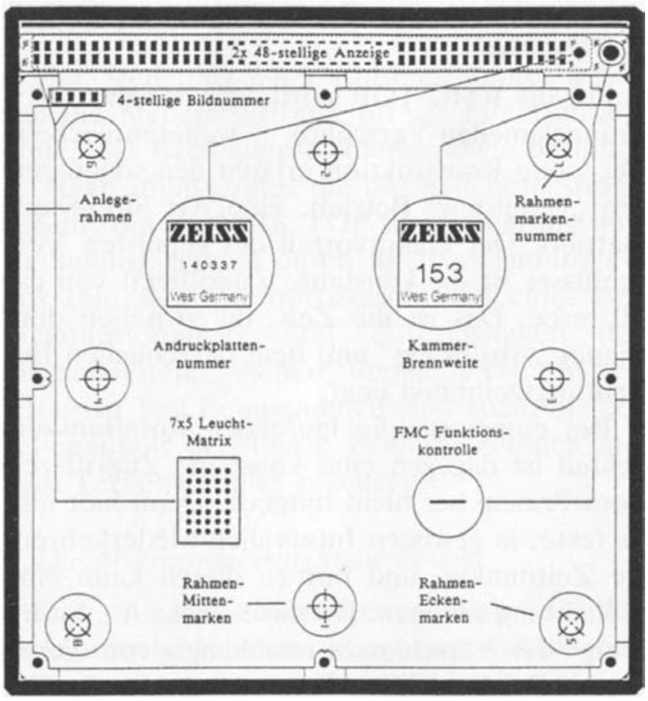


Fig 7.34: Arrangement of RMK TOP data recording

The T-MC film magazine was a further developed CC 24 with the compensation speed doubled to 64 mm/sec. With a sensor measuring the differential pressure the vacuum for the film flattening was now monitored at the terminal together with an indication of the quantity of remaining film which was sensed electrically.

An important new feature was the T-AS gyro-stabilised camera mount. Now image blur resulting from angular motion of the aircraft during the exposure could be widely compensated, thus allowing the exposure time to be extended for flying in poor light conditions. The T-AS was able to reduce the disturbing effect of angular motion down to 3 % of the usual value, and to keep the optical axis of the camera vertical within about 0,5°. The current attitude angle could be recorded for any exposure, which was required for later computing the excentricity vector between the camera entrance pupil and the GPS-antenna.

The T-AS in practice was not only used for the RMK TOP 15 and RMK TOP 30, but also with the Jena LMK 2000 and with other airborne sensors in aircraft as well as in helicopters. In 1996 an additional tilting device was presented for the T-AS, which made it easier to exchange external pre-lens filters, and which allowed a compensation of the aircraft trim of 2.5° or 5° (Fig. 7.36).

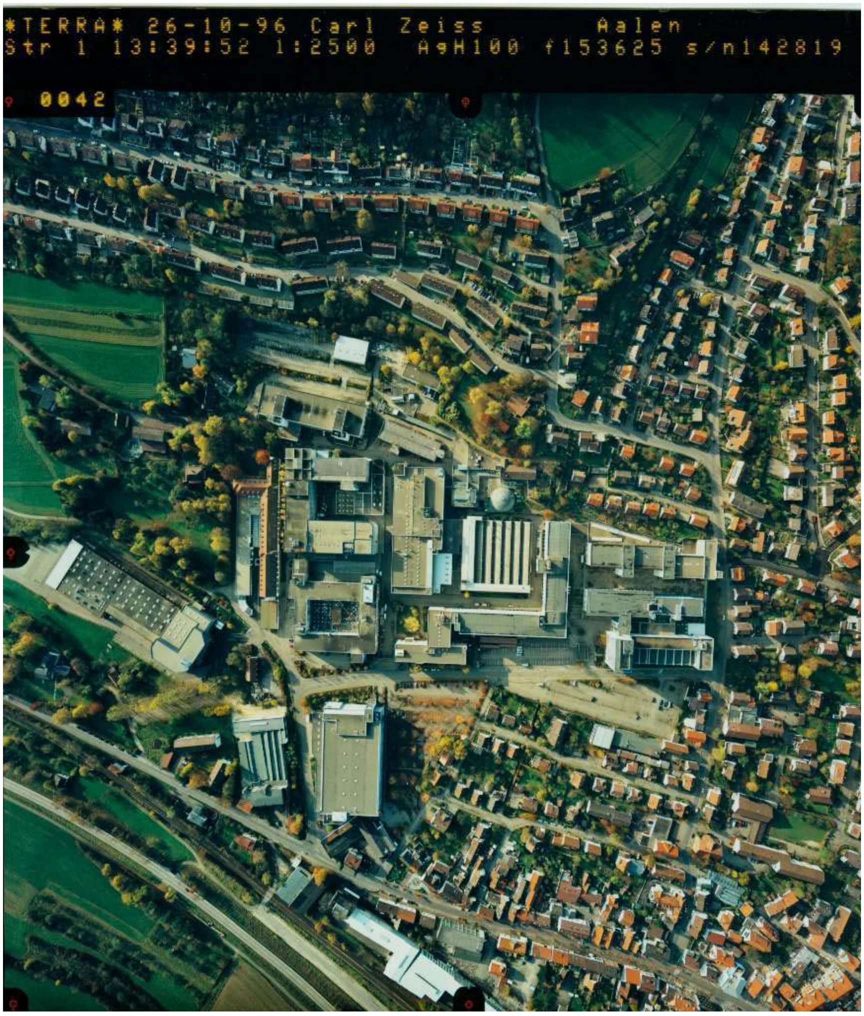


Fig. 7.35: RMK TOP aerial photo with auxiliary data (clipping)

Like the previous RMK versions, any RMK TOP out of series production had to undergo intensive environmetal testing. Fig. 7.37 shows the RMK TOP 15 during a test cycle in the ice chamber.

During the 50 years after World War II CARL ZEISS Oberkochen delivered more than 800 RMK cameras of the different versions. Of these 600 (¾) were wide angle cameras which dominated sales in later years. Together with the 1 760 aerial cameras from the Jena pre-war era this totals 2 500 ZEISS aerial cameras for civilian use. In addition before 1945 Jena had delivered another 6 000 ZEISS aerial cameras to the Deutsche Wehrmacht before and during World War II.

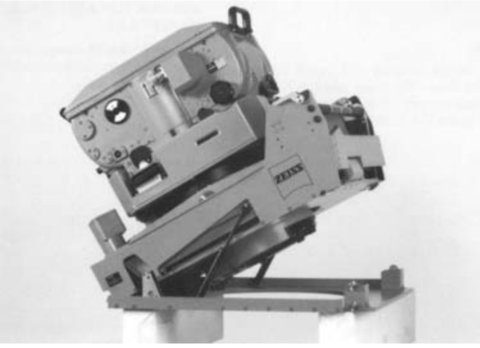


Fig. 7.36: T-AS tilting device of the RMK TOP (1996)

Fig. 7.37: RMK TOP in the cold

7.7 T-FLIGHT photo flight navigation

One reason for the computer-based handling and control of the RMK TOP introduced in 1989 was to ease the flight preparation and the processing of the recorded flight data by bringing the T-TL terminal to the office and connecting it to the office environment. For this way of "managing" the photoflight the product T-FLIGHT was presented with its full range of functions in 1991. This software package was developed and tested by MAPS GEOSYSTEMS in Munich and Sharjah, based on their own long term flight experience. T-FLIGHT consisted of three programs, which could be used individually if required. (LORCH 1991 & 1992):

- *T-PLAN photo flight planning,*
- *T-NAV flight navigation, camera control and automatic data recording,*
- *T-REP photo flight reporting.*

T-PLAN led through the planning phase of the photo survey and was usually used in the office in combination with AUTOCAD and a large graphical terminal. The flight parameters could be entered, the area to be covered defined and presentated in graphical form. The coordinates of the area boundaries could be defined and transformed from the geodetic system into WGS 84 which was necessary for GPS control. A detailed flight plan could be derived with coordinates for all flight paths and even for individual pin-point exposures.

T-NAV was the module for in-flight navigation and control. It was connected via an external interface with the T-CU control module of the RMK TOP and with the GPS receiver. It supplied information for the displays of the navigator / camera operator and of the pilot in dedicated layouts as common in aviation (Fig. 7.38). With T-NAV the exposures could be released by GPS-positions or by selected intervals. The exposure locations could be stored for later evaluation and/or recorded on film as part of the auxiliary data.

Back on ground or in the office, T-REP managed the evaluation of stored flight data (GPS, gyro and altimeter data) and the generation of tailored reports, including a map of the exposure locations. Fig. 7.39 shows the interaction of the various hardware and software components of RMK TOP and T-FLIGHT.

Fig. 7.38: T-NC navigation computer with touch-screen-display for the navigtor and with pilot's display

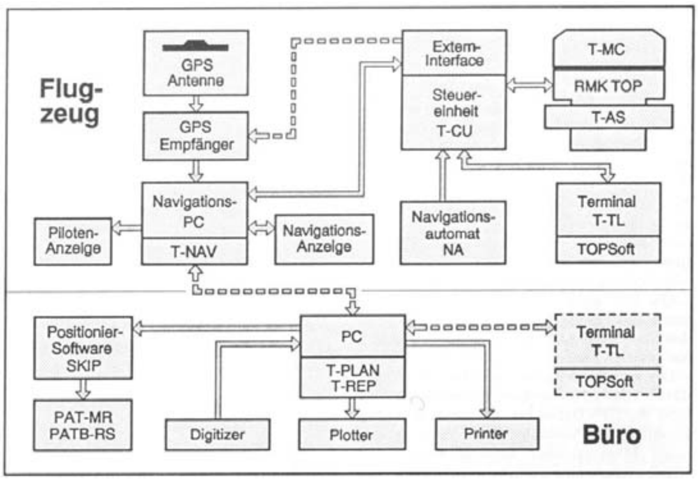


Fig. 7.39: Block diagram for the T-FLIGHT flight management system

With the additional SKIP program of INPHO GmbH. in Stuttgart very precise RMK positions for the mid-time of exposures could be computed based on in-flight GPS recordings. These positions could be used as additional observations for the projection centers in software for aerotriangulation such as PATB-RS and PAT-MR.

7.8 DMC digital modular camera

When introducing the computerised aerial "film" camera RMK TOP into the market in 1989, ZEISS also presented a first image scanner for the digitising of photogrammetric diapositives to support the increased demand for digital image processing (see chapter 12). Soon afterwards Oberkochen began research into the development of future digital cameras for various purposes. Although this work started in the early 1990s with first patent applications and functional models (CLAUS et al. 1991a & 1991b), the first public statements were not made until 1995 (CLAUS 1995). By this time users were already experimenting with the digital acquisition of aerial photographs (THOM et al. 1993) and in 1996 at the International Congress in Vienna ZEISS showed an adapter to the RMK mount to host up to four off-the-shelf digital cameras. After comprehensive market research, some of the results of which were later published (HEIER 1999), and after design studies (HINZ 1997) the kick-off for the "Digital Mapping Camera" development project was in 1996. The work led to several patent applications (TEUCHERT 1997, CLAUS et al. 1998, TEUCHERT et al. 2000, HÜLL et al. 2000), from which only a few were applied.

While the staff at Oberkochen were experts in the optical, mechanical and electronic aspects of a digital metric camera, the expertise of INTERGRAPH in the handling, processing and storage of large amounts of raster data was welcomed. INTERGRAPH in Huntsville/AL, USA was already a long-time partner in the field of analytical plotters (see chapter 11.4) and image scanners (chapter 12.1). With the official start of the joint venture Z/I IMAGING GmbH in Oberkochen on April 1st, 1999 (see chapter 16.5) this most important development project was continued with the same team members and in ongoing close cooperation with other departments within ZEISS and INTERGRAPH. At the Photogrammetric Week in Stuttgart in September 1999 the main aspects of the concept and configuration of the new Digital Modular Camera (DMC) was presented (HINZ 1999). After intensive work a prototype was first exhibited at the International Congress for Photogrammetry and Remote Sensing in Amsterdam in July 2000 (HINZ et al. 2000, HEIER et al. 2000, SCHROEDER 2000). The first test photographs were taken a few months later (HEIER et al. 2002), but it was not until 2002 that successful test flights were made over test areas with a complete DMC system. At this point the photogrammetric evaluation of the results demonstrated the expected high quality of the images and the maturity of the system and series production could begin.

The DMC is compatible with the ZEISS RMK A aerial camera system and therefore can be used by customers as an additional "digital camera body", Fig. 7.40 shows the DMC in a T-AS stabilised mount.

Fig. 7.40: DMC "Digital Modular Camera" from Z/I IMAGING GmbH, a joint venture of CARL ZEISS and INTERGRAPH (2002)

The DMC optics consists of four high performance lenses with 120 mm focal length and a largest stop of 1 : 4 for use in the panchromatic range, and with four additional lenses with 25 mm focal length and largest stop 1 : 4 for the colour channels. These lenses were all developed and are manufactured at the Jena premises of ZEISS. The two different camera heads (Fig. 7.41) each consist of the lens and a CCD-chip with connectors. The panchromatic cameras contain a 7 K x 4 K sensor matrix (Fig. 7.42), and the colour cameras use a 3 K x 2 K chip masked with a colour filter.

Fig. 7.41: Camera heads for the panchromatic (left) and for the colour channels (right)

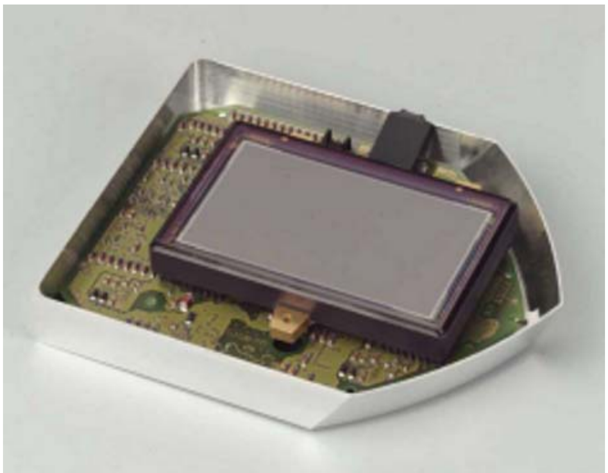


Fig. 7.42: CCD sensor matrix 7 K x 4 K

The CCD chips are high-sensitive full-frame-sensors with a high optical filling factor, supplied by PHILIPS in Eindhoven (HINZ et al. 2001). Pixel size is 12 µm x 12 µm and the dynamic range 12 bit, compared to the usual 6 bis 7 bit of the usual aerial film. Fig. 7.43 documents the enormous gain in contrast range within a shadow of high buildings taken at the ZEISS premises in Oberkochen in January.

Fig. 7.43: Gain in contrast range by CCD technology (10 bit) over film (sample)

The CCDs by design have readout registers at all four corners of the chip allowing a high readout rate. The clock-pulse generator and the chips for signal output are directly connected to the sensor-frame for optimising the signal-to-noise ratio (Hinz et al. 2000). All lenses are equipped with internal electro-mechanical shutters (1/50 sec - 1/300 sec), which are released synchronously. The CCDs are working in the time delay and integration mode (TDI) for image motion compensation, which for large photo scales results in a ground resolution of 5 cm or better.

The optical axes of the panchromatic camera heads are tilted for divergent viewing to allow a wider field of view. By marrying the four images using tie points in the overlapping area and resampling during the post-processing a single central perspective image with 13 824 x 7 680 pixels is generated, which fulfils the usual requirements in geometrical quality (TANG et al. 2000). The resulting aperture angle across the flight pass is 69.3°, which matches the wide angle aerial cameras such as the RMK TOP 15. The four colour camera heads are aligned strictly parallel and vertical and because of their shorter focal length cover the same foot print, but with less geometrical resolution.

Fig. 7.44 shows the bottom of the DMC with the inner four panchromatic and the outer colour lenses. The lens frame with the lenses in a raw condition is presented in Fig. 7.45, and the complete DMC with all electronics but without the housing is shown in Fig. 7.46. The overall system configuration within an aircraft is explained in Fig. 7.47, where the stabilised mount, the flight management system (from which also the DMC is operated), the RAID image storing system and an image display for immediate quality control of the digital images is also shown.

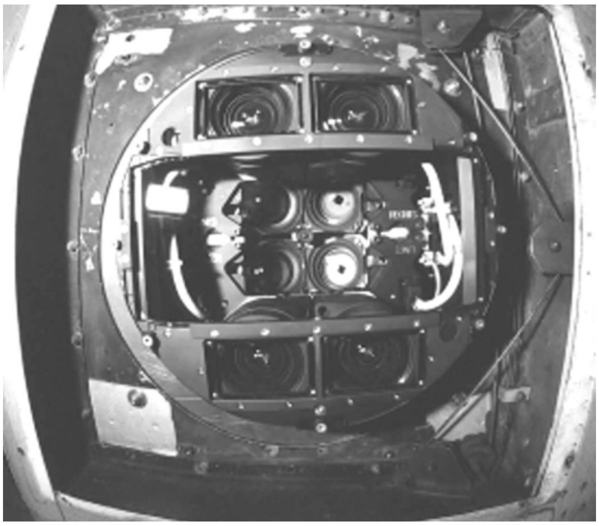


Fig. 7.44: View of the DMC lens configuration: 4 panchromatic camera heads in the center and 4 camera heads for red, green, blue and infrared

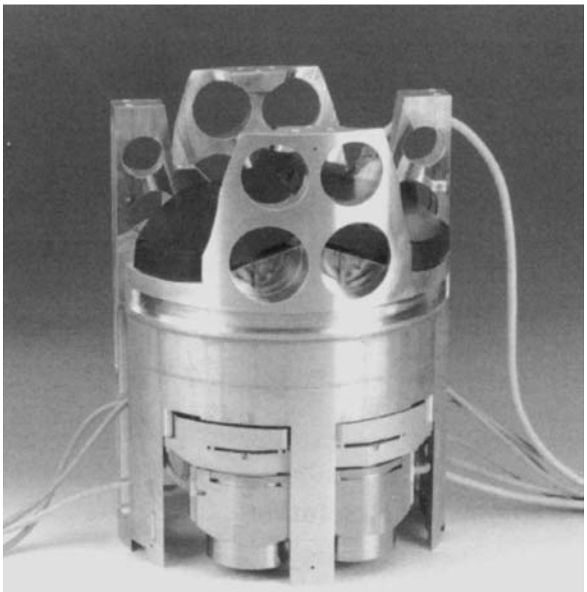


Fig. 7.45: Lens body (raw) with lenses

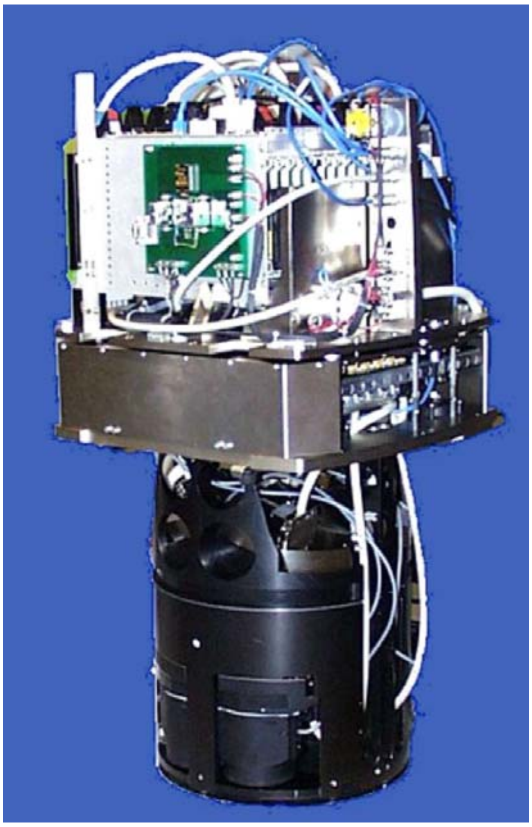


Fig. 7.46: *DMC optics and electronics (without cover)*

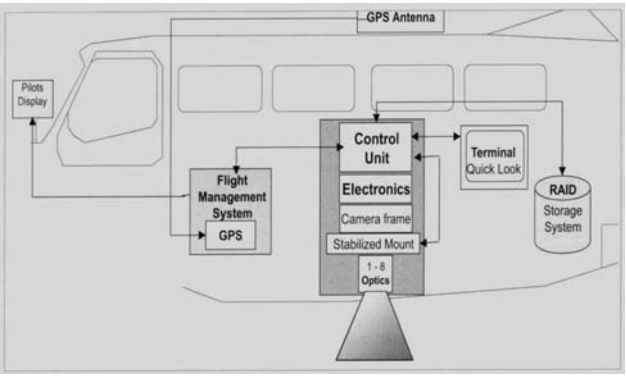


Fig. 7.47: *DMC system configuration in the aircraft*

Fig. 7.48: *DMC storage device (1st generation): MDR mass data recorder with 2 units with each 146 GB capacity*

The mass data recorder is equipped with two units each with 148 GB capacity (Fig. 7.48). With three of these storage devices usually on board, and with 272 MB of data for one "shot" at full resolution 2 000 images can be stored. This would be sufficient for most flying tasks. Due to the continuous progress in data storage technology the disc drives have been replaced by solid state discs, which are smaller, lighter, more robust and offer higher capacity.

After landing the storage devices are read in the office or at a facility near the airfield for further checking and preprocessing of the sensor data. The DMC pre- and postprocessing software consists of the following pre- and postprocessing working steps (HEIER 2001):

- *Normalisation of the raw images of all cameras (Level 1) by eliminating faulty pixels, radiometric correction (gain/offset), and further geometrical enhancement, if necessary and if correction data is available, → Level 1a,*
- *Generating virtual images by mosaicking of the panchromatic Level 1a-images and by transforming into central perspective images, → Level 2,*
- *Generating colour images (R + G + B) and the colour composites (Level 2-images +colour images),*
- *Computation of geo-referenced images by combimimng with GPS/INS-measurements, → preliminary orientation.*

This processing of the huge amounts of data is time-consuming, but it can be run automatically and in parallel.

Since the end of 2002 (and therefore after the complete withdrawal of CARL ZEISS from Z/I IMAGING) the DMC has been delivered out of series production. This digital aerial camera has proved its value to many customers in a large number of applications. Practical experience and many scientific investigations have shown, that the DMC outperforms the geometric quality of the RMK TOP despite the use of a lower base-to-height ratio. The better image quality, especially under difficult light and contrast conditions, and the immediate availability and further processing of the images are benefits of the DMC which can be fully exsploited. Although this has led to the production of aerial film cameras being stopped use of the available RMK cameras continues. This means that there is an ongoing demand for the regular maintenance, repair and certified camera calibration service for the RMK.

7.9 Camera calibration

Aerial metric cameras have to be calibrated not only before they are first delivered to customers but regularly every few years and after maintenance or repair when the camera geometry may have been affected. The calibration procedure for the RMK was developed by the photogrammetric R&D team in Oberkochen following the recommendations of the International Society for Photogrammetry during the 1960s. However, the calibration itself is executed at the ZEISS premises in Oberkochen by the separate and independent test laboratory of ZEISS on behalf of, and certified by, the PTB Physikalisch-Technische Bundesanstalt, the German Federal Bureau of Standards.

The two important, quality defining features of an aerial metric camera are the parameters and the accuracy of the central perspective camera geometry and the photographic image quality (MEIER 1970b & 1970c). The results are documented in a calibration certificate and delivered together with the camera (Fig. 7.49).

DEUTSCHER KALIBRIERDIENST (DKD)
Kalibrierstelle für Meßgrößen der geometrischen Optik
ANERKANNT UND ÜBERWACHT DURCH DIE PHYSIKALISCH-TECHNISCHE BUNDESANSTALT (PTB)

ZEISS
West Germany

Carl Zeiss
Zentralbereich Qualitätssicherung

Kalibrierschein
Calibration Certificate

00059
DKD 5202
Kalibrierzeichen
Calibration label
89-11

Gegenstand
Object
Aerial Survey Camera

Hersteller
Manufacturer
Carl Zeiss, D-7082 Oberkochen

Typ
Type
RMK TOP 15

Fabrikate/Serien-Nr.
Serial number
141 473

Die Kalibrierung erfolgt auf der Grundlage des zwischen der Physikalisch-Technischen Bundesanstalt und dem Träger abgeschlossenen Vertrages.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Physikalisch-Technischen Bundesanstalt als auch der ausstellenden Kalibrierstelle.

Kalibrierscheine ohne Unterschrift und Stempel haben keine Gültigkeit.

Fig. 7.49: Certificate (head) for the camera calibration at CARL ZEISS, Oberkochen, authorized by the PTB

Geometry and image quality are defined with the lens cone already assembled with the lens, the image frame and the fiducial marks.

In Oberkochen the image quality is determined with the "Schwenkkollimator", a panning collimator for photographic registration of the resolution being set up in a darkroom (Fig. 7.50). A so-called 3-line test is flashed onto a photo-sensitive glass plate in angular steps of 7° and in 4 directions. The structure of the 3-line-test consists of radially and tangentially oriented line-pairs with high and low contrast of decreasing width. By viewing the developed glass plate under a microscope the exposed images of the test-figure are checked for the smallest resolved line width. The result is presented in a diagram showing curves for the derived resolution values in line pairs/mm (lp/mm) as a function of the image angle, for any direction and as an average curve. Finally a single area weighted number, the AWAR (Area Weighted Average Resolution), as mean resolution value is calculated.

Also the coordinates of the fiducial marks are determined by photogrammetric exposure, measured and referenced to the computed center of the fiducials.

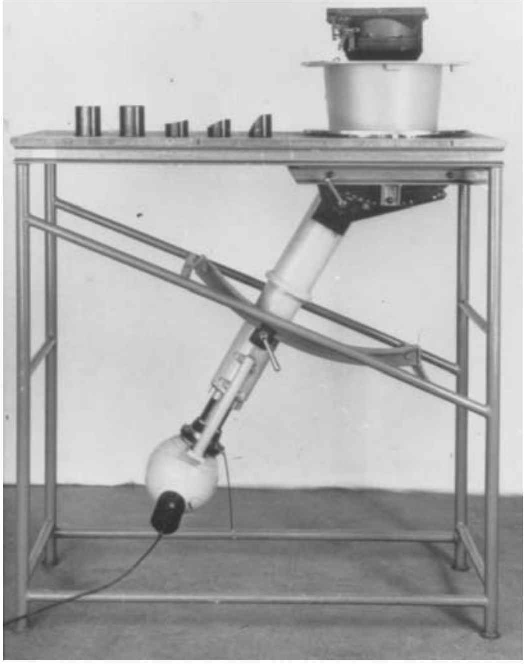


Fig. 7.50: Collimator for measurement of lens resolution at CARL ZEISS, Oberkochen

The internal geometry of the camera cone is determined through optical measurement with the use of a goniometer (Fig. 7.51). A very high precision grid plate with radial grid marks at 10 mm intervals is located and centered in the image plane. Looking through the camera lens onto the grid plate with a high precision theodolite the angle to all grid marks is measured along the four diagonals. By computing a spatial resection the effective focal length, known as calibrated focal length, can be determined. The differences between the nominal and real angles lead to the radial distortion values, which are then referenced to the point of symmetry.

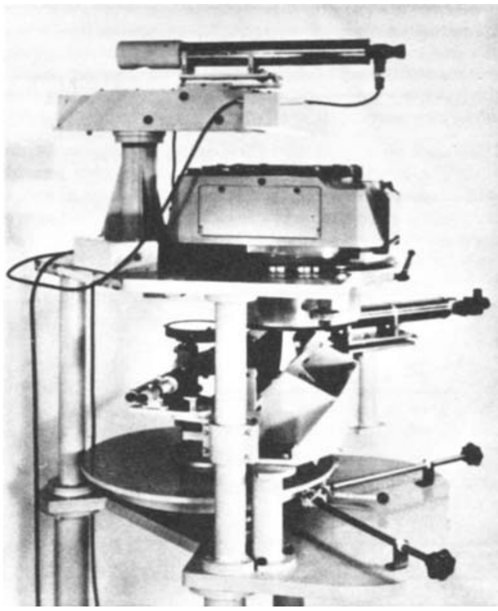


Fig. 7.51: Goniometer for measurement of lens distortion at CARL ZEISS, Oberkochen

For use in projects which demand very high accuracy the relative position of the point of symmetry and the point of autocollimation refered to the center of the fiducials is documented. The certificate also confirms that the optical surfaces of the additional optical filters are parallel within 5 arcseconds, and that the backplane of the associated film magazines is flat within 0,010 mm.

For the DMC the calibration procedure had to be modified due to the 8 single camera heads (Heier et al. 2002). The individual camera heads are calibrated in a similar process as described for the RMK. After assembly of all the camera heads into the DMC frame the determination of the overall DMC-geometry is done by a test and calibration flight over a well-equipped test area. For the computation of the relative orientation of the individual camera heads a matching procedure using tie points as known from aerial triangulation is used (Fig. 7.52).

Finally, it has to be mentioned, that Carl Zeiss in Oberkochen sometimes received orders for the delivery of optical camera windows. These were used for protecting the camera or for flying under pressurised conditions at high altitude. These glass plates always had to be tailored to a specific aircraft and had to be plane-parallel within about 5 arcseconds, like the external glass filters. With a diameter between 350 mm and 800 mm and a glass thickness of at least 40 mm these windows are challenging and high-class products. The thickeness ensured that the effect of minimal bending on radial distortion due to the difference in temperature and air pressure was negligible (Meier 1972c & 1978a).

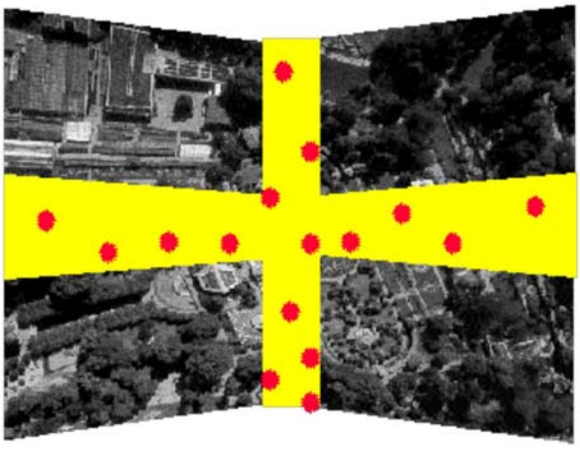


Fig. 7.52: DMC calibration of the relation between the panchromatic camera heads using tie points

8. Rectifiers & Orthophoto equipment

Before the first use of a stereocomparator and the following trials of line mapping with stereo images the rectification of aerial photographs was the only method of obtaining geometric accuracy better than simply sketching or mosaicking using the raw images. In 1898 Theodor Scheimpflug set the foundation of photo rectification by developing the idea of zonal transformation and by registering a patent for the Photoperspektograph in 1903. Although Ernst Abbe at Zeiss had studied the transformation of planes by 1890, the first self-focussing rectifier was not introduced until 1924 as the SEG C/2. This was followed the year after by the C/3 which became well-known as the "Dampfhammer" (steam hammer). Oberkochen presented the newly designed SEG V in 1951. With the introduction of the SEG 6 in 1977 and additional accessories in 1984 (as explained in chapter 5.2) the development of rectifiers was completed. The SEG series production ended in the late 1980s.

The first ideas for reducing the planimetric errors of rectification in hilly terrain by better terrain approximation (Fig. 8.1) were patented by A. Horn in 1916 and 1917. In 1929 Otto Lacmann presented a functional model for a "rectifier for rough terrain".

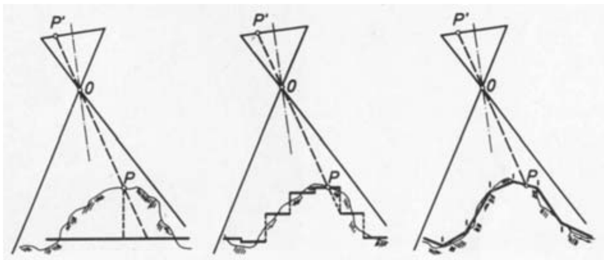


Fig. 8.1: Perspective transformation by rectification, digfferential and ideal rectification

After World War II it was Russell Bean, who in 1953 developed the Orthophotoscope in the USA. In Germany in 1960 Erwin Gigas, the then director of the Institute for Applied Geodesy in Frankfurt, convinced the photogrammetric scientists at Carl Zeiss in Oberkochen to put emphasis on this topic. While in the previous solutions the height positioning in the stereomodel and the projection of the related image area onto photgraphic film were done in a single instrument, Zeiss decided to allocate these two functions to two different instruments (Fig. 8.2).

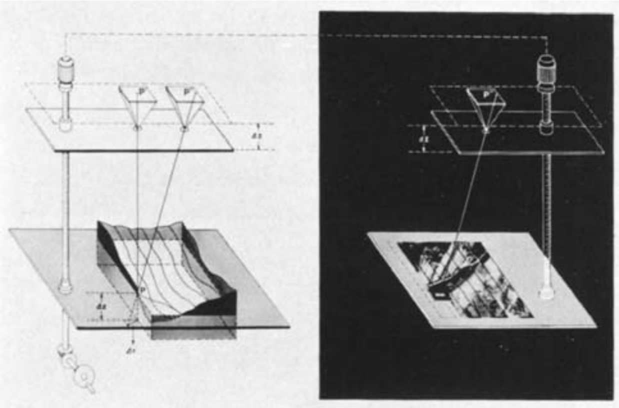


Fig. 8.2: Functional diagram for differential rectification by "objective optical projection"

8.1 GIGAS ZEISS orthoprojector (GZ 1)

The new "Orthophotoskop GIGAS-ZEISS" from CARL ZEISS was first announced at the Photogrammetric Week in 1963 in Karlsruhe (SPENNEMANN 1963), and the prototype of the GZ 1 GIGAS ZEISS orthoprojector was presented in 1964 at the International Congress for Photogrammetry in Lisbon (AHREND et al. 1964).

The GZ 1 orthoprojector unit consisted of proven components of the C 8 STEREOPLANIGRAPH: image carrier, optical autofocus system according to BAUERSFELD and directional illumination. All were mounted on a traverse being movable in height over a projection table (Fig. 8.3).

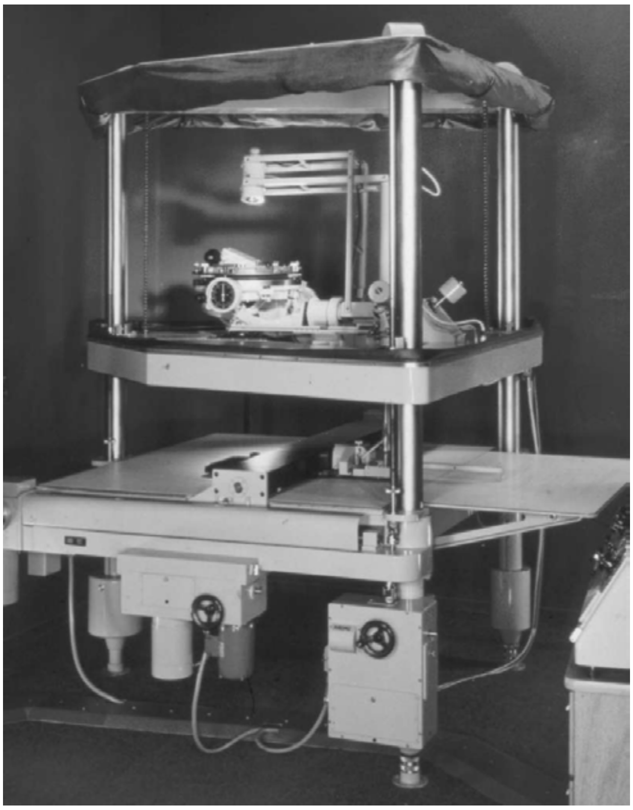


Fig. 8.3: GZ 1 Orthoprojector (1964)

The mechanical arm guiding the optics and the lamp was connected to the scanning slit carriage, which was meander-like moved in y-scanning direction and stepped forward in x-direction. After insertion of the photograph into the image carrier and setting of φ, ω und κ the image space was closed with a light-tight curtain. The orthoprojector unit had to be sited in a darkroom as the photo sensitive film sheet had to be positioned on the open table.

The special advantages of the GZ 1 compared to competitive solutions at that time were the autofocus system guaranteeing image sharpness over the whole magnification range, higher illumination and the possibility of producing colour orthophotos The latter was not possible with online-instruments where stereoviewing was achieved by using anaglyphic filters.

The parameters of the GZ 1 orthoprojektor were:

- *Focal lengths for the 230 mm x 230 mm image format: 153 mm standard, 210 mm and 305 mm optional, optional for the 180 mm x 180 mm image format various focal lengths beween 100 mm and 210 mm as available for the C 8 STEREOPLANIGRAPH,*
- *image angles: φ, ω each ± 10 gon, κ = ± 400 gon,*
- *size of projection table: >1 m x 1 m,*
- *usable projection area: x = 750 mm, y = 880 mm,*
- *z-range: from 335 mm to 620 mm, resulting in 2.2x to 4.0x magnification range at c = 153 mm,*
- *slit length (step width in x): 4 mm standard, 8 mm and 2 mm optional, (slit width: 1 mm),*
- *scanning speed in orthophoto-scale: between 2.5 mm/sec and 10.0 mm/sec selectable by gear change,*
- *synchromotor for very constant y-speed,*
- *high performance stepping system for precision-stepping.*

Super wide angle images had to be entered into the wide angle image carrier. This led to an affine deformation and, for inclined photographs, to planimetric and height errors (Fig. 8.4). However, it was shown, that the x,y accuracy would not be affected, if the camera axis was vertical within the usual 2 to 3 gon, and if the height differences of the terrain were within 5 % of the flying height, which was usually the case for super wide angle projects due to the small photo scales (HOBBIE 1969a).

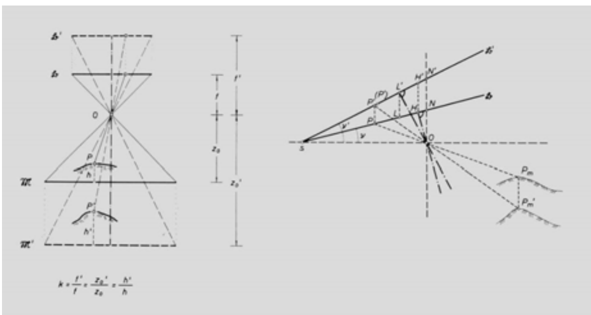


Fig. 8.4: Affine projection, vertical and oblique

In a similar way normal angle aerial photos (f = 30 cm) could be inserted into the 15 cm-carriages, resulting in doubling the magnification range. The deformations were even smaller than in the super wide angle case, beause of the model compression. Doing so required a respective gear change in the z-drive.

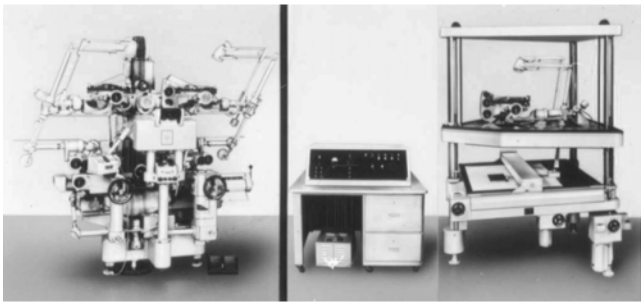


Fig. 8.5: C 8 STEREOPLANIGRAPH and GZ 1 orthoprojector (with program desk) connected on-line

The GZ 1 orthoprojector directly connected to the C 8 STEREOPLANIGRAPH was first presented at the Lisbon-Congress (Fig. 8.5). In this mode the GZ 1 was driven by a servomotor with a very constant y-speed, which could be selected by change gears. The x-positioning was realised by a special stepping-system with an accuracy of 1 to 2 µm. This meander-type scanning was transfered to the stereoplotter via synchros, which allowed both instruments to be placed in different rooms. The synchros, consisting of a stator and rotor similar to a regular motor, transferred a mechanically generated twist of the first synchro electrically to the second one, there causing an identical twist (Fig. 8.6). In the same way the manual height changes of the operator at the stereoplotter were transferred to the z-axis of the GZ 1.

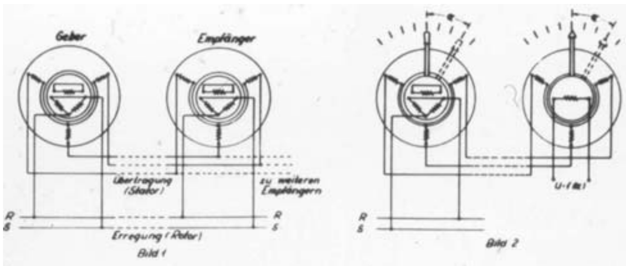


Fig. 8.6: Functional diagram of a synchro connection

The disadvantage of all brands of orthophoto producing instruments working "on-line" was that the operator had to work with the selected constant speed in flat as well as in hilly terrain. Errors could not be corrected but required a restart from the beginning, and breaks, if taken at all, could only be taken at the end of a strip. Therefore in 1964 ZEISS announced the preparation of an off-line mode, where in a first step the stereoscopically measured terrain profiles would be stored by engraving on coated glass plates, which later in a second step would control the projection distance of the GZ 1 (Fig. 8.7).

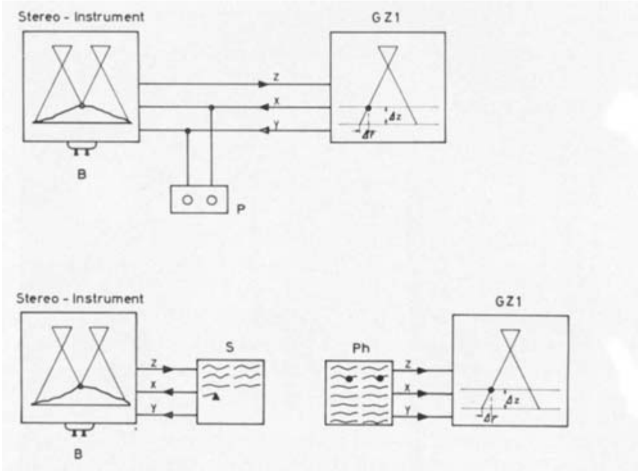


Fig. 8.7: Profile recording separate from orthoprojection (on-line versus off-line mode)

The many advantages of this separation soon resulted in a fading interest in the on-line mode. The advantages of this new and patented ZEISS solution (MONDON 1963) for the off-line version of the GZ 1 orthoprojector were:

- *Orthoprojection in the GZ 1 at highest speed, but profile measurement with a variable speed appropriate for the terrain, even a stop or break was possible,*
- *a profiling error could easily be overcome by moving back, correcting the wrong part with special ink and by repeating the profiling in that section,*
- *because orientation and profile measurement at the stereoplotter took much more time than orientation and the automatic projection at high speed in the orthoprojector, several stereoplotters could feed one GZ 1,*
- *with (patented) profile interpolation and smaller scanning steps a better terrain approximation with less mismatches was achieved, without increasing the manual profiling time at the stereoplotter,*
- *the stored profiles could be re-used for later map revision from a new photo-flight, if no major terrain changes had occured (SCHMIDT-FALKENBERG et al. 1969, ARCH et al. 1974).*

Although first announced in 1964 it was 1967 before the SG 1 storage unit for engraving the profiles and the LG 1 scanning unit for reading these profiles were completed. Fig. 8.8 shows the SG 1 connected to the then new D 2 PLANIMAT (chapter 10.3). The adjustable y-scanning speed and the stepping with either Δx = 2, 4 or 8 mm at the stereoplotter (D 2 or C 8 or any other screw-driven instrument) was driven by motors within the SG 1 and transferred to the neigbouring stereoplotter by cardan shafts. In the same mechanical way the manual height-change of the operator was transferred to the storage unit but reduced in scale by 1 : 5. The profiles were scribed by two rotating styluses, which alternately engraved consecutive profiles onto the black coated glass plates. These plates could accomodate up to 80 profiles each of 104 mm in length (Fig. 8.9).

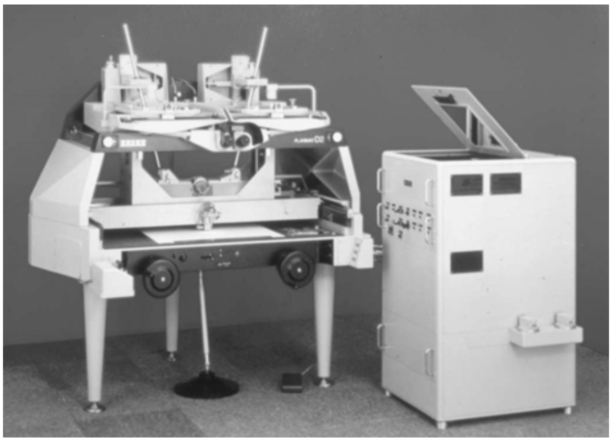


Fig. 8.8: D 2 PLANIMAT with SG 1 storage unit (1967)

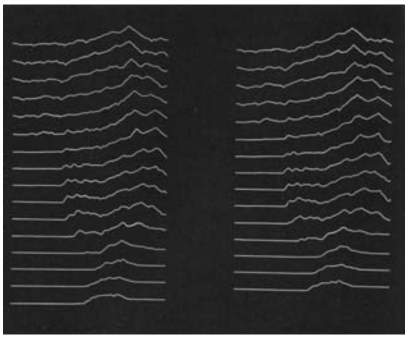


Fig. 8.9: View of a profile storage plate (clipping)

The LG 1 scanning unit controlled the program sequence of the projection within the GZ 1 orthoprojector (Fig. 8.10). The precision stepping system of the GZ 1 was actuated electrically from the LG 1. The scanning speed at the orthoprojector, being 10 mm/sec or 12 mm/sec depending on the 50 Hz / 60 Hz supply frequency for the GZ 1 servomotor, was transferred to the LG 1 by cardan shafts and reduced by the factor of 10. The movement of the z-motor at the GZ 1 was transferred in the same way, but the motor was controlled from the LG 1. The height changes of the scribed profiles could be enlarged either 5- or 10-times by gear change.

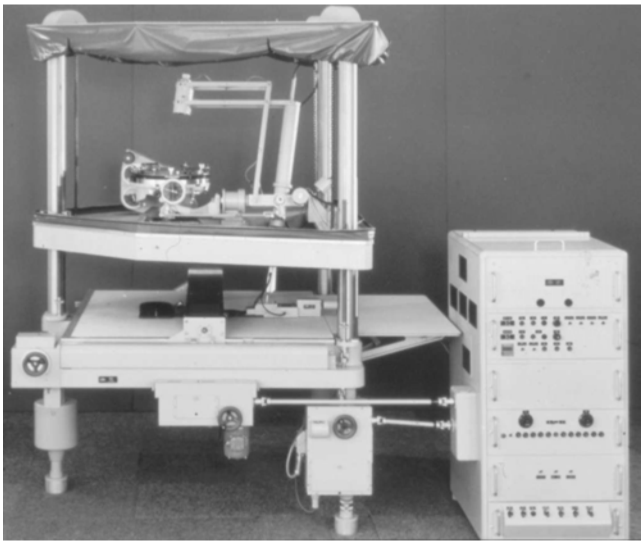


Fig. 8.10: GZ 1 orthoprojector with LG 1 scanning unit

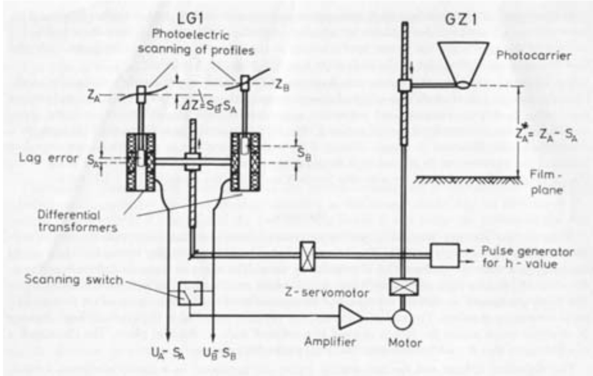


Fig. 8.11: Diagram of profile reading principle in the LG 1

The principle of the simultaneous photoelectric sensing of two consecutive profiles in the LG 1 and the transfer to the GZ 1 is shown in Fig. 8.11. Only one profile at a time is used for z-guidance. With up to 80 profiles stored each with 100 mm maximum readable length, the resulting greatest orthopho size covered by one storage plate was x = 632 mm (79 scanning paths of 8mm width maximum) and y = 500 or 1 000 mm with 5x or 10x enlargement. For exploiting a full aerial image in the x-direction usually a second storage plate was produced by profiling a consecutive stereomodel in the plotter, which during projection would then be inserted after having scanned the first plate.

Fig. 8.1 and Fig. 8.12 explain why there are steps in terrain approximation of hilly terrain at the scan edges resulting in gaps and mismatches in the orthophoto at greater image angles. To avoid this happening the LG 1 was equipped to read parallel neighbouring profiles. A patented electrical interpolation (MONDON 1963) between these profiles allowed the original step width to be divided into smaller scanning paths to reduce the mismatches. According to the interpolation values 1/2, 1/3, and 1/6 a smaller slit and stepping width had to be selected, and the extra time required for the automatic scanning had to be accepted.

8.2 Optical interpolation for the GZ 1

To avoid this extended projection time and any mismatches, Oberkochen introduced the O-INT optical interpolation unit for the GZ 1 in 1969 (Fig. 8.12).

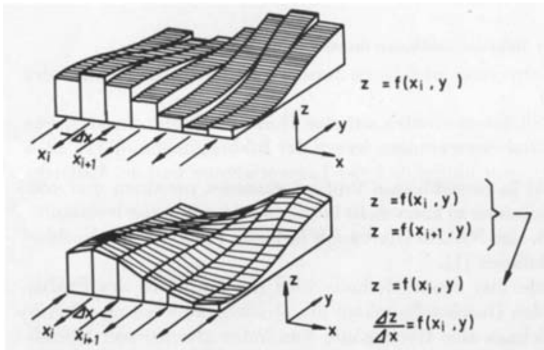


Fig. 8.12: Quality of terrain approximation

For avoiding mismatches at the scanning edges completely, the image has to be projected on to an inclined surface which defines a cross section of the terrain slope at the position of the scanning slit instead of projecting onto the horizontal film directly. The problem to be solved is to generate such an inclined projection surface and then to transfer the image strictly vertically down to the film. ZEISS solved this problem in cutting a toric ring out of an optical plate with parallel glass fibres (Fig. 8.13). This fibre ring was arranged over a plane-parallel fibre plate containing a chrome-plated slit mask, and it was rotated by a servo drive according to the local cross slope as derived from the two neighbouring profiles.

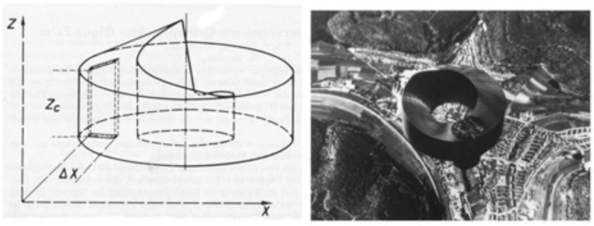


Fig. 8.13: Optical interpolation by a ring of fibre optics

In contrast to the well-known fibre optic waveguides for illumination with unsorted fibres these fibres were arranged strictly parallel. The 6 µm-wide fibres facilitated an image resolution of >80 line pairs/mm, which was more than sufficient when related to the scale of the orthophoto (HOBBIE 1969b). The maximum cross inclination of the ring was 35°, the infrequent steeper terrain slopes were corrected for 35°, which was an improvement over not correcting at all. The ring drive consisted of a motor and a potentiometer (Fig. 8.14).

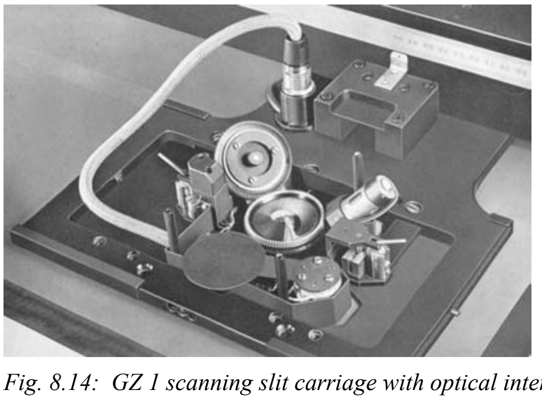


Fig. 8.14: GZ 1 scanning slit carriage with optical interpolation device and swinging shutter (without cover)

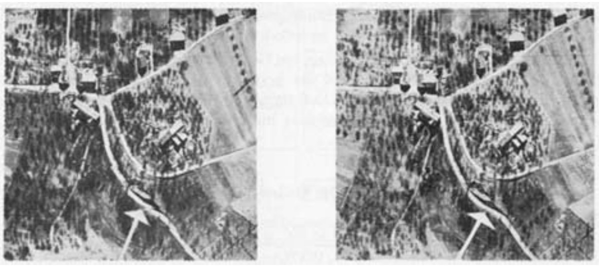


Fig. 8.15: Image improvement by optical interpolation (clippings with and without mismatches)

Fig. 8.15 shows the improvement of using O-INT on a road along a terrain slope. This unique and patented feature for the GZ 1 (MONDON 1965) became a standard accessory for this orthoprojector from ZEISS.

8.3 Mapping terrain height with the GZ 1

By 1958 there were US-reports about "dropped dots" and "dropped lines" as a by-product of orthophoto-generation, representing the scanned terrain model. Following this idea a HS ("Höhen-Schraffen") dropped line attachment for the GZ 1 was developed and patented (MONDON et al. 1966). For the use of HS the projection table was extended to accommodate a second sheet of film, on which an additional projection head produced a partial image of a symbol disc T (Fig. 8.16). This disc was connected with the z-screw via change gears $Ü_{HS}$ and synchros D_{HS} (MEIER 1966a). The result was a straight line along the scanning path, of which the width changed at selected height intervals. By combining the width changes of neighbouring scans, contour lines could be derived manually (Fig. 8.17).

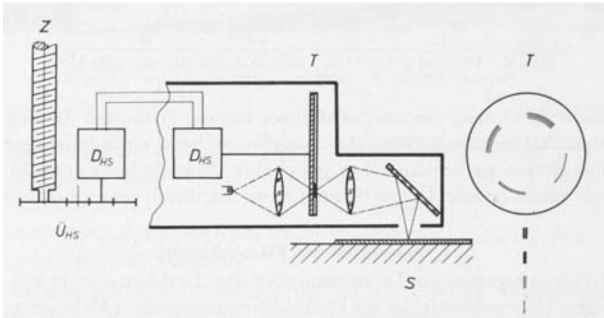


Fig. 8.16: Diagram of the HS dropped line attachement

Fig. 8.17: HS dropped line output of the GZ 1, partly with manual derived contour lines

Three years later in 1969, together with the previously described O-INT optical interpolation, the HLZ electronic contourliner was introduced (FELLE et al. 1969). With this patented solution (FELLE et al. 1966) an encoder attached to the GZ 1 z-screw defined the contour levels. The model heights at the two ends of the scanning slit, z_A and z_B, were available as electric voltage from the two scanning heads of the LG 1 (Fig. 8.11). By calculating $\Delta z/\Delta x$ with the known scan width the slope inclination was also available. The comparison of this slope value with the encoder-defined z-scale was fed into a small cathode ray tube, of which the flying spot was lightened at the position of a contour line only. The screen, masked except for a scanning slit, was optically projected onto the film (Fig. 8.20). The adjustment of the flying spot could be done at the 3 cm-screen after opening the projection head.

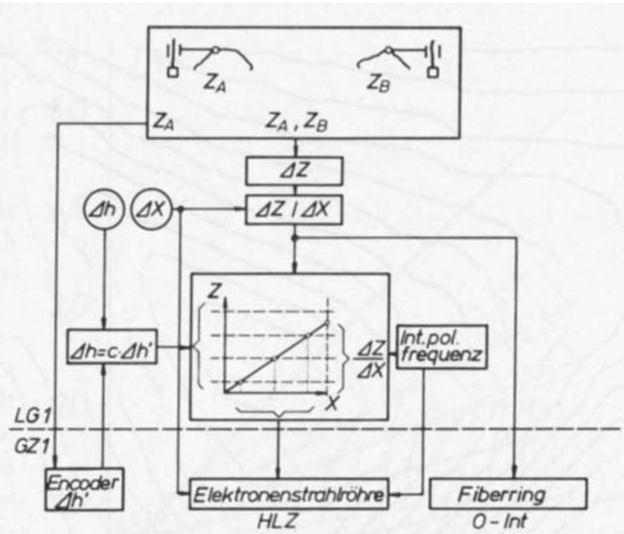


Fig. 8.18: Diagram of generating the control signals for O-INT and HLZ electronic contour liner

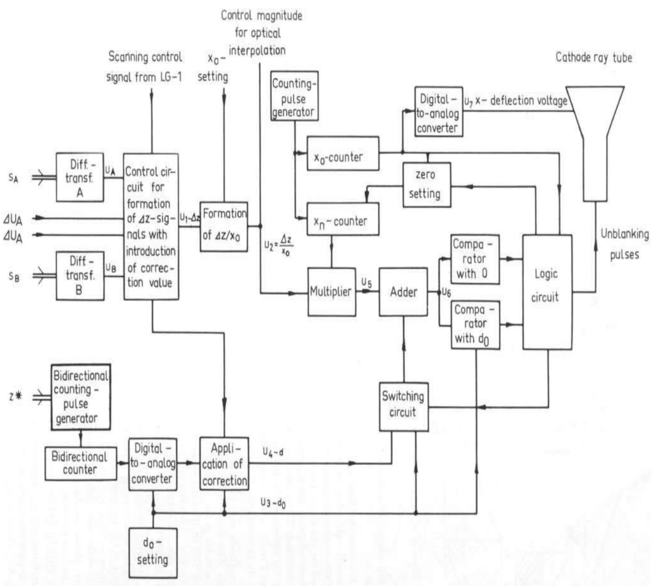


Fig. 8.19: Diagram of the HLZ electronic contour liner

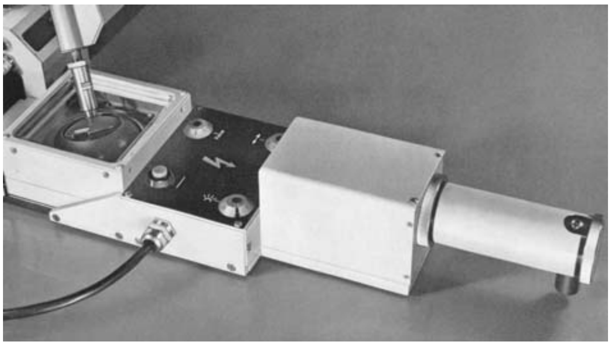


Fig. 8.20: Projection head of the HLZ contour liner

The HLZ control unit and the buttons for setting the necessary parameters were housed in an additional drawer in the lower part of the LG 1 (Fig. 8.10). Before starting a job the operator had to set, at the scale of the orthophoto, the scanning width Δx and the contour interval Δz. With the 6 standard steps 0.4 / 0.5 / 0.625 / 0.8 / 1.0 and 1.25 mm most of the usual height intervals in meters or feet were possible (MEIER 1970f). Every second, fourth or fifth contour line could be emphasised (Fig. 8.21).

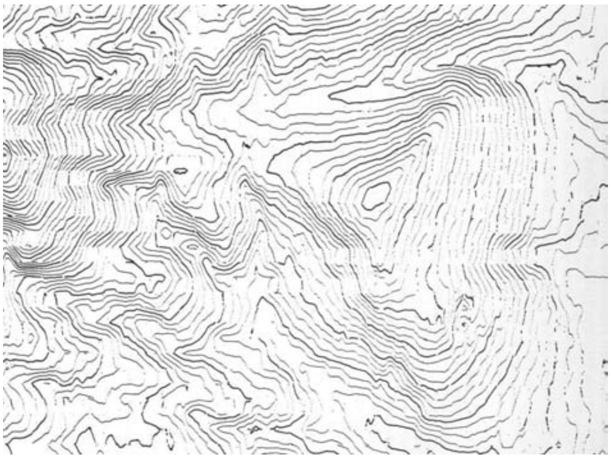


Fig. 8.21: HLZ contour line map of the GZ 1 (clipping)

The geometric and graphical quality of this byproduct did not meet the grade of manually plotted contour lines, but for many customers these contour plans were most welcome in open and undeveloped areas (HOBBIE 1970a).

By 1982 over 60 GIGAS-ZEISS orthoprojecton system had been installed of these about 2/3 were working in the off-line mode generally with three stereoplotters feeding one GZ 1 with profile data. This configuration was a valuable tool and a great success especially for customers with high demand and a huge production volume. Many users have reported their experiences, e. g. about accuracy (MEIER 1966b, ACKERMANN et al. 1969, SCHNEIDER 1969, NEUBAUER 1969a & 1969b), applications (WINKELMANN 1969, KERSTING 1969, STROBEL 1969) and efficiency (MEIER 1970d, BRUCKLACHER 1970a, FORSELL 1969).

8.4 EC 5 correlator from ITEK

During the conceptual work on the GZ 1 orthoprojector, and when introducing the on-line version in Lisbon in 1964, it was already clear, that manual profiling for orthophoto generation was a stupid and tiring job, even in an off-line mode. So, right from the beginning an interest in automating the generation of the necssary height information arose and was encouraged by GILBERT HOBROUGH's invention of an "automatic stereoplotter" published in 1959 and the announcement of the STEREOMAT in 1960. Also in Lisbon WILD, Heerbrugg had shown a B 8 AUTOGRAPH modified for the STEREOMAT from HUNTING Co., Toronto and AUTOMETRIC Corp., New York.

Therefore CARL ZEISS, Oberkochen started a joint development with the ITEK Corporation, Lexington, MA/USA with the goal of developing an automatic stereo correlator for the newly introduced (1967) PLANIMAT (see chapter 10.3) from ZEISS. ITEK had already gained experience with the development of the automatic stereoviewer ARES. At the International Congress for Photogrammetry in Lausanne in 1968 the EC 5 Electronic Correlator was presented attached to the D 2 PLANIMAT (BRUCKLACHER 1968 & DÖHLER 1968). The automatic off-line recording of profiles with the SG 1 storage unit for use in the GZ 1 control was demonstrated (Fig. 8.22).

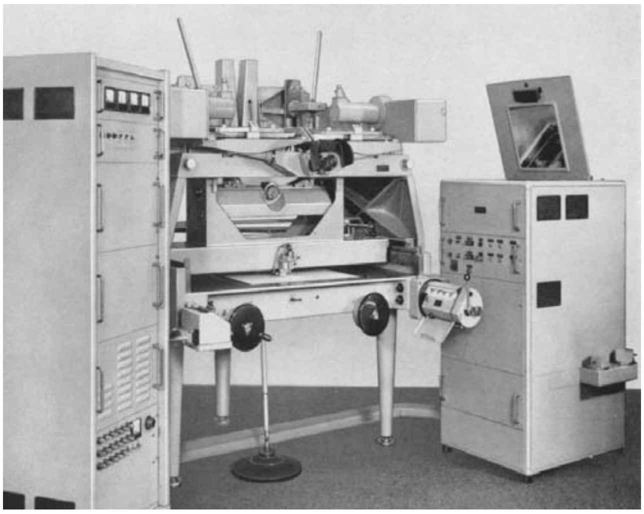


Fig. 8.22: PLANIMAT with SG 1 storage unit and EC5 electronic correlator from ITEK

As in the manual profiling mode the meander-type planimetric advance was contolled by the SG 1, but the height changes were now made by a motor drive, which was controlled by the EC 5 correlator. Two flying spot scanners, which were connected to the optics of the PLANIMAT on the left and right side, were scanning the corresponding image detail (Fig. 8.23).

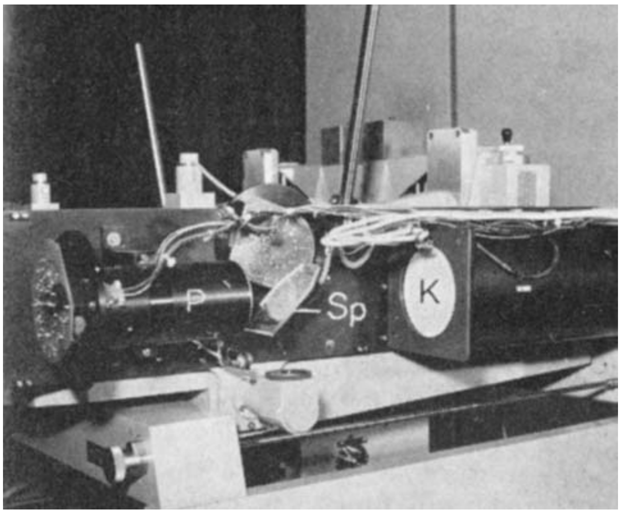


Fig. 8.23: EC5 electronic scanning unit at the right image carrier of the PLANIMAT

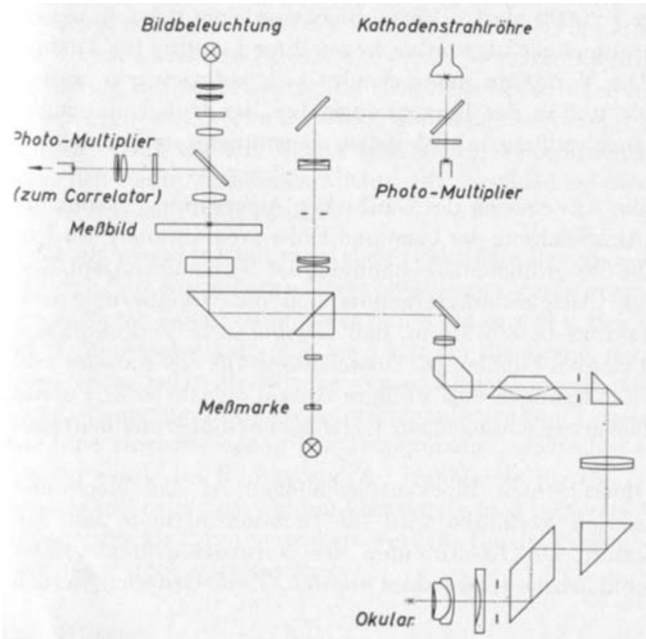


Fig. 8.24: Schematical diagram of the PLANIMAT optics with the EC 5 correlator

The optical diagram for the PLANIMAT in Fig. 8.24 shows the connection to the flying spot generating cathode ray tube and to the ray sensing photo-multiplier by dichroitic mirrors. By this arrangement the operator could view the automatic correlation process through the binoculars.

For reducing the usual instabilities of the cathode ray tube the image of the scan-raster within the aerial photo was reduced by a factor of 10. An additional photomultiplier close to the tube controlled the constant illumination of the flying spot. This scan-raster was shaped like a rhomb (Fig. 8.25). Signal processing took place in the electronics housed in the correlator cabinet, which was placed on the left side of the PLANIMAT (Fig 8.22).

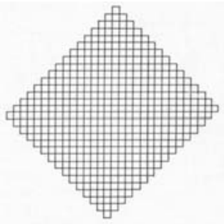


Fig. 8.25:
Shape of the EC 5 scanning pattern

Before correlation the video signals modulated with the image information were corrected for distortion arising from x- and y-skew, for x- and y-scale difference and for x- and y-parallax (Fig. 8.26). The x-parallax determined the height change to be executed by the z-servomotor (HARDY et al. 1969). Fig. 8.27 shows the schematic diagram of the EC 5 electronics.

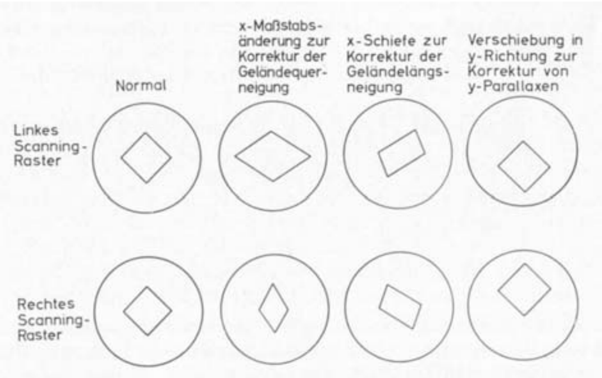


Fig. 8.26: Perspective distortion of the scanning pattern for fitting with the stereo images

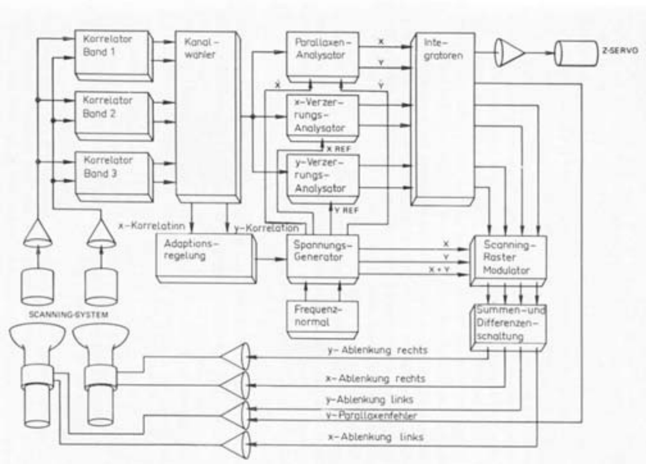


Bild 8.27: Schematic diagram of EC 5 electronics

The ITEK correlator could also be used by the operator for the manual preparation phase, e. g. for clearing the x-parallax during the model orientation (while the operator would clear the y-parallax by the respective orientation element), or for keeping the floating mark on the ground when travelling through the oriented stereomodel. But the primary use was of course the automatic profiling. In case of a loss of correlation during the scan, which could happen to all known correlators where there was poor image texture, the active stylus of the SG 1 would be lifted automatically and while travelling with failing correlation a line would be plotted on the internal tracing table of the PLANIMAT. In this way the operator knew where to repeat and fill the correlation gaps manually after the automatic scan.

The accuracy of the EC 5 correlator was tuned to the static precision of the PLANIMAT, resulting in a parallax as precise as $\pm$ 3 µm. At that time the typical resolution of aerial images was about 25 line-pairs/mm, the finest resolved structures then being not smaller than 20 µm. Comprehensive tests were undertaken (HARDY 1970) which confirmed that the EC 5 correlator achieved a height accuracy of 0.1 ‰ of flying height (static) and 0.2 to 0.3 ‰ (dynamic) which was as good as a human operator.

Nevertheless with just half a dozen installations the success of the EC 5 image correlator from ITEK was rather limited, as were all the other analogue correlators of the 1960s to 1980s. For later activities of CARL ZEISS Oberkochen in the field of automatic image correlation see chapter 11.3 (InduSURF).

8.5 ORTHO-3-PROJECTOR

In Lausanne in 1968 ZEISS Oberkochen not only introduced the ITEK correlator as the "high end" of orthophoto equipment it also presented a new "low end" device, the ORTHO-3-PROJECTOR (O-3-P). After an extremely short development time of three months a functional model was brought to the ZEISS booth after the Lausanne exhibition had already been opened. The O-3-P was derived from the DP 1 double projector, which was introduced the year before at the Photogrammetric Week (see chapter 10.2), by adding a third projector at the back of the instrument (Fig. 8.28).

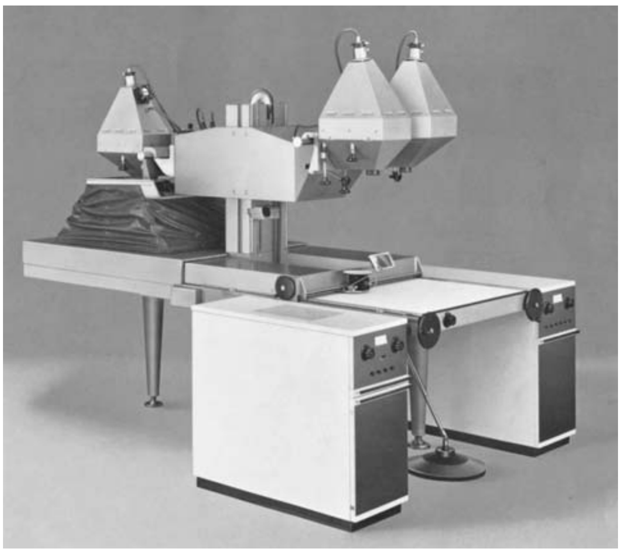


Fig. 8.28: ORTHO-3-PROJECTOR

A copy of the left stereo image was inserted into this additional image projector which, like the two front projectors, was mounted on the z-carriage, which moved up and down according to the terrain height changes while scanning. An xy-carriage carried the small projection table with an illuminated floating mark at the front end within the stereomodel area and the exposure slit in the rear over the projection surface, where the film had to be placed under a curtain. Whereas in the front the entire stereo images were illuminated with Fresnel lens condensors, for the third projector light from an air-cooled halogenlamp with reflector and aspheric double condensor was focused onto the slit mask. The magnification range was limited by the depth of focus (HOBBIE 1970b).

The important parameters of the O-3-P were:

- *Range of magnification: 2.5x (2.0x optional),*
- *focal length: 153 mm,*
- *usable image format: 140 mm x 230 mm,*
- *usable output format: x = 580 mm, y = 980 mm,*
- *image angles:* $\varphi = \pm 6$ *gon,* $\omega = \pm 6$ *gon,* $\kappa = \pm 6$ *gon,*
- *common* φ*:* $\eta = \pm 6$ *gon,*
- *bx: 130 mm - 325 mm,*
- *exposure slits: 1mm x 4 mm and 1mm x 2 mm standard,*
- *scanning speed 1.7 / 3.3 / 5.2 and 10 mm/sec,*
- *for other technical data see DP 1.*

With its basic design principle the ORTHO-3-PROJEKTOR was intended mainly for training and for simple orthophoto production, but it could also be used as a DP 2 double projector. The O-3-P was manufactured at the HENSOLDT premises in Wetzlar on behalf of ZEISS Oberkochen between 1971 and 1980. About 50 instruments were delivered worldwide.

8.6 Z 2 ORTHOCOMP

When in 1971 the basic development of the GZ 1 system and its accessories came to an end, first ideas of a follow-up development were already being discussed internally. The studies dealt with the fundamental questions of the increasingly popular orthophoto maps and their production. The general findings were soon incorporated and published in a doctoral thesis (HOBBIE 1973) and also presented to the photogrammertric community by lectures and papers (HOBBIE 1974 & 1975a). In the early 1970s it also became evident that soon the digital process computer would be fast enough to be used for on-line control of complex operations requiring real-time response.

It was decided that to achieve the best possible image quality a successor to th GZ 1 should no longer use “objective optical projection” but should adopt ”optical image transformation” (Fig. 8.29). The principle of "electronic image transformation" as used in the GESTALT PHOTO MAPPER of HOBROUGH Ltd., Vancouver/Canada (announced in 1970) seemed to be too expensive and of less quality potential.

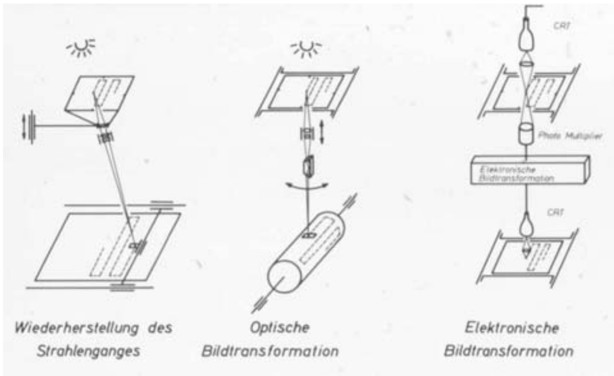


Fig. 8.29: Various functional principles of orthoprojectors

The OP/C introduced in 1968 by OMI, Rome, Italy was indeed the first instrument with optical image transformation and was an off-line instrument, but it was limited to 1 : 1 projection scale and could only be used with the AP/C analytical plotter.

In 1974 the BWB German Federal Office of Defence Technology and Procurement (Bundesamt für Wehrtechnik und Beschaffung) in Koblenz established a contact between CARL ZEISS Oberkochen and BENDIX, Southfield, MI/USA (where UUNO V. HELAVA was employed at that time), to discuss the potential joint development of the LFOOP Large Format Optical Orthoprinter. But these talks were not successful.

In addition ZEISS interrupted the work on a new orthoprojector and focussed on the development of an analytical plotter as this seemed to promise greater economic success. In 1976 this led to the stunning premiere of the C 100 PLANICOMP (see chapter 11.2). Only after the start of series production for the C 100 did, by order of the BWB, orthoprojector development resume. Development was completed during the following three years without an industrial partner.

On February 12, 1980 the UNIPRINT, developed under contract, was presented to and accepted by the customer and was soon after delivered to the Amt für Militärisches Geowesen in Euskirchen. The UNIPRINT was dedicated for special applications with a usable image format of 250 mm x 500 mm. In many other functions it was similar to the Z 2 ORTHOCOMP, which was completed a few months later and first exhibited at the International Congress for Photogrammety in Hamburg in July 1980 (Fig. 8.30). The common development goals for the UNIPRINT and for the Z 2 ORTHOCOMP were:

- *high geometrical, optical and photographic quality,*
- *high productivity,*
- *high flexibility regarding input and output format,*
- *direct use of terrain model data in various formats,*
- *ability to be integrated in network systems,*
- *simple handling without computer knowledge.*

Fig. 8.30: Z 2 ORTHOCOMP orthoprojector

The Z 2 ORTHOCOMP was based on long term experience with the GZ 1 which was until then the dominating system for orthophoto production (FAUST 1980 & HOBBIE et al. 1981). Its optical transformations are shown in Fig. 8.31 and the arrangement of the optical components in Fig. 8.32. Depending on the meander-type scanning by drum rotation (y) and stepping parallel to the drum (x), the position of the exposure slit center is transferred into the image by using the exterior orientation data. The movement of the image stage is computed using the interior orientation data and executed by servomotors.

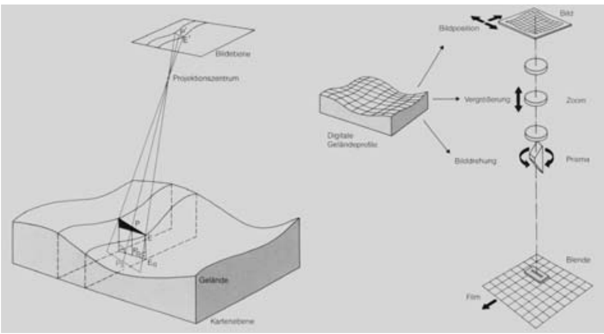


Fig. 8.31: Optical transformation within the Z 2 ORTHOCOMP

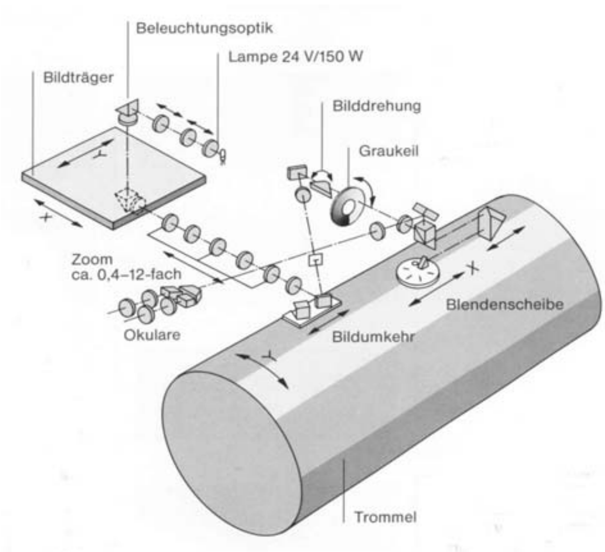


Fig. 8.32: Diagram of the Z 2 optics

Scale and rotation of the slit image, being the other mathematical parameters, were determined by transforming the two endpoints of the exposure slit into the image stage using the orientation and local terrain height data, which were then executed by the servo-controlled zoom lens and dove prism. In relation to the optical magnification a second zoom lens of the illumination system had to be moved. With a motor driven grey-wedge the light intensity was adjusted according to film speed, selected scanning speed and average density of the image. Not shown in Fig. 8.32 is the light meter for measuring this image density.

The turntable for exchangeable exposure slits was standard equipment with 2, 4, 8 and 16 mm slit masks (all with 0.2 mm slit width). In addition there was a small white projection surface with a floating mark of 0.04 mm in diameter, on which the projected image could be viewed at 5x magnification, e. g. for measuring fiducials and control points for interior and exterior orientation.

The main parameters of the Z 2 ORTHOCOMP were:

- *Magnification range: 0.4x to 12x,*
- *usable image format: 240 mm x 240 mm,*
- *usable output format: x = 1 000 mm, y = 900 mm,*
- *maximum film size: x = 1 050 mm, y = 1 040 mm,*
- *positioning accuracy of image carriage: 0.001 mm,*
- *positioning accuracy of slit carriage: 0.001 mm,*
- *rotational accuracy (at drum surface): 0.0025 mm,*
- *slit dimensions: 0.2 mm x 2, 4, 8 and 16 mm standard,*
- *scanning speed: 5, 10, 20, 30, 40 and 50 mm/sec,*
- *light source: halogen lamp 24 V / 150 W.*

The contolling computer for the Z 2 was the HP 1000 minicomputer from HEWLETT-PACKARD, which in a similar configuration had been used by ZEISS since 1976 for the C 100 PLANICOMP (see chapter 11.2). This computer was running with a real time operating system (RTE II at the beginning), which allowed the orthoprojector to be adressed with the highest and absolute priority (Fig. 8.33).

Fig. 8.33: Z 2 ORTHOCOMP with HP 1000 computersystem

But this computer was also fast enough to execute additional program tasks in background mode. Equipped with terminal, printer, magnetic tape drive and possibly being networked to other computers, the HP 1000/RTE system was a full-scale computer workstation. As known, the power of computers including the HP 1000 grew fast over the years.

Contrary to the darkroom required for the GZ 1 the room for the Z 2 only had to be darkened for inserting or removing the photographic film sheet.

One dominating feature of the Z 2 ORTHOCOMP compared to competing instruments was that it could use terrain profiles in ground coordinates without the need of prior transformation or of computing special control profiles linked to a specific image. The easy and user-friendly handling was remarkable as it followed the layout of the C 100 PLANICOMP and also used a dedicated user panel (Fig. 8.34). With four specific turning knobs the step width, scan speed and grey wedge were set and the joystick function was selected, the latter either adressing the image stage, film drum, zoom lens or dove prism.

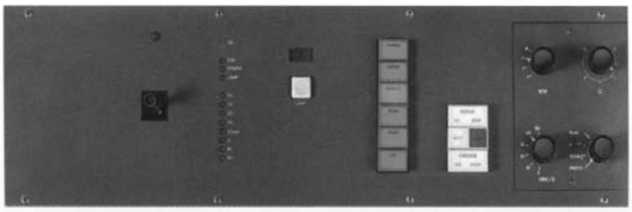


Fig. 8.34: User panel of the Z 2 ORTHOCOMP

As for the C100 there were the "Repeat" and "Continue" buttons for yes/no and similar decisions and the buttons for directly starting the most important program functions for a usual working sequence (FAUST 1981):

- *PARAMETER: As a first step the known data for orientation, sheet corners, memory adress for the profile data etc. had to be entered, or read in from a file, or to be confirmed if unchanged from a previous run.*
- *ORIENT: At least two image fiducials had to be measured for determining the position of the image on the carrier (interior orientation), and, if not already available, the parameters for the absolute orientation had to be determined by measuring control points.*
- *DENSITY: Measurement of image density at significant image locations by moving around with the joystick, reading and storing the values and finally checking the displayed mean and range values at the computer terminal.*
- *SCAN: Film exposure by scanning, with an absolute dynamic accuracy in scanning direction of <0.1 mm (except within the 5mm start/stop-range at the scanning ends).*
- *PRINT: Exposure of names and cartographic symbols by flashing characters or symbols at selected locations (Fig. 8.35) by a patented method (HOBBIE 1980 & ZEISS 1980).*
- *LIST: Displaying and printing of a work report.*

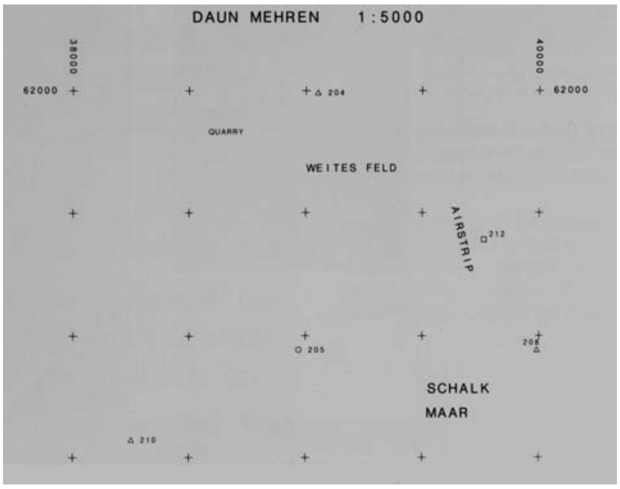


Fig. 8.35: Text- and symbol-output at Z 2 ORTHOCOMP

In addition to these basic program functions the following additional progams were available right from the beginning:

- *GEFIO: Reading, editing and writing of data used within the Z 2.*
- *PREPA: Preparation of the parameters for the next tasks being entered with PARAMETER when needed.*
- *SNUFI: Analysis of the profile data to be used.*
- *HIFI-P: Optional program for generating a digital terrain model and for deriving terrain profiles (see chapter 8.7).*
- *HIFI-PS: HIFI-P with an optional extension for computing "partner profiles" to generate the stereomates of stereo-orthophotos (see chapter 8.7).*

Later more support programs were available (FAUST 1984), and also many users developed program functions for their own requirements and shared these with other Z 2 users.

A special way of generating the digital profile data required for orhopoto production with the ORTHOCOMP was practised in North Rhine-Westphalia and also at other sites. There the analogue profile plates of the GIGAS-ZEISS system, which had previously been used for map revision were digitized using the modified LG 1 scanning unit (ELLENBECK et al. 1981 & TÖNNESSEN et al. 1981). The Z 2 was also embedded into a department wide photogrammetric computer network (Fig. 8.36), based on the DS/1000 product for networking from HEWLETT-PACKARD (ELLENBECK 1983).

In summary the ORTHOCOMP Z 2 perpetuated the success of the GZ 1 orthoprojector, being 10 times more productive (5x faster and with doubled maximum scanning width) and with an improved image and colour quality (better optics, narrower slit width and a more precise positioning). The very high throughput and the use of "standard" terrain data for profiling carried many customers to great economic success.

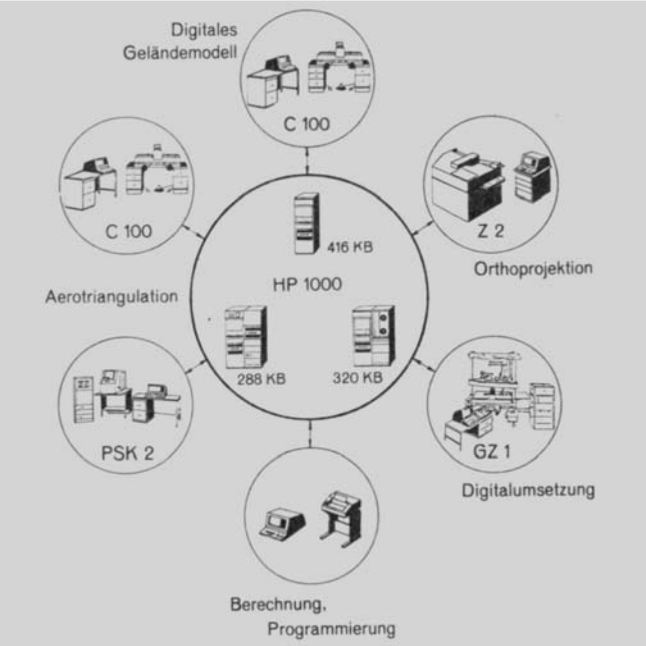


Fig. 8.36: Photogrammetric production network at the Land Survey Office of North Rhine-Westphalia

Between 1980 and the early 1990s, when even better digital methods for generating orthophotos became state of the art (see chapter 8.8 and 12.3), about 50 Z 2 ORTHOCOMP systems were delivered worldwide.

8.7 HIFI program package

At the same time as the Z 2 premiere at the Hamburg congress in 1980, HEINRICH EBNER introduced a program system for computing digital height models named HIFI ("Height-Interpolation with Finite Elements"). ZEISS had supported this development of Ebner and his team in Munich (EBNER et al. 1980b, EBNER 1981, FAUST 1985), the foundation of which had been laid a few years before at the Munich Technical University.

The basic module HIFI-P, as a first step, computed from a wide range of different data sets a digital height model (DHM) by interpolation with bilinear and bicubic finite elements. From this DHM terrain profiles could be derived, e. g. for directly controlling the Z 2. By optional progam modules HIFI could generate other products such as contour maps, perspective terrain views and volume computations. (Fig. 8.37). A special package was the computation of "partner profiles" to generate the stereomates for stereo-orthophotos as mentioned before (EBNER 1981, CLERICI 1983). Stereo-orthophotos had been intensively propagated during the early 1980s and were requested by a few customers.

The HIFI software package was offered by CARL ZEISS, Oberkochen as an independent product and in combination with other photogrammetric instruments.

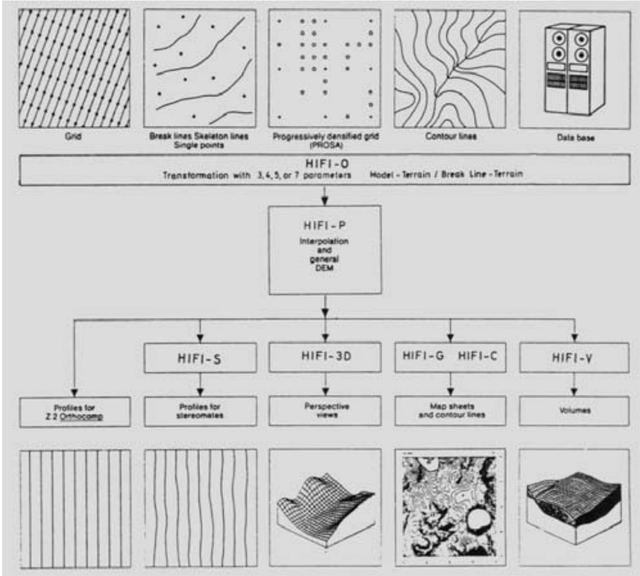


Fig. 8.37: Program structure of HIFI

8.8 PHODIS-OP

By the 1970s digital image processing was a topic of research at universities. By digitising aerial photographs with the early slow single-spot scanners, first experiments with computing digital orthophotos were successful and were reported in 1975 by KREILING and in 1979 by KEATING and KONECNY. CARL ZEISS Oberkochen began studying the methods and the potential of digital products in 1987 when a co-operation agreement with INTERGRAPH, Huntsville, AL/USA was concluded for a joint development of a high performance photoscanner (see chapter 12.1). At this time another project with INTERGRAPH had just been completed succesfully (see chapter 11.4).

ZEISS began at the Photogrammetric Week 1991 in Stuttgart to report on the ongoing activities with digital image processing under the project name PHIPS Photogrammetric Image Processing Systems (MAYR 1991). As the primary goal the generation of orthophotos by digital means with a performance beyond the previous optical-analytical procedure was mentioned. One of the ideas was to avoid the so-called "dead areas" in mountainous regions, resulting in double images in the invisible areas caused by steep slopes under large image angles (Fig. 8.38). Also "flattening" of high buildings and bridges should be avoided by true rectification of objects with a height different from the terrain to aim for what was later called "true orthophoto".

This development was presented in its early form as PHODIS (Photogrammetric Image Processing System) at the 17th Congress of the International Society for Photogrammetry and Remote Sensing in Washington D.C. in August 1992.

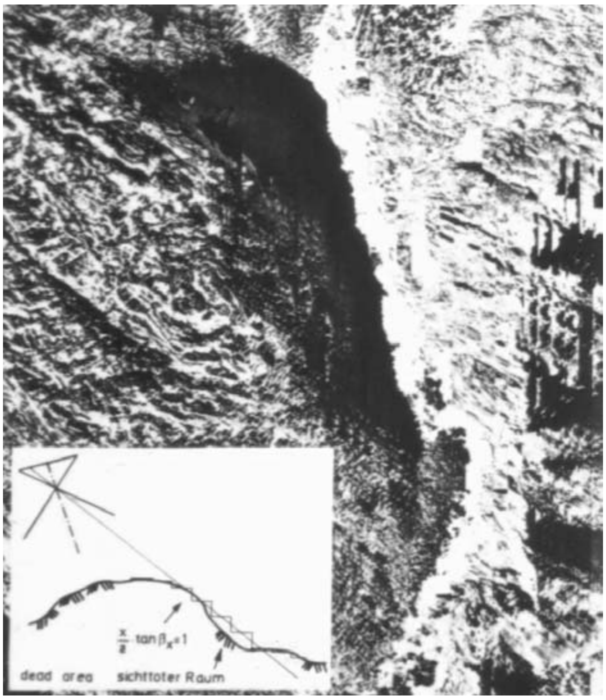


Fig. 8.38: Invisible ("dead") area in orthophoto-production

During an in-house workshop for the German users in Oberkochen in November 1992 and at the Photogrammetric Week in1993 PHODIS was presented extensively as a powerful tool for digital orthophoto production (Kresse 1993), its workflow and results are shown in Fig. 8.39. There the whole range of possibilities already under development was explained, thus expanding PHODIS towards a comprehensive software suite for digital photogrammetry (see chapter 12.3).

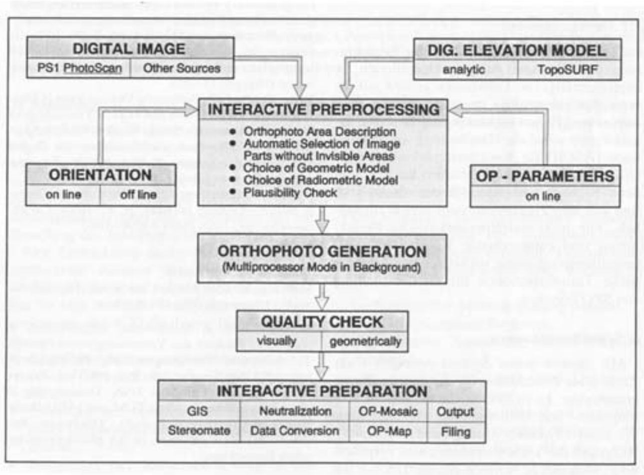


Fig. 8.39: Working steps of digital orthophoto production e. g. with PHODIS-OP

9. Comparators & Point marking devices

The first step into metric stereophotogrammetry was with the PULFRICH-stereocomparator in 1901. Followed by improved and modified versions they enabled the readout of coordinates and parallaxes by metering rules and vernier scales. Later coordinate counters and micrometer screws were introduced, as they were for the upcoming stereoplotters. But with all these devices the values had to be read and recorded by handwriting on paper.

When mechanical recording began in 1950 numerical photogrammetry started to be a widely used method especially for aerial triangulation and for cadastral purposes. Mechanical and later electrical and electronic recording units were first used with (improved) stereo and mono comparators and then with stereoplotters. For aerial triangulation in addition point marking devices were required.

9.1 Recording of coordinates

In 1952 ZEISS introduced a coordinate recording unit called "Druckzählwerk" for the C 8 STEREOPLANIGRAPH (see chapter 4.4), which was the first mechanical recording device. By pulling a lever the print wheels of the coordinate counter were pressed against a sheet of paper (SCHWIDEFSKY 1952). Five years later at the 3rd International Course for Geodetic Distance Measurement in Munich ZEISS presented the ECOMAT for use with the C 8, which allowed the recording in computer-compatible format on either punched tape or on punched cards (SCHWIDEFSKY 1958).

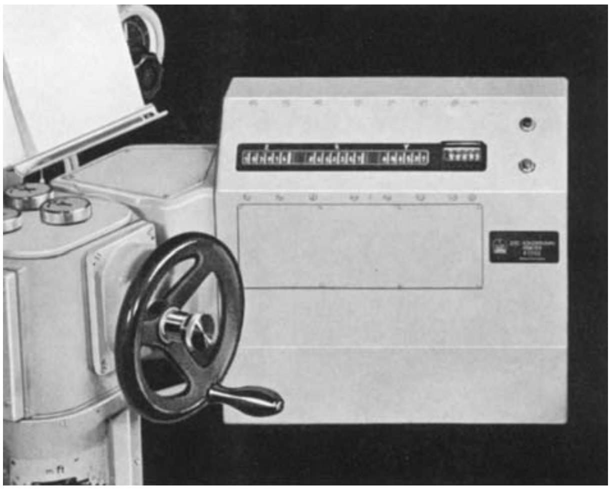


Fig. 9.1: ECOMAT I at the C 8 STEREOPLANIGRAPH (1957)

Fig. 9.1 shows the magnetic counter of the ECOMAT (later called ECOMAT I) on the C 8, consisting of the coordinate display and coding device. The analogue-to-digital conversion was done by a mechanical arm, which during one revolution of an excentric wheel touched 10 neighbouring electrical contacts each one representing 1/10 of a revolution.

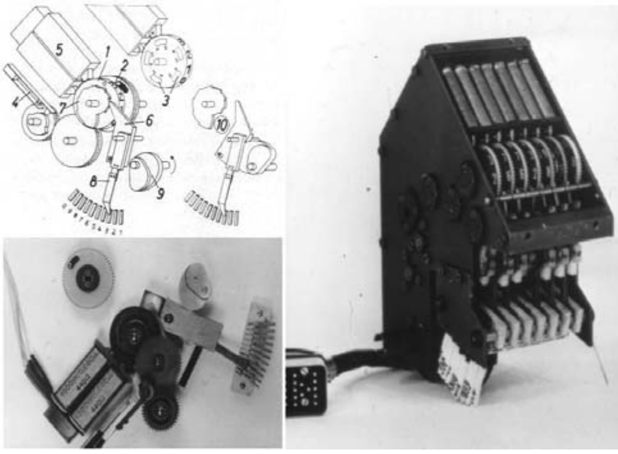


Fig. 9.2: Magnetic counter and counting unit of theECOMAT I

The conversion of a single digit and the counting unit for the x-coordinate with 7-digits is shown in Fig. 9.2. At the C 8 the display and recording of the coordinates was in the sequence z, x, y in units of 0.01 mm. In y and z 6 digits were displayed and in x 7 digits due to the long model strips for aerotriangulation. In a fourth window a 4-digit point number was displayed, which was increased automatically with any recording, and to which a single code-digit could be manually added.

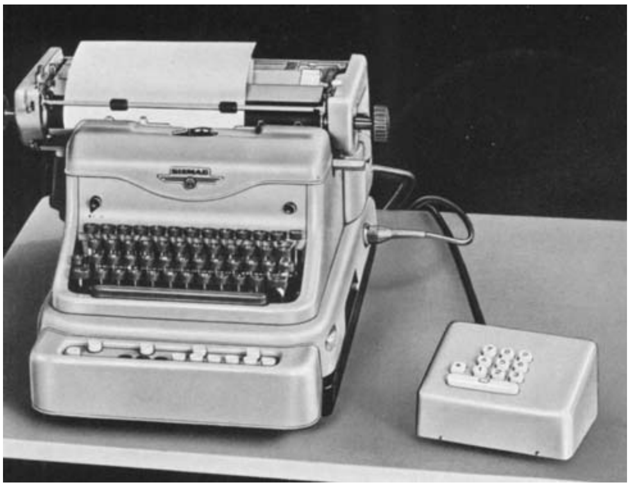


Fig. 9.3: Automatic typewriter with numerical keypad for the ECOMAT I

The magnetic counter was connected via a cable to an automatic typewriter (Fig. 9.3). By pressing one of the two recording buttons at the ECOMAT the recording and the aditional printing with either black or red inked ribbon was initiated. The magnetic counter was ready for a next recording within 1 sec but the typewriter needed about 8 sec for printing all 24 digits.

This automatic typewriter was equipped with an easy exchangeable programming board with mechanical pins defining the sequence of execution (Fig. 9.4).

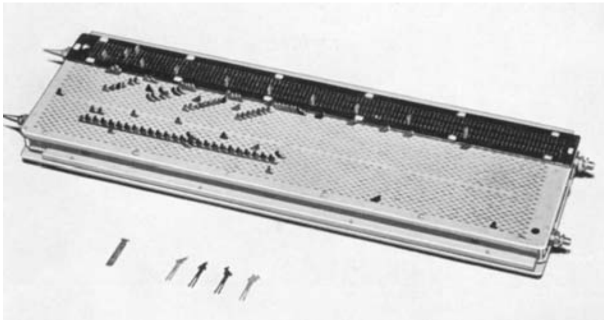


Fig. 9.4: Programming board of the automatic typewriter

The output format could be modified by the operator in the following ways: the recording sequence of coordinate values and spacing, suppressing or adding the digit "null", adding an individual point number from the keypad for replacing the running number from the magnetic unit, or adding of alphanumeric text at the tyewriter (Fig. 9.3).

In 1957 the only machine readable output medium was punched tape in the widely used 5-channel code of teleprinters (Fig. 9.5). However, throughout the electronic computing industry punched cards soon became available. From 1967 onwards a new point number setting unit for the ECOMAT I made the point numbering more comfortable (Fig. 9.6).

Fig. 9.5: Paper tape punch for the ECOMAT I

Fig. 9.6: Number setting unit model 2 for the ECOMAT I (ca. 1967)

In 1960 an additional profiling unit for the C 8 in combination with the ECOMAT I was introduced (Fig. 9.7). Now the floating mark could be moved along profiles with selectable azimuth and adjustable speed. Recordings could be released automatically by selectable increments or manually e. g. at breaklines (SCHWIDEFSKY et al. 1958).

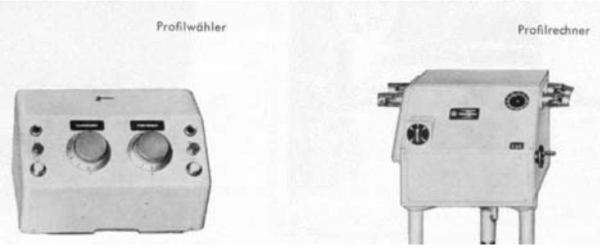


Fig. 9.7: Profile measurement unit for the C 8

The measured profiles could be plotted on the coordinatograph of the C 8. Further, by combined use of the coordinatograph and the ECOMAT I, coordinates could be digitised from existing maps using a viewing device on the coordinatograph. Points recorded on punched cards could also be plotted automatically off-line (see chapter 10.6).

In 1960 the ECOMAT II (see chapter 9.2) was introduced with the output sequence modified to handle four coordinates for use with the new PSK precision stereocomparator.

The tremendous advance in electronics during the second half of the 1960s forced Oberkochen to replace the old relay technique of the ECOMAT with the new transistor technology. The resulting ECOMAT 11 was announced at the symposium of Commission II in Munich in September 1970 and was first presented at the Photogrammetric Week in 1971 in Karlsruhe (SCHWEBEL 1971 & 1973a). Fig. 9.8 shows the electronic cabinet of the ECOMAT 11 with the D 2 PLANIMAT, together with the point numbering unit, automatic typewriter and paper tape punch.

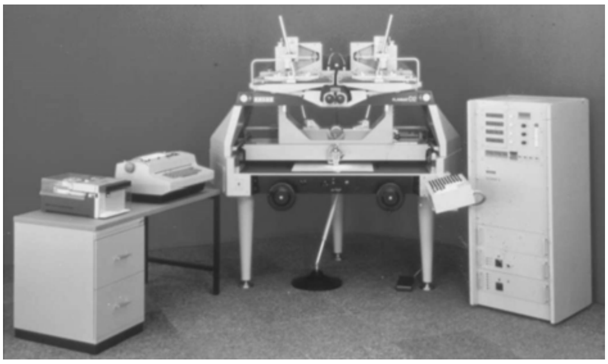


Fig. 9.8: ECOMAT 11 with IBM auomatic typewriter and paper tape punch at the D 2 PLANIMAT (1971)

For the sensing of coordinates the technique of incremental pulse detection was selected which allowed a counting frequency of up to 16 KHz. Photoelectric rotary encoders were used as standard devices (Fig. 9.9). Linear encoders were used at the PLANIMAT (Fig. 9.10) in x and y to allow free-hand-guidance without losing the coordinate reference.

Stereoplotters required coordinate display and recording with 6 digits and 0.01 mm resolution with a selectable counting direction and start value.

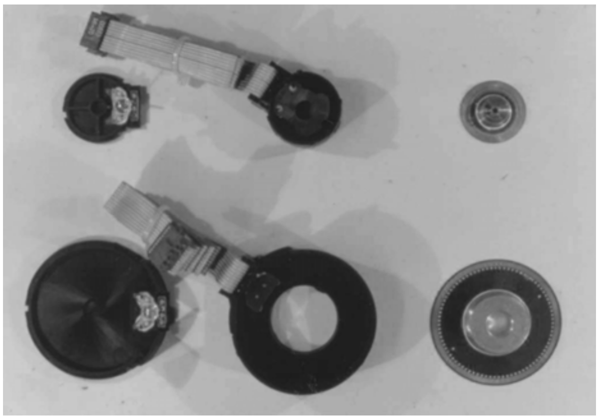


Fig. 9.9: Incremental rotary encoders for the ECOMAT 11

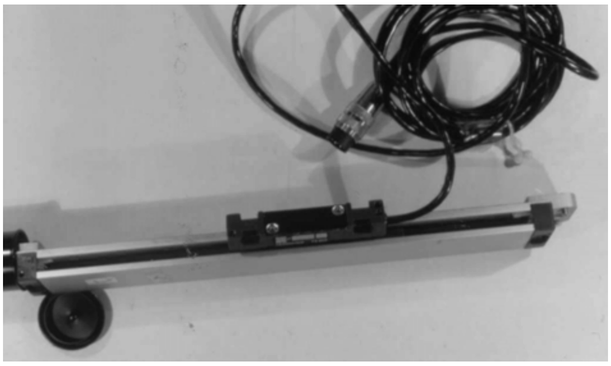


Fig. 9.10: Incremental linear encoder for the ECOMAT 11

Recording devices at this time were the IBM automatic typewriter (15 characters/sec), OLYMPIA tape punch (5- to 8-channel, 20 char./sec), IBM card punch (10 char./sec) or the magnetic tape drive (Fig. 9.11) with max. 1 000 char./sec. Point numbering was done either automatically by increments, or individually through the point numbering units 1 or 2 with a 4- or 12-digit number plus a decimal keypad (Fig. 9.12).

Fig. 9.11: ECOMAT 11 with magnetic tape drive

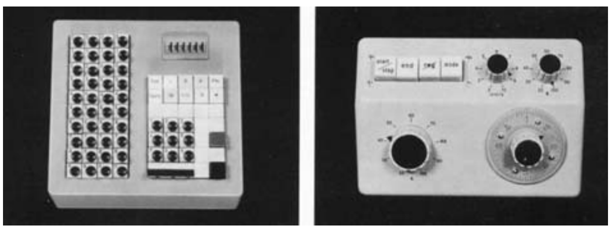


Fig. 9.12: Number setting unit model 1 and DTM 1 panel

Compared to the ECOMAT I with the C 8 profiling unit the ECOMAT 11 allowed much more flexible automatic recording: e. g. selectable coordinate increments of 0.1 / 0.2 / 0.5 / 1.0 / 2.0 / 2.5 / 5.0 and 10 mm or at time intervals between 0.1 and 9.9 sec. With the additional motor driven DTM 1 semi-automatic measurement unit (Fig. 9.12) profiles could be measured with any azimuth. The profile and the point sequence within a profile could be set anywhere between 0.1 and 50 mm. The travelling speed was continously variable between 0 and 10 mm/sec. In a special "discontinuous" mode a reduced speed could be selected to come into operation at a predetermined distance from the next recording position. In the stepwise mode the system automatically stopped at the next location. The measurement area was usually defined by model coordinates.

In the PLANIMAT there was another simple method of defining the area to be measured by placing metal strips (normally used for fixing the plotting sheet) on the internal tracing table with its magnetic surface. When a stylus (Fig. 9.13) made contact with the metal strip the system was prompted to move to the next profile. For fully automatic profile measurement using the EC5 correlator from ITEK the DTM 2 (a modified DTM 1) was used.

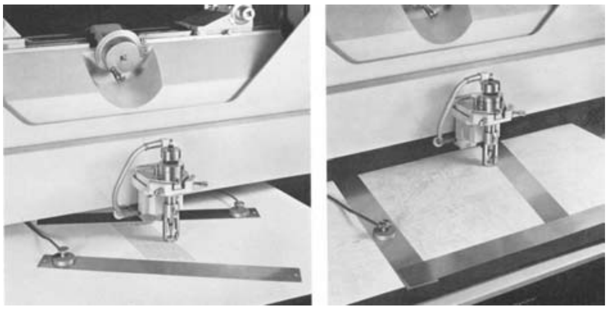


Fig. 9.13: Area limiting for the DTM in the PLANIMAT

Parallel to the ECOMAT 11 in 1971 the ECOMAT 21 for the redesigned PSK 2 precision stereocomparator was introduced. In this the three model coordinates x, y, z were replaced by the four image coordinates x_1, y_1, x_2, y_2, and the incremental recording possibility was eliminated (see chapter 9.2).

With the ongoing miniaturisation of electronic components 5 years later the ECOMAT 12 was presented as a compact desk unit (Fig. 9.14). This development was sponsored by the German Federal Ministry for Research and Technology under the title "Digitaltechnik" (SCHWEBEL 1979b). In view of the need to connect to the increasingly popular desktop computers this new device was not only able to manage the recording as before (off-line), but also to transmit in real time (on-line) recorded coordinates and point numbers (SCHWEBEL 1976b & 1979b). The ECOMAT 12 was designed for counting incremental pulses with selectable counting direction of up to four 6-digit coordinates with 0.01 mm resolution. When connected to a stereoplotter in addition to x, y, z the base-component "by" could be recorded.

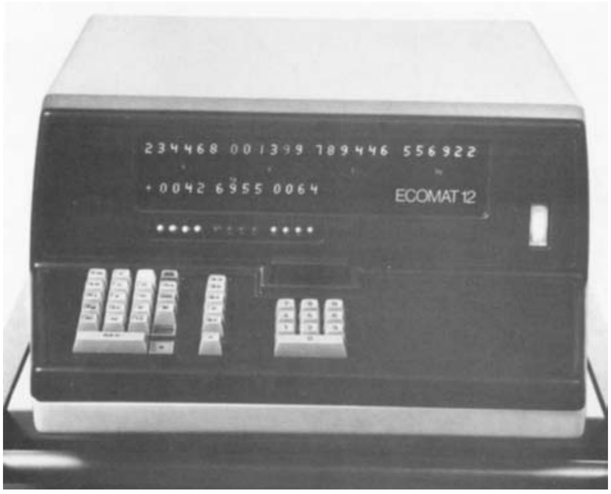


Fig. 9.14: ECOMAT 12 (1976)

The 12 digit point number could be partially used for a running index or for individual entry from a decimal keypad. In the off-line mode the maximum output rate was 1000 characters/sec. Output devices supported were: IBM automatic typewriter, IBM card punch, FACIT paper tape punch and buffered magnetic tape drives from e. g. PERTEC or KENNEDY. As before additonal information such as text could be entered via the typewriter. Recording could be released individually by button or footswitch and/or automatically by a preselected increment (coordinate, distance or time). The output format was controlled by the programmable Read-Only-Memory (PROM, Fig. 9.15), which could accommodate up to four programs each with 64 program steps.

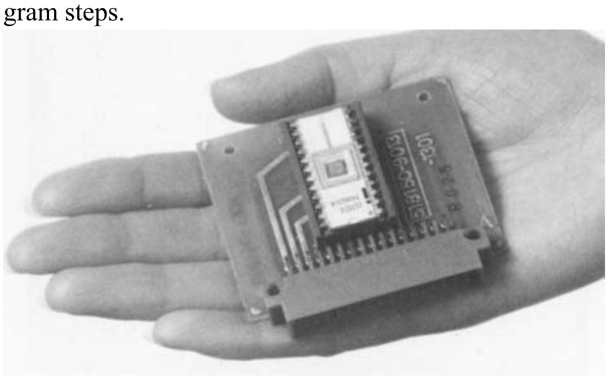


Fig. 9.15: Programmable control chip (PROM) for the Ecomat 12

In the on-line mode, when interfaced in real time to a desktop or minicomputer, not only were the coordinates, point number and optional text sent from the ECOMAT 12 to the computer, but the ECOMAT could also receive from the computer transformed coordinates and point or code numbers which were displayed to the operator, and/or recorded. In addition computer programs could be started from the ECOMAT 12 by additional program buttons (on the right side in Fig. 9.16).

Fig. 9.16: ECOMAT 12 with additional programm buttons and HP 9825 desk computer

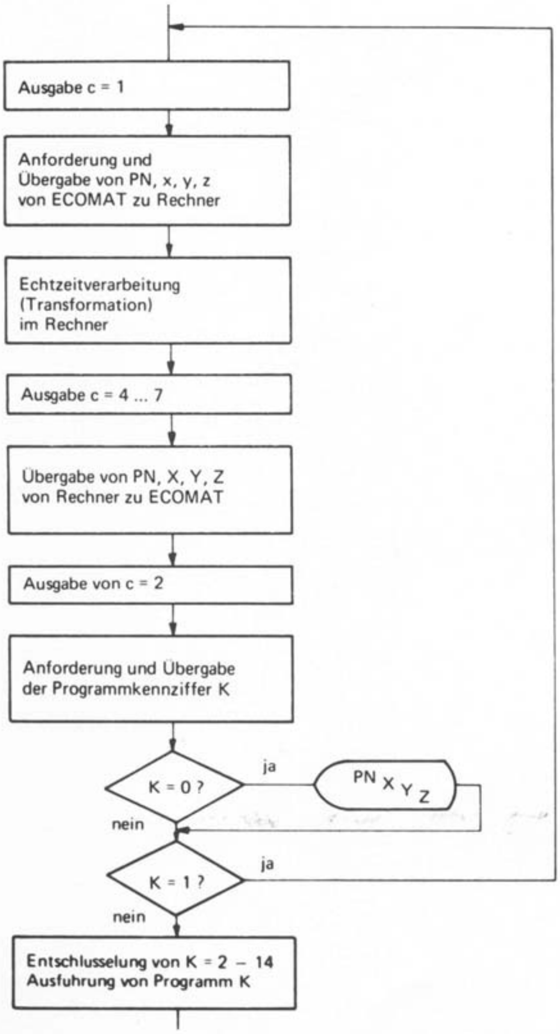


Fig. 9.17: ECOMAT 12 communication with desktop computer

Data exchange was controlled by the desktop computer using the handshake principle. By sending a command digit c (c between 0 and 9) to the ECOMAT, the type and structure of data to be exchanged in the following input or output message was determined. This principle is explained in Fig. 9.17 using the example of a real time loop for reading coordinates from the Ecomat 12, transforming and sending them back, and waiting for a program button to be pressed.

Like the DTM 1 for the ECOMAT 11 in 1971, the DTM 3 for profile measurements was introduced in 1979 for the ECOMAT 12 (SCHWEBEL et al. 1979e). It consisted of digitally controlled servo motors for driving the PLANIMAT or PLANICART in x and y, an electronic control unit with buttons and a remote control with buttons to be used during profiling (Fig. 9.18). Again the planimetric movement along the profiles with a selected azimuth (now as precise as 0.01 gon) was controlled automatically, while the operator kept the floating mark on the ground. The now very flexible incremental recording system allowed a large variety of scanning patterns (Fig. 9.19). The maximum travelling speed was now 25 mm/sec and the maximum speed while measuring 10 mm/sec. When a mistake was made the current profile could be easily marked which would prompt the automatic repetition of that profile.

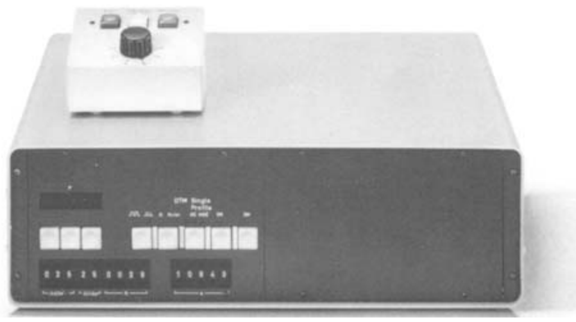


Fig. 9.18: DTM 3 control unit with remote control (1979)

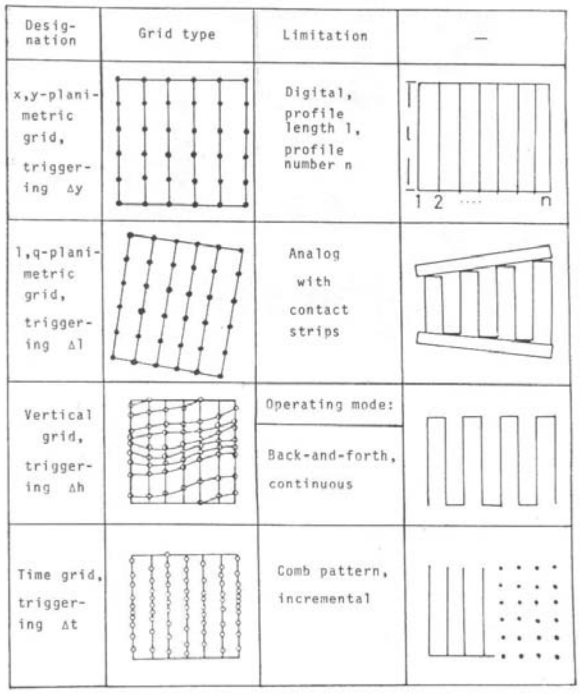


Fig. 9.19: Profiling modes of the DTM 3

The ECOMAT family for coordinate recording, offered by CARL ZEISS Oberkochen since 1957, lost ground in the 1980s as analytical plotters with integral computers and increased processing speed and storage possibilities became mature. In total ZEISS delivered more than 300 ECOMAT systems.

However, soon after the second-generation ECOMAT 11 was introduced in 1970 there was a growing interest in a simpler system for just counting coordinates and immediately transfering them to the upcoming desktop computers. At that time ZEISS was developing a stereocomparator for x-ray photographs (see chapter 14.2), which in an extended version StR 3 was able to send the coordinates x, y, p_x to a computer (MEIER 1971). For this task ZEISS developed a simple electronic unit for counting encoder pulses, displaying the three coordinates with nixie-tubes and transfering these values to a desktop computer from HEWLETT-PACKARD, when a footswitch was pressed. These raw coordinates were further processed using parameters entered at the computer.

By refining this unit the DIREC 1 as a bottom-of-the-line digitising and interface device was created and introduced at the Photogrammetric Week in Stuttgart in 1975 (SCHWEBEL 1975b). The DIREC 1 was not only part of the StR 3 but was also used for computer supported orientation and data acquisition with analogue stereoplotters (chapter 10.7) and as an interface for the new G 2 STEREOCORD low-end analytical plotter (chapter 11.1). In the following year it became available for the OCS 1 orientation system of the SEG 5 (chapter 5.2). Fig. 9.20 shows the DIREC 1 with coordinate display and program buttons but not the associated footswitch.

A functional diagram is shown in Fig. 9.21 in the G 2 STEREOCORD version of the DIREC 1 (HOBBIE 1975b). The data part counts the pulses of the encoders x, y and p_x (at the STEREOCORD) or z (at the analogue plotter) and displays the counts, which can be reset to "1 000" (for avoiding negative values) by respective buttons, at the 6-digit nixie-tubes.

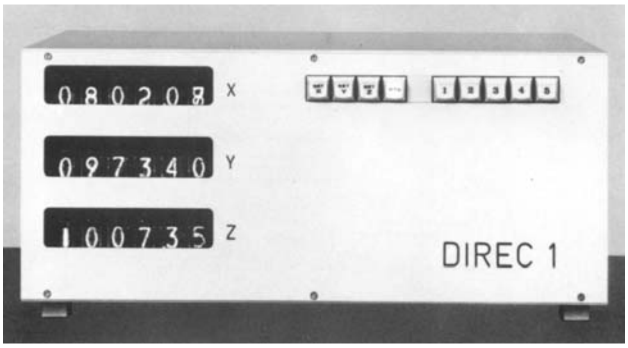


Fig. 9.20: DIREC 1 coordinate recording and interface unit (1975)

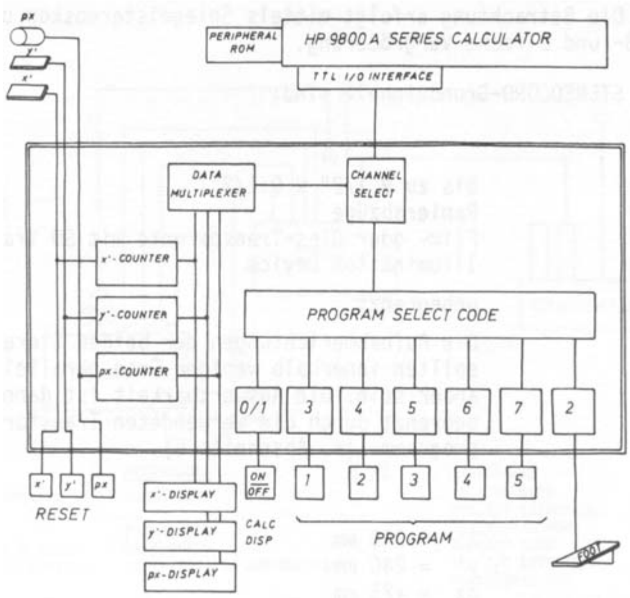


Fig. 9.21: Functional diagram of the DIREC 1 for G 2 STEREOCORD with HP 9800 A desktop computer

By request from the computer the coordinate values were sent via a multiplexer and a common interface. In the program part of the DIREC the pressing of the footswitch or of one of the 5 program buttons entered a specific button code into a register, which was read by the computer cyclically and then lead to a software-defined action. The computer port of the DIREC 1 was designed to be directly connected via the HP I/O interface to all current desktop computers of the HP 9800 series from HEWLETT-PACKARD. After a slight modification it could also be connected to the upcoming minicomputers from HP or DEC.

In 1981 two re-engineered DIREC versions were presented. For display and transfer of four coordinates the DIREC 12 was created (Fig. 9.22), which in the upgraded G 3 STEREOCORD was used for the additional handling of the y-parallax (see chapter 11.1). However, this unit was not a success, because the DIREC 2 (Fig. 9.23) which was also capable of transfering four coordinates, but without the display, was less expensive and in most cases was sufficient for a customer's needs. Because not only the continuous display of coordinates but also the program selection had been moved to the more powerful computer, the only settings left at the DIREC 2 were the footswitch and the on/off-function.

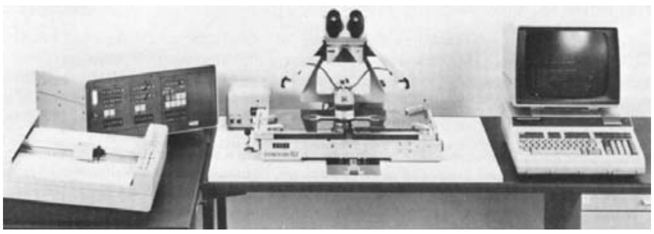


Fig. 9.22: DIREC 12 at the G 3 STEREOCORD (1981)

Fig. 9.23: DIREC 2 coordinate recording and interface unit (1981)

This minimised DIREC 2 was almost the end of CARL ZEISS in Oberkochen developing self-contained devices for independent coordinate acquisition and computer interfacing. As a last step the DIREC P was created in about 1990 for incorporating analogue stereoplotters as a PA-station into PHOCUS, the photogrammetric-cartographic system from CARL ZEISS (see chapter 10.7). DIREC P was a small interface box based on an industrial PC-board, which by two RS232-interfaces was connected to the three encoders, a double-footswitch and to the HP 1000- or VAX-computer of the PHOCUS workstation. In this setup the PC not only controlled the data communication but also the incremental recording of coordinates.

9.2 PSK precision stereocomparator

When the reconstruction and update phase was almost completed in the mid 1950s, Oberkochen planned to resume the pre-war line of the well known Jena stereocomparators. With the advance in electronic data processing automatic data recording in computer readable form was identified as a firm requirement. At the 3rd International Course for Geodetic Distance Measurement in Munich in 1957 CARL ZEISS not only presented the ECOMAT for the C 8 STEREOPLANIGRAPH, but also reported on concepts for new stereocomparators.

At the International Congress for Photogrammetry in London in 1960 the newly developed PSK "Präzisions-Stereokomparator" was presented (Fig. 9.24). For the recording of the image coordinates x_1, y_1, x_2, y_2 the ECOMAT II was used, which was a modification of the ECOMAT I introduced for the C 8 STEREOPLANIGRAPH two years earlier (see chapter 9.1). Extended from three to four coordinates and adapted to a different coordinate readout, it supported the same peripherals for recording. Namely, an automatic typewriter with programmable board, a paper tape punch and card punch.

Fig. 9.24: PSK precision stereocomparator with ECOMAT II (1960)

Regarding the measurement principle Oberkochen decided to use a reseau type measurement system based on high precision grid plates as image stages thus avoiding temperature sensitive lead screws and rigorously following ABBE's comparator principle. (SCHWIDEFSKY 1960). Fig. 9.25 shows the opened right side of the PSK with the vertically positioned image carrier which moved horizontally in x. Behind the image carrier a tilting invariant penta prism of the optical viewing train moved up and down in y.

The image carrier (24 cm x 24 cm) allowed a measurement area of 23 cm x 23 cm and carried an etched square grid of very high precision with a mesh width of 10 mm on the image side, so that grid and emulsion of the image to be measured were in direct contact (Fig. 9.26). For measurement the operator first had stereoscopically to centre the black floating mark, which was 25 µm in diameter,on the image point. In a second phase he had to coincide linear scales for x and y with the 10 mm grid under binocular viewing, separately for each image of the stereo pair.

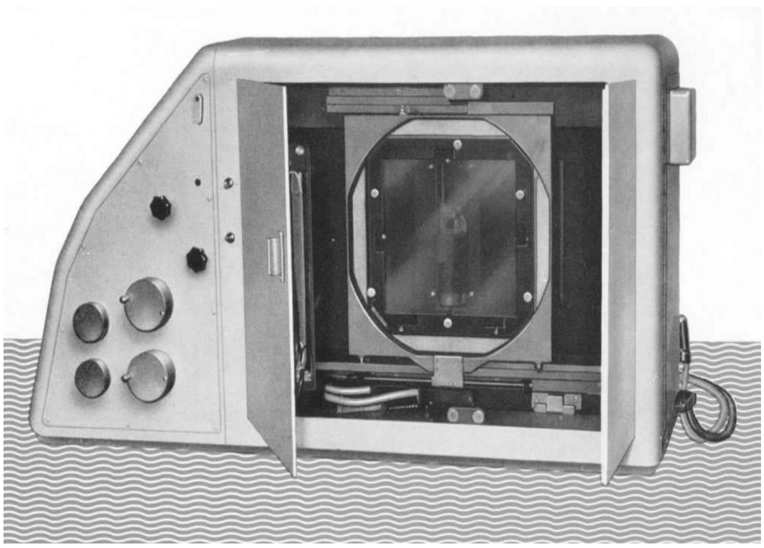


Fig. 9.25: Photo carrier and control knobs of the PSK

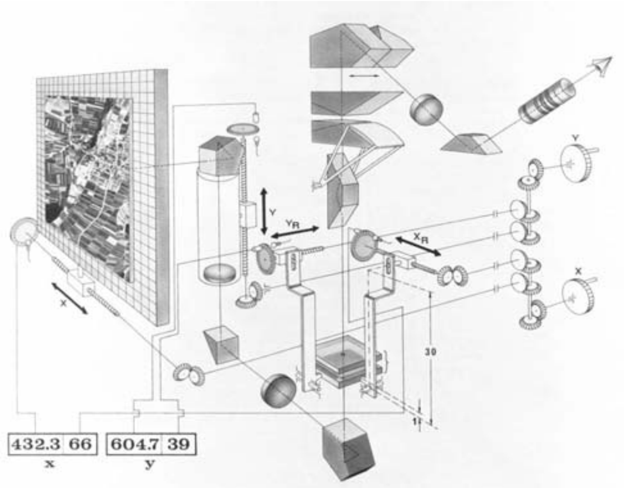


Fig. 9.26: Functional diagram of the PSK 2

The resulting coordinate values were then automatically compiled using the whole millimeter from the carrier and prism movement (coarse value) and the fraction of the millimeter from the scale coincidence (Fig. 9.27). The coincidence movement was measured with a 1 : 30 reduction with 0.001 mm resolution. With the later PSK 2 the tenth of the millimeter was derived from the stage movements (Fig. 9.26). Both the coincidence principle and the coarse-fine compilation were protected by patents (SCHWIDEFSKY 1957 & Utz 1957).

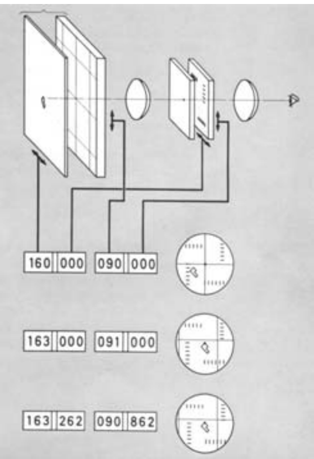


Fig. 9.27: Coordinate generation at the PSK

While stereoscopically centering the floating mark at the image point to be measured, the etched 10 mm grid was nearly invisible due to the illumination by transmitted light and therefore not disturbing. After switching to the coinciding mode with illumination by reflected light the grid became clearly visible and the image was extremely dimmed (Fig. 9.28).

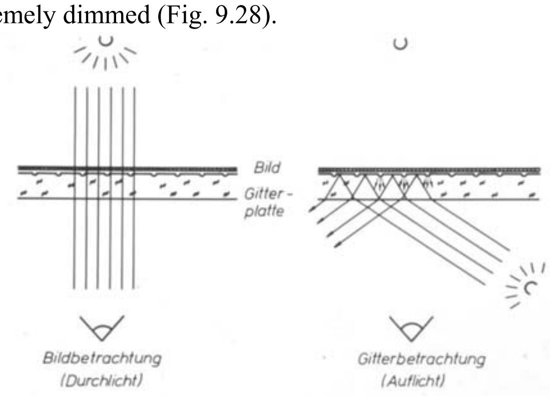


Fig. 9.28: llumination modes at the PSK

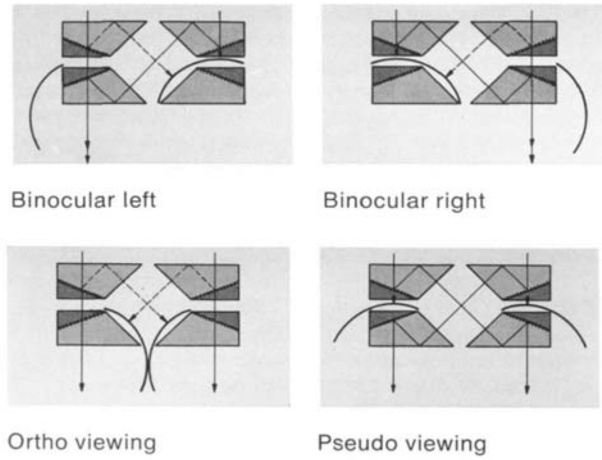


Fig. 9.29: Viewing modes at the PSK

The computer controlled switching between the viewing modes "stereoscopic", "binocular left" and "binocular right", and "stereoscopic" / "pseudoscopic" for strip triangulation was another aid for comfortable viewing. This switching of the optical viewing train was made possible by beam-splitting prisms and motorised covers (Fig. 9.29). ZEISS had patented several different solutions for this viewing requirement, but only one was implemented (ROOS et al. 1949 & ROOS 1957).

By pushing a button at the front of the PSK the next step of the measurement sequence was initiated automatically switching the viewing optics and connecting the moving elements. The sequence could be reprogrammed, by the relay control which was located at the back of the PSK (Fig. 9.30). The exchangeable binoculars allowed a viewing magnification of either 8x, 12x or 16x with a field of view of 15 mm diameter. The image rotation was done by Amici prisms. Adjacent to the eyepiece was the point number display with one selectable digit and a four-digit number which was automatically increased as work progressed. Below the eyepiece was a display showing the four 6-digit stage coordinates. Above the binocular head a copy of the left contact print was mounted on which the approximate position was projected from behind by a small movable light bulb.

Fig. 9.30: Program control with relays at the PSK

All hand wheels for the x-movement were located on the left hand side and the ones for the y-movement on the right side of the PSK. The top large wheels at the back moved both images together (with a selectable 5x fast speed) and the lower ones the parallax adjustment of the right photograph. With the smaller wheels the operator had to coincide the linear scales for x and y with the 10 mm grid in both the left and right image, after an automatic rough adjustment driven by the motors. Further setting elements were potentiometers for varying the light intensity and a lever for switching to the optical reflection depending on whether negatives or diapositives were being used. For safety reasons at any program step only the required wheels were effective. As the last step of each point measurement the push button initiated the recording of an image point or a fiducial mark.

The automated and comfortable handling of this compact and dustproof instrument, in combination with the unsurpassed high accuracy without the need for airconditioning, made the ZEISS PSK stereocomparator a great success. By the time that the instrument was introduced the Hanover Technical University was able to present the results of a thorough testing (LEHMANN 1960b), which was soon followed by further investigations (WUNDERLICH 1962 & SCHÜRER 1964). These studies confirmed the very high pointing accuracy of ± 0.8 µm, the excellent absolute accuracy of ± 1 to 2 µm (which were much above the accuracy potential of the aerial images), and the economic advantage over point measurements with first order stereoplotters such as the C 8 STEREOPLANIGRAPH.

At Karlsruhe Technical University special image adapters were created to allow easier handling and fixing of small format terrestrial photographs and uncut film (Bild 9.31), as well as an optimised measurement procedure for dense point clouds (DÖHLER 1969).

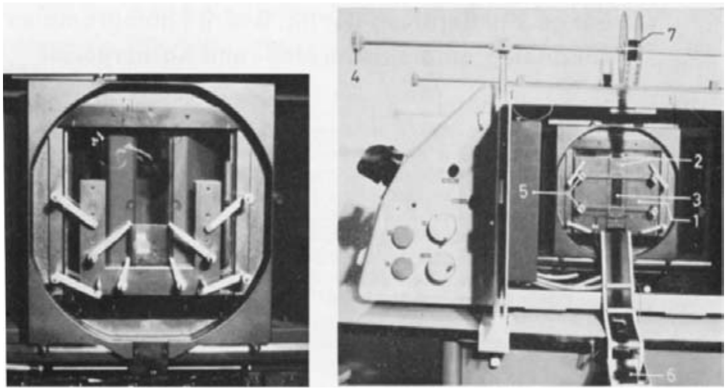


Fig. 9.31: Adapter for small image format (from DÖHLER)

Based on the high accuracy potential a PEK monoversion of the PSK was derived in answer to a demand from astronomers. One system was delivered to the esteemed observatory at the Vatican in Rome, and later the PEK was used for satellite geodesy, too (SEEGER 1970). In a special version the PEK was equipped with an additional punched card reader for automatic prepositioning of the stars to be measured (Fig. 9.32), a solution which was derived from the COORDIMAT (see chapter 10.6).

Fig. 9.32: PEK precision monocomparator with card punch and pre-positioning from card reader

When in 1970 the electronic ECOMAT 11 for analogue stereoplotters replaced the relay-controlled ECOMAT I, there was a need to adapt the PSK to the new technology. This required a major redesign and at the 33rd Photogrammetric Week in Karlsruhe in 1971 the PSK 2 precision stereocomparator with the ECOMAT 21 was introduced (HOBBIE 1971). Later it was also offered in a mono version as the PEK 2 precision monocomparator (SCHWEBEL 1973b). The ECOMAT 21 technically was almost identical with the ECOMAT 11 (see chapter 9.1) and shall not be described here again. Fig. 9.33 shows the larger point numbering unit "Zifferneinstellwerk 2" for the ECOMAT 11 and 21.

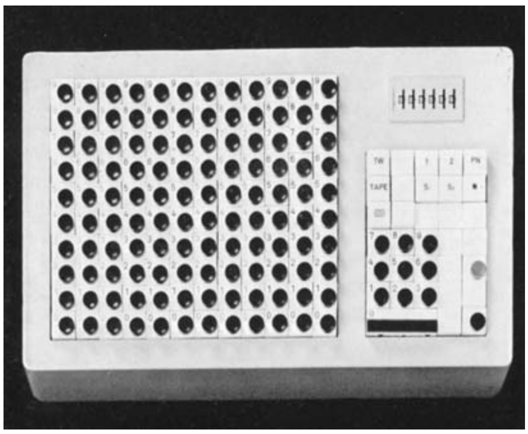


Fig. 9.33: Point numbering unit 2 for ECOMAT 11 & 21

Fig. 9.34: PSK 2 with point numbering unit 2, automatic typewriter and paper tape punch (1971)

The PSK 2 (Fig. 9.34) had several important advantages over its predecessor the PSK 1, although the measurement principle was unchanged and the design was stripped down:

- *the position display was now in the front with a matrix of small lamps instead of a moving light (Fig. 9.35), and the side was reversed when changing from negatives to positives. The active measurement step was now displayed but the coordinate display was transferred to the ECOMAT 21.*
- *the measurement area was increased to 250 mm x 250 mm with a maximum photo size of 290 mm x 290 mm,*
- *the coarse measurement by the lead screws was improved to give a resolution and accuracy of about ±5 µm, resulting in reduced time needed for fine measurement,*
- *the fine measurement by grid coincidence now only replaced the 0.01 mm and 0.001 mm of the coarse coordinate, with an accuracy of ±1 µm as before,*
- *having reduced the mesh width of the grid from 10 mm to 5 mm and the interval of the linear scale for coincidenc from 1mm to 0.1 mm only small shifts were necessary, making the motorised coarse coincidence obsolete,*
- *there was now only one handwheel each for x and y, which were coupled to the element to be moved (either the stages or the linear scales), which still ensured an easy coarse / fine movement,*
- *for easier reprogramming and program control a programming board in a drawer of the ECOMAT 11-cabinet (replacing the relays in the back of the PSK 1) was used, and a toggle switch ensured that a quick change could be made between two prepared program sequences,*
- *the next program step was prompted by a footswitch which allowed the operator to keep his hands on the wheels.*

Over the 25 years of producing the PSK, ZEISS delivered about 90 systems of the PSK 1 and PSK 2 in total. In the early 1980s stereocomparators lost their market against the now tested and proven analytical plotters with just a little less accuracy but with many advantages such as prepositioning and immediate feedback from preliminary computations and adjustments (STARK 1977b).

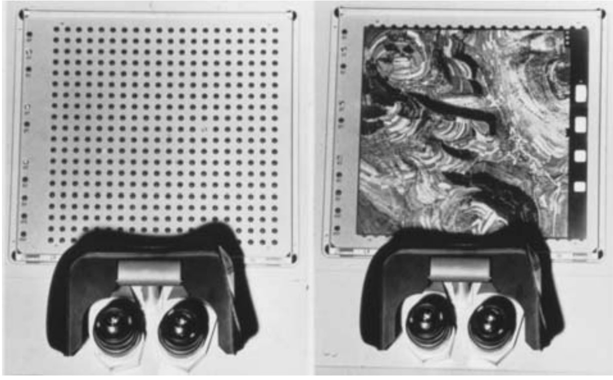


Fig. 9.35: Position display at the PSK 2

9.3 PK 1 precision comparator

In 1932 the astronomical department of ZEISS in Jena had presented an instrument for coordinate measurement in single photographs with very high precision, which also was used for photogrammetric purposes. As mentioned above, in the 1960s Oberkochen had modified the PSK precision stereocomparator into the PEK monocomparator version, also mainly for astronomical and geodetic applications. It was not until the early 1970s that the photogrammetric community, especially in the Anglo-Saxon countries, began to use monocomparators. The main arguments for these instruments compared to stereocomparators were the lower price and the much easier operating especially by unskilled people. One German customer claimed that he had trained a floor-tiler within hours to operate a monocomparator. However, this advantage was partly outweighed by an increased effort in preparing the images for measurement by point marking. After competitors in the USA, in France and later in Switzerland started to offer newly developed monocomparators, CARL ZEISS in Oberkochen decided to follow, and presented the new PK 1 precision comparator at the Helsinki-Congress in 1976 (SCHWEBEL 1976a), together with the previously described ECOMAT 12 (SCHWEBEL 1976b).

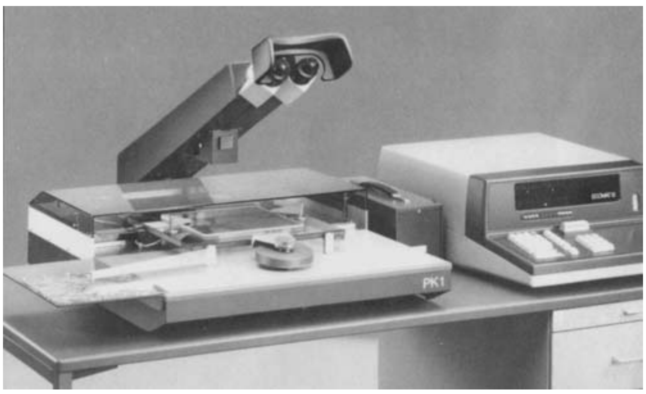


Fig. 9.36: PK 1 precision comparator with ECOMAT 12 (1976)

The PK 1 (Fig. 9.36) was a table-top instrument. The measurement area was 240 mm x 240 mm, but the maximum usable photo size was 280 mm x 360 mm.

Exchangeable binoculars allowed for either 5x, 12x, 20x or 30x viewing magnification and various types of floating marks could be used. A unique feature was the free-hand guidance. A patented solution with a spherical calotte made possible very sensitive and precise fine centering by tilting this "mechanical mouse" (KRASTEL 1975b).

Like the PSK the PK 1 needed strictly to fulfil ABBE's comparator principle and be invariant against temperature changes. Therefore high precision glass reference scales were selected but these were used in an innovative and patented way. This principle of two-dimensional length measurement is shown in Fig. 9.37 (SCHWEBEL 1975c). The two linear scales (3), of which the extensions intersected at the viewed measurement point (5), were also used for the rectangular guidance of the stage. The vernier scales (2) extended over the whole stage side and, together with the linear scales, formed a moiré effect which enabled the interpolation. The anticipated absolute accuracy of "better than ± 1.5 µm" was comfortably achieved (SEEBER et al. 1979). With the later refinement of the basic resolution from 1 µm to 0.5 µm the PK 1 accuracy was enhanced to ca. ± 1 µm (SCHWEBEL 1979c & 1980b).

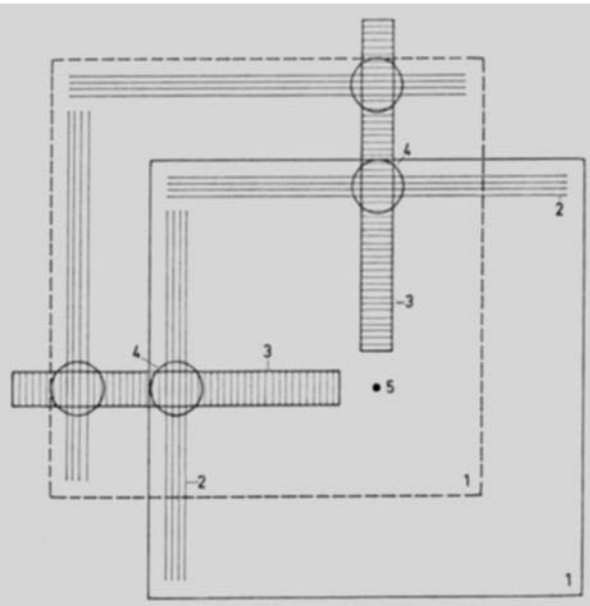


Fig. 9.37: Measurement principle of the PK 1

The PK 1 was introduced at a time when analytical plotters (AP) were already becoming attractive because they used minicomputers for both machine control and for measurement support. Therefore it seemed attractive to use desktop or minicomputers also for supporting monocomparator measurements. In 1978 Oberkochen created a general concept for a hardware and software system to support "non-analytical" instruments such as analogue stereoplotters and comparators by computer programs, either running on dedicated computers or as additional load on AP-computers.

At the Photogrammetric Week in September 1979 ZEISS introduced the AS program system having delivered the PK-AS version to customers 6 months earlier (HOBBIE 1979b). The AS program and its features are described in chapter 10.7.

For interfacing to a desktop or real-time suitable minicomputer the inexpensive DIREC 1 instead of the powerful ECOMAT 12 was sufficient. For entering point numbers and for handling the software, the desktop computer or the CRT-terminal of the minicomputer was used (Fig. 9.38). Working at the PK 1 required only very limited computer support so it did not need a dedicated computer and could usually be connected to a computer that was being used for another purpose (e. g. to the ZEISS PLANICOMP computer).

Fig. 9.38: PK 1 with DIREC 1 and CRT-terminal of a minicomputer from HEWLETT-PACKARD

Nevertheless, a basic program for supporting the PK 1 from desktop computers was also presented as (SCHWEBEL 1979d) CAMOC (Computer Assisted Monocomparator Measurements). This software was developed at Stuttgart University as part of a diploma thesis (SAILE 1980) on the basis of the PRO program, which had been created for the off-line processing of stereocomparator measurements. CAMOC supported monocomparator measurements with the PK 1 and ECOMAT 12 "on-line" with a HP 9825 or HP 9835 desktop computer. It transferred the point number and stage coordinates from the ECOMAT 12 to the desktop computer where the following functions were carried out: interior orientation considering film shrinkage, lens distortion and earth curvature correction; identifying identical points in the overlapping area to neighboured images through identical point numbers; relative orientation with residual parallaxes; interactive error correction; output of image or model coordinates to file or peripherals for block triangulation.

Although the upcoming analytical plotters soon superseded the stereo- and monocomparators, more than 40 PK 1 had been delivered before production was stopped.

9.4 Point marking devices

Mono- and stereocomparators in photogrammetry primarily have been used for aerotriangulation. Because for a safe connection of images artificial tie points are required in areas with poor texture, point-marking devices were necessary. By 1939 ZEISS in Jena had presented a marking accessory for the STEREOPANTOMETER. After centering a metal ring with a small hole bored in the middle over the location to be marked the mark was pricked with a needle through the hole. In 1943 a patent application was made for an electrical marking principle, but this did not go into series production (HESS 1951). When introducing the Oberkochen PSK in 1960 again a marking device was needed.

After several attempts not only the MK marking unit was designed for flagging natural points, but also the KS hammering unit for marking artificial points and the ES centering device for transfering already marked artificial points to an adjacent photograph (BRUCKLACHER 1961).

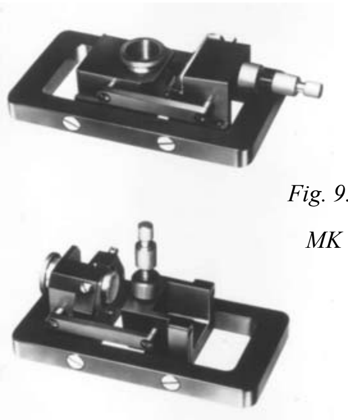


Fig. 9.39: MK marking device (1960)

The MK (Fig. 9.39) consisted of a rectangular metal frame with a centering device (setting mark on glass plate) and a marking device (rotatable stylus) on either side. Both devices met the identical location when being lowered. After centering to a point a ring-type mark of 1 mm diameter was produced.

The KS hammering unit (after a proposal of DONGELMANS from the ITC International Training Center in Delft) had a small steel ball of 0.2 mm diameter which stuck out of the lower side of an acrylic glass plate. The ball itself was the setting mark, and through a spring-loaded small hammer it became the marking tool as well (Fig. 9.40). The result was a circular hole in the emulsion of about 0.1 mm diameter.

For tansfering a point on to a stereo-partner the ES centering unit was used (Fig. 9.40). After centering a ring mark onto the point to be tansfered with two knurled-head screws, this ringmark was replaced by a point mark. Then the KS was manoeuvered into the correct position over the stereo-partner by making a stereoscopic observation under a stereoscope (Fig. 9.41),

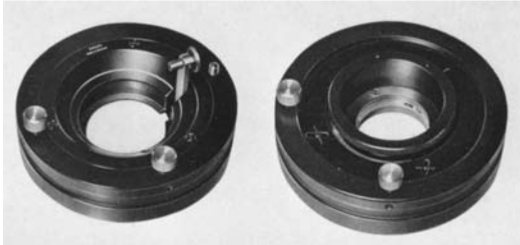


Fig. 9.40: KS hammering and ES centering device (1960)

Fig. 9.41: Transfer of an artificial point under a stereoscope

The accuracy of these basic tools was about $\pm$5 to $\pm$7 µm. Since the late 1960s several competitors had offered more powerful point marking instruments with viewing magnification and higher accuracy potential but it took CARL ZEISS Oberkochen about 10 years to address a higher level of point marking. However, in 1979 at the Photogrammetric Week in Stuttgart the PM 1 point marking instrument was introduced (Fig. 9.42).

Fig. 9.42: PM 1 point marking instrument (1979)

By experiencing the high accuracy of the modern comparators and the high end analytical stereoplotters the aerotriangulation results showed that the quality of point transfer is of great importance for the overall accuracy and should therefore match the measurement accuracy. Therefore the PM 1 was, like the PK 1 monocomparator, designed for a positioning accuracy of $\pm$ 1 µm (SCHWEBEL 1979d).

The selected design principle allowed freehand coarse positioning of both images on the stages under direct viewing. After fixing the images on the stages with footswitch released arms (Fig. 9.43) the stages could be moved within ± 15 mm for joint or separate fine positioning.

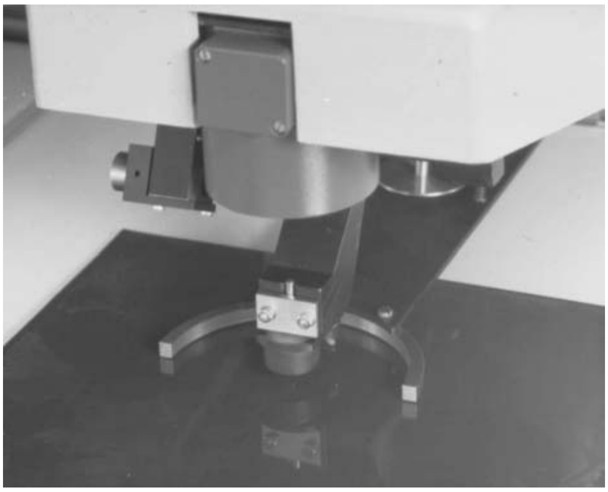


Fig. 9.43: Fixing of image and marking head of the PM 1

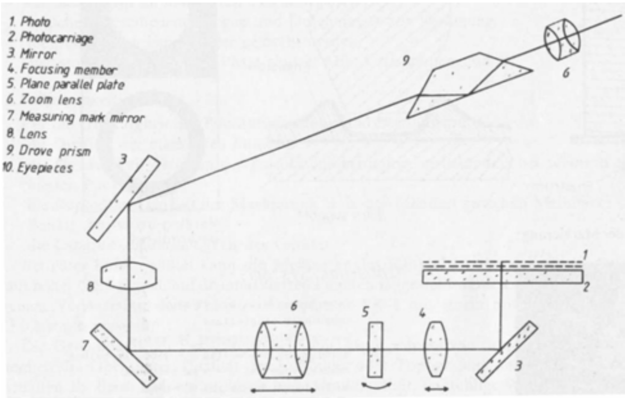


Fig. 9.44: Optical diagram of the PM 1

Fig. 9.44 shows the optical setup. Whereas the viewing optics with connectable dove prisms (0° to 360°) for image rotation were housed within the optical arm, the measurement optics were secured to a stable cast base. The measurement optics included a concentric floating mark (black or luminous), zoom magnification (6.5x to 26x), tiltable plane-parallel optical plate for centering the floating mark to the marking position, and focussing to the emulsion side.

The artificial marks were created by a needle, which was pressed against the emulsion and inductively heated up to 150° C for 2 sec. This was similar to the previously mentioned invention in Jena from 1943 for which CARL ZEISS, Oberkochen had applied for a fresh patent in 1951. The heated needle melted a hole in the emulsion and generated a ring-shaped wall, resulting in a light center spot with a dark ring around. (Fig. 9.45). This technique garantueed visibility of the mark in dark and in bright image areas (Fig. 9.46). Various needle diameters from 40 μm to 200 μm were available. With swiveling in a rotating felt-tipped pen an additional coloured ring mark could be added for easier identification of the small mark.

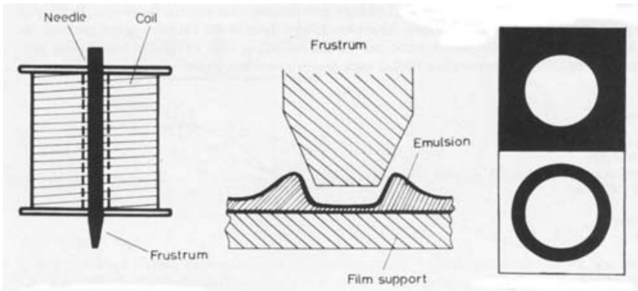


Fig. 9.45: Marking principle of the PM 1

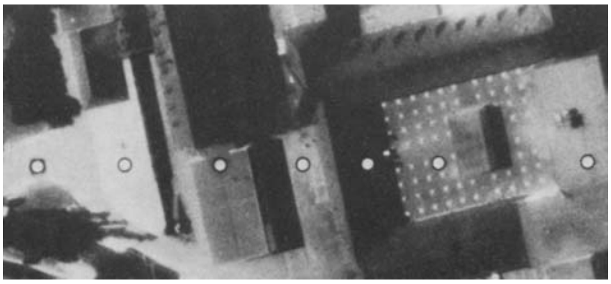


Fig. 9.46: Sample of the marking with PM 1

The excellent marking accuracy of ± 3 μm using the PM 1 for clearly identifable points was demonstrated by independent researchers (SIGLE 1981).

When the PM 1 was introduced in 1979 the photogrammetric market was already saturated with point marking and transfer devices. Further, analytical stereoplotters with their "digital" point marking by digitally recording image positions had started to make these instruments obsolete. However, between 1980 and 1990 more than 30 PM 1 instruments were sold.

10. Analogue stereoplotters & graphic accessories

With the restart in 1951 CARL ZEISS in Oberkochen had available the reconstructed C7 STEREOPLANIGRAPH 1st order stereoplotter which was soon followed by the C 8, which in the beginning was mainly used for precision mapping at large scales and for strip triangulation. In the following year a newly developed 3rd order stereoplotter, the STEREOTOP, was created for small and medium scale mapping. Because WILD in Heerbrugg had not suffered from World War II as had ZEISS by 1949 this competitor was able to present the A 7 AUTOGRAPH as their 1st order instrument and one year later the stripped down A 8. The A 8 AUTOGRAPH from WILD very soon became the favoured 2nd order stereoplotter and was sold in quantities especially to developing countries to fulfil the urgent need for topographic mapping at medium and large scales.

For this growing demand other competitors soon started to introduce appropriate instruments: in 1947 the KELSH plotter (USA), in 1950 the STEREOTOPOGRAPH D after POIVILLIERS from SOM (France), in 1952 from Italy the STEREOSIMPLEX III after SANTONI from GALILEO and the PHOTOSTEREOGRAPH model Beta after NISTRI from OMI, in 1954 the THOMPSON-WATTS plotter model 1 from HILGER & WATTS in London, and in 1955/1956 from the USSR the SPR-2 STEREOPROJEKTOR after ROMANOWSKI and the SD STEREOGRAPH after DROBYSCHEW. The pressure on ZEISS Oberkochen was further increased in 1958 by the B 8 from WILD and in 1960 by the PG 2 from KERN in Aarau and the Jena made STEREOMETROGRAPH.

Although since 1948 Oberkochen was primarily engaged with the reconstruction and completion of the pre-war range of instruments (see chapters 4 & 5), the designers observed these activities of their competitors carefully and started planning their own 2nd order instrument. Due to the weak organisational structure of CARL ZEISS Oberkochen at that time the search for a solution attracted the interest of three different departments each of which followed and patented different approaches.

BAUERSFELD, the inventor of the STEREOPLANIGRAPH and now a member of the executive board in Oberkochen, still favoured the optical principle and concentrated on an extended C 8 variant (BAUERSFELD et al. 1953b). Within the central office for mechanical design SONNBERGER developed a solution with mechanical gears, based on his Jena experience with mechanical computers for military aiming devices (SONNBERGER 1954f). In the photogrammetic development laboratory AHREND, as a young postdoc engineer, managed a team working both with electrical analogue computation and with a „Lichtlenker“, a light ray as a space rod (PENNING et al. 1959 & AHREND 1961). Based on their efforts various prototypes were built and, except for the "C 9 STEREOPLANIGRAPH" (BAUERSFELD died in 1959), presented to the public in 1960 and 1962.

10.1 Development of prototypes 1960 – 1963

At the 9th International Congress for Photogrammetry in 1960 in London CARL ZEISS, Oberkochen presented two new stereoplotters: the PLANITOP and the AEROMAT.

This E PLANITOP (not to be confused with the F 2 PLANITOP of 1973, see chapter 10.5) was intended to be an improved and more precise 3rd order stereoplotter. It differed from the STEREOTOP by a patented electrical (instead of a mechanical) analogue computer (AHREND 1958). Fig. 10.1 shows the visual similarity of F PLANITOP and STEREOTOP. Fig. 10.2 describes the schematics of the electrical curcuits for one of the five necessary computations (model flattening, height computation, planimetric correction in x and y, vertical parallax).

Fig. 10.1: E PLANITOP with electrical computer (1960)

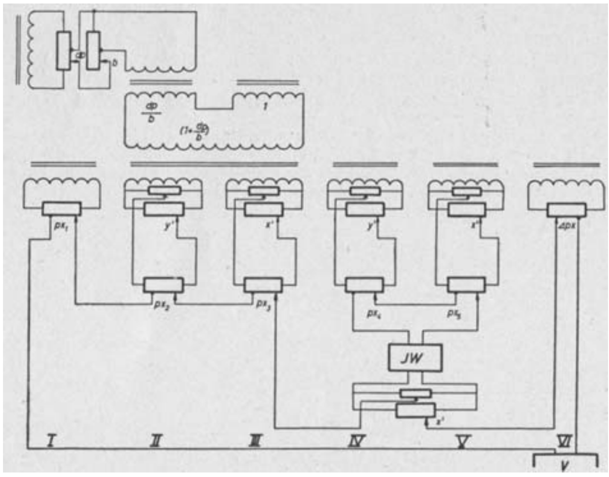


Fig. 10.2: Curcuit schematics for the model flattening

Based on the good experience with the analogue electrical vanishing control computer of the SEG (since 1952), and with knowledge of HELAVA's first analytical plotter, which in 1958 was still also using an analogue electronic computer, ZEISS expected a higher accuracy compared to the STEREOTOP which would mean that the instrument could be used for plotting of lager scales (AHREND 1960a). Testing at the Hanover Technical University confirmed that the requirements for the German base map (Deutsche Grundkarte) 1 : 5 000 were just reached (LEHMANN 1960a). However, in spite of the now cleared vertical parallax, the direct reading of heights and improvements to floating mark, viewing optics and pantograph, several disadvantages remained: the orientation procedure was still unorthodox as in the STEREOTOP, the floating mark movement had to be done by shifting the image carrier and thus took place in the right image space instead of the model space, and the continued use of approximate formulas affected the accuracy even at moderate photo inclination. As a result the E Planitop did not go into series production.

Parallel to the E Planitop, Carl Zeiss intended to introduce their 2nd order stereoplotter into the market, the Aeromat, which was designed to handle super-wide angle photographs, too.

In Fig. 10.3 the arrangement of the orientation elements near the handwheels, the display of the hidden position of the stages on a contact print on the left (similar to the PSK), the height counter on the right and the plotting suface on the top can be seen. Height and plotting scale were selected by changing gears.

The stereo modeling was done in the instrument by rays of light (Penning et al. 1959 & Ahrend 1961). The model point was formed by a light source, the projection centers each by a pinhole and the image points were represented by photoelectric cells (Fig. 10.4). Being divided into four parts the latter were able to center to the light ray and to detect any shift, which then was compensated by a respective image movement (Ahrend 1960b). For relative orientation the image stages were inclined as was the model carriage system for the absolute orientation.

Fig. 10.3: Aeromat, a 2nd order stereoplotter (1960)

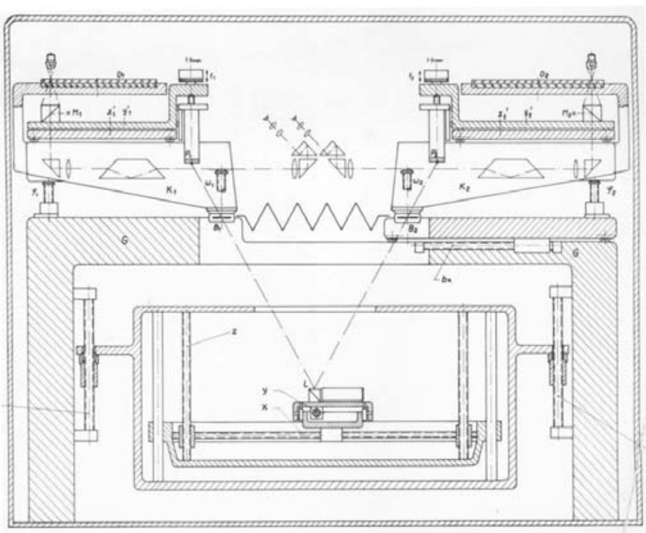


Fig. 10.4: Light rays simulating space rods in Aeromat

The intention of the Zeiss engineers was to achieve a cost-saving model formation and to avoid the suspected model deformation by bending and wearing of mechanical space rods. In fact the electrical control systems became very complex and costly and the achieved accuracy was not satisfied. Therefore this development, like the E Planitop, was stopped soon after having presented the prototype at the 1960 London congress. Four years earlier Kern had announced a concept similar to the Aeromat which had also failed.

The ongoing scepticism against mechanical space rods (successfully used by Wild in the Autograph stereoplotters) guided Zeiss in Oberkochen immediately to a third attempt to realise a different approach following in-house ideas. Based on the already mentioned experience with mechanical gears for calculation (as in the Stereotop) the design concept of Sonnberger was implemented as Supragraph and presented in 1962 at the "March Meeting" in Washington, D. C. (Fig. 10.5).

Fig. 10.5: Supragraph (1963)

This instrument should allow plotting at very high accuracy with unreduced aerial photographs (including super-wide angle) and therefore also be usable for aerotriangulation (Träger 1962). Use as a stereocomparator should also be possible. By computing the projective relation between images and model the photo carriers could be designed as planar cross slide systems as in comparators. Fig. 10.6 shows the mathematical formulas as written for use in the mechanical computer sections of the Supragraph. The schematic diagram and the view of the gears are shown in Fig. 10.7 and Fig. 10.8 respectively and foreshadow the huge effort of the many mechanical gears and cardan shafts, which made the Supragraph much more expensive than expected. Although the high accuracy potential was confirmed with $\pm$ 3 µm coordinate accuracy from grid measurements, the prototype remained the only unit built and was sold to a US government agency, where it was used successfully for several years.

$$m = x \cdot tg\varphi + y \cdot tg\omega$$

$$a = \sqrt{tg^2\varphi + tg^2\omega + 1}$$

$$K = \frac{[z-(x \cdot tg\varphi + y \cdot tg\omega)] \cdot [1-\sqrt{tg^2\varphi + tg^2\omega + 1}]}{\sqrt{tg^2\varphi + tg^2\omega + 1}}$$

$$x' = \frac{f}{z+K-m} \cdot x + tg\varphi \cdot \frac{2z+K-m}{1+a}$$

$$y' = \frac{f}{z+K-m} \cdot y + tg\omega \cdot \frac{2z+K-m}{1+a}$$

Fig. 10.6: Mathematics of SUPRAGRAPH

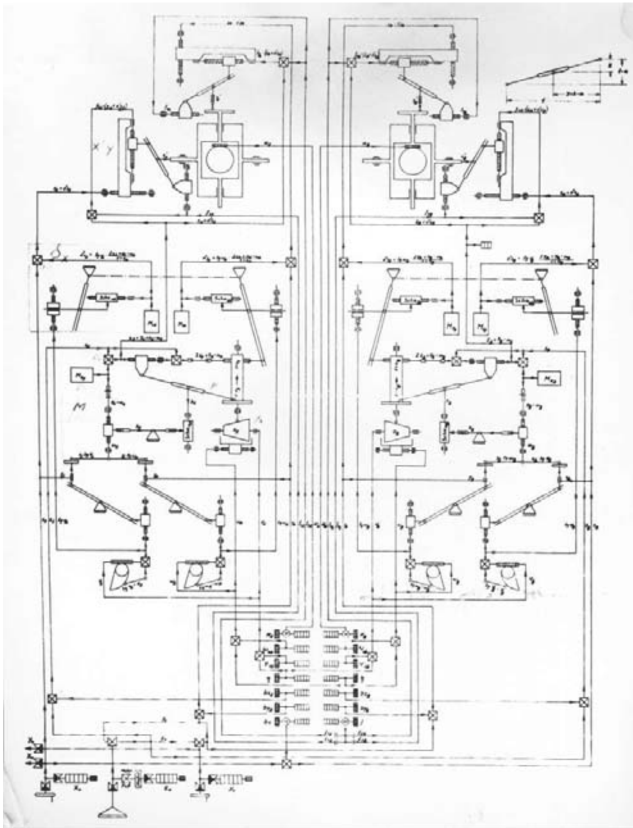


Fig. 10.7: Schematic diagram of the gears within SUPRAGRAPH

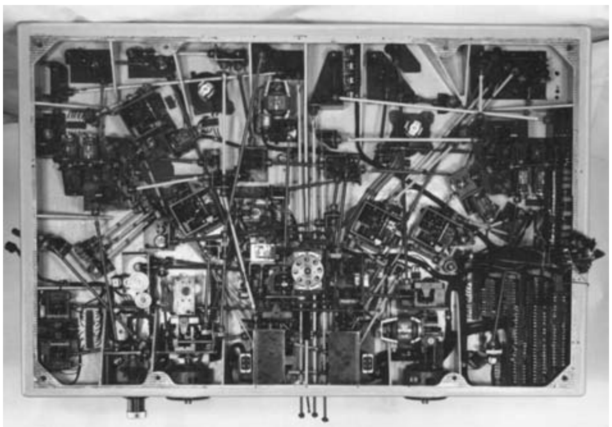


Fig. 10.8: View of the gears at the bottom of SUPRAGRAPH

This sequence of failures somehow was extended by OTTO HOFMANN at ZEISS-AEROTOPOGRAPH (ZA) in Munich, where he was employed between 1962 and 1964. Previously he had been manager for photogrammetric stereoplotters in Jena from 1954. In Munich he described the concept of a mechanical affine plotter, but at this time the integration of ZA into CARL ZEISS, Oberkochen was already ongoing and HOFMANN left ZA and joined MBB in Ottobrunn.

In the meantime the pressure on ZEISS by competitors had increased by the introduction of further new stereoplotter models. In 1963 and 1964 the THOMPSON-WATTS plotter model 2, the STEREOKARTOGRAPH model V and the STEREO-SIMPLEX II from GALILEO as well as the PRESA 224 from SOM had been introduced. In 1965/1966 Jena followed with STEREOTRIGOMAT and STEREOMETROGRAPH. Therefore Oberkochen finally decided to trust the mechanical space rod and to use it in a design variant, which was already proposed and patented by BAUERSFELD in 1954 (ZEISS 1954b). As a result the the PLANIMAT was developed between 1963 and 1966 (see chapter 10.3).

10.2 DP double projector

Since 1947 the KELSH-Plotter had become very popular in the USA. This stereoplotter followed the principle of the "objective optical projection" as patented by GASSER in 1915 and used photographs in the original format. It continued the tradition of several pre-war instruments from different suppliers including the MULTIPLEX from ZEISS in Jena which used a reduced format.

By 1951 Oberkochen had completed a prototype of such a double projector named DUPLEX, which, like the KELSH plotter, could handle full size aerial photographs but was working with a model enlargement of only 2x to 3x instead of 5x. The then necessary smaller base was realised by diverting the projection direction (Fig. 10.9). At that time this development and several related and similar patent applications for some reason were not followed up (SONNBERGER 1951, ZEISS 1953 & AHREND 1959).

Fig. 10.9: DUPLEX (1951)

Only after the kick-off of the PLANIMAT development as the 2nd order stereoplotter did Oberkochen resume the idea of a double projector in 1965. Remarkable impetus came from the Land Survey Office in North Rhine-Westphalia, which was looking for a simple instrument for the revision of the 1 : 25 000 topographic map. The device should allow a directly viewed comparison between stereomodel and the map and should be more precise than the STEREOTOP (KRAUSS 1967).

The DP 1 double projector was first presented at the Photogrammetric Week in 1967 (AHREND et al. 1968). The special characteristics of the DP 1 were the asymmetric projectors for film diapositives and negatives, of which only the 60 % model overlap was projected (Fig. 10.10). The projectors were tiltable in φ and ω and mounted on a base tube, which was fitted to the z-carriage, the latter being movable in height by a foot-disk. By turning the base tube the canted ball bearings of the projectors caused a base change. To adjust for the swing κ of the photographs the photo stages in the projectors were rotated. The height values were read from exchangeable glass scales through a small projector screen at the z-carriage. Scales were supplied as standard for the following model scales: 1: 5 000, 1: 10 000 and 1: 25 000 and 1: 12 000, 1: 24 000, 1: 36 000 were optional. Other scales could be supplied on request. The model enlargement by exchangeable projection lenses was adapted to the usual photo scales for the revision of topographic maps, for which the depth of focus range with 20 % was sufficient in most cases. The entire model area was illuminated by Fresnel lens condensors similar to the SEG rectifier from ZEISS, and for the image separation the anaplyphic principle was applied with optimised red and green filter foils (Fig. 10.11). For the model evaluation the stereomodel could either be projected onto the basic table and therefore into a black & white map , or onto the small movable projection table with tiltable surface, luminous floating mark and a drawing pencil that could lowered and raised.

In 1969 a modified variant of the DP 1 was created and delivered as DP 1b to the topographic units of the German Armed Forces for mobile use in special vans (Fig. 10.12).

Fig. 10.10: DP 1 double projector (1967)

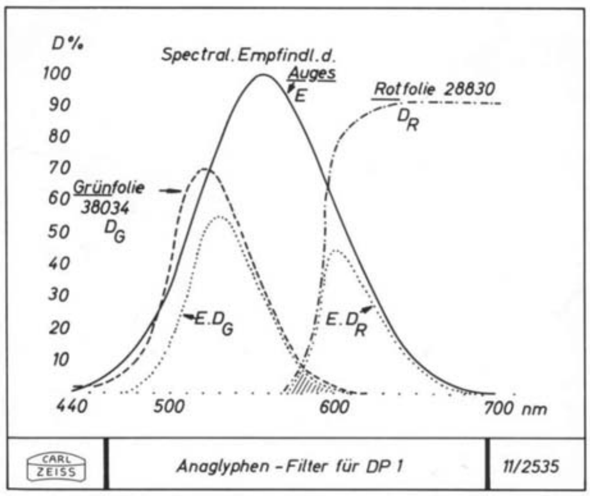


Fig. 10.11: Spectral transmission of the anaglyphic filters

Fig. 10.12: DP 1b, mobile version of the DP 1 double projector (left: ready for transport, righ: ready for use)

The most important parameters of the DP 1 were:

- *Focal length: 153 mm,*
- *image format in mm: 230 x 230, (140 x 230 usable),*
- *phi: ± 6 gon,*
- *omega: ± 6 gon,*
- *kappa: ± 16 gon,*
- *common phi: ± 6 gon,*
- *bx: 130 mm to 325 mm,*
- *enlargement: 2.5x,*
  (2.0x and 1.6x with optional projection lenses),
- *depth of focus range: up to ± 20 %*
  (depending on lens stop 1: 22 to 1: 80),
- *z-range: 250 mm to 620 mm over main table,*
  170 mm to 540 mm over small movable table,
- *size of main table: 600 mm x 800 mm,*
- *diameter of small projection table: 120 mm,*
- *floating mark diameter (variable brightness): 0.4 mm.*

By the measurement of grid models at 2.5x enlargement the mapping precision was determined as ± 0.12 mm in planimetry and as ± 0.15 % of h in height, which met the known accuracy of the KELSH plotter with 5x enlargement (SCHWIDEFSKY 1964).

Also in 1969 the DP 2 and DP 3 configurations were presented. In the DP 2 the small floating mark table was mounted on an additional cross slide system and moved by hand wheels. X- and y-coordinates could be read from mechanical counters with 0.1 mm resolution. The DP 3 (Fig. 10.13) was a DP 2 connected with the EZ 3 external tracing table (800 mm x 1 200 mm) via synchros and change gears (see chapter 10.6).

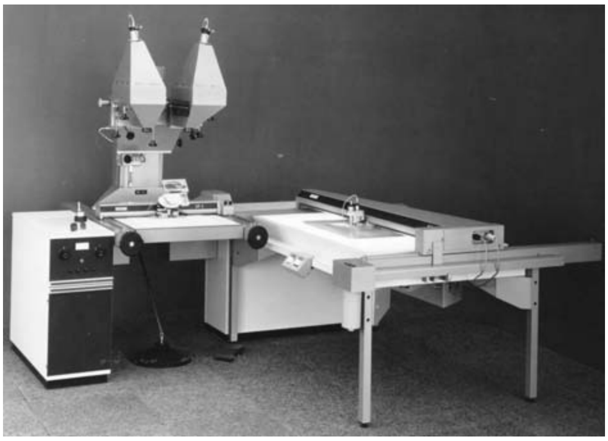


Fig. 10.13: DP 3 with EZ 3 external tracing table (1969)

A potential error source for all kinds of stereoplotters but being especially dangerous when using double projectors is the so-called "Fertsch effect" which PULFRICH had already investigated and described in 1922. The phenomenon can occur during dynamic measurements parallel to the stereo-base, e. g. when drawing contour lines or when profiling in x-direction. The reason is the latency of the human viewing system whereby, if the illumination of the left and right image is not equal, the darker image arrives in the brain a few 1/100 seconds later. The x-component of the movement then causes a virtual x-parallax and the floating mark is seen above or below the terrain. During contouring the operator will "change course" and misplace the contour line. During profiling an erroneous z-correction results in a wrong profile height. The impact on plotting accuracy can be as great as 0.5 mm in planimetry or 0.3 ‰ of h in height (HOBBIE 1972). The necessary true equalisation of illumination can be easily gained by oscillating with the x hand wheel and viewing the floating mark. Uneven illumination will result in looping of the floating mark, which then have to be flattened by adjusting the light of the left or right image.

By the mid 1980s about 200 DP double projectors had been assembled at the ZEISS subsidiary HENSOLDT in Wetzlar, where also the ORTHO-3-PROJECTOR (chapter 8.5) and the external tracing tables EZ 3 and EZ 4 were manufactured (chapter 10.6).

10.3 PLANIMAT

After failure of the projects presented in 1960 and 1962 (see chapter 10.1) Oberkochen concentrated on using the mechanical space rod principle. Unlike the "two-armed" rod (as used for example in the AUTOGRAPH family from WILD), ZEISS used an own registered design proposed by BAUERSFELD (ZEISS 1954b) but in a modified version using a "single-armed" rod. This type is more resistant to bending, because it can be shorter and because the load imposed between the fixed projection cardan and the model point by the moving image stages is less. Another advantage is the simpler design of the focal length setting. Fig. 10.14 shows the principle of the two-armed and the single-armed rod, and in addition the cranked space rod, which was discussed for the later PLANITOP (see chapter 10.5).

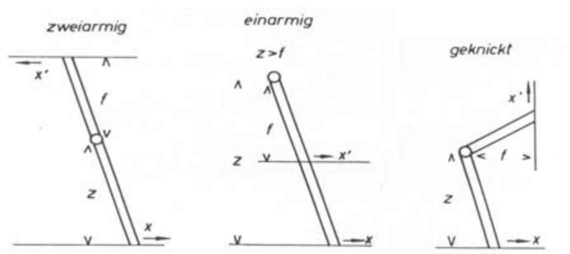


Fig. 10.14: Various mechanical space rod designs

In August 1964 a full-scale wooden mockup of the resulting concept of an analogue stereoplotter with an appropriate external tracing table was constructed (Fig. 10.15). After intensive testing and refinement (AHREND 1964b & 1966b) it was 1967, when technically mature prototypes of the new ZEISS PLANIMAT and the EZ 2 tracing table (see chapter 10.6) were presented at the Photogrammetric Week in Karlsruhe (Fig. 10.16).

Fig. 10.15: Wooden mockup of PLANIMAT and EZ 2 external tracing table (1964)

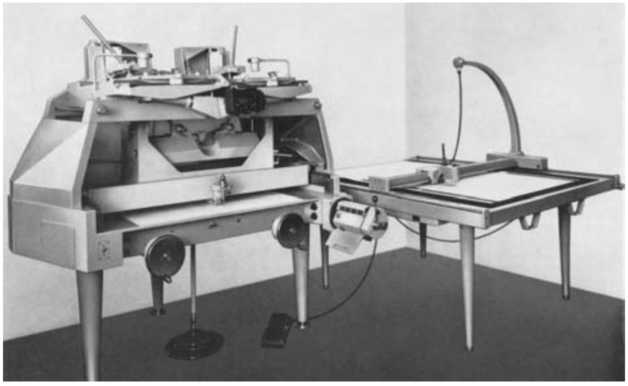


Fig. 10.16: PLANIMAT with EZ 2 external tracing table (1967)

One prominent feature of the D 2 PLANIMAT was the internal tracing table below the model carriage with dimensions of 1200 mm x 1100 mm. The drawing paper was fixed with thin flexible metal rulers on a magnetic rubber sheet. Upon the upper cross bars the tiltable stage carriers were supported at three points. They carried the cross slide system of the image stages as well as the mechanical arms for the eccentric projection cardans. The latter were height-adjustable according to the focal length to be set (Fig. 10.17). The pivot of the stage carriers was positioned eccentrically at the front bar, and the optical viewing train was guided through these pivots. According to the findings of GOUDSWAARD in 1960 this led to a faster convergence of the empirical relative orientation.

The continuous setting of the calibrated focal length was possible over a range of 128 mm, either between 84 mm and 213 mm for wide angle and super-wide angle photographs or, after resetting the cardans, between 180 mm and 308 mm for intermediate angle and normal angle images (in the later D 3 PLANIMAT the whole range was divided into three sections).

The mechanical space rods were pulled apart by the base bx (Fig. 10.18), thus creating the so-called "ZEISS parallelogram". This had the advantage that it permitted a very small base bx, and by and bz could be used to simplify the relative orientation. Further it avoided the need for a common φ for the absolute model levelling.

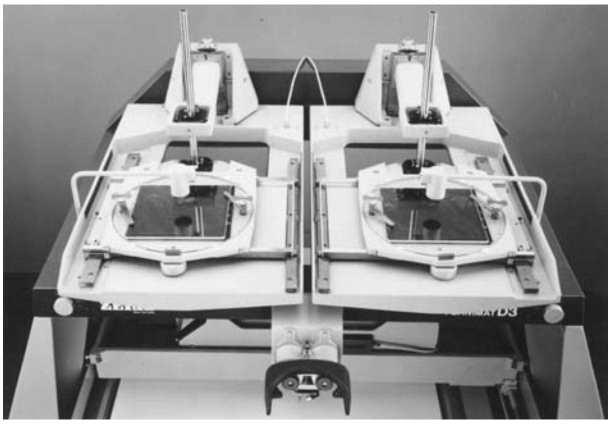


Fig. 10.17: Image carrier and projection cardans

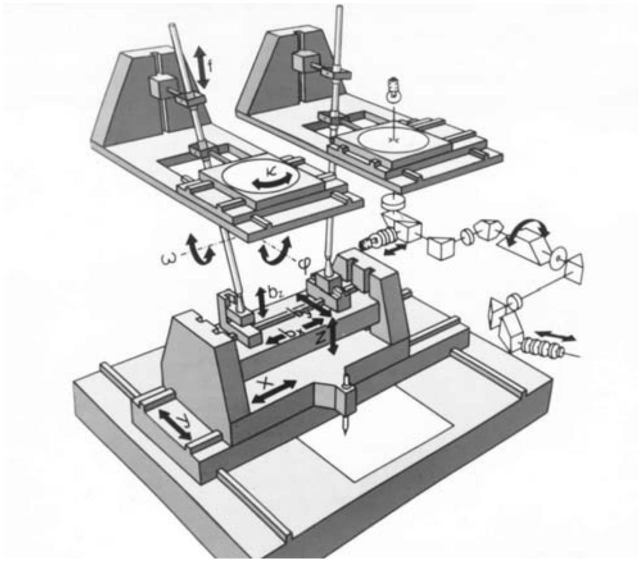


Fig. 10.18: PLANIMAT design principle

By using by and bz the relative orientation could not only be done by manually clearing the y-parallax at the GRUBER-points with the usual sequence "κ_1, κ_2, φ_1, φ_2, ω_1" but also in a modified and faster converging sequence: "by, κ_2, bz, φ_2, ω_1".

Within the PLANIMAT the image stages were moved and not the viewing optics (except the tilting of one mirror with the ω-setting) and the optical train passed through the photo carrier cardans. This simplified the optical design and resulted in a very high viewing quality. Viewing magnification was 8x and the field of view 31 mm. Image rotation was executed by dove prisms and the floating mark with 40 μm diameter was a luminous one with adjustable brightness.

The stage plates carried 9 etched grid crosses of very high precision, which not only enabled an instrument calibration without the need for extra grid plates, but also a simple and patented method for measuring the coordinates of the projection centers for aerotriangulation (BRUCKLACHER 1970b). As an option aspheric compensation plates could be delivered for the removal of camera distortion.

In x and y the model carriage was guided along separate solid steel rails for height and lateral guidance which were ground to very high precision. The broad primary y-carriage was driven by precision lead screws on both sides (connected by cardan-shafts) to avoid a twist. The z-carriage was guided by two steel tubes and driven from the footdisk by four lead screws connected to each other by a transmission chain.

By pulling the x and y handwheels they could be switched from a fine (2 mm per revolution) to a coarse movement (10 mm/rev.). The alternative freehand guidance could be used during orientation and for mapping on the internal tracing table. For this the screw-to-nut connection was released by a lever. This was made possible by a spring-loaded roller nut, which was patent-registered in 1959 (MONDON 1959b & 1959c). The nut was running on the wired lead screw (a hardened steel wire embedded in the screw pitch), which avoided heating and wearing (Fig. 10.19 & 10.20).

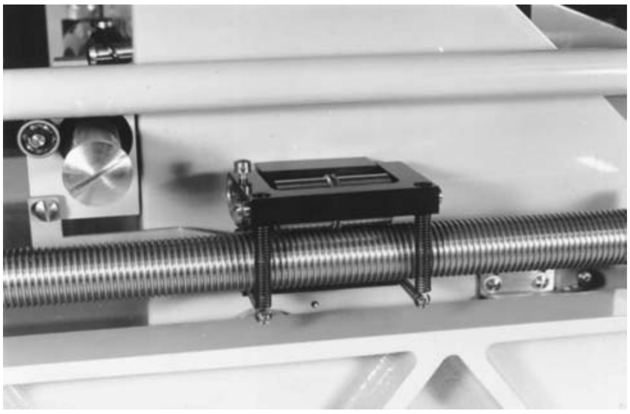


Fig. 10.19: Roller nut and wired lead screw of Planimat

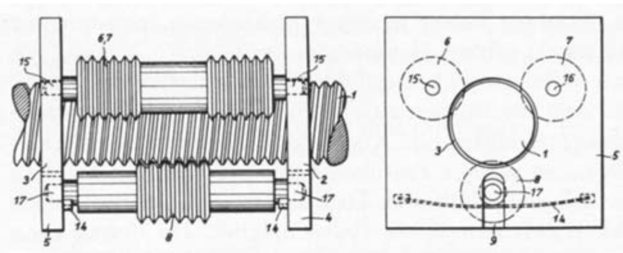


Fig. 10.20: Principle of the spring-loaded roller nut

An optional earth curvature correction device for plotting with medium and small image scales was available. This introduced a small correction between the height setting and the z-lead screws, depending on the y-coordinate only. The influence of x was neglected as due to the shorter model dimension its influence was only 1/4 of that in the y-direction (Fig. 10.21).

In 1969 special optional arms for the projection cardans were designed to permit the use of focal lengths <84 mm in order to allow evaluation of terestrial photographs e. g. the TMK 6 (Fig. 10.22).

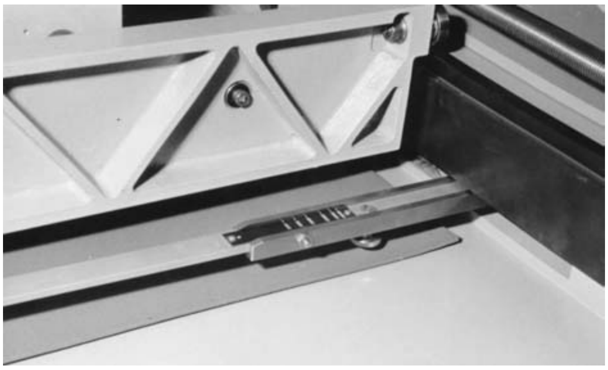


Fig. 10.21: Setting of earth curvature correction

Fig. 10.22: Optional projection cardans for the use of (terrestrial) focal lengths <84 mm

The main parameters of the D 2 PLANIMAT and the later D 3 were:

- *Focal length: 84 mm to 305 mm,*
- *image format: up to 230 mm x 230 mm,*
- *phi, omega: ± 5.5 gon,*
- *kappa: ± 400 gon, (D 3: ± 20 gon),*
- *bx: 0 mm to +340 mm,*
- *by: ± 17 mm,*
- *bz: ± 42 mm,*
- *x: 415 mm, (D 3: 460 mm),*
- *y: 700 mm,*
- *z: c+40 mm to c+310 mm (c = calibrated focal length),*
- *field of view: 31 mm, 8x viewing magnification.*

The accuracy of the PLANIMAT as determined by grid measurements was ± 5 µm in x and y at image scale and ± 0.04 % of h for single point settings (AHREND 1967a). Later results of aerotriangulation with independent models confirmed these values (EBNER et al. 1970), which are equivalent to the potential of known 1st order instruments. For aerotriangulation the coordinates of the projection centers could be determined by two different methods: either by the previously described resection using the etched cross marks on the stage plates, or by positioning the space rods vertical using a bubble level magnetically fixed to the rod, and measuring the z-difference to the next calibrated ring mark on the rod.

Besides aerotriangulation with independent models the PLANIMAT was used for the measurement of digital terrain models and for precision mapping. Coordinate recording was possible either by reading from elementary counters, with the coordinate recording unit already known from the C 8, or with the ECOMAT, with 0,01 mm resolution. For reading height values directly in meters or feet change gears were available for the usual model scales. For the automatic measurement of terrain profiles for orthophoto production the EC 5 correlator from ITEK was available (see chapter 8.4). An impressive example for an early semi-automatic large scale mapping application (between 1: 500 and 1: 10 000) was the Ontario Ministry of Transportation and Communication in Canada, which, since 1969, was using four PLANIMAT with magnetic tape recording and an automatic drafting machine for plotting (MCLEOD 1973).

In 1970 the PLANIMAT was slightly modified, differently painted and named D 2 PLANIMAT. Fig. 10.23 shows a D 2 setup for digital mapping with ECOMAT 12, desktop computer and magnetic tape drive.

Fig. 10.23: D 2 PLANIMAT with ECOMAT 12 and HP 9825

From 1980 the model D 3 (Fig. 10.24) was delivered with slightly modified ranges after a redesign for cost reduction purposes. For the supporting structure alloy casting (as in the PLANICART) now replaced steel, thus reducing weight and cost. The internal tracing table was now illuminated and the mechanical coupling of the EZ 2 external tracing table was suspended. The EZ 4 or EZ 3 could be connected via synchros although by this time encoders were already prefered for digitizing with later off-line plotting. By using linear instead of rotary encoders for x and y the freehand guidance could be used without disturbing the relationship between the floating mark and the encoders.

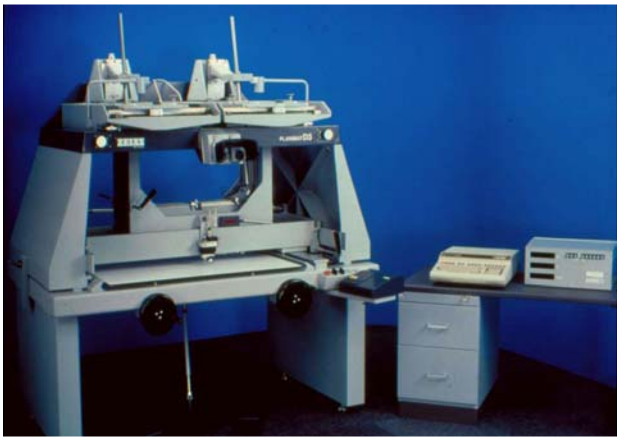


Fig. 10.24: D 3 PLANIMAT (1980)

Fig. 10.25 Serial assembly of D 2 PLANIMAT and EZ 2

By the end of the 1980s about 200 PLANIMAT instruments had been delivered. Fig. 10.25 shows the PLANIMAT assembly hall in the 1970s.

10.4 PLANICART

With the fast acceptance of the PLANIMAT as a universal and very precise stereoplotter for all near vertical aerial images ZEISS came to the conclusion, that a modified version, reduced to drafting purposes, would be less expensive and therefore more competitive for the still dominant mapping requirements.

After an intensive value analysis and a dedicated design the E 2 PLANICART was presented at the Photogrammetric Week in 1971 as an optimised instrument for stereoplotting for all map scales but with focus on the 1: 5 000 to 1: 10 000 scale range (SCHWEBEL 1972). Compared to the D 2 the E 2 consisted of only 300 instead of 650 designed parts and 1 050 instead of 1 700 manufactured components. This resulted in production costs of only 60 % of the costs for the D 2, and a total instrument weight of only 47 % of the D2. The PLANICART had an excellent start (Fig. 10.26) and by the end of production around 1990 had also sold about 200 units.

Fig. 10.26: E 2 PLANICART with EZ 3 tracing table at the Ordnance Survey, Southampton (1973)

The design principle of the PLANIMAT was kept for the PLANICART: single-armed space rods, eccentricity of projection centers and cardans of the photo stages, the stage carriers resting on three points, the movement of image stages and model carriage, and the internal tracing table (now being slighty smaller and illuminated). The calibrated focal length was now set in one of the following steps: 87, 115, 153, 210 or 305 mm (each ± 3 mm). The viewing magnification was reduced to 6x, the field of view was 30 mm and the diameter of the now black floating mark was 80 µm.

In 1974 the PLANICART was further optimised and made more cost-efficient and labelled E 3, but the main parameters were nearly unchanged:

- *Focal length in mm: 87, 115, 153, 210, 305 (each ± 3),*
- *image format: up to 230 mm x 230 mm,*
- *phi, omega: ± 5.5 gon,*
- *kappa: ± 400 gon, (E 3: ± 20 gon),*
- *bx: 0 mm to +370 mm,*
- *by: ± 17 mm,*
- *bz: ± 42 mm,*
- *x: 460 mm,*
- *y: 700 mm,*
- *z: c+40 mm to c+390 mm (c = calibrated focal length),*
- *field of view: 31 mm, 6x viewing magnification,*
  (E 3: 26 mm, 8x viewing magnification).

The precision of the PLANICART derived from grid measurements was ± 12 µm in planimery at image scale and ± 0.06 % of h in height (mean coordinate error for a single setting). So the PLANICART was less accurate compared to the D 2 and D 3 by a factor of 3 in planimetry and 1.5 in height, but this still exceeded the requirements for graphical mapping.

For drafting and engraving on the internal tracing table both PLANICART and PLANIMAT were equipped with an adjustable and illuminated ZZ 3 tracing head (later ZZ 4) with various tools being lowered by footswitch.

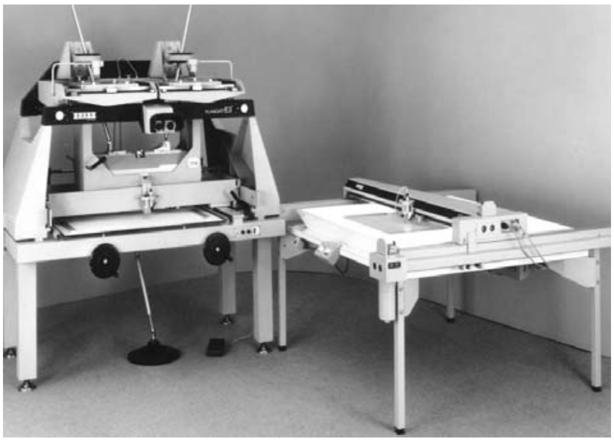


Fig. 10.27: E 3 PLANICART with EZ 4 tracing table (1974)

Fig. 10.28: E 3 PLANICART with DIREC 2 and CRT-Terminal

For greater model to map enlargements the external tracing tables EZ 3 or EZ 4 could be used (Fig. 10.27). By installing encoders and connecting to an ECOMAT or DIREC unit digital coordinate acquisition was also possible for immediate recording, computer supported plotting, or for transfer to an interfaced desktop or minicomputer (Fig. 10.28).

10.5 PLANITOP

At the time of the succesful market introduction of the PLANIMAT (1967) and PLANICART (1971) WILD Heerbrugg also presented in 1971 the B 8 S as an improved version of their successful freehand guided B 8 stereomapper for medium and small map scales. Therefore Oberkochen decided to develop a successor for these applications and for the still available but low selling STEREOTOP. Based on the design experience of the PLANIMAT / PLANICART a rigorous solution was planned. Several design variants allowing further cost reduction were investigated, such as plane rulers for the xz- and yz-plane (similar to the Jena TOPOCART) instead of space rods, or a " cranked space rod " after a proposal from VAN DEN HOUT. These approaches would have avoided the need to incline the photo carriers, and therefore VAN DEN HOUT proposed to introduce φ and ω as a respective crank into the space rods at the projection cardans (Fig. 10.29). However, after negative tests the mechanical designers decided on the classical mechanical space rods for the new F PLANITOP (not to be confused with the E PLANITOP from 1960, see chapter 10.1) as used in the PLANIMAT and the PLANICART.

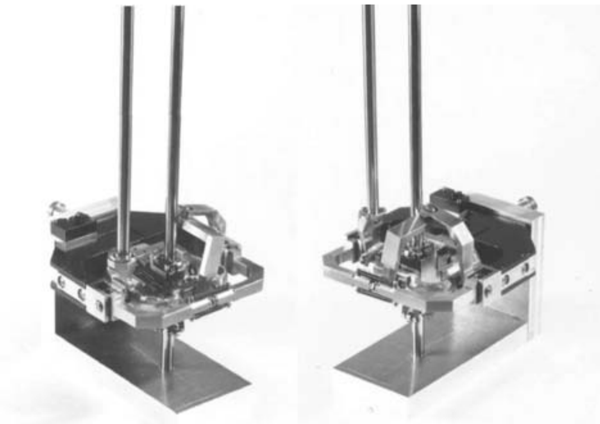


Fig. 10.29: Functional model of a "cranked space rod"

For mapping at medium and small scales where a smaller enlargement between photo and map scale is usually required an instrument can be designed with smaller dimensions thereby reducing costs further. Therefore the new stereoplotter was designed for a 0.5x to 1.5x range of enlargement. This was not possible with the single-armed rod previously favoured in Oberkochen but required a two armed space rod (Fig. 10.30). The resulting design principle of the F PLANITOP is shown in Fig. 10.31.

For enabling fixed viewing optics the inclination axis of the stage carriers was positioned within the image plane and intersected the viewing axis following a patented ZEISS internal proposal (KRASTEL 1973). For stability reasons the cardans of both the stage carriers and the projection centers were shifted inwards.

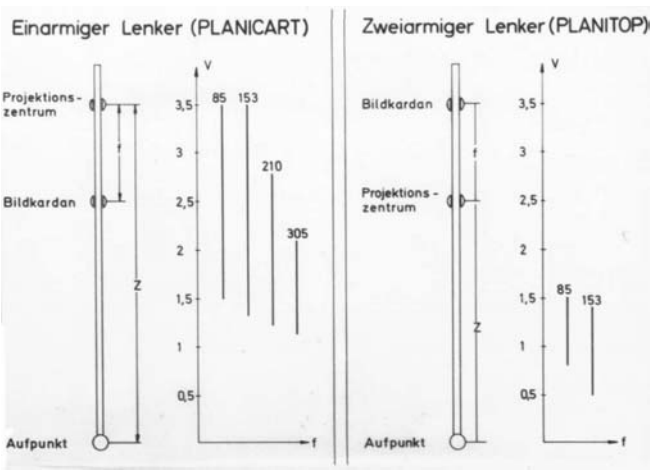


Fig. 10.30: Model enlargement in PLANICART and PLANITOP

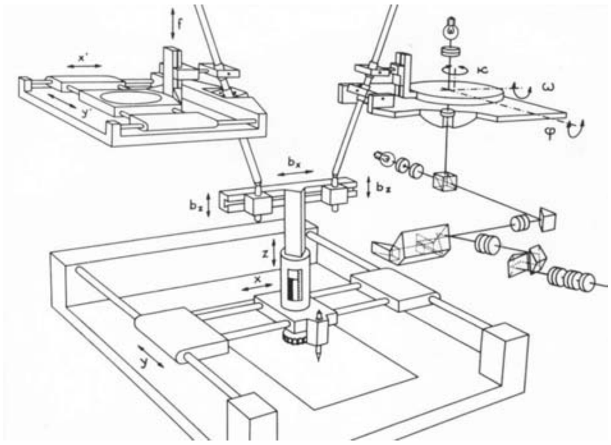


Fig. 10.31: Design principle of the F 2 PLANITOP

Fig. 10.32: F 2 PLANITOP - freehand guided model carriage

The mechanical space rods rested on ball shaped heads on the model carriage which were pulled apart by the bx base, thus forming a "ZEISS parallelogram". Both heads were movable in bx and bz. Instead of the missing by-setting the images had to be rotated by the swing κ. Fig. 10.32 shows the freehand guided model carriage running on steel tubes and not touching the illuminated internal tracing table. The height values were read from exchangeable z-scales with 15x magnification. Between the two hand grips of the model carriage there was the z-thumbwheel for fine movement and at the side a toggle switch for motorised fast up or down movement.

For smooth travelling of the floating mark during contouring and continuous line plotting the operator should feel some resistance when pushing the model carriage forward. Therefore an adjustable friction brake could be applied. The thrust at larger image angles, caused by the inclined guide rods, was compensated.

The F 2 PLANITOP was a table-top stereoplotter with a weight of 56 kg (being only 1/10 of the PLANICART) and consisted of 210 designed and 520 manufactured parts. It was introduced in 1973 at the first Photogrammetric Week in Stuttgart (SCHWEBEL 1973c), where it was shown with the PP 2 Polar-pantograph (Fig. 10.33), which allowed enlargements from photo to map of more than 1.4x (c = 153 mm) and 1.5x (c = 85 mm).

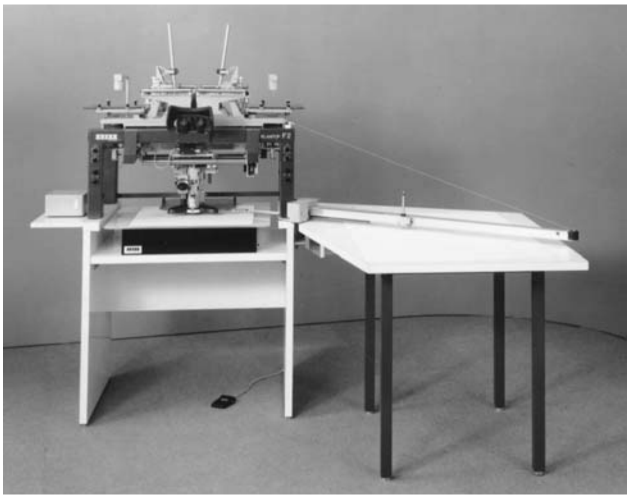


Fig. 10.33: F 2 PLANITOP with PP 2 pantograph (1973)

The enlargement between model and pantograph scale was defined by change gears (Fig. 10.34).

The slightly upgraded F3 PLANITOP was completed by October 1979, but was not exhibited until 1980. The main improvements were an additional and more sensitive fine movement achieved by a kind of reducing pantograph (Fig. 10.35), and an optional earth curvature correction device (Fig. 10.36).

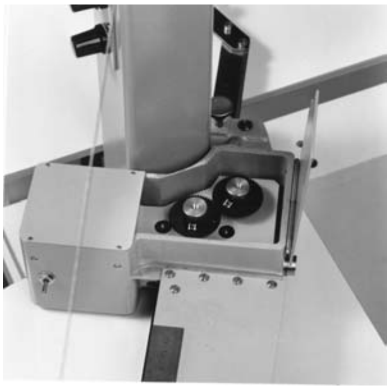


Fig. 10.34:

Change gears for the PP 2 pantograph

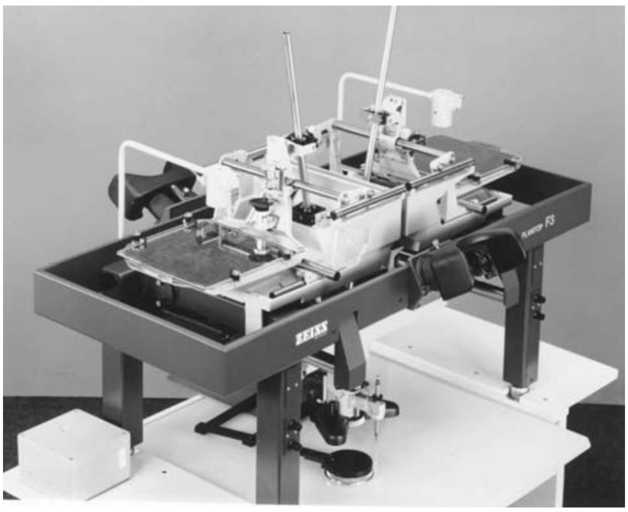


Fig. 10.35: F 3 PLANITOP with new freehand guidance (1979)

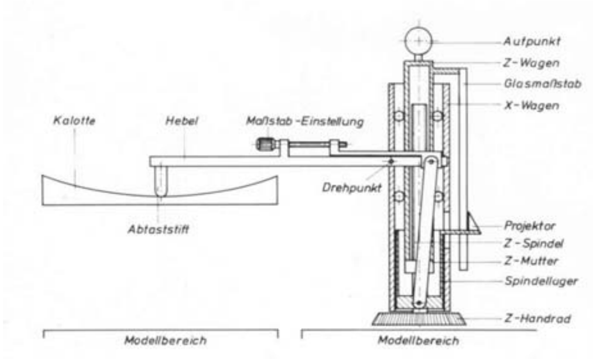


Fig. 10.36: Principle of optional earth curvature correction

The main parameters of the F 2 / F 3 PLANITOP were:

- *Focal length in mm: 87, 153 (each ± 3),*
- *image format: up to 230 mm x 230 mm,*
- *phi, omega: ± 5.5 gon,*
- *kappa: ± 15 gon,*
- *bx: 40 mm to +150 mm,*
- *bz_1: ± 15 mm,*
- *bz_2: ± 15 mm,*
- *x: 240 mm,*
- *y: 320 mm,*
- *z: 60 mm to 240 mm (Δz = 110 mm)*
- *v: 0.8 x - 1.4 x (0.5 x - 1.5 x at 87 mm focal length),*
- *field of view: 30 mm, 6x viewing magnification.*

A comprehensive investigation at Stuttgart University (STARK 1977a) showed the following accuracy results which are all related to the photo scale. With grid measurements ± 9 µm in planimetry and ± 0.06 % of h in height and from model measurements using proven wide angle aerial photographs of a test field ± 12 µm in planimetry and ± 0,11 % of h in height. From super-wide angle images ± 14 µm and ± 0,19 % of h.

By the end of the 1980s, when ZEISS stopped production of all of their analogue stereoplotters, about 100 PLANITOP instruments had been delivered. The F 2 development had been supported by the German Federal Ministry for Research and Technology under the title "Topographisches Kartiergerät" (SCHWEBEL 1979a).

10.6 Graphical plotting

Since the 1920s independent external tracing tables were used in connection with the early stereoplotters for drawing with pencils as the then main form of graphical output. Fig. 4.15 in chapter 4.4 shows one of the last pre-war coordinatographs with the C/5 STEREOPLANIGRAPH. Oberkochen had closely copied this tracing table in 1951, when presenting the Z 2 precision coordinatograph together with the C 7 STEREOPLANIGRAPH. The Z 2 was manfactured nearly unchanged until the late 1960s (Fig. 10.37).

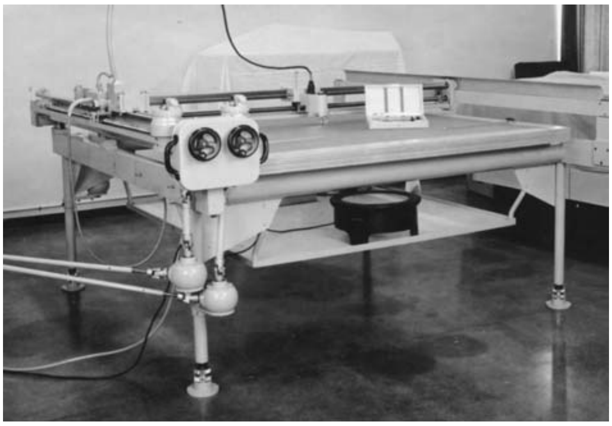


Fig. 10.37: Z 2 coordinatograph (photograph from 1965)

The main parameters of the Z 2 coordiatograph were:

- *Usable area / table area in cm: 120 x 120 / 120 x 150,*
- *positioning: precision lead screws with 5 mm pitch,*
- *coordinate-reading (estimation):*
  at scales: 0.1 mm,
  at illuminated counters: 0.02 mm,
- *change gears: 25 enlargements (standard)*
  between 5: 1 and 1: 5,
- *connection by cardan shafts.*

Several design details of the tracing head with adjustment screws, lifting magnet and several tools were protected by design or by patent (WOLF 1953, ZEISS 1958a & 1958b).

For profile measurements with STEREOPLANIGRAPH and ECOMAT (e. g. volume determination for road construction or for open pit mining) the Z 2 coordinatograph could be equipped with a viewing device (Fig. 10.38) and a patented PR profiling unit (SCHWIDEFSKY et al. 1968), the latter connecting the Z 2 with the C 8 (Fig. 10.39 & 10.40).

Fig. 10.38: Viewing device for the Z 2 coordinatograph with 10x magnification

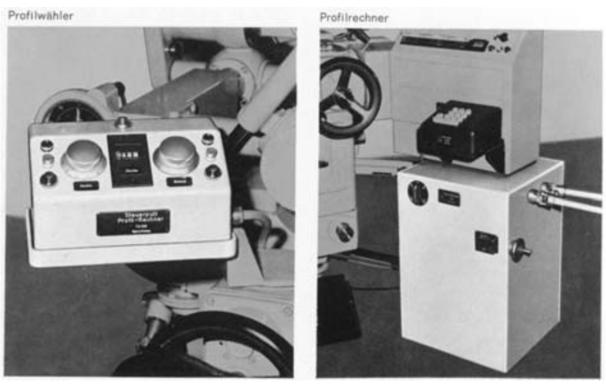


Fig. 10.39: Profile setting at the C 8 and profiling gearbox between C 8 and the motor drive at the Z 2

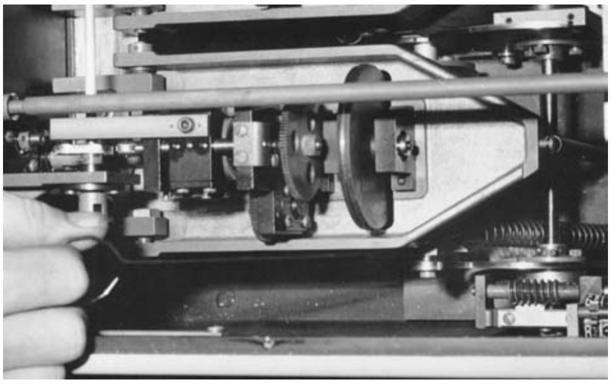


Fig. 10.40: Gearbox of the optional profiling unit for the coordinatograph

At the IX. International Congress for Photogrammetry in 1960 in London CARL ZEISS, Oberkochen presented an automated coordinatograph, the KOORDIMAT (SCHWIDEFSKY et al. 1960). Fig. 10.41 shows the equipment with the IBM punched card reader and the ST printing head, which was already available for the Z 2. With this printing head line maps, symbols and characters could be drawn automatically by reading plot commands and coordinates from punched cards (Fig. 10.42). The maximum x,y-traveling speed was 25 mm/sec.

Fig. 10.41: KOORDIMAT with printing head and card reader

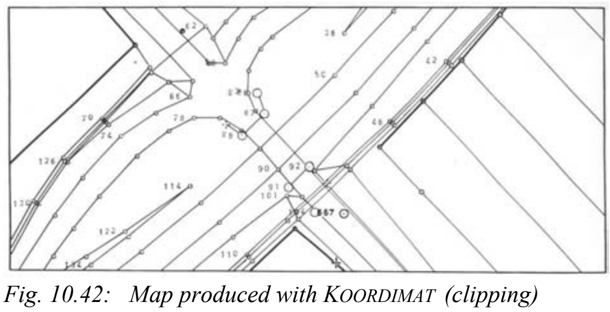


Fig. 10.42: Map produced with KOORDIMAT (clipping)

In 1969 a reading unit was added by which graphical maps could be digitised. The points to be digitised were centered using the handwheels and the viewing device of the table, and after entering a point number or code a record on punched cards was actuated (Bild 10.43). However, soon after the large digitising tablets of the graphics industry came onto the market which, without sophisticated mechanics, were less expensive, more robust and easier in handling.

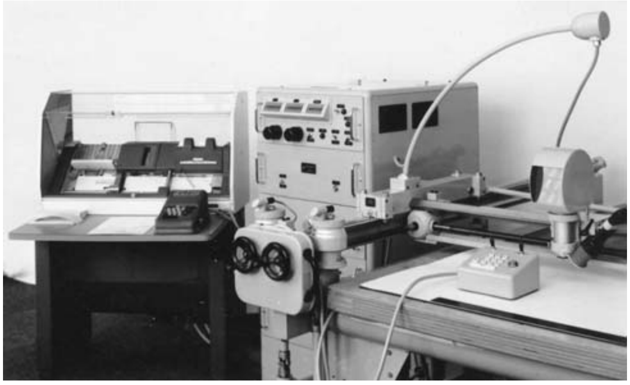


Fig. 10.43: KOORDIMAT digitising unit with EP viewing device and card punch

A new external tracing table, the EZ 2, was also introduced for use with the D2 PLANIMAT on which the drawing paper was fixed by steel rulers on magnetic rubber sheet as on the internal tracing table of the D 2 (Fig. 10.44). The main parameters of the EZ 2 were:

- *Usable area in cm: 120 x 120,*
- *no reading of coordinates,*
- *change gears: 15 enlargements (standard) between 6: 1 and 0.66: 1,*
- *connection by cardan shafts,*
- *ZZ 2 tracing head with electrical lifting and lowering of the stylus, or ZZ 1 with additional stylus rotation for engraving.*

In the following year a profile measurement unit was added (Fig. 10.45).

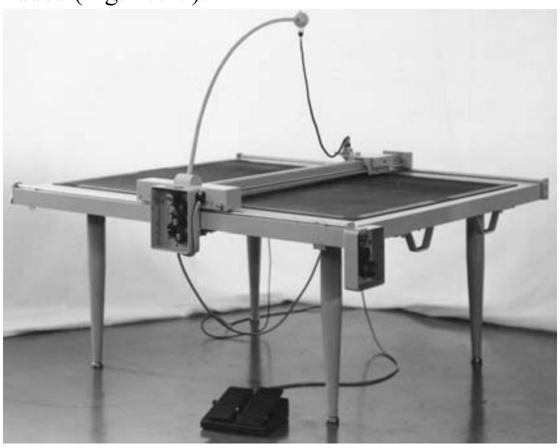


Fig. 10.44: EZ 2 external tracing table (prototype 1966)

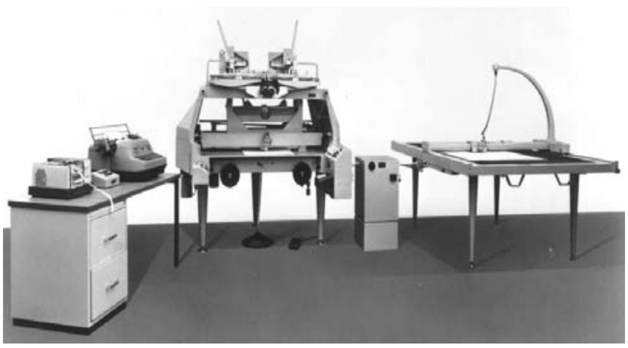


Fig. 10.45: Profiling unit with D 2 and EZ 2 (1968)

The "EZ 3", announced in 1968 as a reduced version of the EZ 2 with only 80 cm x 80 cm plotting area, was not realised. Instead in 1969 the EZ 3 and EZ 4 external tracing tables with illuminated plotting areas of 80 cm x 120 cm and 120 cm x 120 cm were introduced. Like the DP double projector and ORTHO-3-PROJECTOR they were designed and manufactured by ZEISS owned HENSOLDT in Wetzlar. By connecting to the stereoplotter via synchros they could be positioned in any locally convenient position. The EZ 3 is illustrated in Fig. 10.13 and Fig. 10.26 with DP 3 and PLANICART. Fig. 10.46 shows the EZ 4 as a stand alone table. EZ 3 and EZ 4 were often selected for use with the PLANIMAT and PLANICART and both were equipped with change gears for 17 enlargements (standard) between 8 : 1 and 1 : 2. The ZZ 2 tracing head was further developed to ZZ 3. And in 1977 an optional TV-camera and monitor were added for easier viewing of the drawing from the operators seat. (Fig. 10.47).

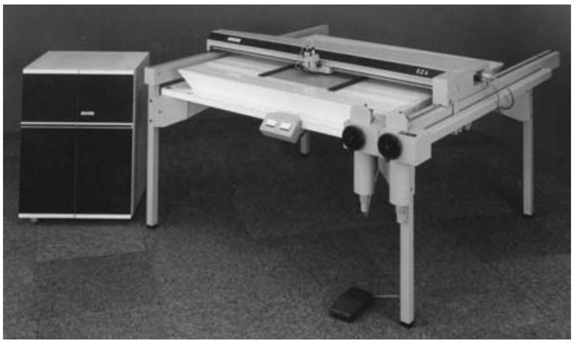


Fig. 10.46: EZ 4 external tracing table (1969)

Fig. 10.47: EZ 4 with TV-monitoring (1977)

A surprisimg and rare development for ZEISS was a precision pencil sharpener, which guaranteed the pencil or lead to be sharpened exactly rotation-symmetric as required for omni-directional drawing (Fig. 10.48).

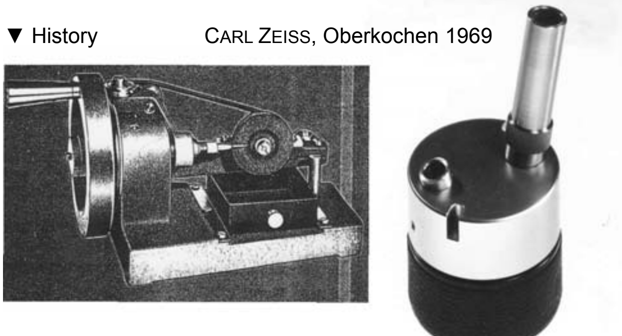


Fig. 10.48: Precision pencil sharpener

The rapid progress in electronics and microprocessing since 1970 not only influenced the recording of coordinates (see chapter 9.1) but also resulted in new processor-controlled tracing tables. CARL ZEISS, Oberkochen introduced the new DZ 5 digital tracing table in 1975 (SCHWEBEL 1975a). And in 1976 a modified version was presented as DZ 6 for use with the C 100 PLANICOMP (see chapter 11.2). The DZ 5 and 6 looked like the EZ 4 and also had an illuminated plotting area of 120 cm x 120 cm (Fig. 10.49). The tracing head was driven by servo motors with a resolution of 0.01 mm and a maximum speed of 100 mm/sec under processor control, but could also be moved manually using a joystick, e. g. for orientation.

The DZ 5 was intended for use with PLANIMAT, PLANICART and PLANITOP from ZEISS but could be used with any analogue stereoplotter equipped with incremental encoders. In the basic operating mode F (Following) the tracing head followed the movement of the floating mark for direct line mapping. The enlargement from model to the plot was set with 1-digit decade switches at the DZ 5 panel (Fig. 10.50).

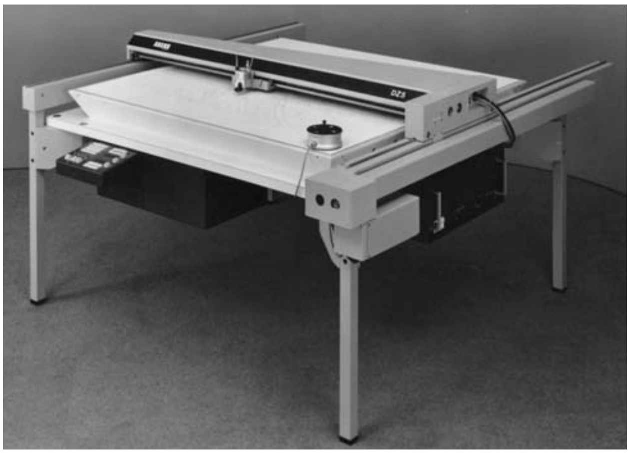


Fig. 10.49: DZ 5 digital tracing table (1975)

Fig. 10.50: DZ 5 user panel with vector plotting control

The P mode (Positioning) enabled direct point positioning at the tracing table by entering the coordinates with 6-digit decade switches at the panel. And in the G mode not only the processor controlled drawing of a straight line ("Gerade") was possible but also of polygons (e. g. land parcels), rectangles (e. g. buildings) or a cross symbol. The microprocessor of the DZ 5 could also receive coordinates together with pen-up or pen-down signals via a standard interface from a computer, which allowed it to be used as an output device for any available mapping software. One of these applications offered by ZEISS was the CASP program for desktop computers (see chapter 10.7).

To exploit fully the tremendous advance in microprocessor technology ZEISS five years later presented the successor DZ 7 (LORCH et al. 1980). This development was partially supported by the German Federal Ministry for Research and Technology (BÖTTINGER et al. 1981). The eye-catching feature was the motor-driven table inclination between 0° (horizontal) and 70° (Fig. 10.51), which was already available for tables from competitors.

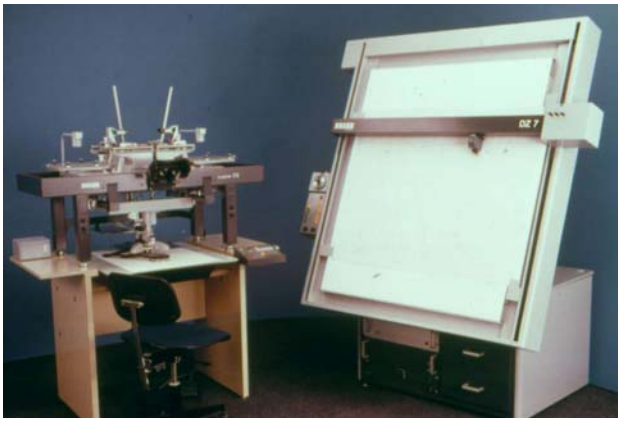


Fig. 10.51: DZ 7 digital tracing table at the PLANITOP F3 (1980)

The main parameters of the DZ 7 digital tracing table were (SCHWEBEL 1981):

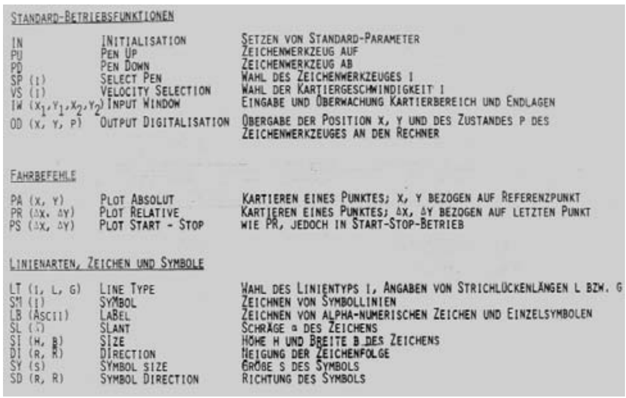
- *Usable area / table surface in cm: 93 x 119 / 100 x 120,*
- *positioning resolution: 0.01 mm,*
- *enlargement model to map for direct mapping with stereoplotter: between 9: 1 and 1: 9,*
- *plotting speed selectable between 70 mm/sec, 110 mm/sec and 210 mm/sec (quality-dependant),*
- *triplex tracing head for pencil, ballpen, ink and engraving with a lowering rate of up to 30 Hz for dashed lines, and with TV-monitoring .*

The DZ 7 was available in three different, upgradable versions:

- *DZ 7-A: for photogrammetric, microprocessor supported on-line drafting with an analogue stereoplotter, connected by transfering the pulses from rotary or linear encoders,*

- *DZ 7-P: for photogrammetric on-line drafting with the C 100 PLANICOMP analytical stereoplotter, including off-line drafting with the C 100-programs, connection via the parallel IEC-interface (see chapter 11.2),*
- *DZ 7-C: for off-line drafting with software running on a desktop or minicomputer, especially from HEWLETT-PACKARD, and with the GEOS program from CARL ZEISS for graphical geodetical applications (see chapter 14.4), connection via the serial RS232-interface (V 24).*

When connected to a computer (DZ 7-P and -C), the plotter commands had to follow the command language as described in Fig. 10.52. Fig. 10.53 shows typical samples of the microprocessor functionality.


STANDARD-BETRIEBSFUNKTIONEN

IN	INITIALISATION	SETZEN VON STANDARD-PARAMETER
PU	PEN UP	ZEICHENWERKZEUG AUF
PD	PEN DOWN	ZEICHENWERKZEUG AB
SP (I)	SELECT PEN	WAHL DES ZEICHENWERKZEUGES I
VS (I)	VELOCITY SELECTION	WAHL DER KARTIERGESCHWINDIGKEIT I
IW (X_1, Y_1, X_2, Y_2)	INPUT WINDOW	EINGABE UND ÜBERWACHUNG KARTIERBEREICH UND ENDLAGEN
OD (X, Y, P)	OUTPUT DIGITALISATION	ÜBERGABE DER POSITION X, Y UND DES ZUSTANDES P DES ZEICHENWERKZEUGES AN DEN RECHNER

FAHRBEFEHLE

PA (X, Y)	PLOT ABSOLUT	KARTIEREN EINES PUNKTES; X, Y BEZOGEN AUF REFERENZPUNKT
PR (ΔX, ΔY)	PLOT RELATIVE	KARTIEREN EINES PUNKTES; ΔX, ΔY BEZOGEN AUF LETZTEN PUNKT
PS (ΔX, ΔY)	PLOT START - STOP	WIE PR, JEDOCH IN START-STOP-BETRIEB

LINIENARTEN, ZEICHEN UND SYMBOLE

LT (I, L, G)	LINE TYPE	WAHL DES LINIENTYPS I, ANGABEN VON STRICHLÜCKENLÄNGEN L BZW. G
SM (I)	SYMBOL	ZEICHNEN VON SYMBOLLINIEN
LB (ASCII)	LABEL	ZEICHNEN VON ALPHA-NUMERISCHEN ZEICHEN UND EINZELSYMBOLEN
SL (α)	SLANT	SCHRÄGE α DES ZEICHENS
SI (H, B)	SIZE	HÖHE H UND BREITE B DES ZEICHENS
DI (R, R)	DIRECTION	NEIGUNG DER ZEICHENFOLGE
SY (S)	SYMBOL SIZE	GRÖßE S DES SYMBOLS
SD (R, R)	SYMBOL DIRECTION	RICHTUNG DES SYMBOLS

Fig. 10.52: Plot commands of the DZ 7 microprocessor (sample)

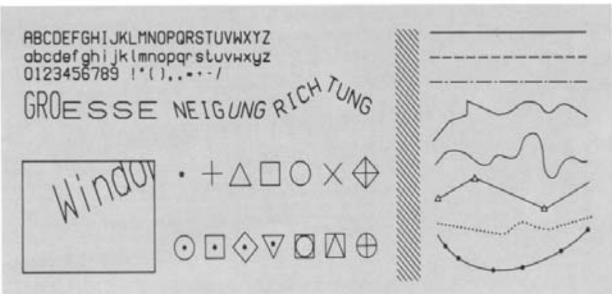


Fig. 10.53: Plot functions of the DZ 7 microprocessor

To alleviate the writing of computer programs for plotting with the DZ 7, libraries for graphical subroutines were offered: in the BASIC language especially for the HP 9835/45 desktop computer, and in FORTRAN IV for minicomputers including the HP 1000 minicomputer used by ZEISS (LORCH et al. 1980). The FORTRAN IV library in the following years was extended to a package named GRAPH F 1, by which not only the DZ 7 could be adressed but also the plotters HP 9872, HP 7225, HP 7580 and HP 7585 from HEWLETT-PACKARD using the HP-GL language, and the graphic-terminals HP 2648, HP 2647 and HP 2623 by using so-called "escape" sequences (HOBBIE 1983). In 1985 the possibility of generating a plot file with "ASCII-general plot commands" was added (2-character commands followed by xy-coordinates as integer values in units of 0,01 mm (HOBBIE 1985).

When using the DZ 7 connected to analogue plotters (DZ 7-A), a panel similar to the DZ 5 was used (Fig. 10.55), but with extended microprocessor functionality (Fig. 10.54).

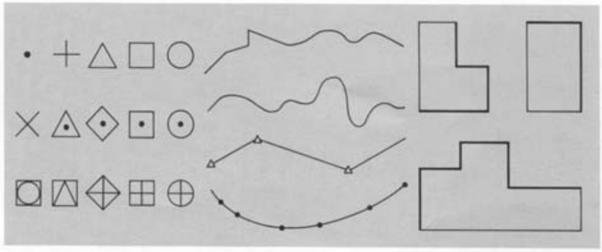


Fig. 10.54: On-line-drafting with the DZ 7-A

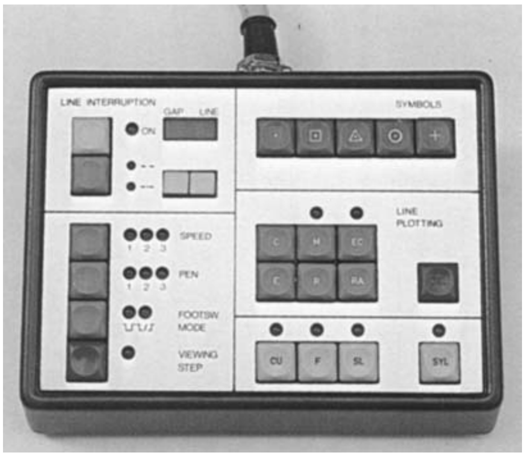


Fig. 10.55: DZ 7 user panel for on-line mapping

In summary CARL ZEISS Oberkochen delivered about 200 units of the types DZ 5, DZ 6 and DZ 7 during the period from 1976 to 1986. This number did not fulfill the expectations, because on the one hand many competitors were offering comparable tracing tables, and on the other hand the procedure of photogrammetric mapping experienced a paradigm shift based on the computer / software development. More and more the mapping data was at first viewed on computer screens and digitally stored, before, in a later step, being refined, partly by cartographers, and finally (if at all) plotted off-line with plotters of the computer or graphics industry.

In the 1980s the R & D expenditure grew extraordinarily for all suppliers of photogrammetric products. This was due to computerisation, increasing software complexity and the beginning of the transition from analytical to digital. On the other hand the photogrammetric market was not growing and this forced the bigger companies to think about co-operation, and several smaller ones to cease trading (e. g. KERN, Aarau). The intention of co-operating was that no single vendor should need to develop a complete range of products but would exchange and share selected items.

After having shared this mutual interest between Oberkochen and Heerbrugg and agreed to co-operate, Carl Zeiss decided to stop further development of the DZ 7 tracing table and to sell in future a comparable product from Wild. Unfortunately, Wild did not fulfill its part of the arrangement to sell an agreed Zeiss product. This was probably due to its own temporary difficulties. Starting in 1985 Zeiss offered the Wild precision tracing tables Aviotab TA 2 and TA 10 in Zeiss colours under the name Planitab T 102 and T 110 (Fig. 10.56) and with an adopted Graph F 2 subroutine library. About 60 units were sold by 1995.

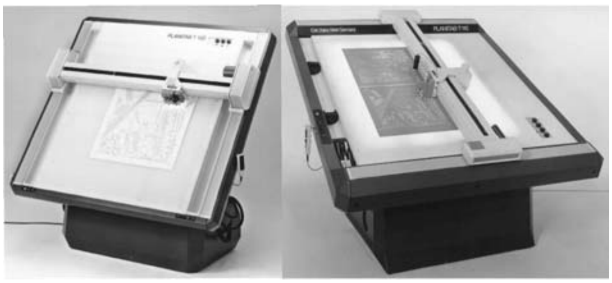


Fig. 10.56: T 102 and T 110 Planitab (1985)

Around 1988 the photogrammetric development department in Oberkochen temporarily considered the development of a raster plotter. In view of the previously described trend to powerful off-line plotting not only of vector maps but also of photo maps, an output scanner was drafted with a huge film drum, based on the experience with the Z 2 Orthocomp and on studies for remote sensing (see chapter 15.3). By using patented ideas (Felle 1986 & Scherle 1990) an argon laser with acousto-optical modulation and a fast rotating polygon mirror should sequentially produce monochrome films for the printing colours cyan, magenta, yellow and black. This "R 9"-project could have been the successor for the Orthocomp as well as for the digital tracing tables and thus the ouput device for the upcoming digital photogrammetry. But at an early stage this project was stopped in 1992 and an established product from Barco in Belgium was recommended and offered (Fig. 10.57).

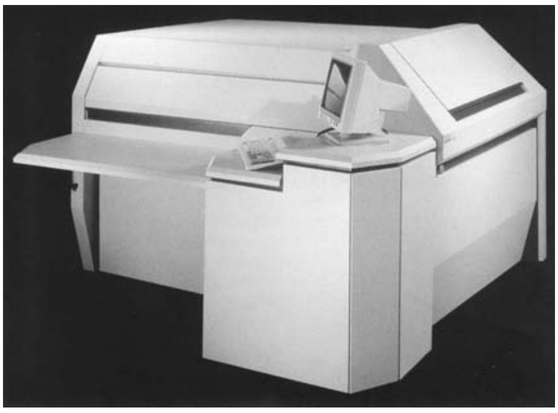


Fig. 10.57: BG 3900 Barco Rasterplotter (1993)

The graphical output becoming a domain of the computer industry is visible in Fig. 10.58, where a HP-Plotter is attached to an E 3 Planicart and the graphics are also displayed on as many as two CRT-screens. One of these is the monitor for superimposition attached to the left side of the E 3. This high resolution vector screen is part of the Videomap, which Zeiss introduced at the XV. International Congress in Rio de Janeiro in 1984. The superimposition of the measured graphics with the left stereoimage allowed the monocular checking of the precision, correctness and completeness of the measurements (Fig. 10.59). Although its function will be explained here together with the graphical output devices, its main task is to support the acquisition of graphical information in digital form, which will be described in the following chapter 10.7.

Fig. 10.58: E 3 Planicart for software-supported mapping with graphical superimposition and HP 7580-Plotter (1984)

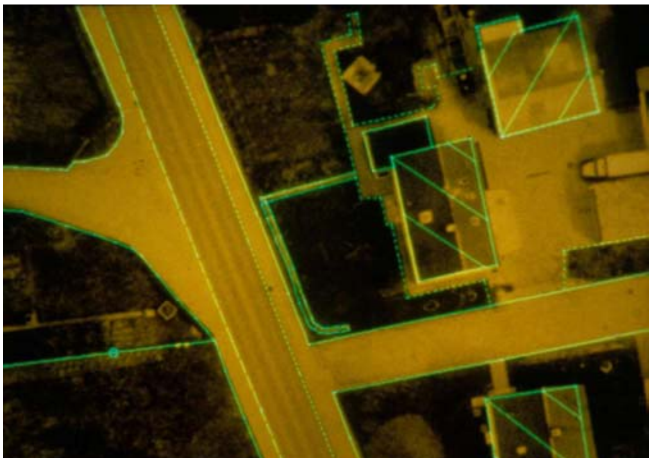


Fig. 10.59: Superimposition of aerial photo and Videomap-graphics within the steeoplotter field of view

Videomap was first described in (SAILE 1984), a more detailed explanation is given in (UFFENKAMP 1986). Fig. 10.60 shows the VIDEOMAP control unit (at right) and the HP 1336 S graphics monitor with supply unit. The monitor was a vector screen with very high image stability and resolution. The screen size used was 80 mm x 80 mm and the width of displayed lines 0.1 mm. With a 2,8x reduction the graphics overlay within the field of view of the PLANICART or PLANICOMP had a size of 25 mm x 25 mm, and the line width for lines, symbols and text equaled the 40 µm floating mark diameter. While moving through the model, the image on the screen was shifted synchronously, which then appeared to be static within the field of view.

Fig. 10.60: VIDEOMAP - control unit and vector screen (1984)

The continuous precise matching of the graphics with the image was guaranteed by two computational steps. Firstly, the newly acquired graphical data had to be transformed from the model scale into the perspective and scale of the left hand photograph. Secondly, the information for the window to be displayed had to be read in from the whole data set and shifted on the screen in real time without any visible delay. To achieve this the monitor used a refresh rate of 100 Hz, and an additional display memory was used between the graphics memory with the whole data set and the monitor with the displayed window (Fig. 10.61). With covering 32 mm x 32 mm at the image scale the display memory was slightly larger than the displayed window, therefore it had to be updated from the graphics memory only during movement and then only about every 1 to 3 seconds. The graphics memory covered an area of 500 mm x 500 mm with 0.032 mm resolution at image scale, and it could store up to 80 000 vectors and 15 000 alphanumeric characters.

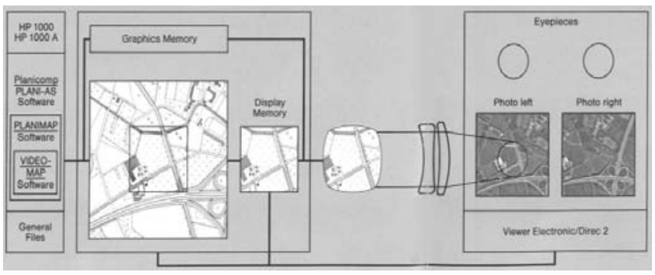


Fig. 10.61: Block diagram for the VIDEOMAP function

In practice the superimposition was not only used for checking the data aquisition of topographic features and digital terrain models (REINHARDT 1986), but also to compare "old" graphical information from a data file with the current situation in the "real world" of the stereomodel. Applications were map revision or superimposing the virtual information such as land parcel boundaries of cadastral maps or projected construction work with the stereo-model topography.

At the Kyoto-Congress in 1988 VIDEOMAP 2 for stereo-superimposition was presented, which was dedicated as an option for the new P-series PLANICOMP introduced the year before (see chapter 11.5). Finally in 1993 VIDEOMAP 30 for the P 3 and P 33 PLANICOMP became available (ROTH 1993). This less expensive successor was based on a PC 486 (50 MHz) board with graphic-coprocessor and MS-DOS operating system as the VIDEOMAP control unit. It used a monochrome raster monitor with 1 024 x 1 280 pixel, a dot size of 0.2 mm and 4x reduction. In total 250 VIDEOMAP systems had been delivered by 1995. A total of more than 300 were sold before production ceased.

The first contact between ZEISS and INTERGRAPH in Huntsville, AL/USA was established in spring 1981 to discuss prospective joint projects for connecting the ZEISS stereoplotters with the IGDS interactive cartographic software from INTERGRAPH. Later this resulted not only in the interfacing of the INTERGRAPH workstation to the E 3 PLANICART for on-line data acquisition, but also in an optical interface for the superimposition of an additional INTERGRAPH monitor (Fig. 10.62), which was first realised in the autumn of 1982 (HOBBIE 1983 & 1984a). In 1983 the connection to the C 120 PLANICOMP was available (see chapter 11.3), while the previously described VIDEOMAP was not ready until the summer of 1984.

Fig. 10.62: INTERGRAPH-workstation at E 3 PLANICART with superimposition (1982)

Describing these two solutions for graphical superimposition in stereoplotters is already the bridge from the here described graphical output to the graphical data acquisition to be documented in the following chapter.

10.7 Acquisition of graphical data

It has already been mentioned, that the rapid advance in electronics and microcomputing in the early 1970s led to a paradigm shift in photogrammetric mapping. Whereas before the direct drawing on tracing tables produced analogue map originals, now the graphical information could be digitised and sent to a computer for editing and storage as a graphical data set (the master file), for plotting or displaying only as needed. Numerical recording devices such as the ECOMAT and DIREC originally developed for measuring aerotriangulation data and digital terrain models as previously described in chapter 9.1 now also became interesting for topographic mapping. Microprocessors and computers made the acquisiton of graphical data very flexible and powerful in a new field of application, for which dedicated software and a few specific hardare components shall be described here.

At the Photogrammetric Week in 1975 CARL ZEISS, Oberkochen presented several new products which were examples of computer support: the DZ 5 digital tracing table for analogue stereoplotters with automatic plotting of straight lines, buildings and symbols (chapter 10.6); the G 2 STEREOCORD with measurement of geometrcal data and graphical output on a HP-plotter (chapter 11.1); and finally the CASP program for "Computer Assisted Stereoplotting" on analogue stereoplotters. CASP was developed by EGON DORRER on behalf of ZEISS, after his earlier studies, begun in 1972, (DORRER 1975) on numerical and graphical plotting with PLANIMAT, PLANICART and PLANITOP equipped with ECOMAT 12 or DIREC 1. It was written in a simple computer-specific language for the then up to date desktop computer HP 9810 and, due to limited memory capacity, divided into 5 program modules, of which DYNRECORD was used for graphical plotting:

- *STATRECORD: inter alia for real-time coordinate transformation, recording of single points, point numbering and area computation in real time.*
- *DYNRECORD: inter alia for real-time coordinate transformation, recording of single points, dynamic recording and generation of object codes.*
- *LISTMANIPUL: for checking and modification of point lists.*
- *ABSOLOR-1: for absolute orientation and computing the transformation parameters for real-time transformation of model- into ground coordinates.*
- *ABSOLOR-2: for absolute orientation and output of orientation data for the manual model orientation at PLANIMAT, PLANICART or PLANITOP.*

Compared to the desktop computers being offered from e. g. HEWLETT-PACKARD and WANG since 1970, the minicomputers such as those from HEWLETT-PACKARD for the C 100 PLANICOMP in 1976 (chapter 11.2) were much more powerful. With the change fom the HP 21 MX real time minicomputer to the HP 1000 computer family it became obvious, that the processor speed would allow the on-line support of at least one additional operator seat besides the C100 control.

Based on the software experience gained during the PLANICOMP development the photogrammetry lab in Oberkochen developed the AS program system in the FORTRAN IV programming language (HOBBIE 1979b). Three different packages were drafted: PK-AS for the PK 1 monocomparator, which was released first and described in detail in 1979; PSK-AS for the PSK 2 precision stereocomparator, which was not completed due to a lack of interest; and PLANI-AS released in 1981 for the PLANIMAT, PLANICART or PLANITOP and any other analogue stereoplotter (HOBBIE 1981b).

Fig. 10.63 shows the system components of an analogue stereoplotter prepared for the on-line data acquisition with PLANI-AS. The minicomputer with peripheral equipment, software and data files had spare capacity to control additionally one PLANICOMP or several analogue instruments. Due to the then limited core memory of these minicomputers the programs had to be segmented (Fig. 10.64), but all modules had access to a common data area.

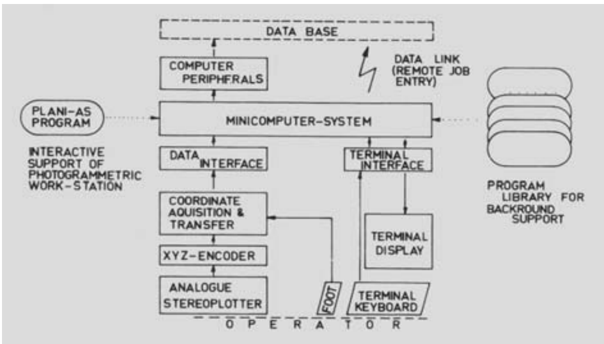


Fig. 10.63: System configuration of analogue stereoplotter with PLANI-AS Software

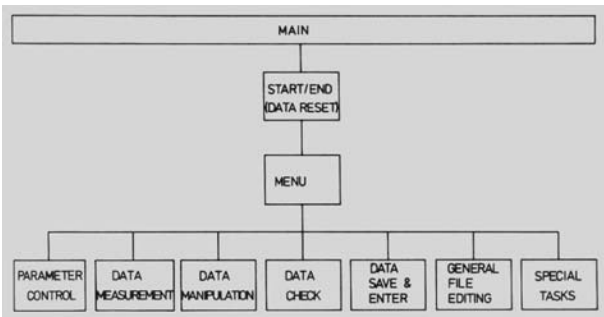
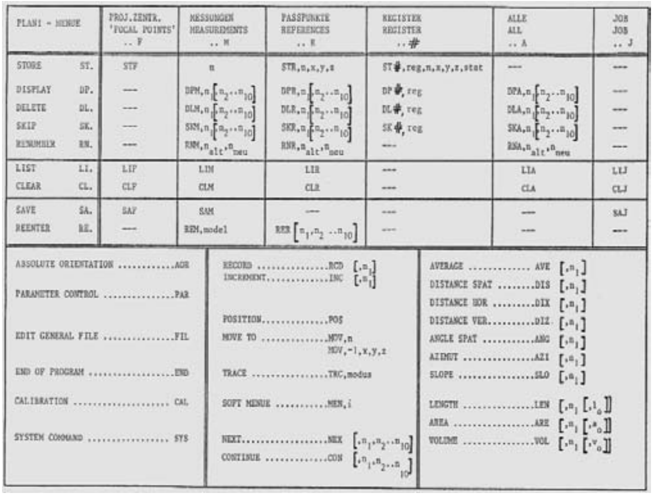


Fig. 10.64: Program structure of the AS software (1979)

The user interface of the AS programs was designed as a menu, where the menu commands consisted of three characters following a mnemonic rule (Fig. 10.65). Depending on the selected function the command had to be entered at the computer terminal (Fig. 10.66), eventually followed by additional parameters: e. g. point or symbol number when measuring individual points, delta values for incremental recording, or a factor for smoothing quality of the dynamic line following.



PLANI - MENUE		PROJ.ZENTR. 'FOCAL POINTS' .. F	MESSUNGEN MEASUREMENTS .. M	PASSPUNKTE REFERENCES .. R	REGISTER REGISTER .. #	ALLE ALL .. A	JOB JOB .. J
STORE	ST.	STF	n	STR,n,x,y,z	ST#,reg,n,x,y,z,stat	---	---
DISPLAY	DP.	---	DPM,$n_1[n_2..n_{10}]$	DPR,$n_1[n_2..n_{10}]$	DP#, reg	DPA,$n_1[n_2..n_{10}]$	---
DELETE	DL.	---	DLM,$n_1[n_2..n_{10}]$	DLR,$n_1[n_2..n_{10}]$	DL#, reg	DLA,$n_1[n_2..n_{10}]$	---
SKIP	SK.	---	SKM,$n_1[n_2..n_{10}]$	SKR,$n_1[n_2..n_{10}]$	SK#, reg	SKA,$n_1[n_2..n_{10}]$	---
RENUMBER	RN.	---	RNM,n_{alt},n_{neu}	RNR,n_{alt},n_{neu}	---	RNA,n_{alt},n_{neu}	---
LIST	LI.	LIF	LIM	LIR	---	LIA	LIJ
CLEAR	CL.	CLF	CLM	CLR	---	CLA	CLJ
SAVE	SA.	SAF	SAM	---	---	---	SAJ
REENTER	RE.	---	REM,model	RER $[n_1,n_2..n_{10}]$	---	---	---

ABSOLUTE ORIENTATION ....AOR	RECORD ....RCD $[,n_1]$	AVERAGE .... AVE $[,n_1]$
	INCREMENT.............INC $[,n_1]$	DISTANCE SPAT ....DIS $[,n_1]$
PARAMETER CONTROL ....PAR		DISTANCE HOR ....DIX $[,n_1]$
	POSITION.............POS	DISTANCE VER.........DIZ $[,n_1]$
EDIT GENERAL FILE ....FIL	MOVE TO ....MOV,n MOV,-1,x,y,z	ANGLE SPAT ....ANG $[,n_1]$
		AZIMUT ....AZI $[,n_1]$
END OF PROGRAM ....END	TRACE ....TRC,modus	SLOPE ....SLO $[,n_1]$
CALIBRATION .... CAL	SOFT MENUE ....MEN,i	LENGTH ....LEN $[,n_1[,l_o]]$
		AREA ....ARE $[,n_1[,a_o]]$
SYSTEM COMMAND .... SYS	NEXT.................NEX $[,n_1,n_2..n_{10}]$	VOLUME ....VOL $[,n_1[,v_o]]$
	CONTINUE ....CON $[,n_1,n_2..n_{10}]$	

Fig. 10.65: Command set of the PLANI-AS software (1981)

Fig. 10.66: CRT-terminal with PLANI-AS at the PLANIMAT

Altogether PLANI-AS supported the following tasks:

- *Sampling, saving, checking, transforming, recording and output of coordinate measurements, also in ground system,*
- *flexible point numbering with variable and fix components (also generating of object codes),*
- *individual and incremental recording of mass points,*
- *graphical protocol (logging) of measurements,*
- *measurement of geometrical values such as length, angle, area and volume content,*
- *absolute orientation with control point management and computing of orientation elements for many analogue stereoplotters, not only from ZEISS,*
- *determination of the projection centers for aerotriangulation either by resection using a grid measurement, or by direct measurement with mechanical space rods in vertical position,*
- *stereoplotter calibration.*

The possibilities of the graphical data acquisition with PLANI-AS, introduced in 1981, were still rather limited. But by 1983 its successor PLANIMAP was presented by CARL ZEISS, Oberkochen as a comprehensive system for digital mapping with analogue stereoplotters (HOBBIE 1983 & SAILE 1984).

Besides the interactive mapping solution with the IGDS system from INTERGRAPH, Oberkochen could now offer its own complete solution via a real time interface. Fig. 10.67 shows the system components of the PLANIMAP, based on the HP 1000 A minicomputer. This real time computer was so powerful that it could serve not only one PLANICOMP plus any analogue stereoplotter equipped with ZEISS encoders and connected via DIREC but, since 1985, an additional 2D-digitising station for the capture of graphical documents (Fig. 10.68).

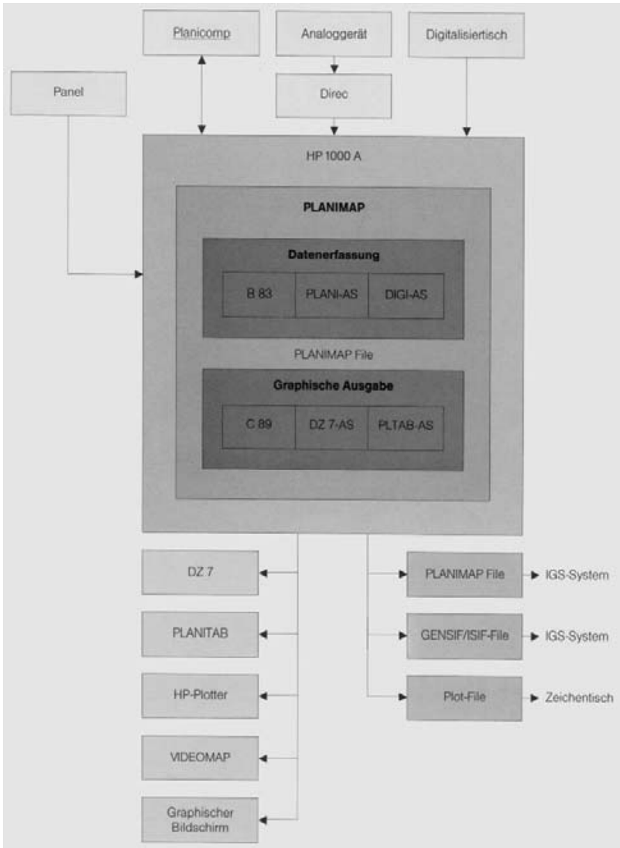


Fig. 10.67: System components of PLANIMAP (1983)

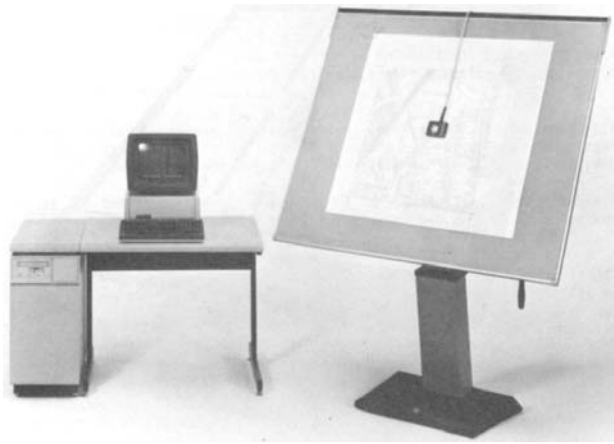


Fig. 10.68: 2D-digitising with DIGI-AS (1985)

Fig. 10.67 also names the three different programs for acquiring graphical data: program B 83 (RECORD PLOT DATA) at the PLANICOMP, PLANI-AS at the analogue stereoplotter and a new DIGI-AS for the ARISTOGRID 2D-digitiser (system 100 or 200). DIGI-AS was a modification of PLANI-AS, reduced to the xy-plane (HOBBIE 1985). All three programs recorded the data in a uniform graphical code independent from the instrument. Also the handling and the variety of functions including the editing possibilities were consistent. A valuable feature was the "snap"function for precisely connecting to points and lines already stored .

For immediate or later graphical display and output the previously mentioned GRAPH F 1 routine library was used, which supported the DZ 7 tracing table from ZEISS and plotters and monitors from HEWLETT-PACKARD. From 1985 onwards the extended GRAPH F 2 also supported the T 102 / 110 PLANITAB tables from ZEISS, which were technically identical to the AVIOTAB from LEICA, together with the high resolution graphic terminals from TEKTRONIX and SIGMEX. For data transfer to other systems conversion routines for several exchange formats were available. Plotting in an off-line mode was supported: at the PLANICOMP with the established C 089 DIGITAL PLOTTING program or with the programs DZ 7-AS or PLANITAB-AS. These off-line programs were also used for map sheet preparation and for designing individual symbols, which then could be adressed by a given code.

For an easier and faster handling of the PLANIMAP program a programmable user panel was presented in 1985 (Fig. 10.69). This PLANIMAP panel was a touch pad with 53 touch sensitive areas arranged like an alpha-numeric keyboard, on which an exchangeable mask with the description of the active functions was overlayed. A command or a predefined macro command now no longer had to be iniated by keying in a command. With using this softkey pad and VIDEOMAP for immediate checking by superimposition, and with the snap-command and other powerful functions, the photogrammetric acquisition of graphical data was now at its best.

Fig. 10.69: Programmable PLANIMAP user panel (1985)

At a ZEISS conclave in 1985 for defining future photogrammetric developments the project VISOR was proposed. The defined goal was to ease the stressful precise digitising of line features with the off-the shelf 2D-digitisers. An optical matrix-sensor added to the 2D-cursor should observe and determine any deviation between the cursor center and the (only roughly followed) line to be measured, so that a correction value could be computed and added to the cursor position. This would allow for much faster and less concentrated line following. Unfortunately, this unique solution had to be abandoned because projects with even higher potential were identified and given a higher priority. These projects are described later.

Based on the positive experience with PLANI-AS and PLANIMAP for computer supported photogrammetric mapping interest arose in incorporating the further steps of cartographic editing and management into one integrated program system. As the photogrammetric software development team in Oberkochen had been extended since the early 1980s, it was decided to develop a new and universal photogrammetric and cartographic software package, parallel to the running modernisation of the PLANICOMP family. Special requirements were the compatibility with relevant previous ZEISS products and the ability to be integrated easily into existing production environments of the user community. In spring 1987 CARL ZEISS, Oberkochen introduced PHOCUS, a universal photogrammetric and cartographic software system together with the new PLANICOMP P-series (HOBBIE 1987a & 1987b, MENKE 1987a & 1987b). The P-series will be described in chapter 11.5.

PHOCUS not only supported data acquisition in photogrammetric stereomodels but also the digitising of existing maps as PLANIMAP had done before but now digitisers from many suppliers could be used. Geodetic measurements and computations could be incorporated, too. As a conseqence the software hierarchy was turned upside down: whereas previously the mapping programs were embedded within the C 100 software, now the programs for the digitising instruments such as the P-series PLANICOMP were running under PHOCUS (Fig. 10.70).

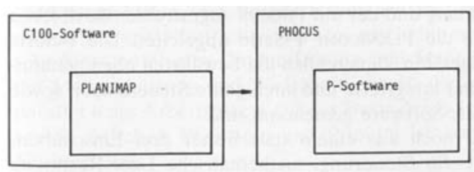


Fig. 10.70: Program structure of PHOCUS (1987)

Because the photogrammetrically generated topographical data is too valuable to be be stored just as graphical data for a specific use or map scale, an object-oriented, hierarchical data structure was embedded in PHOCUS. Fig. 10.71 shows the 7 hierarchy levels (with one example each).

- *coordinates - points of footprint,*
- *planimetry - geom. footprint of chimney,*
- *part of object - chimney,*
- *object - industrial building,*
- *object class - buildings,*
- *area - location,*
- *project - Topographic Map 1: 10 000.*

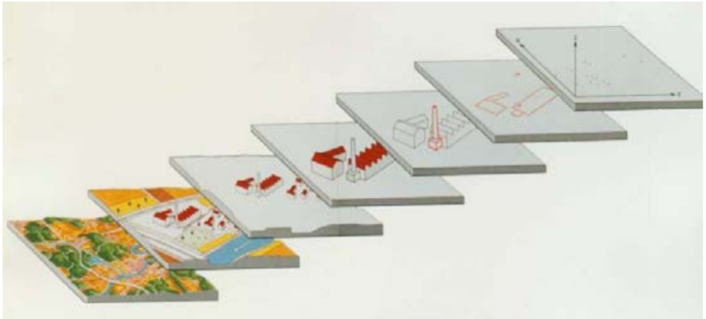


Fig. 10.71: Data structure of Phocus (1987)

The object oriented data structure enabled a fast and easy change of appearance of the data by exchanging the code and symbol tables which now definined how to present the topographic objects. The same data could now be used for different map scales or map types (Fig. 10.72), or could be shown in a different form on different displays or plotters (e. g. Videomap and tracing table).

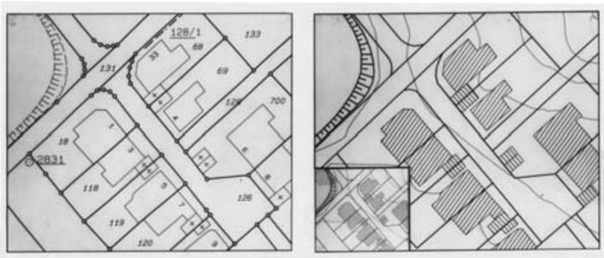


Fig. 10.72: Phocus data with different symbolisation

Phocus soon became a valuable, powerful and widespread mapping tool, especially, but not only, for photogrammetric production. It is still used today by many users, due to its many versatile functions: flexible geometric, semantic and topological data acquisition; editing, management, storage and output of data; adaptive user handling regarding user interfaces, language and help functions; and the possibility to process a project from many workstations simultaneously. Typical non-photogrammetric workstations were Phocus PD for 2D-digitising of maps and Phocus PE for editing and data management (Fig. 10.73).

Fig. 10.73: PD digitising and PE editing station of Phocus

Fig. 10.74 shows the applications being supported by Phocus. From 1991 PHOCUS was installed on analogue stereoplotters as Phocus PA using Direc P (see chapter 9.1).

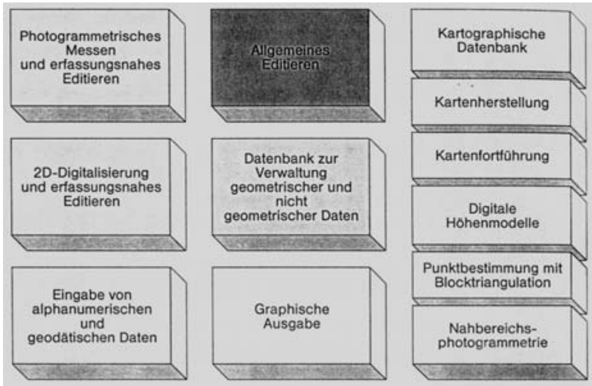


Fig. 10.74: Applications for Phocus

Phocus was continuously enhanced until the mid 1990s (Menke 1989, Braun 1989, Menke 1991, Saile 1992, Roth 1993, Menke 1994, Schwebel 1994). After early investigations regarding cartographic exchange formats (Menke 1985) from 1989 the interchange with existing customer environments was supported by converting from the Phocus format, Phodat, to the following systems, e. g.: ISIF (Intergraph), DXF (AutoCad from Autodesk), Sicad and Digsy (Siemens), Arc/Info (Esri), Moss (McDonnell Douglas), EDBS (AdV - Arbeitsgemeinschaft der Deutschen Vermessungsverwaltungen) and Isok (Swedish Lantmäteriet).

Whereas at the beginning Phocus was developed for the HP 1000 computer from Hewlett-Packard with the RTE real time operating system (as for the Planicomp), since 1990 workstation computers such as Vax and Alpha with the VMS operating system from Digital Equipment were used. From 1993 Unix-workstations from Silicon Graphics were also introduced. In 1992 the Oracle relational database for storing the attributes and the SQL-standard were incorporated, and thus a complete geographical information system was realised. Last but not least Phocus revision 5 and 6 supplied many further improvements and extensions after 1993. From 1993 Phocus could be used with Phodis ST, the new digital stereoplotter from Zeiss (see chapter 12.3).

In the first 10 years of delivery more than 350 Phocus licences were granted.

11. Analytical stereoplotters

If in a photogrammetric stereoplotter the photo to model relationship is not reconstructed by analogue means such as optical projection or mechanical space rods but by mathematical formulas in a computer, it is called an "Analytical Plotter" (AP). The idea of an AP was first published by UUNO V. HELAVA in 1958 and patented in 1961. He at that time was working for BENDIX in Southfield, MI/USA, where in the 1960s the first instruments of this kind were developed for the military, with optics and mechanics supplied by OMI in Italy. For a first prototype an electrical analogue processor was used due to the slow speed of the early digital computers. Until the first half of the 1970s the speed was insufficient for APs to compete with the analogue stereoplotters in satisfying the users with respect to response time and convenience. Therefore, for the time being, CARL ZEISS Oberkochen started to evaluate the use of the first available desktop computers for approximate solutions.

11.1 STEREOCORD

In 1971 ZEISS had presented the StR x-ray stereocomparator, which in the StR 3 configuration supported coordinate recording and transmission to a desktop computer, where model coordinates and derived distances, angles and volumes were computed (see chapter 14.2). At the same time similar devices for the evaluation of aerial photographs were built by several institutions in North America, among them BENDIX, where ROBERT B. FORREST developed the "Image Space Plotter" concept. Oberkochen decided to realise a similar solution based on the STEREOTOP which was still in series production, and this led to the introduction of the G 2 STEREOCORD in 1975 (HOBBIE 1975b).

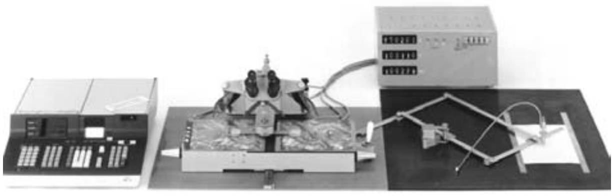


Fig. 11.1: G 2 STEREOCORD with HP 9810 computer (1975)

In Fig. 11.1 the G 2 prototype is shown together with a pantograph, by which the geometry of the left image could be plotted at a selected enlargement, with the new DIREC 1 (see chapter 9.1) and the HP 9810 as the then newest desktop computer from HEWLETT-PACKARD. In the basic instrument, called "viewer", the common image carriage was moved as in the STEREOTOP, but now a joy-stick like lever on the side enabled fine positioning (Fig. 11.2). The right image stage was moved relative to the left image by thumbwheels for the y-parallax (left) and the x-parallax (right), the latter being digitised by a rotary encoder (Fig. 11.3).

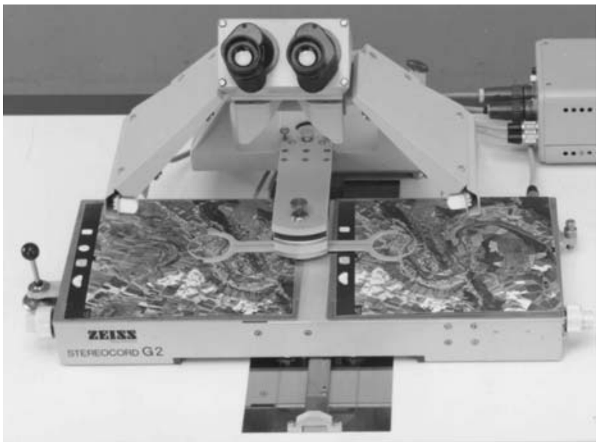


Fig. 11.2: G 2 STEREOCORD viewer

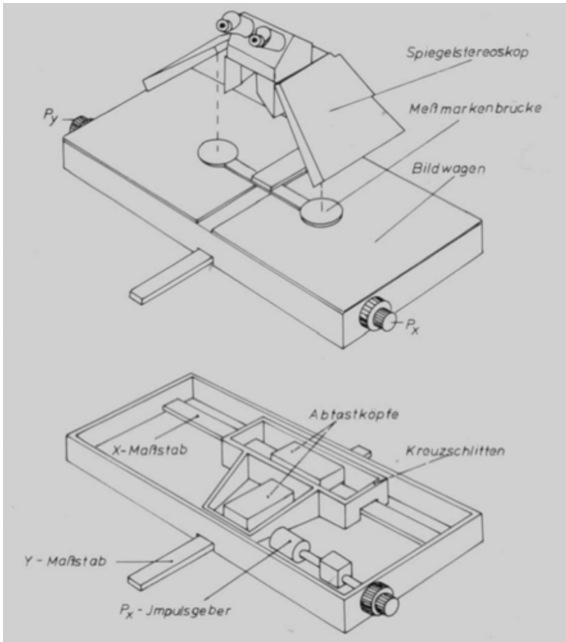


Fig. 11.3: Mechanical structure of the G 2 STEREOCORD

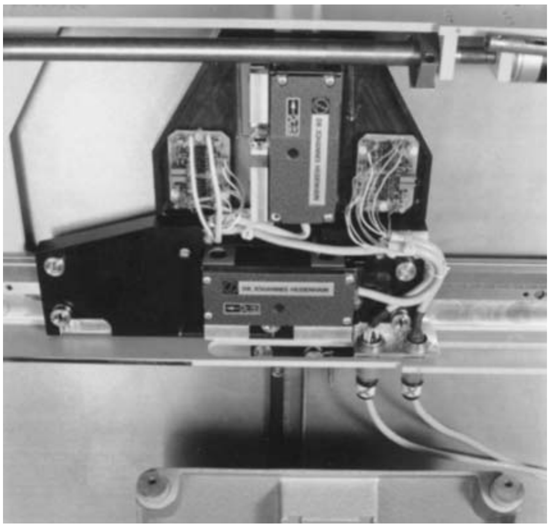


Fig. 11.4: G 2 intermediate carriage with linear encoders (view from below)

The linear encoders for x' and y' were mounted at the main image carriage and baseplate (Fig. 11.4) and were serving as guide rails for the intermediate carriage, which contained their sensing heads.

The main parameters of the viewer were:

- *Image material: paper copies, with optional SD light unit also film and glass, diapositives & negatives,*
- *area of measurement: x', y' = 240 mm, $p_x = \pm$ 25 mm,*
- *resolution of measurement: 0.01 mm,*
- *accuracy: $\sigma_{x'}$, $\sigma_{y'} = \pm$ 0.02 mm, $\sigma_{px'} = \pm$ 0.01 mm,*
- *range of y-parallax: $\pm$ 15 mm,*
- *viewing magnification: 1x, with binoculars 3x or 6x,*
- *floating mark: black or red with diameter 0.10 mm, 0.18 mm or 0.28 mm.*

The system configuration consisted of the viewer, the DIREC 1 interface unit with electronic coordinate counting, footswitch, program buttons, and the desktop computer as shown in Fig. 11.5.

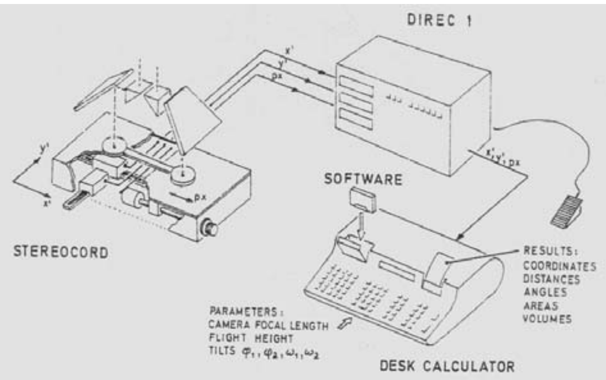


Fig. 11.5: G 2 STEREOCORD - system configuration with DIREC 1 and HP 9815A

The initially used HP 9810 desktop computer could read the image coordinates and compute the model coordinates about 5 to 10 times per second. But this was reduced to once per second when displaying results, because this model still could either compute or display but could not do both in parallel. Due to the limited processor speed the model coordinates were computed by using different approximate equations. The simplest form COORD A corrected for terrain height differences only, COORD C (Fig. 11.6) in addition corrected for the photo inclinations. With a planimetrc accuracy of 0.1 to 0.2 mm in image scale and between 0.7 and 2.0 ‰ of h in height (at inclinations of 3 to 4 gon and 10 % variation in flying height) the G 2 exceeded the STEREOTOP.

The potential of the STEREOCORD soon grew with faster computers (Fig. 11.7). The HP 9815 with its trigonometric functions made possible the more precise computation COORD D, which improved the accuracy by a factor of 2. HANS MOHL had developed COORD D in 1977, and he also renewed the orientation and measurement programs (MOHL 1980).

Stage coordinates x', y', p_x

$$x^* = x' - \frac{a_1 + (a_2 * x' + a_3 * y') * x'}{1 + a_2 * x' + a_3 * y'}$$

$$y^* = y' - \frac{a_4 + (a_2 * x' + a_3 * y') * y'}{1 + a_2 * x' + a_3 * y'}$$

$$p_x^* = p_x + b_1 * y' + (b_2 * y' + b_3 * x' + b_4) * x'$$

$$\Delta h = c_1 * \frac{p_x^*}{c_2 + p_x^*}$$

Ground coordinates X_G, Y_G, H_G

$$X_G = x_0 + \frac{c_1 - \Delta h}{f} * x^*$$

$$Y_G = y_0 + \frac{c_1 - \Delta h}{f} * y^*$$

$$H_G = H_0 + \Delta h$$

Fig. 11.6: G 2 real time computation (COORD C) (1975)

Fig. 11.7: G 2 with HP 9830 & HP-Plotter (1977)

In 1981 the delivery of the G 3 STEREOCORD as a redesigned model together with the new DIREC 2 or DIREC 12 and the HP 9835 or HP 85 desktop computers began (MOHL 1981). The only slightly improved viewer could now be upgraded from a stereo-interpretoscope to a full-scale STEREOCORD which now also digitised the y-parallax. The DIREC 2 was reduced to just coordinate counting and transmitting (and no longer displaying), whereas the DIREC 12 still displayed up to four coordinates.

The application software, in the beginning being limited to the determination of coordinates, distances, angles and area contents for photo interpretation (FAUST 1975), now included programs for volume computation (FINKE et al. 1977), for graphical plotting (JORDAN et al. 1981 & MOHL 1989), for geo sciences (SCHWEBEL 1983 & 1984) and for close range applications (MOHL 1985). A very special use was the search for unexploded bombs in old reconnaissance photographs from World War II, for which the focal length varied between 85 mm and 915 mm (MOHL et al. 1987).

Fig. 11.8 shows the structure of the STEREOCORD application software.

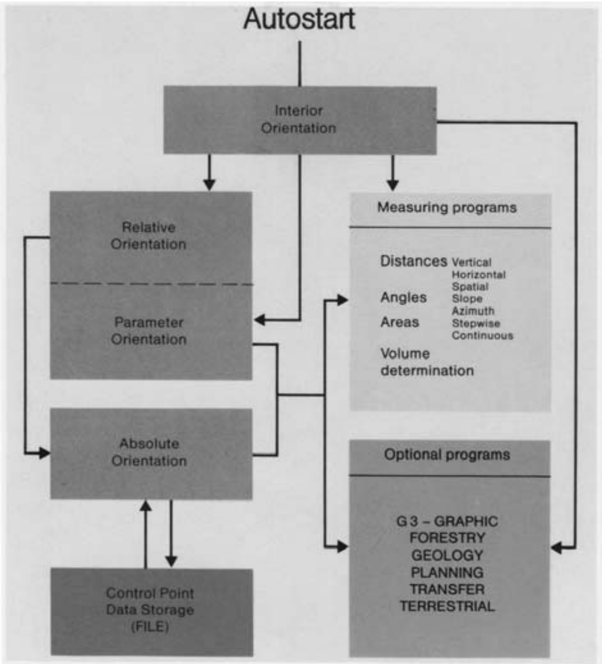


Fig. 11.8: Structure of the STEREOCORD application software

Fig. 11.9: G 3 STEREOCORD with IBM-PC (1987)

Following a general trend the G 3 STEREOCORD at the Photogrammetric Week in 1987 was used together with the now popular Personal Computer from IBM (Fig. 11.9). Until 1996 in total about 140 instruments of the ZEISS STEREOCORD had been delivered. As a "poor-man's analytical plotter" it soon became a favourite in the field of thematic photogrammetry, so that the product name "Stereocord" was often used as a category name for the otherwise called image space plotters (KONECNY 1977).

11.2 C 100 PLANICOMP

When GOTTFRIED KONECNY in New Brunswick / Canada was appointed to the professorship at the Hanover Technical University in 1971, he brought the newest AP of the "Helava"-type, the AP/C-3 from OMI to the Institute for Photogrammetry. However, with the still slow IBM 1130 computer this version seemed to be unacceptable to the photogrammmetric production world.

Oberkochen at this time not only was developing the STEREOCORD but also was watching carefully the increasing performance of the computers used for gathering data from laboratory processes in real time, which later developed into the minicomputers. And in December 1973 CARL ZEISS decided to develop a "real" analytical plotter of the "Helava" type in addition to the image space plotter such as the STEREOCORD.

As at this time there was only limited experience with scientific computers and software development, ZEISS looked for a joint development. The first choice was BENDIX with their then employee UUNO V. HELAVA, because a previously mentioned contact had just been established for the preparation of an orthoprinter project for American and German Federal Agencies. However, the intended joint AP-development did not materialise due to diverging opinions in conceptual and financial matters. For the same reasons a co-operation with OTTO HOFMANN, the former employee of ZEISS in Jena and ZEISS-AEROTOPOGRAPH in Munich, fell through. HOFMANN, now working for MBB in Ottobrunn, had presented a concept for a hybrid photogrammetric affine plotter at the ISP-Congress in Ottawa in 1972, which would have made use of a digital process computer.

In the end CARL ZEISS decided to accomplish this AP development alone, relying upon its own knowledge of the practical requirements and upon the skill and experience of its own development team. By postponing the intended project of a computer-controlled orthoprojector which did not result in a prototype until 1979, the intensive work in mechanical and electronic design started in September 1974. In a focused final spurt the system integration of the prototype took place in March 1976 (Fig. 11.10). On April 20th the first successful absolute orientation of a stereo model within the prototype was achieved and on July 12th, 1976 the C 100 PLANICOMP had its public premiere at the ISP-Congress in Helsinki (MEIER 1976a).

Fig. 11.10: C 100 PLANICOMP prototype with teletypewriter (April 1976)

According to the exhibition report in the German perodical "Bildmessung und Luftbildwesen" the C100 PLANICOMP was "the star", which "gleamed by its high user comfort and faultless reliability" (Kreiling 1976). The special attraction was an automatic sightseeing tour through an oblique stereomodel through the tourist highlights of Munich.

The pre-development of the application software had to be done at the scientific computing center of ZEISS by delivering a pack of punched cards for each of the only two daily services, and even during the final testing at the prototype the user interface to the C100 computer was an old-fashioned teletypewriter with a printing speed of three characters/sec ! The first CRT terminal available for this type of computer arrived in Oberkochen just in time for the final congress preparation (Fig. 11.11).

Fig. 11.11: C 100 PLANICOMP - Helsinki configuration

This initial system configuration (HOBBIE 1976b) for several years remained the typical equipment: the robust and self-containing viewer resting on ordinary cabinets made of sheet metal, the computer cabinet with three electronic racks (two of which housed the power electronics for the servo drives of the photo stages) and the HP 21 MX real time computer from HEWLETT-PACKARD with exchangeable disc drive, frequently a second computer cabinet wih optional peripheral equipment such as paper tape punch or magnetic tape drive, the CRT terminal with a printer subsystem, and usually the DZ 6 digital tracing table from ZEISS for on- and off-line plotting.

The viewer contained two photo carriages as x,y-cross slide systems, which could be viewed anytime through tinted acrylic glass windows, and the fixed viewing optics with binoculars at the top of the optics column. In front of the viewer the dedicated user panel with the handwheels was attached.

The innovative and patented floating mark consisted of a chrome-plated ellipse within a beamsplitter. This floating mark in an intermediate image plane occured as a black circular dot but by illuminating from the side it appeared as a luminous mark (KRASTEL 1975a).

The main parameters of the viewer during these early years were:

- *measurement area: x', y' = 240 mm*
- *measurement resolution: 0.001 mm,*
- *accuracy: $\sigma_{x'}$, $\sigma_{y'}$ = $\pm$ 0.002 to $\pm$ 0.003 mm for grid measurements, depending on viewing magnification,*
- *viewing magnification: binoculars for 8x and 16x,*
- *field of view: 30 mm at 8x magnification,*
- *image rotation: dove prisms for $\pm$ 100°,*
- *floating mark: identical black and adjustable luminous mark with 0.040 mm diameter,*
- *image viewing: orthoscopic, pseudoscopic, binocular left, binocular right; manually and computer controlled.*

The precision of the photo carriages (Fig. 11.12) was defined by solid steel rails separate for height and lateral guidance, ground to very high precision, and by precision wired lead screws with 1 mm pitch and roller nuts, both previously proven in the PLANIMAT. Rotary encoders with 1 000 pulses per revolution and servo-motors (Fig.11.13) formed the feed-back control systems for very precise, fast positioning.

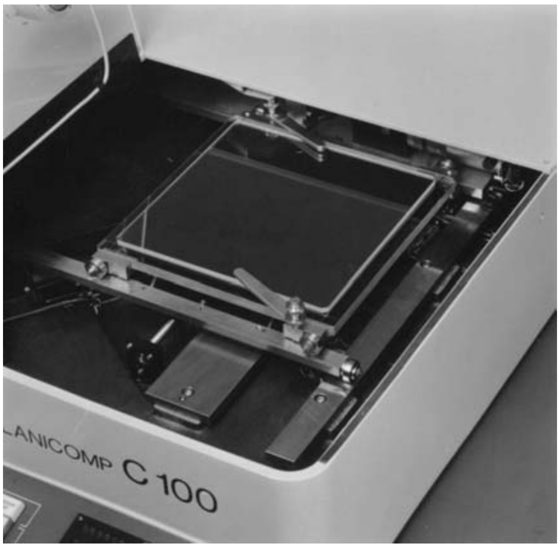


Fig. 11.12: Right image stage (cover opened)

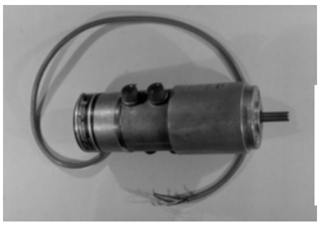


Fig. 11.13: Servo-motor for moving image stages

The area of movement was limited by a threefold system: inner numeric limits, medium electric switches and outer spring-loaded mechanical stops. For insertion of the photographs the carriages were moved automatically below the windows. The image stages carried an area designation for the coarse positioning of the photographs, and 9 etched grid crosses of very high precision with a mesh width of 90 mm for stage calibration.

For the operator's acceptance of the new analytical plotters it was necessary that there was no significant time lag between turning the handwheel and the computed and viewed movement of the image. To accomplish this, all the necessary stage shifts had to be computed and executed at least 25 times or, better, 40 times per second. In addition, a connected tracing table had to be driven and ground coordinates computed in real time. Fig. 11.14 explains these necessary computations. Fig. 11.15 shows the respective formulas and Fig. 11.16 the coordinate display at the panel. For the C 100 all transformations for the real time control were executed 50 times per second within the HP 21 MX computer.

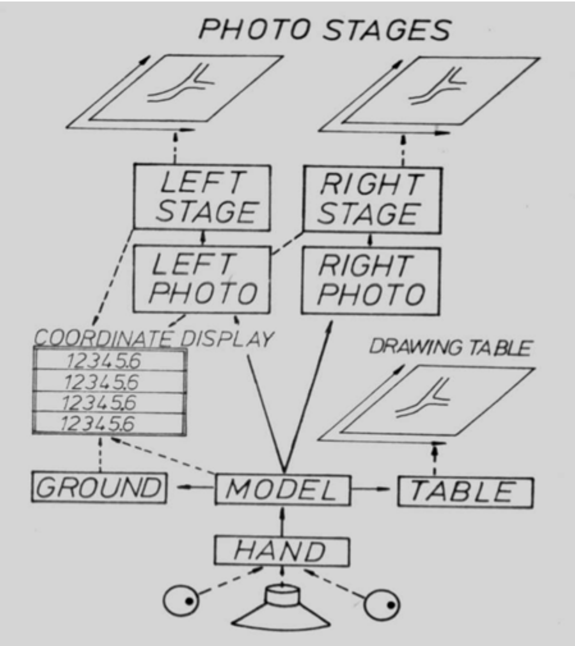


Fig. 11.14: C 100 real time control ("Loop"-program)

To achieve the computation precision necessary in photogrammetry of at least 10^{-5} to 10^{-6} (equivalent to 20 bit), the 16-bit processor had to be equipped with the floating point hardware option, thus slowing down the computations. Nevertheless the "Loop" program only used 50 % of the available computing time. The remaining time therefore could be used by the application software for work control, measurements and computing tasks.

An important special feature of the HP 21 MX minicomputer was the ability to react immediately if required, e. g. an external peripheral device such as the C 100 controller could stop the RTE II real time operating system by an interrupt call for the immediate execution of the "Loop" computations (Baeck 1977). By this ability, developed for real time response in lab environments, it was garantueed, that the "Loop" program, written in machine language (assembler), was started exactly every 20 msec, thus securing quick and smooth stage movements.

Model coordinates x, y, z

$$z^* = z + \frac{1}{2R}(x^2 + y^2)$$

$$x_L = x - bx/2 \qquad x_R = x + bx/2$$

$$y_L = y - by/2 \qquad y_R = y + by/2$$

$$z_L = z^* - bz/2 \qquad z_R = z^* + bz/2$$

Image coordinates $x_L^*, y_L^*, x_R^*, y_R^*$

$$x_L^* = -f\,\frac{a_{11} * x_L + a_{21} * y_L + a_{31} * z_L}{c_{11} * x_L + c_{21} * y_L + c_{31} * z_L}$$

$$y_L^* = -f\,\frac{b_{11} * x_L + b_{21} * y_L + b_{31} * z_L}{c_{11} * x_L + c_{21} * y_L + c_{31} * z_L}$$

$$x_R^* = -f\,\frac{a_{12} * x_R + a_{22} * y_R + a_{32} * z_R}{c_{12} * x_R + c_{22} * y_R + c_{32} * z_R}$$

$$y_R^* = -f\,\frac{b_{12} * x_R + b_{22} * y_R + b_{32} * z_R}{c_{12} * x_R + c_{22} * y_R + c_{32} * z_R}$$

$$x_L' = x_L^* + \Delta x_L \qquad x_R' = x_R^* + \Delta x_R$$

$$y_L' = y_L^* + \Delta y_L \qquad y_R' = y_R^* + \Delta y_R$$

Stage coordinates $x_L'', y_L'', x_R'', y_R''$

$$x_L'' = x_{L0} + d_{11} * x_L' + d_{21} * y_L'$$

$$y_L'' = y_{L0} + d_{31} * x_L' + d_{41} * y_L'$$

$$x_R'' = x_{R0} + d_{12} * x_R' + d_{22} * y_R'$$

$$y_R'' = y_{R0} + d_{32} * x_R' + d_{42} * y_R'$$

Ground coordinates x_G, y_G, z_G

$$x_G = x_{G0} + g_1 * x - g_2 * y$$

$$y_G = y_{G0} + g_2 * x + g_1 * y$$

$$z_G = z_{G0} + g_3 * z$$

Table coordinates x_T, y_T

$$x_T = x_{T0} + t_1 * x + t_2 * y$$

$$y_T = y_{T0} + t_3 * x + t_4 * y$$

Fig. 11.15: Formulas for C 100 real time computation

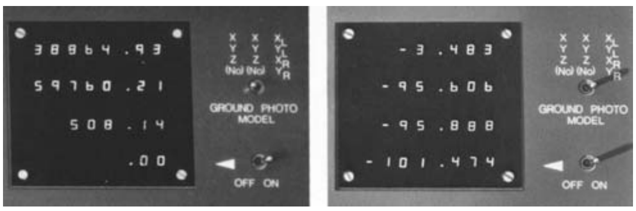


Fig. 11.16: Real time display of either photo (on the right), model or ground (left) coordinates at C 100 panel

Therefore the control and interface electronics of the C 100 Planicomp for the minicomputer was the peripheral with the highest and absolute priority. Via this interface for every cycle at first the changes of stage position and new display values (derived from the previous transfer) were received from the computer for immediate execution, before input values from handwheels, footdisk and joy-stick for the next cycle were sent to the computer. Actuating the footswitch or any panel control key was transmitted through a second, lower priority interface to the computer, together with further status and switch information. In addition the computer with its dual disc drive (one being a removable disc cartridge) was driving the user terminal and further optional peripherals for data recording and printing (Fig. 11.17).

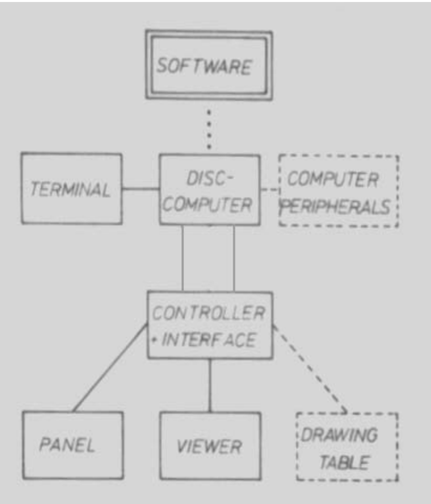


Fig. 11.17: Hardware-configuration of the C 100

Besides the handwheels and footdisk for moving the floating mark a joy-stick for fast moving in x and y as well as a speed control for profile measurements were available at the user panel next to the left handwheel (Fig. 11.18). The status of the handwheels as well as of the viewing optics could be switched and checked by luminous buttons above the right handwheel (but also changed by the software). The handwheels could be, via software, connected either to the stages directly for interior orientation and in different modes (e. g. left, right, left & right), or to the virtual model space, also in different modes (e. g. normal, terrestrial, profiling). The optical switching between binocular left/right and stereo viewing (ortho/pseudo) was very comfortable and was already known from the PSK (Fig. 11.19).

The center of the panel was dedicated to program control, avoiding the need for the operator to turn to the computer terminal during the measurement procedure. Fig. 11.20 shows the call buttons for the most often used programs such as interior, relative, absolute and table orientation, for further level A and B programs, three toggle switches for selecting the most important alternatives within programs, and yes/no-buttons for requested decisions, important program status indicators and the "Execute" button for starting a selected program.

Fig. 11.18: C 100 PLANICOMP user panel

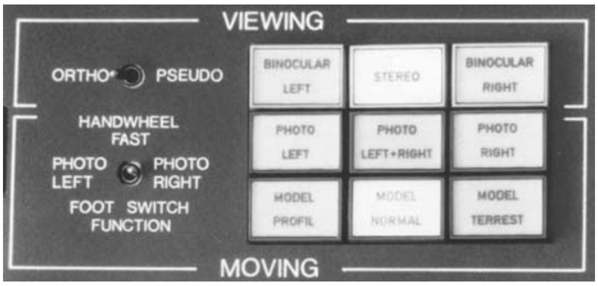


Fig. 11.19: Control elements for viewing and moving

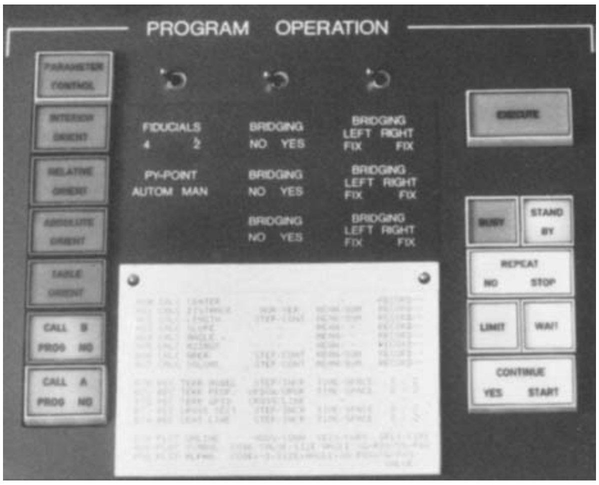


Fig. 11.20: Program control at C 100 user panel

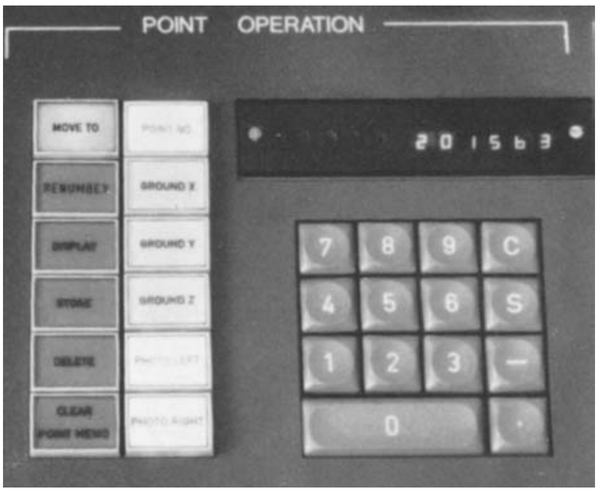


Fig. 11.21: Control elements for point measurement / editing

The keys just to the right of this center block (Fig. 11.21) were for point related activities such as store, move-to and edit, applied either to image or ground position, and for entry of point numbers or program numbers. It was this philosophy of a functional and practise-oriented handling through a dedicated user panel "hiding" the need for computer manipulation as much as possible, which made the C 100 PLANICOMP unique, and which produced the outstanding reputation and the fast and excellent acceptance of this analytical plotter from CARL ZEISS, Oberkochen.

Another important factor for the comfortable use was the software structure (Fig. 11.22): the "Loop" control with absolute and immediate priority of the stage movements, the fast execution of user commands entered through the "Panel"-program, and the grouping of all other application functions into short term priority tasks (level A), into interactive (on-line) measurement functions (level B) and into background programs such as block adjustment, DHM processing or off-line plotting (level C).

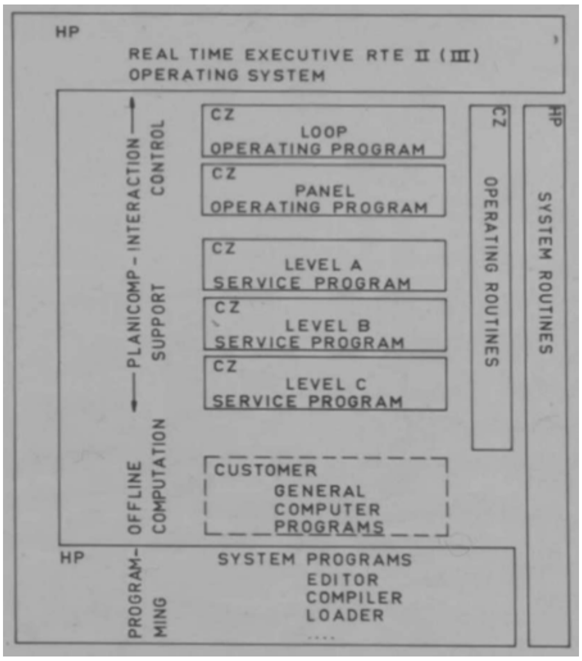


Fig. 11.22: C 100 software structure within RTE II

In 1976 the very limited memory size was a bigger problem than the somewhat low computer speed, at least for the programmers. The memory type was just changing from core memory to semiconductor modules and only after the C 100 premiere was the greatest possible working memory size for the HP minicomputer increased from 24 to 32 Kbyte ! The total capacity of the dual magnetic disc drive was 4.9 Mbyte, shared between a fixed disc and a removable disc cartridge. The personal computers of today have at least 100 000 times more memory, and furthermore are 1 000 times cheaper.

At that time careful memory management was necessary which consumed a big part of the programming time. The RTE operating system, the "Loop" program and the shared common data block all had to be resident in the working memory at any time. The remaining capacity had to be shared between all application programs, and was not even large enough to house a single program completely. Therefore most of the programs for the orientation steps, for measurement and for all off-line tasks had to be segmented. The general organisation of memory use is shown in Fig. 11.23. All the operational software with RTE operating system and C 100 related programs and functional data sets were backed up and loaded from the fixed disc, whereas the exchangeable disc cartridge was used for project related measurements.

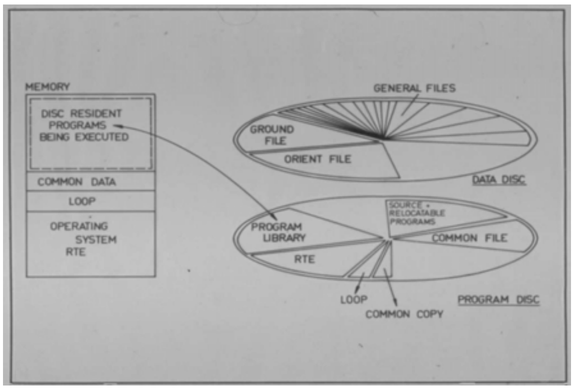


Fig. 11.23: Data organisation in HP 21 MX computer

By the introduction of the C 100 PLANICOMP in Helsinki the software was working very reliably, which was impressively demonstrated by the previously mentioned guided sightseeing tour of the tourist highlights in Munich using an oblique stereomodel.

In the following year the number of application programs had been increased from 40 to 75 (Fig. 11.24), among them all necessary and useful functions for orientation and data management, for aerotriangulation measurement and strip adjustment, for height measurements by contouring, profiling, cross sectioning or gridding, measurement of distances, angles, area and volume contents, for graphical plotting and for the instrument testing and calibration (HOBBIE 1977b).

Based on the experience with two prototypes, reports at the 1977 Photogrammetric Week said, that the expectations in reliability and accuracy were fully met. The PLANICOMP, although using on-line correction from a calibration with the 3 x 3 grid crosses on the image stages, was still slightly less precise than the high precision mono and stereocomparators from ZEISS, but it showed a remarkable advantage regarding speed and comfort of aerotriangulation measurements (STARK 1977b), thus becoming well accepted for this application.

- B 2	*Interior Orientation (measurement & computation)*
- B 3	*Relative Orientation (measurement & computation)*
- B 4	*Absolute Orientation (measurement & computation)*
- B 5	*Table Orientation (measurement & computation)*
- A 6	*Manual Orientation (orientation parameter-input)*
- A 8	*Parameter Control (parameter editing)*
- A 9	*Move to (center to a given point)*
- A 10	*Record (record actual position)*
- A 11	*Display (display a stored point)*
- A 12	*Store (store actual position)*
- A 13	*Delete (delete a stored point)*
- A 14	*Clear Point Memory (delete all points of a kind)*
- A 20	*List Model Data Engl (orientation report in English)*
- A 21	*List Model Data Germ (orientation report in German)*
- A 22	*List Model Data Fren (orientation report French)*
- A 23	*List Model Data Span (orientation report in Spanish)*
- A 24	*List Ground Memory (list actual control points)*
- A 25	*List photo Memory (list stored image coordinates)*
- A 26	*List Camera Data (list actual camera data)*
- A 27	*List transform Data (list transformation parameter)*
- A 28	*List Calibration Data (report on instrum. calibration)*
- A 29	*List Program Library (list of available programs)*
- A 30	*List Orient File (list stored model orientation data)*
- A 31	*Clear Orient File (delete all stored orientation data)*
- A 32	*Save Orient Data (store actual orientation data)*
- A 33	*enter Orient Data (load stored orientation data)*
- A 34	*Record Orient Data (export of orientation data)*
- A 35	*Read Orient Data (import of orientation data)*
- A 39	*Transform Ori Data (orient. data for analogue plotters)*
- A 40	*List Ground File (list stored control points)*
- A 41	*Clear Ground File (delete stored control points)*
- ……..	*(A 42 - A 44 for Save, Enter, Record ...)*
- A 45	*Read Ground Data (import of control points)*
- A 46	*Find Ground Data (search control points by area)*
- A 50	*List General File (list stored measurements)*
- A 51	*Clear General File (delete stored measurements)*
- A 52	*Transfer Gen. Data (copy stored measurements)*
- A 54	*Record General Data (export of stored measurements)*
- A 55	*Read General Data (import of stored measurements)*
- A 56	*Edit General Data (edit stored measurements)*
- A 57	*Tansfer Atx Data (copy triangulation measurements)*
- A 58	*Save Atb Data (store data for bundle adjustment)*
- A 59	*Save Atm Data (store data for model adjustment)*
- A 60	*Calculate Center (calculates & centers to mean value)*
- A 61	*Calculate Distance (calculates horiz. & vertic. distances)*
- A 62	*Calculate Length (calculates length of travel)*
- A 63	*Calculate Slope (calculates vertical angle)*
- A 64	*Calculate Angle (calculates spatial angle)*
- A 65	*Calculate Azimut (calculates horizontal angle)*
- A 66	*Calculate Area (calculates area content)*
- A 67	*Calculate Volume (calculates volume content)*
- A 69	*Distribution (calculates statistics of stored data)*
- B 70	*Record Terrain Model (point & line measurement)*
- B 71	*Record Terrain Profil (profile measurement)*
- B 72	*Record Terrain Grid (grid measurement)*
- B 73	*Record Cross Section (measurement of cross sections)*
- B 80	*Plot Online (on-line plotting)*
- A 81	*Plot Symbol (plotting of symbols & characters)*
- A 82	*Plot Alpha (text annotation)*
- C 85	*Grid Plotting (off-line plotting of grids)*
- C 86	*Point Plotting (off-line plotting of points)*
- C 87	*Vector Plotting (off-line plotting of vectors)*
- A 90	*List Common File (list stored system data)*
- ……..	*(A 91 - A 95 for Clear, Save, Enter, Record, Read ...)*
- A 96	*Set Common Data (reset system data)*
- A 97	*List Common Data (list actual set of system data)*
- B 98	*C100 Calibration (grid measurement & adjustment)*
- C 99	*Function Test (semi-automatic test of system),*
- C 101	*Point Correction (editing of stored point data)*
- C 101	*Atm Strip (off-line computation of strip adjustment)*

Fig. 11.24: C 100 user programs (as of 1977)

Therefore the support for on-line aerotriangulation (Hobbie 1978) was expanded by implementing the famous "Stuttgart programs" on the HP 21 MX computer of the C 100 as options (Klein 1977 & 1978): for block-adjustment with independent models, Pat-M 43 (later Pat-MR), and for bundle blockadjustment, Pat-B (later PatB-RS). Since 1980 the optional program HiFi (already described in chapter 8.7) for the computation of height models by interpolation with finite elements and for the derivation of contour lines and profiles was also available (Ebner et al. 1980b).

By 1979 Hewlett-Packard had developed its real time computer family further into the HP 1000 system with the RTE IV operating system (Hobbie 1979c), which significantly improved the computational speed and the memory capacity. Now the C 100 minicomputer was able to serve additional interactive operator seats (Fig. 11.25). At the "Bayerische Flurbereinigung", the Bavarian state agency for land consolidation, as a special requirement, two C 100 Planicomp were successfully driven by a single HP 1000 F computer (Zippelius 1979).

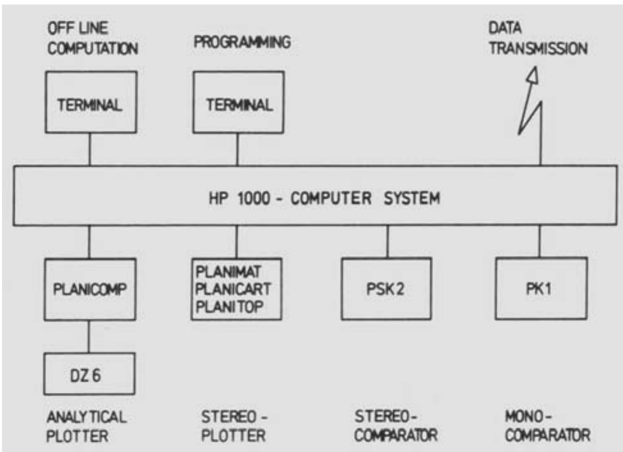


Fig 11.25: Multiple use of the HP 1000 minicomputer

In the meantime many customers in state agencies, in private enterprise and in academia had very positive experience using the C 100 (Strerath 1979, Rose 1979 & Ebner 1979). Four years after its introduction the analytical plotter from Carl Zeiss, Oberkochen was not only mature, and used by many customers for manifold tasks (Hobbie 1980a), but also known as being the state of the art and extremely reliable. The hardship of the early years, when the software for any instrument had to be loaded from about 100 paper tape rolls, was over. In the meantime the precision of the viewer, by constructive measures, was increased to ± 2 µm in x and y determined as a mean of all the instruments delivered so far, based on a calibration with a 25-point grid.

For checking the correct functioning of the C 100 the operators were able to use programmed test procedures. A service technician could verify the correct communication from and to the ZEISS control electronics with special testing devices (Fig. 11.26), emulating the HP computer (HOBBIE 1980b).

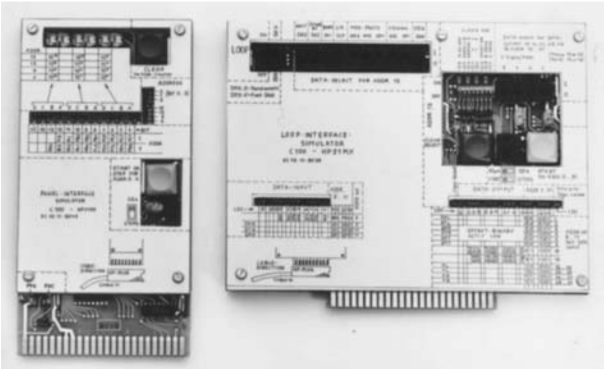


Fig. 11.26: Testing tools for the C 100 control electronics

11.3 C 100 enhancements

During the following years the C 100 PLANICOMP was further refined and extended to a wide product family, following the recommendations and wishes of the users and exploiting the progress of the computers.

In 1983 a modified C 100 viewer with a zoom lens for 7.5x to 30x viewing magnification was introduced and the filament lamp substituted by a halogen bulb. By replacing the now exchangeable 8x binocular with a 16x version this range could be changed to 15x - 60x, by which the viewing resolution was enhanced to 200 lp/mm (RÜDENAUER 1983 & HOBBIE et al. 1984c).

Both viewer types also received optical gateways, either for the previously described graphical superimposition (e. g. by VIDEOMAP, see chapter 10.6), or for digitising the image within the field of view with CCD cameras. This optical gateway since summer 1983 was also used for superimposing an INTERGRAPH monitor, when connecting the PLANICOMP to the stereodigitiser-workstation from INTERGRAPH (Fig. 11.27). The year before an on-line setup between the PLANICART and the INTERGRAPH system had been presented (see chapter 10.6), and even before that off-line measured graphical data could be passed from ZEISS stereoplotters to the IGDS Interactive Graphic Design System with the ISIF INTERGRAPH Standard Interchange Format for further processing.

Fig. 11.27: Stereodigitiser workstation and superimposition from INTERGRAPH at C 100 PLANICOMP (1983)

The on-line connection to INTERGRAPH systems was enabled by the new progam B 76 RECORD INTERGRAPH DATA for interactive communication and measurement with the following functions: e. g. transfer of present floating mark position, move to a requested location, measurement of single points, traced lines or profiles, emulation of INTERGRAPH soft keys at the C100 panel, and exchange of large data sets (HOBBIE 1983 & 1984a).

Also in 1983 various new computer configurations of the HP 1000 A family were offered with the models A 600, A 700 and A 900 (marketed as MICRO 26, 27 and 29). Based on this variety and the two viewer variants several standard packages were now available, which differed in hardware performance, amount of software and price:

- *C 100 / C 110: zoom viewer with HP 1000 A 900,*
- *C 120: zoom viewer with HP 1000 A 700,*
- *C 130: normal viewer with HP 1000 A 600.*

Two years later the C 140 was added as a C 130 with further reduced equipment (SCHWEBEL 1985). The higher value sets were looking similar to the previous installations (Fig. 11.28) and were called "plotting system" or "plotting station", whereas for the lower level "workhorses" the electronic and computer racks were stored in the cabinets below the viewer (Fig. 11.29).

Fig. 11.28: C 120 PLANICOMP with HP 1000 A 700 computer

Fig. 11.29: C 140 PLANICOMP with HP 1000 A 600 computer, without cabinet doors (1985)

From 1985 onwards the improved RTE-A operating system from Hewlett-Packard was used, and the PLANITAB plotting tables could be connected to the PLANICOMP. Therewith the hardware development for the C 100 PLANICOMP family was complete.

Many important software extensions were created by development partners and by customers, and several of these results had been supported by ZEISS or were distributed through ZEISS. Not yet mentioned are the BLUH program for bundle blockadjustment from Hanover Technical University since 1980, and the BINGO bundle block adjustment since 1986, by which also SPOT-images from space could be evaluated at the C 100 (KONECNY et al. 1987). In 1983 Bonn University completed the C007 BUNDLE ORIENTATION as a one-step absolute orientation for close-range stereopairs with the possibility of using additional infomation. And also the program B 198 EXTENDED CALIBRATION for reseau-correction of (non-metric) close range cameras came from Bonn.

The unique method of progressive sampling for the acquisition of height models was the topic of a doctor thesis in Hanover (RÜDENAUER 1980) and later, with support from ZEISS, implemented at the C 100 as the PROSA progam by the Munich Technical University (REINHARDT 1983 & REINHARDT et al. 1989). PROSA was an ideal measurement tool for the PLANICOMP to refine dynamically the terrain appoximation while minimising the measurement effort for further processing with HIFI. An American user (KUCERA INTERNATIONAL in Mentor, OH/USA) developed the "Highway Design Package" for the PLANICOMP, which managed the required measurements, computations and the mapping according to US-regulations.

THE C 100 PLANICOMP at Stuttgart University was equipped in 1983 by ZEISS with two CCD cameras from HAMAMATSU (Fig. 11.30 and 11.31), by which images with 243 x 256 pixels (with pixel size 20 µm at the image scale) were digitised and read into the HP 1000 computer 60 times per second (GÜLCH 1984 & 1985). This allowed implementation of the previous university research in digital image correlation (ACKERMANN 1983) for on-line use at the C 100. The further successful development was supported by VOLKSWAGEN AG and CARL ZEISS. In the autumn of 1986 a second system was installed for a pilot customer in Wolfsburg, where the system was used for the automatic measurement of car body designs (SCHEWE 1987). This hard and software equipment was marketed by ZEISS under the label INDUSURF and sold to several car manufacturers. An important part of the related camera system was a newly developed texture projector for the SMK 40 stereometric camera from ZEISS (see chapter 13.1), for obtaining usable photographs for the correlation of the otherwise un-textured body surfaces (Fig. 11.32).

This method of digital image evaluation at an analytical stereoplotter, here described for the C 100, was a registered patent (Ackermann et al. 1984).

Fig. 11.30: C 100 PLANICOMP with digital image correlation

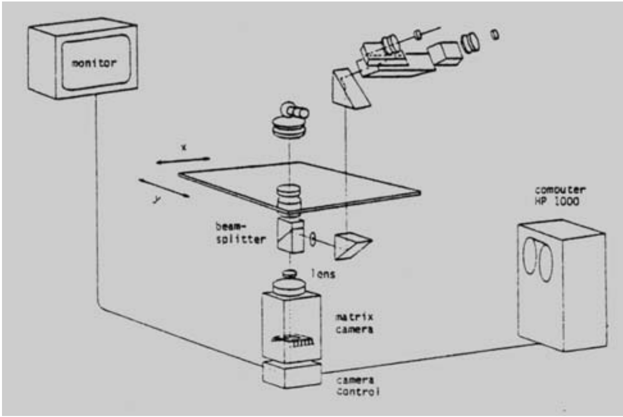


Fig. 11.31: Optical diagram of C 100 with CCD-camera

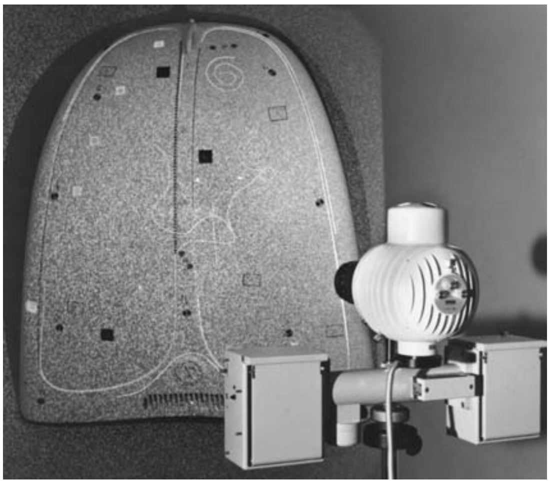


Fig. 11.32: SMK 40 stereometric camera with texture projector taking images for use with INDUSURF

With INDUSURF in 1985 CARL ZEISS, Oberkochen had again realised computer controlled image correlation on-line at a stereoplotter, after having presented the ITEK-Correlator EC 5 with the PLANIMAT in 1968. As in 1968 only a few systems of the new solution were sold. Half way between these two realised solutions ZEISS temporarily was one of the sponsors of the RASTAR project at Hanover Technical University (KONECNY et al. 1980 & PAPE 1983), which was mainly driven by GILBERT L. HOBROUGH as visiting scientist, but cancelled in 1983.

11.4 "ZIP" ZEISS-INTERGRAPH project

The talks with INTERGRAPH in Huntsville, AL/USA since 1981 about joint projects resulted in the following years in the previously described interfacing between their stereodigitiser workstation and the ZEISS E 3 PLANI-CART and C 120 PLANICOMP. During this co-operation in late 1983 INTERGRAPH showed interest in a joint development of a new analytical plotter, which should be tightly integrated in their graphical workstations and also be prepared for special requirements demanded by one of their federal US-customers. At this time Oberkochen was already in a pre-development phase of a new "C 200" generation and therefore immediately was able, to make an attractive proposal entitled "CAPI". And after a few discussions and detailed presentations, also involving the prospective end-user, ZEISS won this contract against a smaller Swiss competitor in July 1984.

This huge order with a very tight schedule was extremely challenging for both the photogrammetric product division and for the manufacturing shops. However, after 12 months the first instrument was delivered on time to INTERGRAPH, in the presence of the customer, under the name ZIP "ZEISS-INTERGRAPH-Project" (Fig. 11.33).

Fig. 11.33: "ZIP" - first delivery in July 1985

Between July 1985 and the end of 1988 in total 320 ZIP units were delivered. This meant that in addition to ZEISS's own orders for the PLANICOMP 10 units per month had to be assembled for INTERGRAPH. This was made possible by establishing a dedicated assembly hall for all analytical plotter types of CARL ZEISS in Oberkochen (Fig. 11.34).

Fig. 11.35 shows the still unready viewer during the assembly. The very large stage carriages are visible, which defined the overall size of the viewer. The unusually large measurement area was needed for super-size image formats, e. g. to enable stereo models with the 9" x 18" images from the LFC Large Format Camera from ITEK, Lexington, MA/USA with 60 % end lap.

Fig. 11.34: Assembly hall for analytical plotters at CARL ZEISS in Oberkochen (1986)

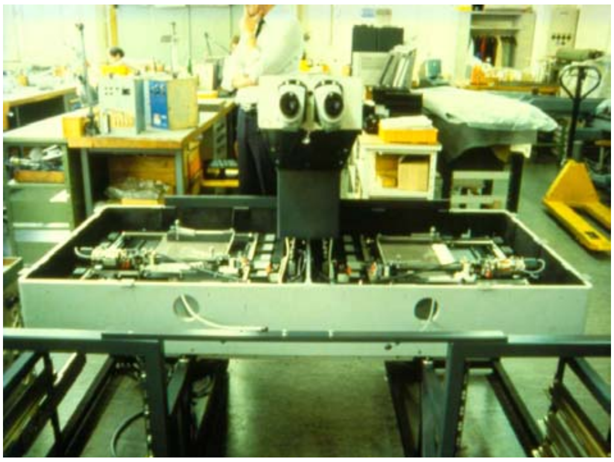


Fig. 11.35: Inside view of the ZIP viewer

The main optical and mechanical parameters of the ZIP viewer were (HOBBIE 1986):

- *measurement area: x' = 330 mm, y' = 240 mm,*
- *measurement resolution: 0.001 mm,*
- *ortho/pseudo/binocular left & right-switching, computer controlled,*
- *image and floating mark illumination: computer controlled,*
- *image rotation: dove prisms 360°, computer controlled,*
- *viewing magnification: 10x to 40x, computer controlled,*
- *floating mark diameter: 10 - 70 µm, computer controlled ,*
- *viewing resolution: 200 linepairs/mm,*
- *optical interface for 15" colour raster screen display.*

While ZEISS delivered the optics, mechanics and the electronics of the "naked" viewer, INTERGRAPH completed the system with the basic support structure, covers and working table, with the monitor for superimposition, and with all the computer hardware and software.

Special emphasis had been put on ergonomics to be able to fit comfortably to operators of almost any body height (Fig. 11.36).

Fig. 11.36: Ergonomics at stereoplotters: variation of body heights

To accomplish this the whole viewer with superimposition screen and table top working surface could be lifted or lowered by a motor-driven mechanism. This was also a standard feature of the commercial version of ZIP which was announced to the market in 1986 under the name IMA "INTERMAP ANALYTIC" (Fig. 11.37). IMA was exhibited at the ISPRS-Congress in Kyoto in 1988 as an analytical plotter being completely integrated into a geographical information system. At the same event ZEISS were present with, among other instruments, its "brother", the P 1 PLANICOMP, which was very similar regarding the optics, mechanics and the basic electronics of the viewer.

Fig. 11.37: IMA INTERMAP ANALYTIC from INTERGRAPH (1987)

11.5 P-series PLANICOMP

During the pre-development phase of a new "C 200" as a high end successor to the C 100 PLANICOMP an additional lower-cost version of a HELAVA-type analytical plotter was discussed. When the ZIP-project was on its way and the technical concept of the "C 200" was decided upon in summer 1985, reduced models were designed under the working titles "C 150" and "G 5", both carrying on the C 100 / C 140 line and the G 3 STEREOCORD. All three developments were first presented at an in-house seminar in Oberkochen in March 1987 as the PLANICOMP P-series with its members P 1, P 2 and P 3, together with PHOCUS, the photogrammetric and cartographic software previously described in chapter 10.7 (Fig. 11.38). The public premiere followed in April at the "March Meeting" in Baltimore and in September at the Photogrammetric Week in Stuttgart (HOBBIE 1987a & 1987b, SAILE 1987a & 1987b).

Fig. 11.38: Logo for P-series PLANICOMP and PHOCUS (1987)

The basic viewer of the P 1 PLANICOMP (Fig. 11.39) from ZEISS was identical with the IMA from INTERGRAPH regarding the mechanics, including the size of the image stages (Fig. 11.40). This not only allowed the setup of stereomodels with the 9" x 18" images of the LFC Large Format Camera with 60 % end lap, but also enabled e. g. the evaluation of the Russian 30 cm x 30 cm images from space (when rotated by 90°), or the parallel setup of two consecutive stereomeodels of the standard 9" x 9" format, or several stereomodels with smaller formats as used in close range photogrammetry. The optics of the P 1 and IMA were very similar, but differed by several parameters and by the optical gateway for superimposition: whereas ZEISS selected to superimpose into the intermediate image plane at the floating mark (Fig. 11.41) as proven with the C 100, the IMA superimposed into the intermediate image viewed with the binoculars, which required electronically zooming and rotating of the monitor image to fit with the computer controlled movements of the optical zoom and dove prism rotation.

Fig. 11.39: P 1 PLANICOMP from CARL ZEISS (1987)

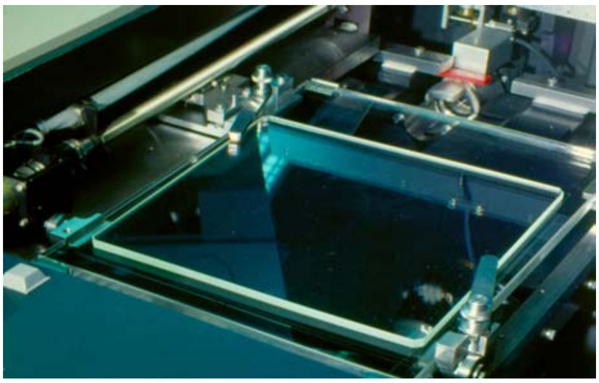


Fig. 11.40: Image carriage of the P 1 PLANICOMP

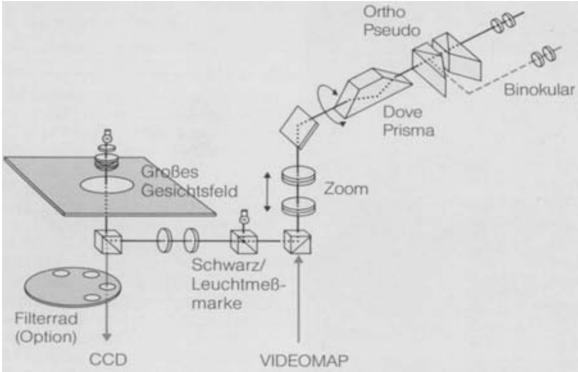


Fig. 11.41: Optical diagram of the P 1 PLANICOMP (right side)

The main parameters of the P 1 PLANICOMP were:

- *measurement area: x' = 330 mm, y' = 240 mm,*
- *measurement resolution: 0.001 mm,*
- *accuracy:* $\sigma_{x'}$, $\sigma_{y'}$ = $\pm$ *0.002 mm,*
- *floating mark: identical black and adjustable luminous mark with diameter 30 µm (optional 60 µm),*
- *viewing magnification: 5x to 20x, separately adjustable (optional 10x to 40x with 16x binculars),*
- *field of view: 40 mm at 5x magnification,*
- *viewing resolution: up to 120 linepairs/mm,*
- *image rotation: dove prisms 360°,*
- *viewing condition: orthoscopic, pseudoscopic, binocular left, binocular right; manual and computer controlled,*
- *height of the binocular: manual change between 475 mm and 535 mm above table,*
- *optical interface for image input and output.*

A special feature of the P 1 was the large table top working surface with an integrated digitising tablet of 800 mm x 400 mm in size and 0.025 mm resolution, on which the CRT terminal was placed as well. Instead of the usual sensor head for this digitiser the newly developed P-Cursor was used (Fig. 11.42). This "P-Mouse" enabled comfortable freehand guidance of the floating mark, but also fast movement by four buttons for x and y on the top and, above a knurled wheel for the fine z-movement, two buttons for z in front. Additional five soft keys on the top could be programmed for the most important control commands of each task. In addition to the movement control, the P-Cursor with its attached reticule could be used to center to a point in an oriented map or contact print, to address a command in a menu on paper, or to digitise details from any graphic overlay.

A unique feature of this P-Mouse was the patented progressive sensitivity of the freehand movement (HANSSEN et al. 1983): slow moving as for line following resulted in a fine movement and with increasing speed the ratio to the image scale was raised (Fig. 11.43). Of course handwheels, footdisk and footswitches were available as usual.

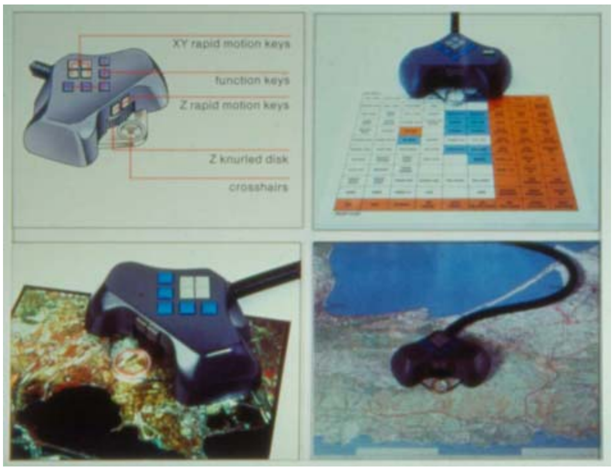


Fig. 11.42: P-Cursor and its use

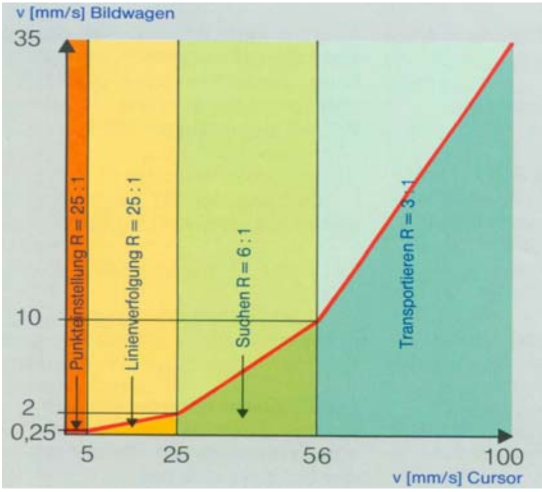


Fig. 11.43: P-Cursor - progressive sensitivity

Fig. 11.44: P 2 PLANICOMP (1987)

The P 2 PLANICOMP in principle was a C 100 adapted to the electronics, software and the handling of the P-series (Fig. 11.44). The previous dedicated user panel, typical for the C 100 family, was now replaced by a wooden board, on which the programmable soft-keypad, already known from the PLANIMAP software, was placed. The available space did not allow for the use of the P-Cursor. After 1989 ZEISS offered a conversion kit and at the request of many customers upgraded several dozen C 100 to a P2 (SCHWEBEL 1994).

The important parameters of the P 2 were:

- *measurement area: x' = 240 mm, y' = 240 mm,*
- *measurement resolution: 0.001 mm,*
- *accuracy: $\sigma_{x'}$, $\sigma_{y'}$ = $\pm$ 0.002 mm,*
- *floating mark: identical black and adjustable luminous mark with diameter 40 µm (optional 20 µm),*
- *viewing magnification: 7.5x to 30x, separately adjustable,*
- *field of view: 26 mm at 7.5x magnification,*
- *viewing resolution: up to 120 linepairs/mm,*
- *image rotation: dove prisms $\pm$ 105°,*
- *viewing condition: orthoscopic, pseudoscopic, binocular left, binoular right; manual and computer controlled,*
- *height of the binocular: fixed,*
- *optical interface for image input and output.*

A complete new design was the viewer of the P 3 PLANICOMP (Fig. 11.45). The very compact size of this table top instrument was achieved by an overlapping travelling range of the usual 240 mm x 240 mm stages in x-direction (Fig. 11.46). This and the simpler optical design (Fig. 11.47) did not allow for pseudoscopic evaluation ("base out"), but enabled an end lap of up to 100 %. The P 3 had optical gateways for input and output, too. An ergonomic feature was the motorised height adjustment of the viewer, by which the vertical distance of the eyepiece over the table could be adapted.

Fig. 11.45: P 3 PLANICOMP (1987)

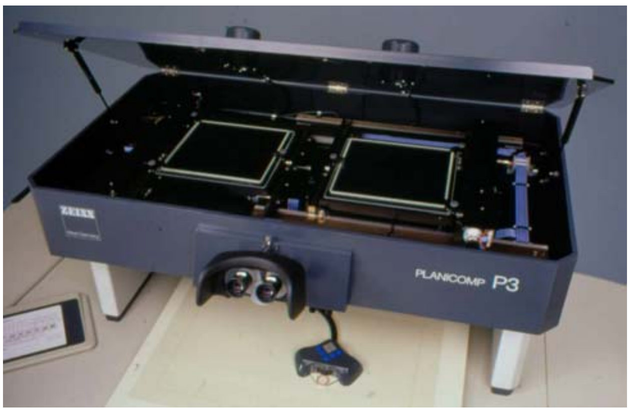


Fig. 11.46: P 3 PLANICOMP - image carrier

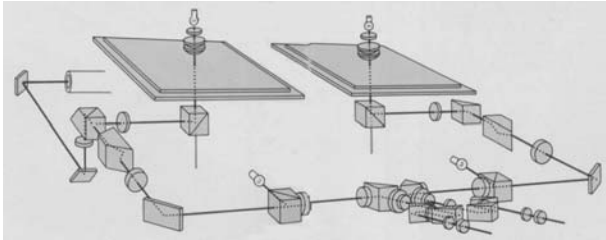


Fig. 11.47: Optical diagram of the P 3 PLANICOMP

At the P 3 the P-Cursor was used together with an off-the-shelf digitising tablet of size 594 mm x 420 mm and with a typical resolution of 0.025 mm. An optional dual eyepiece for training and difficult interpretation jobs is shown in Fig. 11.48.

Fig. 11.48: P 3 PLANICOMP - viewing for two

The main parameters of the P 3 PLANICOMP P 3 were:

- *measurement area x' = 240 mm, y' = 240 mm, usable image format: 270 mm x 270 mm,*
- *measurement resolution: 0.001 mm,*
- *accuracy: $\sigma_{x'}$, $\sigma_{y'}$ = $\pm$ 0.003 mm,*
- *floating mark: identical black and adjustable luminous mark with diameter 72 µm, optional 36 µm,*
- *viewing magnification: 5x to 20x,*
- *field of view: 40 mm at 5x magnification,*
- *viewing resolution: up to 100 linepairs/mm,*
- *image rotation: dove prisms $\pm$ 25°,*
- *viewing condition: orthoscopic only,*
- *height of the binocular: adjustable with motor drive between 440 mm and 570 mm above table,*
- *optical interface for image input and output.*

The very compact P 3 PLANICOMP was successfully focussed onto the requirements and main workload of photogrammetric production and therefore became a very popular and successful workhorse, which even today, more than 20 years after its introduction, is still in use at many customer sites. In spite of its already favourable price a further slimmed down version was offered as P 33 PLANICOMP in 1992. The additional cost reduction was obtained by replacing the motorised height adjustment by the choice of a fixed eyepiece height of either 510 or 560 mm above the table, by replacing the optical zoom with a magnification changer allowing 6x, 10x or 16x, and by using only a luminous floating mark. Reducing the viewing resolution to about 60 to 80 linepairs/mm, which is sufficient for the usual aerial images, allowed a further saving in manufacturing its optics.

At the Washington Congress in 1992 a "P 25" as an upgraded P 3 PLANICOMP was announced. This instrument would have had new optics with a patented ortho/pseudo-/binocular switching (FAUST et al. 1991), motorised change of zoom and floating mark diameter (separate for both sides), and other slightly extended ranges. But the "P 25" was not realised. Also in Washington the PC-based SCAN program for a P 3 with CCD cameras, which had been developed by Bonn University on behalf of CARL ZEISS was described (SAILE 1992).

For all three different PLANICOMP of the P-series the electronics were nearly identical. The control electronics now consisted of printed circuit boards which were double the size of those used in the C 100. Together with the power electronics for the motor drives (Fig. 11.49) these were stored in a single drawer instead of three drawers.

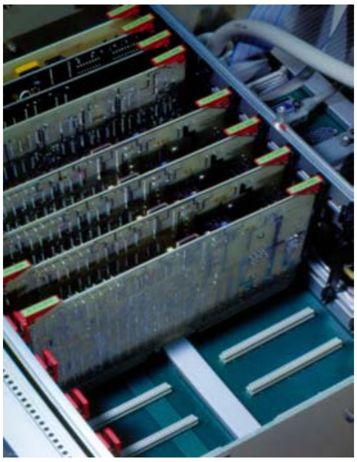


Fig. 11.49: Printed circuit boards of the P-series electronics

Based on an INTEL 8086 microprocessor with 8087 arithmetic coprocessor this "P-processor" of the PLANICOMP P-series was autonomous in real time computations, incremental recording and handling the commands of the operator. The firmware was written in the PASCAL language and it controlled all device-relevant real time tasks such as: monitoring the operating status, reading the input from the moving elements, computation of the necessary shifts of the image carriers and output to the servo drives, serving operator commands, execution of individual and incremental records and communication with the workstation computer. For this communication the microprocessor was adressable via an IEC or RS232 interface through a documented set of about 50 commands. This enabled any computer to act as a host or workstation computer for the PLANICOMP P-series. The user was no longer restricted to the HP 1000 computer which at the start of the P-series was primarily used by ZEISS. With these commands, addressable through a program library written in the FORTRAN language, experienced programmers were able to drive a P-series PLANICOMP by their own user programs and without the P-software and PHOCUS from ZEISS.

The important features of the P-software embedded in PHOCUS (see chapter 10.7) were:

- *PHOCUS basic software for control of and handling with the P PLANICOMP by communicating with the P-processor, with computer peripherals, and with the output devices,*
- *object oriented and structured data base with basic management and editing functions,*
- *flexible and comfortable interior, relative and absolute orientation of stereomodels,*
- *installation, management, editing and reporting regarding data files for aerial cameras, orientation parameters, control points, calibration data and other parameters,*
- *object recording with handling of object code tables, measurement in various recording modes, automatically connecting with already known points, display on VIDEOMAP and other output devices, and editing functions related to measurements,*
- *manifold and comfortable editing,*
- *map sheet preparation and graphical output,*
- *manifold measurement functions for aerotriangulation,*
- *manifold measurement functions for digital height models.*

The possible system configuration of the P-series with PHOCUS is shown in Fig. 11.50.

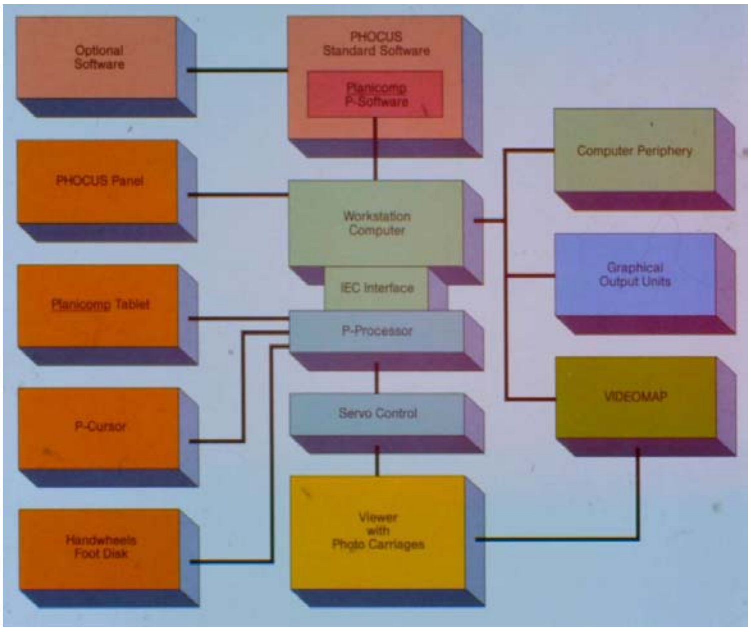


Fig. 11.50: System configuration of P-series and PHOCUS

In addition to the mini- and microcomputer of the HP 1000 family with RTE operating system from HEWLETT-PACKARD, from 1989 ZEISS alternatively offered the VAXstation and the MicroVAX with VMS operating system from DIGITAL EQUIPMENT CORPORATION (DEC). In 1992 the DECstation as well as a graphics computer from SILICON GRAPHICS, both with UNIX operating system, also became available.

With the increasing performance and success of the IBM personal computer with MS-DOS operating system the PC became interesting for use with analytical stereoplotters. Being announced at the Kyoto Congress in 1988, the PC-based P 3 PLANICOMP was presented at the "March Meeting" in 1989 in Baltimore (Fig. 11.51). For this configuration the Ohio State University in Columbus, OH/USA had developed the P-CAP orientation software (SCHENK et al. 1989 & SAILE 1989).

Fig. 11.51: P 3 PLANICOMP P 3 with PC-based P-CAP program (1989)

P-CAP with all of its photogrammetric project and model management and its orientation functions was already running under the WINDOWS operating system. As usual the orientation was done in three steps: interior, relative and absolute orientation. P-CAP managed the communication with the P-processor and supported the P-Cursor for all measuring and editing functions, thus creating a very similar handling to the P-software and PHOCUS.

After completing the orientation the parameters for the model to photo transformation were stored in an ASCII file with a defined PHOREX format. From there this data could be used for interactive tasks programmed by third parties or on other stereoplotters. In early 1991 several program functions for DHM acquisition by raster or profile measurements and for aerotriangulation measurements were added. Ten years after presentation more than 300 licences for P-CAP had been granted.

The PC based P 3 PLANICOMP was especially demanded as a workhorse for mapping and for capturing object data for GIS/LIS systems. Therefore the data compatibility, which was already given by PHOCUS, was also established for the PC version through so-called "drivers" for the following systems:

- *AutoCAD from AUTODESK,*
- *MICROSTATION PC from INTERGRAPH,*
  (since 1995 again from BENTLEY Inc., Exton, PA/USA),
- *pcARC/INFO from ESRI.*

In 1993 ZEISS exclusively offered CADMAP in the PC version, wich had been developed in the USA by MIKE KITAIF since 1985 (ROTH 1993). At this time CADMAP was already well accepted by North-American photogrammetric companies. Many of the popular and efficient functions of CADMAP were adopted in 1994 to the aforementioned programs under the designation MICROSTATION driver (or CADMAP/dgn for MICROSTATION 5) and AutoCAD driver (or CADMAP/dwg for AutoCAD 12) (SCHWEBEL 1994). In 1997 another device driver for the PLANICOMP P-series was added for the on-line connection to the ALK-GIAP geographic information system for photogrammetric data acquisition (Kresse 1997). ALK-GIAP was used in Germany by public authorities. The aforementioned named third party GIS/CAD systems in connection to the P 3 PLANICOMP since 1993 could make use of the graphical superimposition with VIDEOMAP 30 (MENKE 1994).

For evaluating the aerotriangulation and height measurements with the PC-based P-series PLANICOMP the known programs were available also in a PC-version: PATM-PC, PATB-PC and BINGO, as well as SCOP (PC) and HIFI-88.

Altogether the P-series PLANICOMP was very popular and with over 700 units the most successful AP-family on the market. Especially the workhorses P 3 and P 33 were in great demand and had a 90% stake in the sales. Together with the previous C 100 generation and the special ZIP version for INTERGRAPH the total number of analytical plotters produced at CARL ZEISS in Oberkochen exceeded 1300 instruments.

12. Scanners & digital stereoplotting

After being a topic in academia for two decades in the early 1990s the metric evaluation of digitised aerial images began to find its way into photogrammetric practice. Research into digital image correlation at Stuttgart University in 1984 had led to the INDUSURF product from CARL ZEISS for the automatic measurement of industrial surfaces with the C 100 PLANICOMP (see chapter 11.3). However, as with all correlator solutions in connection with stereoplotters, only a small part of the image within the field of view was sampled for on-line use.

For digitising whole images for off-line image processing Oberkochen started the pre-development of a photogrammetric scanner in 1986, which resulted in a scanner jointly developed by ZEISS and INTERGRAPH in 1989 (chapter 12.1). The follow-up model, presented in 1995, was a complete in-house development of CARL ZEISS Oberkochen (chapter 12.2).

By the early 1980s the corporate research division of ZEISS was continuously investigating methods of digital image aquisition and processing in order to check their suitability for the various imaging and measurement products of ZEISS. The findings related to the processing of high resolution images were described at the Photogrammetric Week in 1989 (GROSSKOPF 1989). At this time the photogrammetric product division not only presented its first photoscanner, but was also drafting a program package for photogrammetric evaluation of digitised aerial images the results of which were not published until 1991 (chapter 12.3).

12.1 PHOTOSCAN

With the success of INDUSURF and the C 100 PLANICOMP in the German automotive industry since 1986 it became clear, that the automatic processing of whole digital images and stereomodels would soon be adapted for specific photogrammetric applications. Therefore Oberkochen began its first research into the digitising and recording of whole aerial photographs (FELLE 1986 & FAUST et al. 1986). During the successful cooperation with INTERGRAPH on the ZIP project it became obvious that Huntsville was also ready to launch the development of an image scanner. So both parties decided to conduct this project jointly too and to sell the resulting product through both INTERGRAPH and ZEISS. After jointly discussing and agreeing on the specification the scanner hardware with optics, mechanics and electronics was developed by ZEISS, and the computer hardware and the software with application functions and data management by INTERGRAPH.

As the result the PS 1 PHOTOSCAN was introduced at the Photogrammetric Week in 1989 (FAUST 1989) and delivered out of series production from mid 1990. In Fig. 12.1 the scanning unit is shown on the left in ZEISS colours, and the INTERSERVE workstation series 6000 from INTERGRAPH with a large graphical screen on the right.

Fig. 12.1: PHOTOSCAN PS 1 with INTERGRAPH workstation

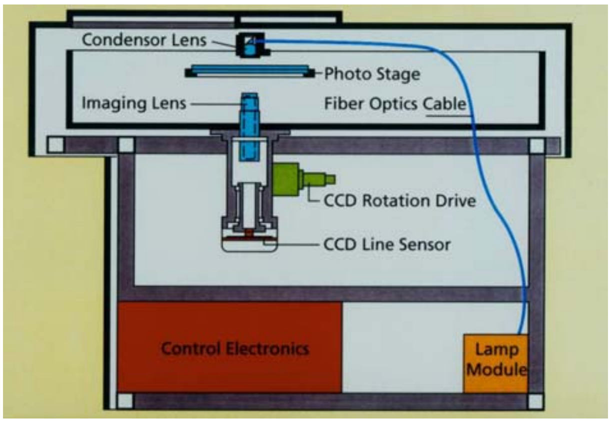


Fig. 12.2: PHOTOSCAN PS 1 design principle

For the photo carrier the well proven concept of an x,y-cross slide system as in the PLANICOMP was selected. For avoiding any heating effect by the illumination a fibre-optic light guide with a distant halogen lamp was selected. The imaging lens was distortion free, and a CCD line sensor with 2 048 pixels with 7.5 µm pixel size was used (Fig. 12.2). The line sensor could be rotated up to $\pm$10 gon by a servo drive, to enable scanning directly parallel to the image coordinates. By this patented principle (KRASTEL et al. 1989) a first resampling step due to the interior orientation could be avoided (Fig. 12.3). The 100 watts halogen lamp and a condenser with high aperture assured enough light to saturate the CCD sensor at the highest scanning speed of 30 mm/sec. A filter wheel with four positions for red, green, blue and clear, for white light, allowed sequential colour scanning (Fig. 12.4).

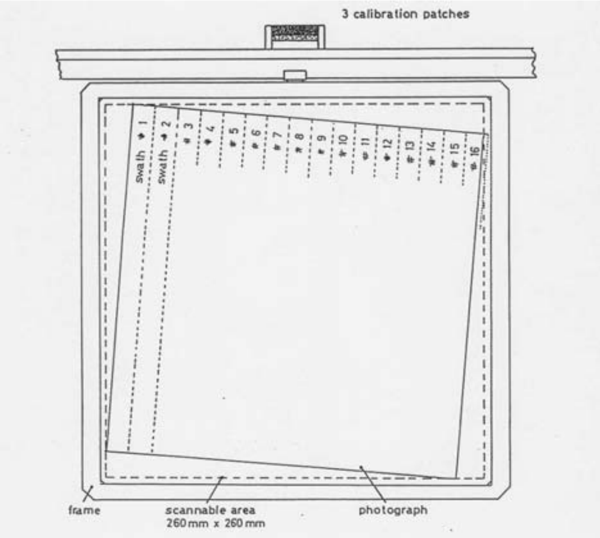


Fig. 12.3: PHOTOSCAN PS 1 scan pattern

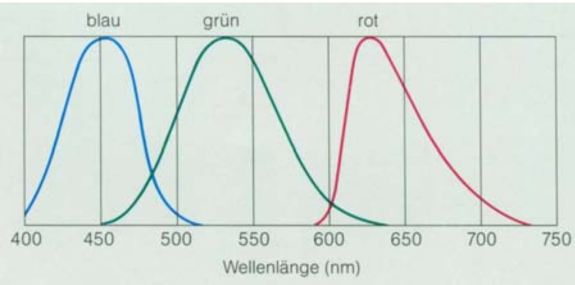


Fig. 12.4: Colour separation with PS 1

The main parameters of PS 1 PHOTOSCAN were:

- *Scan area: 260 mm x 260 mm,*
- *geometric resolution: 0.001 mm,*
- *geometric accuracy: $\sigma_{x'}$, $\sigma_{y'}$ = $\pm$ 0.002 mm,*
- *pixel size: 7.5, 15, 30, 60 and 120 µm,*
- *CCD sensor: 1 x 2048 pixel,*
- *scan width: 15.36 mm,*
- *scan direction selectable: $\pm$ 10 gon,*
- *radiometric resolution: 8 bit,*
- *colour scanning: sequential,*
- *filter wheel for e. g.: clear, red, green, blue,*
- *illumination: 100 W halogen lamp with condenser,*
- *scan speed: max. 30 mm/sec,*
- *data rate: max. 2 MPixel/sec.*

The basic software for the PS 1 PHOTOSCAN, developed by INTERGRAPH, supported the following functions:

- *Scanner adjustment and calibration,*
- *defining scan area and scan direction (interior orientation),*
- *image overview by quick scan,*
- *digitising of selected area with selected resolution,*
- *storage of scanned image data on mass storage device,*
- *display of scanned image data on screen,*
- *export of image data via network or data medium.*

The computer configuration for the PS 1 was the same as that usually being offered by INTERGRAPH for their common graphical workstations, always with the INTERGRAPH proprietary CLIPPER RISC processor and additional graphics processor. Between the prototype being presented and the first delivery of the PS 1 out of series production, less than one year later, the processor speed and the memory capacity grew by a factor of three and later by a factor of 10. In total 120 PHOTOSCAN PS 1 systems were manufactured by ZEISS.

12.2 SCAI

Based on experience with the PS 1 PHOTOSCAN Oberkochen developed a follow-up model (Fig. 12.5), which was presented in 1995 at the Photogrammetric Week as SCAI (SCanner with Autowinder Interface) (MEHLO 1995). This scanner with the optional Autowinder attachment (Fig. 12.6 and 12.7) was designed for fully automatic digitising of complete aerial films. Both SCAI and Autowinder were protected by patents and design (MEHLO et al. 1994 & KRASTEL et al. 1995). A special adjustment procedure was also patented (FAUST et al. 1992).

Fig. 12.5: SCAI prototype with computer terminal (1994)

Fig. 12.6:

SCAI photoscanner with rollfilm attachment

Fig. 12.7: SCAI rollfilm attachment (Autowinder)

The servo-driven film transport within the Autowinder could be as fast as 1 m/sec, which allowed fast access to selected individual images anywhere on the film. An electronic meter which measured film length enabled positioning as precise as 3 mm. During film transport the cover glass plate as well as the deflector rollers were lifted by motors to avoid scratches on the film.

During scanning the image was fixed to the image stage and the scan optics were moved, meander-like, below the stage. The optics were mounted on the secondary carriage (Fig. 12.8) which carried the fibre optics light guide for illumination, the distortion and aberration free imaging lens in the form of mirror optics, and the CCD module. The triple line sensor with colour filters red, green and blue enabled a one-pass colour scan. The diffuse illumination principle (Fig. 12.9) avoided scratches and dust on the film from disturbing the scanned pixels.

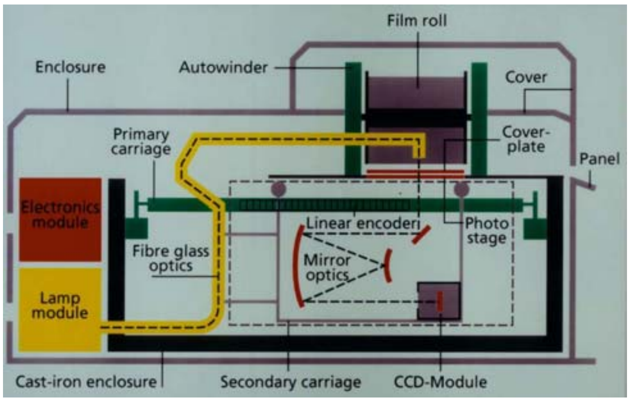


Fig. 12.8: SCAI design principle

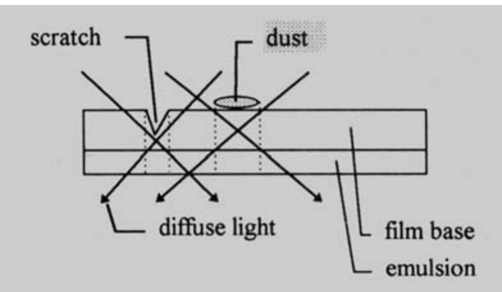


Fig. 12.9: SCAI diffuse illumination principle

The main parameters of the basic unit of SCAI were:

- *Scan area: 250 mm x 275 mm,*
- *geometric resolution: 0.001 mm,*
- *geometric accuracy: $\sigma_{x'}$, $\sigma_{y'}$ = $\pm$ 0.002 mm,*
- *pixel size: 7, 14, 28, 56, 112 and 224 µm,*
- *CCD sensor: 3 x 5 632 pixel,*
- *Scan width: 39,424 mm,*
- *radiometric resolution: 10 bit,*
- *colour scanning: parallel,*
- *illumination: 250 (later 150) W halogen lamp, diffuse,*
- *scan speed: max. 50 mm/sec,*
- *data rate: max. 4 MPixel/sec.*

The control unit was integrated into the scanner chassis and consisted of the motor electronics, the CCD electronics with the A/D conversion, the process control and the SCSI-2 interface for the connection to a graphics workstation for data transfer and user guidance.

Concurrently with the SCAI development ZEISS extended its photogrammetric digital image processing system PHODIS (see chapter 12.3), which was introduced a few years earlier, by the scan module PHODIS SC. In this way SCAI was integrated into the PHODIS work environment, which was implemented on a graphics computer from SILICON GRAPHICS (Fig. 12.10).

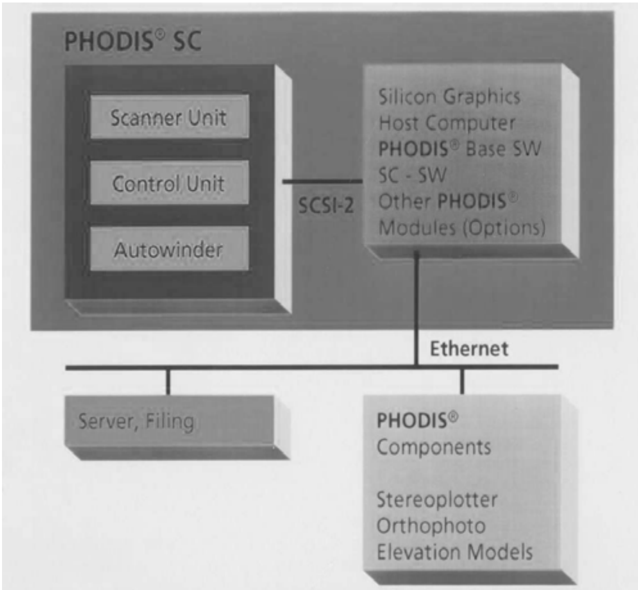


Fig. 12.10: PHODIS SC system configuation

PHODIS SC consisted of the following scan-related functions (ROTH 1996 & VOGELSANG 1997):

- *Image overview by quick scan with 224 µm resolution (about 1 min),*
- *input of geometric and radiometric scan parameters,*
- *input of destination file, data format and automatic post-processing steps,*
- *digitising of selected area with selected resolution (time about 8 min for scanning an aerial image with 14 µm),*

- *generation of image pyramid,*
- *automatic interior orientation,*
- *storage of scanned image data on mass storage device,*
- *Autowinder functions for film transport, image selection and positioning.*

Continuing the excellent cooperation so far (especially ZIP and PS 1) INTERGRAPH decided to obtain SCAI as an OEM product and to sell it as PHOTOSCAN TD (later under the names PHOTOSCAN 2000, 2001 and 2002) together with the INTERGRAPH TDZ 2000 workstation and their own AUTOSCAN software (Fig. 12.11).

Fig. 12.11: PHOTOSCAN TD (1996)

By the start of the ZEISS/INTERGRAPH joint venture Z/I IMAGING in 1999 more than 200 scanners based on the SCAI unit had been delivered and by the end of production in 2007 the total number rose to 320. Thereby making SCAI the most successful photogrammetric image scanner worldwide.

It is interesting that SCAI was extremely popular in the field of biology. For the molecular biologists it was the first satisfying way of digitising electron microscopic images on film without a loss in accuracy.

12.3 PHODIS

At the Photogrammetric Week in 1991 CARL ZEISS began to release information on the development of PHIPS, a "Photogrammetric Image Processing Systems" (MAYR 1991). The first aim was to produce orthophotos digitally with the intention of establishing a first application for aerial images digitised with the PS 1 PHOTOSCAN, and also to create an even more flexible tool to replace the powerful Z 2 ORTHOCOMP. In the following year the system was renamed PHODIS for "PHOtogrammetric Digital Image Processing System" (Fig. 12.12). Further photogrammetric applications were progressively added from 1993 onwards.

Fig. 12.12: PHODIS logo

PHODIS was designed for powerful computers with the UNIX operating system and first implemented on graphics workstations from SILICON GRAPHICS. Software, data formats and network compatibility were developed almost completely in accordance with the common standards.

Right from the beginning a basic function for stereo-measurements with respect to quality control was implemented by stereoviewing with special spectacles which used liquid crystal shutters.

For furthering the automation of orthophoto production an optional add-on named TOPOSURF for automatic generation of digital terrains models (DHM) was described with the introduction of PHIPS in 1991. TOPOSURF was more or less identical with MATCH-T from INPHO GmbH, Stuttgart, which resulted from research on feature-based matching at Stuttgart University (KRZYSTEK 1991) and from earlier program development for automatic measurement of close range stereopairs which was marketed by ZEISS as INDUSURF for the C 100 PLANICOMP (see chapter 11.3).

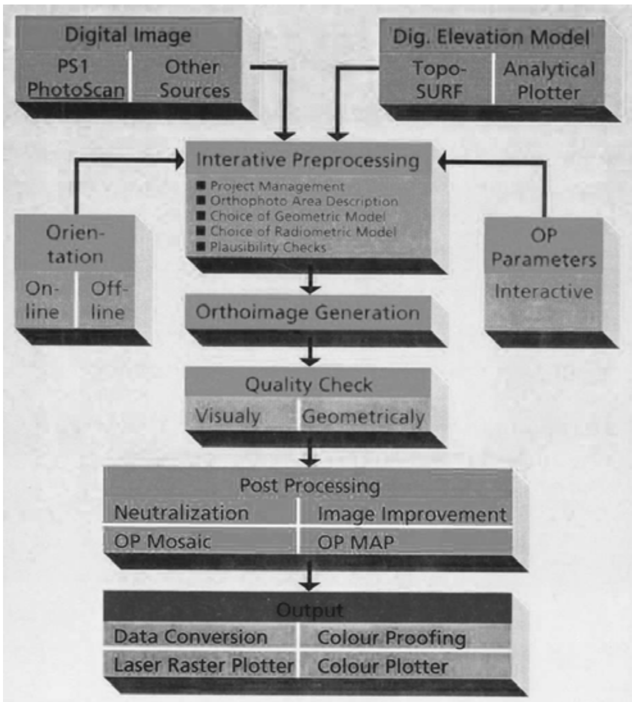


Fig. 12.13: PHODIS OP work flow

Fig. 12.13 shows the work flow of digital orthophoto production with PHODIS, since 1992 named PHODIS OP (MAYR 1992). The photo to be differentially rectified could be scanned in the PS 1 or SCAI photo scanner or be imported from other systems. The DHM could be generated automatically by TOPOSURF within PHODIS or be measured in analytical stereoplotters. It could also be taken from other sources. The orientation data could either be determined at the workstation or, again, imported from other sources. For exchange within the ZEISS family (e. g. PLANICOMP with PHOCUS or P-CAP) the compatible PHOREX data format was created (KRESSE 1993).

After entering additional project parameters the automatic orthorectification process was started which was then followed by a quality check, post-processing (e. g. mosaicking, map sheet preparation) and output. From 1996 the ORTHOVISTA program was offered as an option to obtain smooth harmonisation at the mosaick boundaries with regard to brightness and colour. This software was developed by STELLACORE, Parker, CO /USA. In 1993 the rudimentary possibility for stereoscopic measurements within PHODIS OP was extended to a full-scale digital stereoplotter and presented as PHODIS ST (MAYR 1993). Due to the fact that the resolution of graphics terminals is much lower than binocular viewing in stereoplotters the monitor for stereoviewing was exclusively used for displaying the stereomodel. A second monitor was added to communicate with the user (Fig. 12.14).

Fig. 12.14: PHODIS ST stereo workstation

The main control element of the PHODIS ST workstation was the P-Mouse, which was similar to, and derived from, the P-Cursor of the P-series PLANICOMP. One difference was the track-ball for detecting the horizontal movement as in the early computer mouses thus avoiding the need for an off-the-shelf digitising tablet. Two additional buttons allowed the operator to change quickly the assignment of the other function buttons (MENKE 1994). The P-Mouse and the stereo spectacles with the liquid crystal shutter are shown in Fig. 12.15.

Fig. 12.15: PHODIS ST with P-Cursor and stereo spectacles

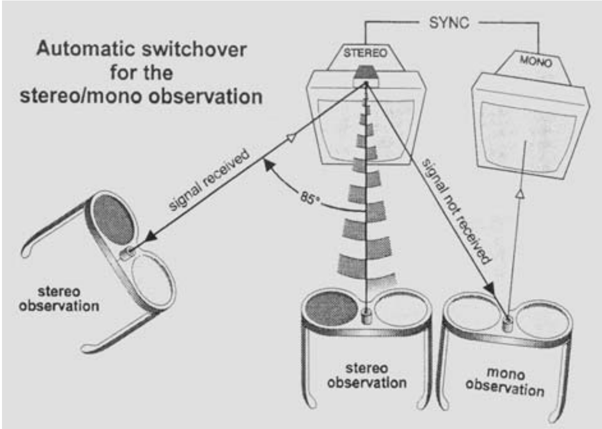


Fig. 12.16: PHODIS - functional principle of stereoviewing

Fig. 12.16 explains the principle of synchronisation and control of the off-the-shelf stereo spectacles. As a unique and patented feature the shutter function was interrupted when not looking to the stereo screen (DÖRSTEL et al. 1993). This avoided the alternating dimming effect by the liquid crystal shutter, when looking to the second monitor or elsewhere. A second registered invention relating to the use of two adjacent monitors with different display modes was no longer applied (Mehlo 1994).

Due to the limited speed of processors and interfaces at the beginning the display of the stereomodel on the monitor followed the concept of "image fix - floating mark moving". This required a larger image update when approaching the border of the screen. This principle was kept for the inexpensive PHODIS ST 30 version when increased computer performance permitted the more comfortable method "Floating mark fix - image moving" to be used in the PHODIS ST 10 version. Photogrammetric operators were acquainted with the latter through the use of analogue and analytical stereoplotters.

The general configuration of the PHODIS ST workstation is shown in Fig. 12.17. Besides the described hardware the software with basic functions, orientation and application programs mainly defines the performance of this digital stereoplotter from ZEISS.

The basic software package of PHODIS comprised the UNIX operating system with project and control point management, storage and conversion of measured data, image processing procedures, help functions and orientation programs. Interior and relative orientation of the stereo pair was executed by automatic fiducial recognition and feature based matching of the orientation points. Basic application programs from ZEISS were inter alia PHOCUS and CADMAP, but due to the documented gateway and data format other CAD and GIS-systems such as AUTOCAD and MICROSTATION could also be adapted (DÖRSTEL et al. 1994).

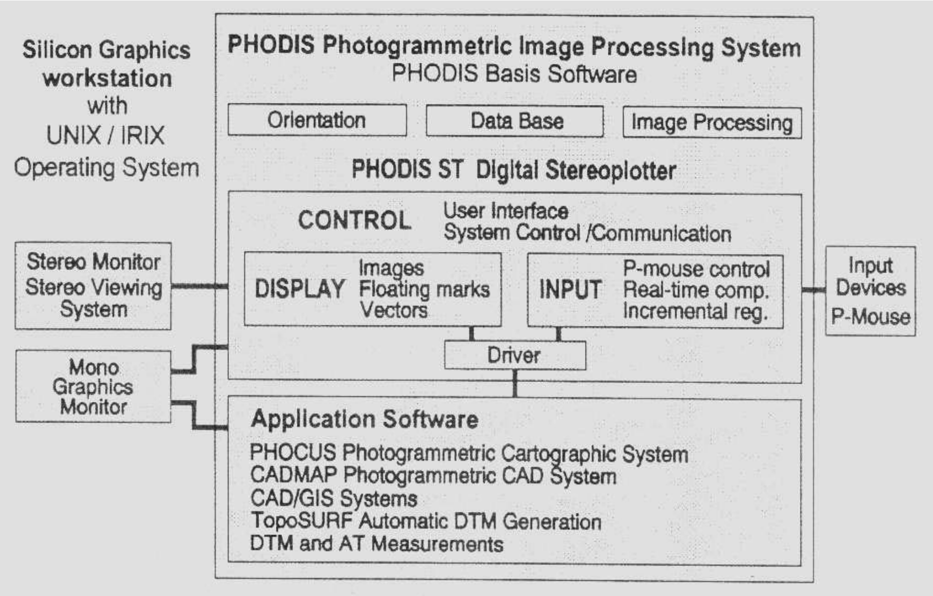


Fig. 12.17: PHODIS ST - configuration of stereo workstation

In 1995 the new photoscanner SCAI was integrated into the digital photogrammetry world of ZEISS by the PHODIS SC software as already mentioned in chapter 12.2. In 1998 this module was the first, and remained the only, PHODIS application to be ported into the WINDOWS NT world.

Finally, at the Photogrammetric Week in 1995 the automatic aerotriangulation package was added, thus completing PHODIS (Mayr 1995). PHODIS AT was designed for handling very large projects with a flexible arrangement of flight paths and photographs, and for a robust automatic determination of tie points. The workflow consisted of block preparation, measurement, adjustment and postprocessing:

- *Block preparation by allocation of digitised images, camera data, photoflight data and control points, by generation of a block overview and dividing into sub-blocks, by consistency check, by bulding image pyramids, and by automatic or manual interior orientation (if not previously done),*
- *block measurement by automatic block building and search for conjugated points in all images, by program-controlled presentation of weak areas, where the operator had to add tie points through precise pointing only in one photograph (beause the system then would automatically complete the fine measurement of all connections),*
- *block adjustment with one of the off-the-shelf programs such as PAT B, BINGO, BLUH or other bundle block programs,*
- *block postprocessing with presentation of results, inspection and manual re-measurement of blunders if necessary, with computation of image orientation data, point coordinates and orientation parameters for stereoplotters.*

Initially PHODIS was designed for central perspective camera geometry but was later expanded to handle alternative geometry such as SPOT and the 3-line-scanners MOMS-02, HRSC and WAOSS (DÖRSTEL et al. 1996 & BRAUN 1997).

A simplified version of PHODIS ST was PHODIS M (also labelled PHODIS MO and PHODIS PM in the beginning) for so-called monoplotting. Monoplotting is the measurement of point and vector data on a single image such as a digital ortho image (WILLKOMM et al. 1995).

In 1995 the DHM module within PHODIS OP became the independent product PHODIS TS for the generation of digital terrain models (DÖRSTEL 1995). Its workflow consisted of forming stereomodels, data preparation, automatic measurement with TOPOSURF, checking of results, editing and output (Fig. 12.18).

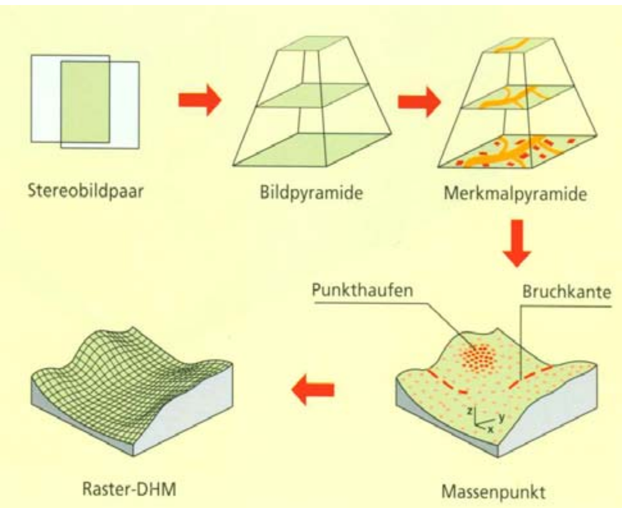


Fig. 12.18: PHODIS TS work flow

The main part of an automatic aerotriangulation is the automatic determination and measurement of tie points. PHODIS AT was based on research of the Munich Technical University on automatic relative orientation (TANG et al. 1994) and then programmed for ZEISS by LIANG TANG, Munich. Based on the very positive experience with PHODIS AT (BRAUN et al. 1996 & HARTFIEL 1997) this software was still maintained and offered under the aegis of INTERGRAPH after 1998 (DÖRSTEL 1999 & DÖRSTEL et al. 2001).

So in 1995 ZEISS had completed PHODIS to a full-scale system for digital photogrammetry (MAYR et al. 1996):

- ***PHODIS Basis**, basic program with data management, interfaces etc. as well as automatic interior and relative orientation of images,*
- ***PHODIS SC**, automatic scanning of single images and complete aerial films,*
- ***PHODIS AT**, automatic aerotriangulation,*
- ***PHODIS ST**, digital stereoplotter with various automatic measurement functions,*
- ***PHODIS TS**, automatic generation of digital height models,*
- ***PHODIS OP**, automatic rectification and generation of orthophotos and orthophotomaps,*
- ***PHODIS M**, interactive workstation for monoplotting.*

This listing documents very well the status and degree of the extensive automation of photogrammetry at the end of the 20th century, especially for the stupefying and boring actions of the operators (BRAUN 1997 & MAYR 1997). This enabled them to concentrate on the more motivating interpretative tasks and decision making.

By the start of the ZEISS/INTERGRAPH joint venture, Z/I IMAGING, in 1999 more than 200 basic installations of PHODIS were being used in practice while the number of PHODIS seats was much larger. For some time Z/I continued to maintain and offer PHODIS.

13. Terrestrial photogrammetry

Terrestrial applications were the first aim, when ZEISS began with photogrammetry in Jena in 1901: PULFRICH developed his first stereocomparator, and 5 years later the stereometer camera with the stereometer as allocated comparator. In 1934 ZEISS-AEROTOPOGRAPH in Jena presented the stereometric double cameras DK 40 and DK 120 with 55 mm TESSAR normal angle lenses for a film and plate sizes of 6 cm x 9 cm. In 1955 Oberkochen decided to develop a similar but new stereometric twin camera and a dedicated steroplotter, in close contact with German police departments. One of the primary goals was easy handling by non-photogrammetrists in the police departments for investigating traffic accidents, also at night and in bad weather.

13.1 Close range metric cameras

A first report on the experience with a prototype of the ZEISS stereometric camera was presented in 1959 at the 2nd International Congress of the Traffic Police in Essen. But it was September 1960 at the International Congress for Photogrammetry in London before the SMK 120 wide angle stereometric camera (Fig. 13.1) was introduced (HOTHMER 1960), together with the TERRAGRAPH stereoplotter (see chapter 13.2), and described in detail in the "BILDMESSUNG UND LUFTBILDWESEN" periodical (MEIER 1960b).

The SMK 40 was also announced in 1960 but was not exhibited until 1962. The fixed base length of 40 cm instead of 120 cm was more appropriate for documenting crime scenes and for cattle breeding studies, whereas the SMK 120 was not only ideal for photographing traffic accidents but also for architecture and geology (BERLING 1969a & 1969b).

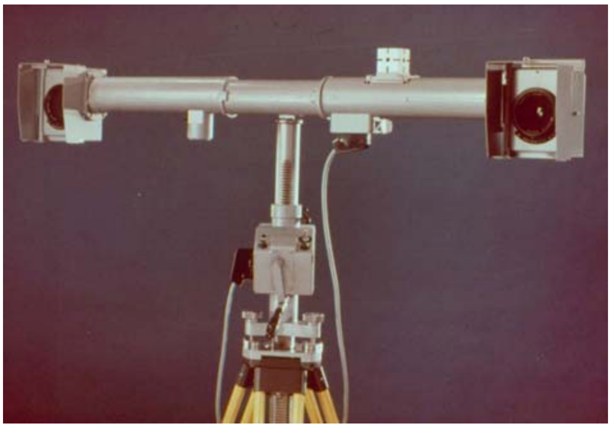


Fig. 13.1: SMK 120 stereometric camera (1960)

The main parameters of SMK 120 and SMK 40 were:

- *Stereo base: 120 cm or 40 cm,*
- *plate format: 9 cm x 12 cm, in off-the-shelf exchangeable cassettes (auxiliary data at image border),*
- *image format: 8 cm x 10 cm (prototype 8 cm x 8 cm),*
- *lens: TOPOGON with 60 mm focal length and fixed aperture 1 : 11,*
- *shutters: COMPUR 1/400 sec - 1 sec,*
- *object distance: ca. 6 m to 25 m (SMK 120) or ca. 2.5 m to 10 m (SMK 40).*

Especially for applications in architecture and monument conservation (BRUCKLACHER 1972) a wide range of accessories was available, e. g. to support oblique photography (± 30, ± 70, ± 100 gon), to allow a vertical base, or to use a synchronised electronic flash unit for indoor tasks (Fig. 13.2).

In 1984 a texture projector was built as an accessory for the SMK 40 (Fig. 13.3), which was used for photographing car bodies for evaluation with the INDUSURF package on the C 100 PLANICOMP (see chapter 11.3).

Fig. 13.2: SMK 120 and SMK 40 with accessories

Fig. 13.3: SMK 40 with texture projector (1984)

At the premiere of the SMK 120 its metric camera was also presented as a single camera (TMK) for user-defined, larger base lengths, e. g. >25 m for large objects. The technical data of the TMK 6 terrestrial metric camera were the same as for the SMK, including the TOPOGON wide angle lens with 60 mm focal length. For large-scale applications additional sighting targets for orientation and tilting adapters for compensating height differences of the two photo stations were available (Fig. 13.4). Typical applications were the collection of tectonic data or other tasks in geology (ADLER et al. 1970) and the construction of barrages (BRUCKLACHER 1967a).

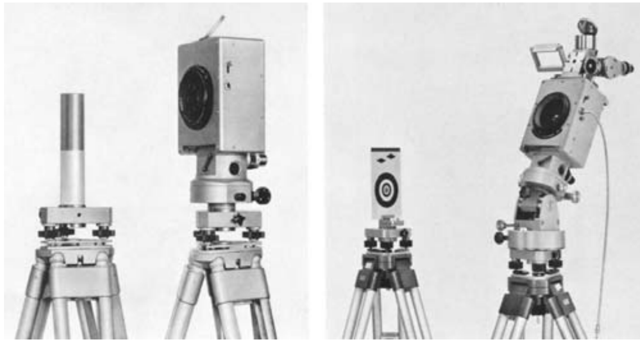


Fig. 13.4: TMK 6 with accessories

At the Congress in Ottawa in 1972 the TMK 12 with the STEREOTAR 8/120 lens and lens stops 1 : 8, 1 : 11 and 1 : 16 was introduced with otherwise identical technical data to the TMK 6. This version with a longer focal length was to allow an image scale larger than 1 : 10 with a larger taking distance which was often necessary for certain work. The larger scale meant that the instrument operator could draw smooth lines more easily (BRUCKLACHER 1972).

During the production period between 1962 and the mid 1980s about 100 TMK (80 % as TMK 6) and 140 SMK (3/4 as SMK 120) were sold. At this time almost all manufacturers of photogrammetric instruments stopped production of metric terrestrial cameras because analytical stereoplotters enabled easy and sufficient accuracy enhancement using photographs taken with cheaper off-the-shelf professional cameras from companies such as HASSELBLAD or ROLLEI.

13.2 TERRAGRAPH

Just as ZEISS in Jena had offered the "Kleinautograph" as a stereoplotter dedicated to the pre-war terrestrial stereometric camera, Oberkochen also developed a new stereoplotter especially for use with the SMK 120 and SMK 40 stereometric cameras. Again the proven concept of the stereoautograph from V. OREL in 1911 was selected and constrained to the normal case of parallel optical axes perpendicular to the stereobase (MEIER 1960).

This stereoplotter for terrestrial photogrammetry from CARL ZEISS, Oberkochen was named the TERRAGRAPH. This instrument was introduced at the London Congress in 1960, together with the stereometric camera SMK 120. Between 1963 and 1984 a total of 35 units were delivered.

The typical shape of an inclined desk originated from the tilting of the mechanical ruler system (Fig. 13.5). Fig. 13.6 shows on the left the arrangement of the mechanical rulers and on the right the principle of performing the intersection. The carriers for the photo plates were connected to two straight rulers forming the intersection in planimetry where the pivotal points represented the projection centers.

Fig. 13.5: TERRAGRAPH (1960)

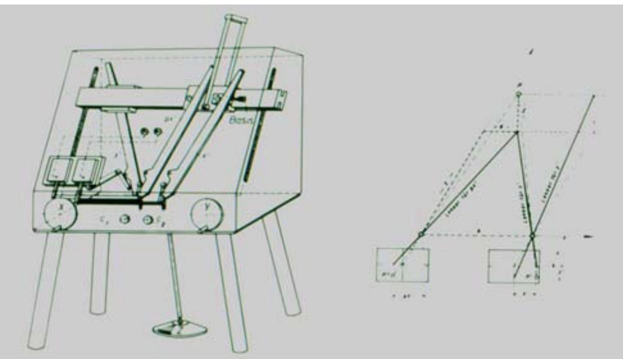


Fig. 13.6: TERRAGRAPH design principle

The plotting scale was determined by the relationship of the distance from the pivot of the levers to the image point, which represented the calibrated focal length, and to the pencil which represented the projection distance. With both handwheels the rulers were moved and caused a shift of the photo carriages in x and p_x and a shift of the drawing pen in x and y. A change in height with the footdisk (z) caused a shift of the viewing optics against the images via a height ruler, with the binoculars not being moved. The plotting surface at the inclined front of the TERRAGRAPH was covered with a magnetic rubber sheet (later used in the D 2 PLANIMAT and in the EZ 2 tracing table). Thus the operator had a direct view of the plotting sheet which was fixed by flexible steel rulers.

The main parameters of the TERRAGRAPH were:

- *Image format: 9 cm x 12 cm plate size (upright format), usable 8 cm x 10 cm,*
- *focal length: 52 mm - 67 mm,*
- *model base: 0 mm - 50 mm,*
- *viewing magnification: 6x,*
- *field of view: 15 mm diameter,*
- *floating mark diameter: 0.1 mm,*
- *model area: x = $\pm$ 250 mm,*
  y = 60 mm - 610 mm,
- *size of plotting area: 50 cm x 60 cm,*
- *z-parallax range: $\pm$ 4 mm for compensating a potential height difference between photo positions,*
- *height scales: 1 : 10, 1 : 15, 1 : 20, 1 : 25, 1 : 30,*
  1 : 40, 1 : 50, 1 : 75.

The setting of the focal length and the height reading were carried out at counters placed between the handwheels. Photographs with a focal length other than approximately 60 mm had to be evaluated in an affine mode when using the TERRAGRAPH. e. g. for the TMK 12 the model scale was compressed by a factor of 2. When plotting on the EZ 2 external tracing table, which could be connected from 1964, this compression was compensated by a gear ratio of 2 : 1.

Also since 1964 the TERRAGRAPH could be equipped with the optional NR tilting device for the evaluation of oblique photographs with $\pm$ 30 gon or $\pm$ 70 gon. Fig. 13.7 shows (on the left) the NR mechanical computer, which was a gear box at the mechanical outlet for the EZ 2 connection. On the right the electrical connection for the EZ 3 tracing table is shown. In 1972 the UNR universal tilt computer was added (Fig. 13.8).

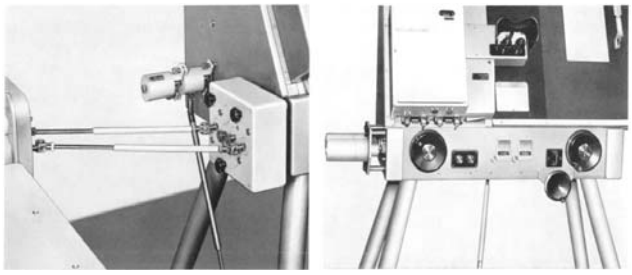


Fig. 13.7: NR tilt computer for connection to EZ 2 tracing table (left) and synchro-connection to EZ 3 (right)

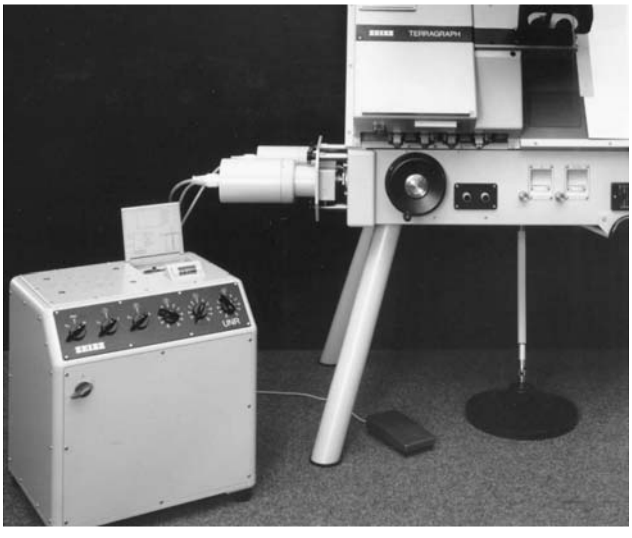


Fig. 13.8: UNR universal tilt computer at the TERRAGRAPH

With the UNR the plotting plane on an EZ 2, EZ 3 or EZ 4 external tracing table could be tilted by any user defined angle ω, following the formula:

$$x = x',$$
$$y = y' \cdot \cos\omega - z' \cdot \sin\omega,$$
$$z = z' \cdot \cos\omega + y' \cdot \sin\omega.$$

The UNR could not only be connected to the TERRAGRAPH by synchro motors but also to the PLANIMAT, for which already in 1969, a terrestrial attachment in the form of special projection center arms was developed (see Fig. 10.22). This allowed photographs from cameras with very short focal lengths to be plotted.

13.3 Other

A small special rectifier shall be mentioned here, which was solely dedicated to terrestrial photogammetry, the KEG 30 "Kleinentzerrungsgerät" (Fig. 13.9). It was developed in 1970 for rectifying 30 gon oblique photographs, e. g. of building façades. Photographs with a format of 9 cm x 12 cm exposed on photo plates 13 cm x 18 cm, could then be enlarged or fine rectified e. g. with the SEG 5 rectifier (BRUCKLACHER 1972). However, interest in the KEG 30 was low.

Fig. 13.9: KEG 30 small rectifier for 30 gon glass plates (1970)

It was not only for ZEISS Oberkochen that equipment for terrestrial photogrammetry did not obtain much economic importance. At its zenith in the early 1970s its value share in potogrammetric sales of ZEISS hardly reached 5 % p. a. and its overall share in all sales after World War II was less than 1 %.

14. Special instruments

This chapter describes the activities of the development team for photogrammetic products in the 1960s and 1970s, which applied its photogrammetric knowledge of aerial cameras and stereoplotting for use in the non-photogrammetric world. These on the one hand were metric cameras for satellite geodesy, and on the other hand stereo evaluation of x-ray photographs and stereo quality checks of industrial components. And lastly, a trial from the end of the 1970s has to be mentioned which used newly gained expertise in software engineering for creating a program package for the processing of geodetic measurements. After these mostly unsuccessful "excursions" Oberkochen concentrated on photogrammetry and reconnaissance.

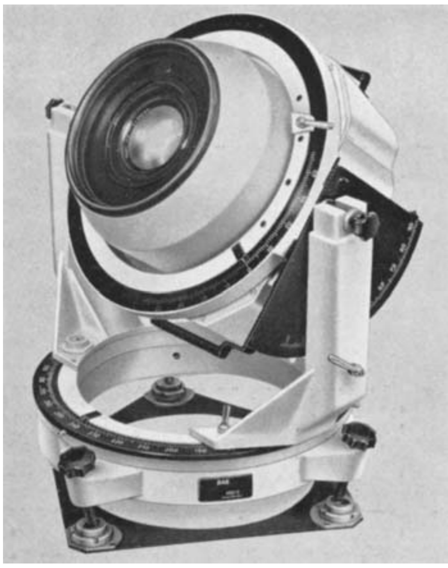


Fig. 14.1: BMK 21/18 Ballistic Camera (1958)

14.1 BMK satellite cameras

With the first earth satellites in the 1950s the interest in the geodetic-physical mensuration of the earth arose, for better determination and analysis of satellite tracks. One of the procedures for track measurements was satellite geodesy with special cameras (e. g. the BAKER-NUNN camera and the proven BC 4 from WILD). CARL ZEISS started to design a high resolution camera, looking to the sky and not the ground, using a RMK 21/18, which had come out of series production in 1953. In 1958 several BMK 21/18 ballistic cameras in an azimuthal mount (Fig. 14.1) were manufactured for an US systems house, which then added the electronics for the shutter control and the necessary precise time measurement.

In 1964 new lenses for the RMK were designed with the A-characteristics and in principle these could also be used for the BMK. In addition to the 30 cm TOPAR and the 60 cm TELIKON in 1962 a TOPAR 46 had been developed. By using a parallactic mount from the ZEISS astronomic department (where it was being used for the COUDÉ refractor) the BMK could now be oriented in relation to the equator and tracked synchronously to the earth rotation if required (AHREND 1964a). The resulting BMK A 30/23 in a parallactic mount was shown at the Lisbon Congress in 1964 (Fig. 14.2).

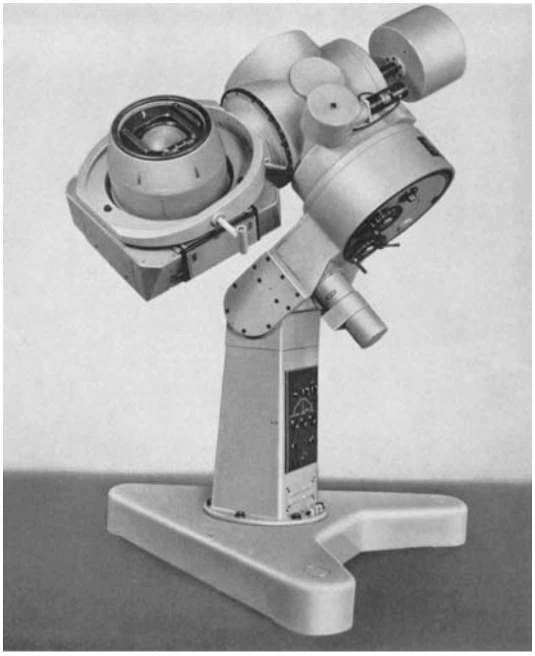


Fig. 14.2: BMK 30/23 (1964)

Satellites in the 1960s which were usable for dynamic satellite geodesy were not reflecting much light. Thus the interest in ballistic cameras with large aperture and long focal length arose and Oberkochen developed the BMK 46/18/1:2 with the extreme aperture of 1 : 2, which was delivered to Berlin Technical University in 1969, to Bonn University in 1971 and to Tainan University in Taiwan in 1972. The BMK 46/18 was equipped with the ASTRO-TOPAR 2/460 lens with very high resolution and low distortion for the 18 cm x 18 cm image format and a field angle of 31°. The A-characteristics included the 694 nm wave length of the rubin laser which was used for illuminating the satellites for specific tasks (SCHWEBEL 1970).

Fig. 14.3 shows the BMK 46/18 in a parallactic mount for sidereal tracking and the electronics cabinet with the ZMS 2 time recording device with a resolution of 0,02 msec. An automatic plate changer with a capacity of 6 plates and an intermitting shutter for interrupting the satellite tracks (Fig. 14.4) were special features.

Soon after delivery of these three BMK 46/18 a further increased focal length was requested, and in 1972 at the Ottawa Congress the BMK 75/18/1:2.5 with the ASTRO-TOPAR 2.5/750 lens and a field angle of 19° was announced (Fig. 14.5). At the Photogrammetric Week in 1973 the head of the electronics development for photogammetry, KARL FELLE, gave a short report on this new camera. The BMK 75/18 was delivered in 1975 to the "Sonderforschungsbereich Satellitengeodäsie" at the Munich Technical University to be installed at the geodetic observatory in Wettzell in Bavaria, and to Graz Technical University in Austria. No more BMK were developed and manufactured.

Fig. 14.3: BMK 46/18 with control cabinet (1969)

Fig. 14.4: BMK photograph of a satellite passage

Fig. 14.5: BMK 75/18 with ZMS 3 control unit (1972)

Fig. 14.6 shows the electrical design of the BMK 46/18 and BMK 75/18.

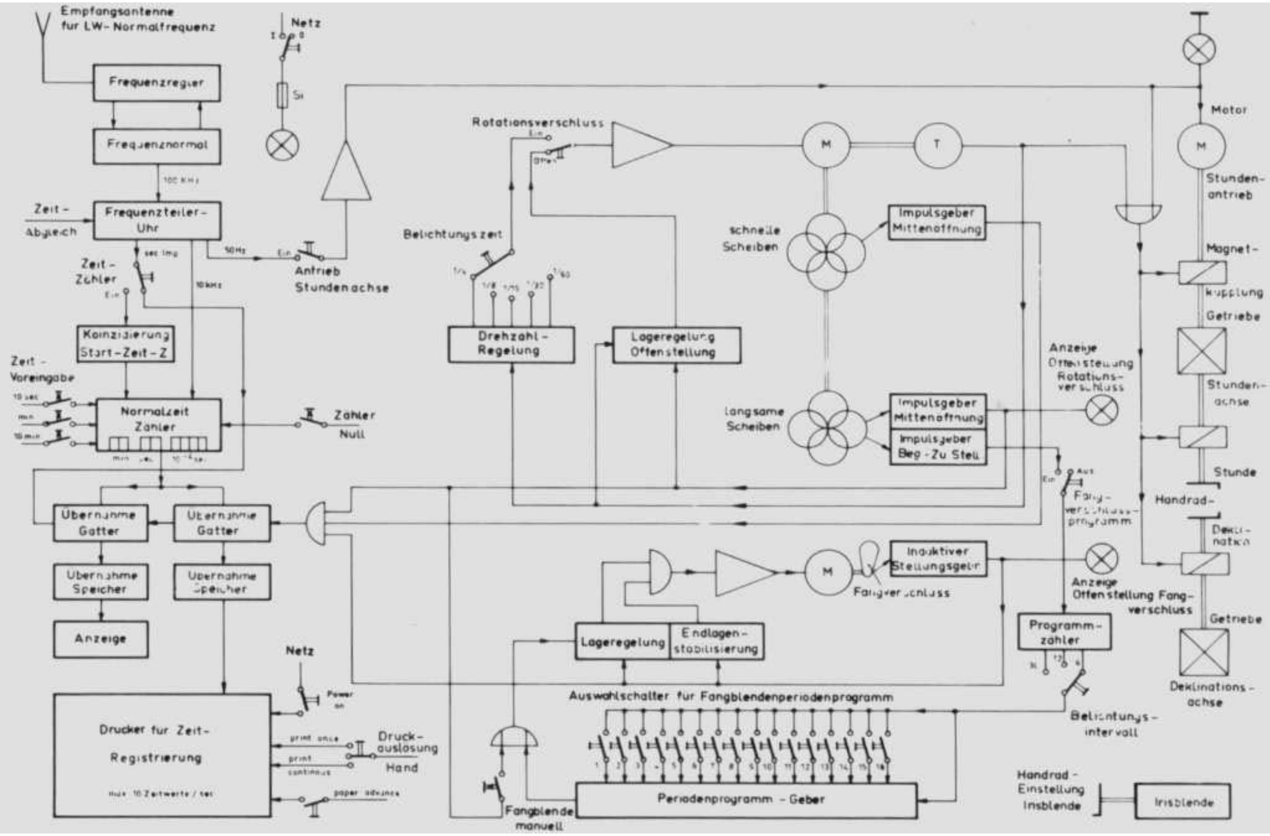


Fig. 14.6: Electrical design of the BMK 46/18 and BMK 75/18

14.2 StR x-ray stereocomparator

In the 1960s the RWTH Aachen Technical University did some research into stereoplotting with x-ray photographs. In 1968 the RWTH was succesful in convincing CARL ZEISS in Oberkochen to build such a stereoplotter. Back in 1917 Pulfrich had developed a "Raumbildmessgerät" for stereoscopic x-ray images (Fig. 14.7). Having engaged professor H. GREUEL, head of "Universitäts-frauenklinik Düsseldorf", as a consultant with experience in measuring x-ray images first design studies started. The concept after DEVILLE (Fig. 14.8), proposed by the Aachen group, soon emerged as unhandy and inaccurate.

Based on the concept of the STEREOPRET, produced in series for many years, the comparator principle was selected and introduced in 1971 at the Photogammetric Week as the StR "Stereo-Röntgenkomparator" (MEIER 1971 & 1973a). The basic instrument was designed for an image format of 40 cm x 40 cm and prepared to be offered in thee different configurations. The basic viewer was a large format stereoscope with either 1x or 3x viewing magnification (for viewing by two people from both sides), 3x required enlarging binoculars. This version was named StR 1.

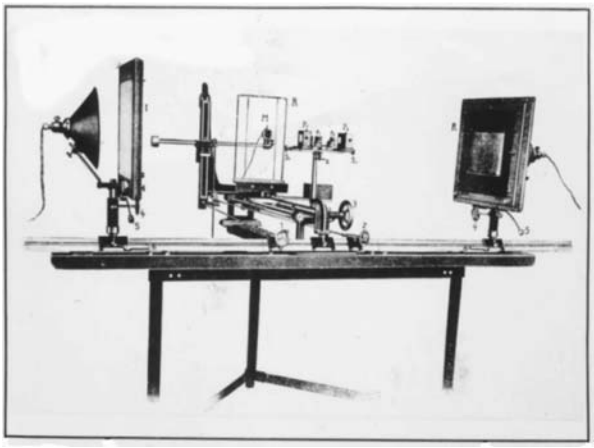


Fig. 14.7: X-ray stereoplotter by PULFRICH (1918)

Fig. 14.8: X-ray stereo-comparator after DEVILLE (functional model)

By adding floating mark projectors with adjustable brightness, as well as scales and nonius, the image coordinates x_1, y_1 and the parallax p_x could be read with 0.1 mm resolution for manually calculating distances, angles or other geometric values (StR 2). With incremental encoders in the StR 3 version these values were counted in an electronic unit and transferred to a connected desktop computer (Fig. 14.9).

Fig. 14.9: StR 3 x-ray stereocomparator from Zeiss (1971)

For this connetion to the HP 9800 (later HP 9810) desktop computer a simple electronic device for counting encoder increments, as well as for displaying and (upon footswitch activation) transmitting coordinates, was created. This later became the Direc 1 unit (see chapter 9.1). With simple calculations distances, angles or volume contents could then be derived from these measurements of relative coordinates. As basic parameters only the distance between the film and the focus of the x-ray tube and the tube shift (stereo base) had to be entered before measurement. In contrast to usual photogrammetric images here the object is located in the image space, that is between the projection center and the image plane, close to the x-ray film.

In spite of the successful design and configuration of the StR 3, which was quite understandable even for medical doctors, and although other parties such as Göttingen University published similar developments at the same time, stereophotogrammetry did not achieve a breakthrough in x-ray diagnostics. It therefore experienced the same fate as the trials before World War II. The surgeons apparently prefer to inform and orient themselves directly at the human body by using the scalpel. Between 1972 and 1979 only 18 StR units were sold.

14.3 Vitest visual inspection device

The development in 1976 of Vitest for visual inspection (Fig. 14.10) was a disappointment, too. Stereoscopic viewing generates a spatial impression, a virtual 3D-model, and is very sensitive to a local image aberration in one of the two images. This effect can be used to detect differences between the images of objects, which should look identical. Therefore this principle is very well suited to compare a produced flat component such as a printed circuit board with a master for deviations. Instead of stereoviewing the quick toggling between the alternating binocular viewing of master and proband would show a deviation by flickering.

Vitest, for which the design was registered and protected (Seeh 1975), used zoom optics (selectable between 3x and 17x) and a colour camera to alternate the display between master and proband on a monitor. After positioning the objects on the stage and equalising the illumination, the stage would be moved sensitively to search for possible flickering.

This project was initiated by Siemens, but between 1979 and 1983 only 15 instruments were delivered.

Fig. 14.10: Vitest visual inspection device (1976)

14.4 Geos-1

During the 1970s the photogrammetric development laboratory in Oberkochen accumulated much expertise in computer programming. Based on this, the Geos-1 "Geodätische Auswerte- und Kartiersystem" was developed and introduced in May 1980, to extend the application of the DZ 7 digital tracing table (see chapter 10.6). As a tool box for the processing and output of geodetic surveying measurements it was first presented at a seminar "Automatisierte Verfahren in der Vermessungstechnik" at the Esslingen Technical Academy, and a few months later at the "Geodätentag" in Wiesbaden (Schwebel et al. 1980).

GEOS-1 especially supported the editing and processing of total station measurements (e. g. of ELTA 2 from CARL ZEISS, Oberkochen) and a wide range of software functions for the HP 9845 B desktop computer and the DZ 7 digital tracing table from ZEISS (Fig. 14.11). For the bi-directional exchange of data between the total stations and the computer the MEM solid state memory of the field instruments was entered into the DAC reading station (in Fig. 14.11 left of the computer). The GEOS software was written in the BASIC programming language, and the program interface was documented to allow individual functions to be added.

Fig. 14.11: GEOS-1 geodetic evaluation and mapping system (1980)

The main program functions of GEOS-1 were:

- *Comprehensive and comfortable program package GAP for geodetic computations,*
- *TANA program package for automatic evaluation of large-scale total station measurements by adjustment in planimetry and height (developed by LOTHAR GRÜNDIG, Stuttgart University),*
- *DACA project related data base with fast access, for processing of mapping data,*
- *MAP program for geodetic mapping.*

This development was sponsored by the German Federal Ministry for Research and Technology between August 1978 and June 1981 (BÖTTINGER et al. 1981). GEOS-1 was intended for managing the data flow between field and final result especially in smaller surveying offices without large computer systems. Because it was not aimed at the photogrammetric market, it shall not be described here in more detail. Also further development, and marketing, was soon handed over in order to restore development capacity for the department's own photogrammetric projects.

15. Remote sensing & reconnaissance

With the appearance of dirigible airships and aeroplanes CARL ZEISS in Jena in 1909 started to build its first balloon camera which was soon followed by improved versions. Hand held aerial cameras with focal lengths up to 120 cm were regularly used for reconnaissance during World War I. Parallel to the development of the first RMK metric aerial survey cameras around 1920 more cameras for reconnaissance and interpretation tasks were designed together with terrestrial tele-cameras on a tripod with up to 3oo cm focal length. The HK 19 hand held camera from 1931 with an image format of 13 cm x 18 cm could be used with a film magazine or a cassette with exchangeable plates. A vertical mount was also available. Thousands of this camera were produced for use as reconnaissance cameras in World War II. During this time, together with the ZEISS-IKON subsidiary in Dresden, the HKS hand held camera was created. Furthermore the RMK S 6/7 "Klein-Reihenbildner" and the Rb 7/18 "Reihenbildner" with a PLEON super-wide angle lens were developed in 1941.

So CARL ZEISS, Oberkochen could look back on a long standing company tradition when in 1965 it started the development of cameras for reconnaissance. Since 1961 Oberkochen had become acquainted with the post-war requirements for this task through a contract for maintaining reconnaissance cameras of the American FAIRCHILD company. Having completed the RMK A family in 1967, with the new super-wide angle camera, a competent camera development team was ready to go.

Although later the reconnaissance related activities were concentrated in a separate laboratory and department, but always in the same business unit, due to the large thematic and personal overlap with the photogrammetric work in Oberkochen the resulting products shall be included in this documentation. While the reconnaissance cameras were very successful the few attempts to derive sensors for civilian remote sensing were a flop (chapter 15.3).

15.1 KRb / TRb reconnaissance cameras

Whereas in the early days of reconnaissance only long distance imaging with long focal lengths was required, with fast jet planes there was also a requirement for wide angle cameras capable of covering a wide range across the flight path on low flying missions. At first panoramic cameras were built in the USA with rotating mirrors, which created a perspectively and dynamically distorted image. When CHICAGO AERIAL INDUSTRIES in the USA offered the KA-63A reconnaissance camera with several lenses in the early 1960s, CARL ZEISS

Oberkochen also proposed a concept with an array of divergent looking lenses with equal focal length. The lenses formed an overall field angle of 143° across the flight path, thus fulfilling the requirement of covering 6 times the flying height across the flight path (Fig 15.1).

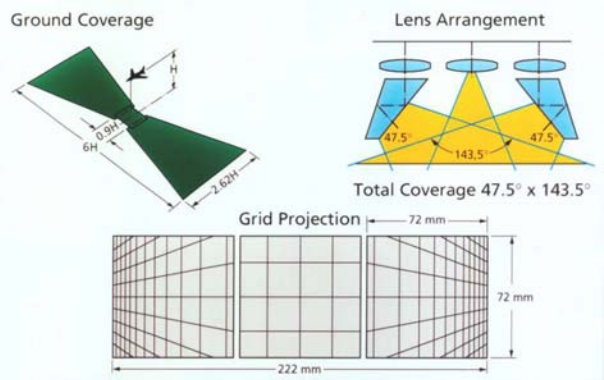


Fig. 15.1: Imaging scheme of the KRb 8/24 (Trilens)

In 1968 the prototype of the KRb 8/24 C "Klein-Reihenbildner" with three lenses was presented to potential customers, which after intensive trials, led to the first large order. The KRb 8/24 C reconnaissance camera was designed for an unmanned aerial vehicle (UAV, then called a "drone") of Canadair in Canada, and had to fit within a diameter of 33 cm. During the following years several orders for improved camera versions followed (KRb 8/24 D, KRb 8/24 Dm and KRb 8/24 F), which all looked very similar (Fig. 15.2 & 15.3). Later the models KRb 8/24 E and "KS-153A Trilens" were adapted to jet fighters where space was not so extremely limited. These cameras looked different (see chapter 15.2).

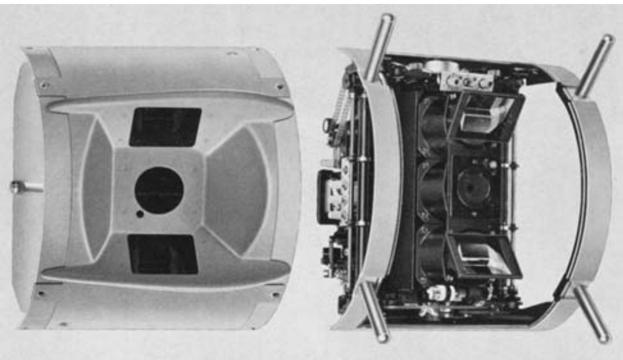


Fig. 15.2: KRb 8/24 C reconnaissance camera (1968)

Fig. 15.3: KRb 8/24 F reconnaissance camera (1989)

Reconnaissance cameras from Carl Zeiss not only distinguished themselves by patented true-angle forward motion compensation, which also functioned well at low-altitude (Prinz 1984), but by a very high cycling rate and by being suitable for night missions with a synchronised electronic flash light or by shooting a flash cartridge. The main later improvements futher increased the cycling rate, the v/h rate and the capacity of the film cassettes.

The main parameters of e. g. the versions KRb 8/24 C and 8/24 E were:

- *lens: 3 x Zeiss Topar AS 2/80,*
- *focal length: 80 mm,*
- *lens aperture range: 1 : 2 to 1 : 16,*
- *inclination between lenses: 47.5°,*
- *angular coverage: 48° along and across flight pass, totally 143° across flight pass,*
- *image format of each image: 71.5 mm x 71.5 mm,*
- *shutter speed: 1/150 to 1/2 000 sec,*
- *filter: e. g. orange (Zeiss D) and yellow (Zeiss B),*
- *cycling rate: max. 4 frames/sec [KRb 8/24 E: max. 5 frames/sec],*
- *forward motion compensation: moving film, true-angle corrected across entire format,*
- *max. v/h rate: 1.4 rad/sec [KRb 8/24 E: 3.6 rad/sec],*
- *film width: 9.5 " (240 mm),*
- *film capacity: 50 ft (15 m), [KRb 8/24 E: 167 ft (51 m) with 4 mil base or 242 ft (74 m) with 2.5 mil base in small cassette, 2.5x more in large cassette],*
- *dimensions: 330 x 330 x 264 mm, [KRb 8/24 E: 422 x 443 x 504 mm],*
- *weight: 11.6 kg, [KRb 8/24 E: 50 kg].*

Besides aerial films with a film base thickness of 0.1 mm (4 mil base), as normally used for civilian photo flights, very thin films with 0.06 mm (2.5 mil base) were often used for reconnaissance. This was necessary, because the space for the cameras and the film cassettes was scarce. These thin films required special measures to reduce the high dynamic stress during film transport (Prinz 1975 & Tull et al. 1989).

The necessitiy to build such a powerful, preprogrammed and remotely controlled multiple-image camera within extremely tight limits with respect to dimension and weight was a really challenging task which caused a lot of head aches to the mechanical and electronic designers (Fig. 15.4).

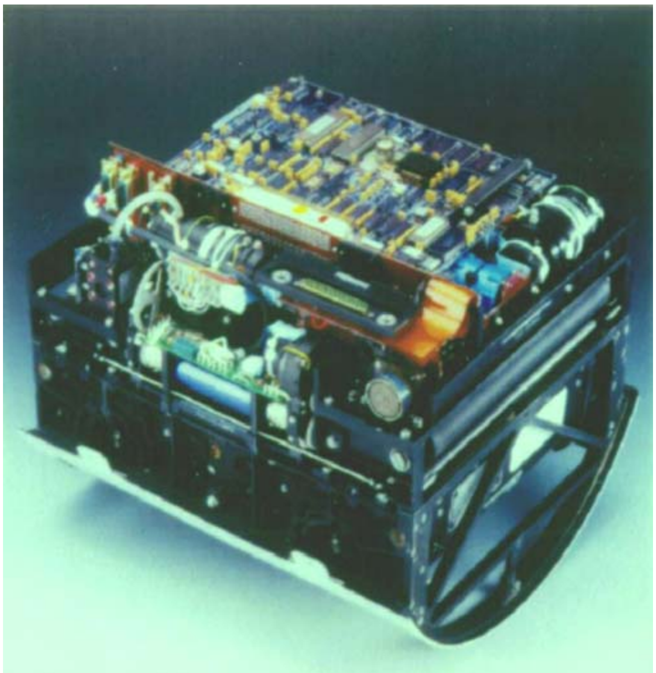


Fig. 15.4: KRb 8/24 Dm recce camera, without cover

Not much larger were the reconnaissance "recce" pods which were attached to reconnaissance fighters. In addition this later requirement demanded a modular structure for simple handling and for a quick repair and replacement service. (Fig. 15.5).

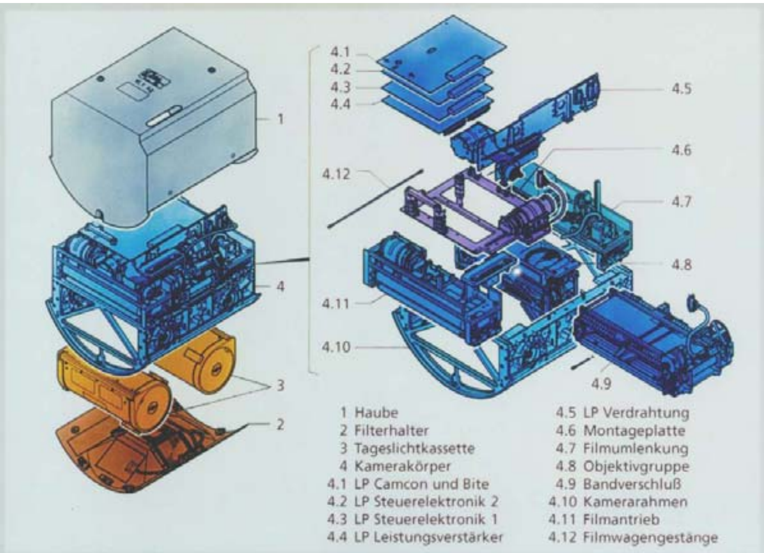


Fig. 15.5: Exploded view of the KRb 8/24 recce camera

Military customers expect not only a ready-to-go camera but also all the tools for its operation, test and check equipment, a comprehensive spare parts kit for covering a long period, and an intensive education and training programme. Fig. 15.6 shows top left the camera test set for the fighter-camera KRb 8/24 E, which as "built-in-test-equipment" (BITE) could deliver status information and error messages even during a flight mission, and in the lower left a simulator, which on the ground could test the camera function and its coordination with a ruling control system. The right part of the figure shows the main in-flight operation panel (top) and a simplified version for the pilot (below), by which only the start/stop-function and the selection between day and night operation were controlled.

Fig. 15.6: Test sets and control panels for the KRb 8/24

The KRb 8/24 C, built for the CANADAIR drone, was named KA-105A by the user (following the numbered labelling as used by the North American military organisations) and 400 units were delivered to several NATO members between 1969 and 1975. This camera was first exhibited by ZEISS to the public in 1972, at the International Congress for Photogrammetry in Ottawa, together with the derived MUK multispectral camera (see chapter 15.3). Between 1978 and 1982 another 10 systems of the further developed KRb 8/24 D for an enhanced drone were delivered. One of the rare public reports about the reconnaissance systems from CARL ZEISS, Oberkochen was given in August 1982 at the SPIE-Congress on Airborne Reconnaissance in San Diego (DREYER 1986).

The requirement for a fighter camera for completely covering the area beside the flight path from horizon to horizon arose in the mid 1970s. Regarding the optical requirements the ZEISS internal studies recommended an array of 5 lenses with an image format of 40 mm x 50 mm each (Fig. 15.7). Starting in 1976 the prototype of the KRb 6/24 reconnaissance camera was built. Fig. 15.8 shows a clipping from a test flight over the ZEISS Oberkochen compound with a cross coverage of 182.7°.

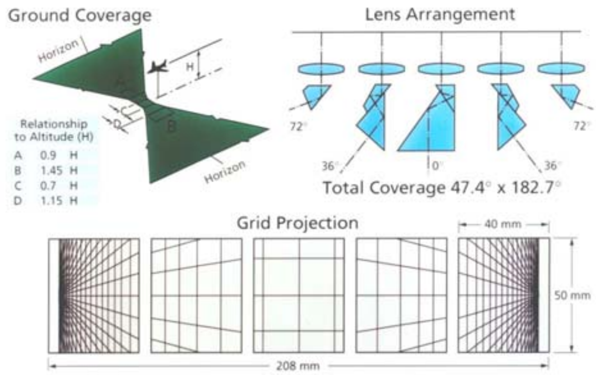


Fig. 15.7: Imaging scheme of the KRb 6/24 (Pentalens)

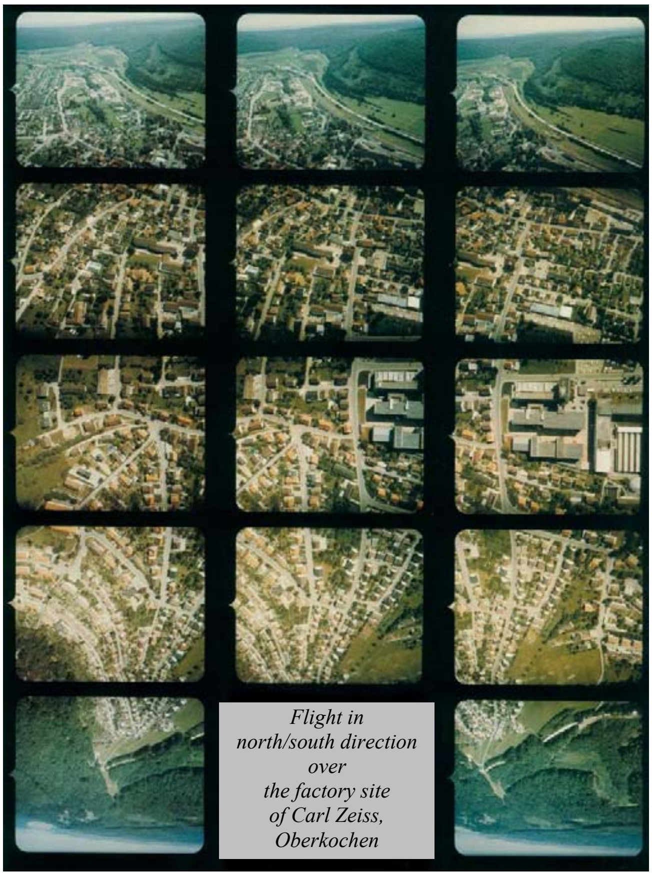


Fig. 15.8: KRb 6/24 sample images (Pentalens)

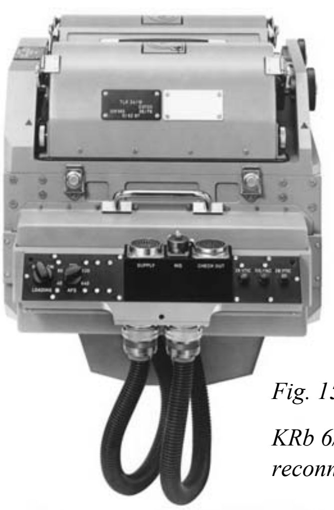


Fig. 15.9:

KRb 6/24 (KA-106A) reconnaissance camera (1979)

The main parameters of the KRb 6/24 prototype and for the later series camera, named KA-106A (Fig. 15.9), were:

- *lens: 5 x ZEISS TOPAR AS 2/57,*
- *focal length: 57 mm,*
- *lens aperture range: 1 : 2 to 1 : 16,*
- *inclination between lenses: 36.0°,*
- *angular field: 47.4° along flight path,*
  38.7° across flight path,
  totally 182.7° across flight path,
- *image format: 50 mm x 40 mm,*
- *shutter speed: 1/150 to 1/2 000 sec,*
- *filter: e. g. orange (ZEISS D) and yellow (ZEISS B),*
- *max. cycling rate: 6 frames/sec*
  [KA-106A: 7 frames/sec],
- *forward motion compensation: moving film,*
  true-angle corrected across entire format,
- *max. v/h rate: 2.0 rad/sec*
  [KA-106A: 5.0 rad/sec],
- *film width: 9.5 " (240 mm),*
- *film capacity: 242 ft (74 m),*
  [KA-106A: 167 ft (51 m) with 4 mil base or
  242 ft (74 m) with 2.5 mil base in small cassette,
  2.5x more in large cassette],
- *dimensions: 326 x 390 x 442 mm,*
  [KA-106A: 492 x 390 x 504 mm],
- *weight: 35 kg, [KA-106A: 50 kg].*

Parallel to the KRb 6/24 the development of the TRb 60/24 "Tele-Reihenbildner" was started in 1976. Thereby in 1979 a complete family of reconnaissance cameras was created with the tele-lens TRb 60/24, the tri-lens KRb 8/24 E and the penta-lens KRb 6/24. An additional concept for a very compact "strike camera" with the working title SRb 8/7 was not carried out. A main feature would have been an angular field in the flight direction of 180°, with true-angle forward motion compensation and a focal length of 80mm.

During 1979 to 1984 about 75 units from this family were delivered, among these were the KRb 8/24 E (KA-107A) for a recce system of the Canadian military, the KRb 6/24 (KA-106A) for the reconnaissance version of the LOOKHEED Starfighter (RF-104G) of the German Navy, and the TRb 60/24 (KA-108A) for the fighters RF-104G and MRCA (later called TORNADO).

A special feature of the TRb 60/24 Telelens recce camera was the in-flight rotatable lens with a broken optical path (Fig. 15.10), so that the camera (when installed along the flight path) could be directed to any downward direction between the left and the right horizon (Fig. 15.11). For satisfying the high mechanical requirements of the TRb innovative solutions had to be found (PRINZ 1980).

Fig. 15.10: Reconnaissance camera with rotable tele-lens, here already as KS-153A/610mm version

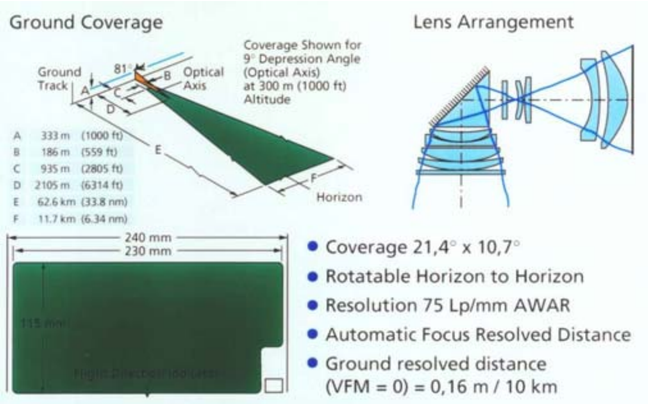


Fig. 15.11: Imaging scheme of TRb 60/24 and KS-153A/610mm

The main parameters of the early TRb 60/24 (KA-108A) and the later KS-153A/610mm were:

- *Lens: ZEISS TELIKON A 4/612, [KS-153A: TELIKON A1 4/610],*
- *focal length: 612 mm, [KS-153A: 610 mm],*
- *in flight rotatable: -90° to +90°,*
- *angular coverage: 10.7° along flight path, 21.4° across flight path,*
- *image format: 115 mm x 213 mm, [KS-153A: 115 mm x 230 mm],*
- *shutter speed: max. 1/1 000 sec, [KS-153A: 1/150 bis 1/2 000 sec],*
- *filter: e. g. yellow (ZEISS B),*
- *max. cycling rate: 4 frames/sec,*
- *forward motion compensation: moving film, true-angle corrected across entire format,*
- *max. v/h rate : not published, [KS-153A: 7.87 rad/sec, less for longitudinal overlap or vertical viewing angle],*
- *film width: 9.5 " (240 mm),*
- *film capacity: 250 ft (75 m), [KS-153A: 125ft (38 m) with 4 mil base or 200 ft (61 m) with 2.5 mil base in small cassette, 2.5x more in large cassette],*
- *dimensions: 736 x 417 x 400 mm, [KS-153A with large film cassette: 883 x 427 x 491 mm],*
- *weight: not published, [KS-153A: 110 kg].*

In 1984 significantly improved lenses were introduced for the KS-153A/610mm, the TELIKON A1 4/610, and for the Trilens and Pentalens: ZEISS S-TOPAR A1 2/80 and ZEISS S-TOPAR A2 2/57. In addition the fastest possible speed for moving the film to compensate the forward motion was doubled to 570 mm/sec (Pentalens), 800 mm/sec (Trilens) and 1300 mm/sec (Telelens). And also the equipment for testing and checking was further enhanced and partly automated (Fig. 15.12).

Fig. 15.12: KS-153A with LM-230A automatic test unit

With these improvements in 1984 all three reconnaissance cameras were accepted as the KS-153A system within the US-family of military cameras in use. Subsequently many KS-153A/80mm (Trilens) were delivered to the US Marine Corps for the reconnaissance airplane RF-4B from MCDONELL DOUGLAS, and a larger number of the KS-153A/610mm (Telelens) for the reconnaissance version of the TORNADO to the Italian and German Air Force.

15.2 KS-153 recce camera system

Soon after the aforementioned deliveries the department "Luftbildspezialsysteme" started to redesign slightly these three cameras to create a unified modular reconnaissance system, named "KS-153". As in a construction set, the components of this modular family (Fig. 15.13) of the three previous camera versions could be assembled by combining one of the lens cones Trilens, Pentalens or Telelens with the now identical and shared parts (Fig. 15.14).

Fig. 15.13: System components of the modular KS-153 reconnaissance system (1994)

Fig. 15.14: KS-153 in Trilens and Pentalens configuration

The performance parameters of all three versions remained almost unchanged. New and patented was an electronic view finder with an integrated exposure meter function (RAASCH 1996). These camera systems represented the latest and last level of development of reconnaissance cameras at CARL ZEISS Oberkochen and were ordered by the "Deutsche Luftwaffe" for the reconnaissance pods of their TORNADO (Fig. 15.15).

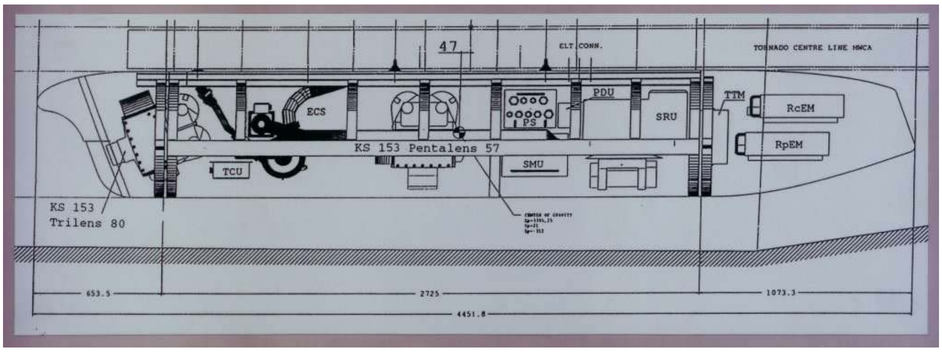


Fig. 15.15: Content of the reconnaissance pod with inter alia the KS-153 Trilens and Pentalens

For this recce pod several dozen of camera pairs KS-153 Trilens 80 and Pentalens 57 were delivered in the 1990s. Within the pod the Trilens 57 was installed forward looking with a downward inclination of 21°. The Pentalens 80 was mounted in the center with vertical orientation. In addition a thermal scanner from HONEYWELL was on board (N.N. 1999). Fig. 15.16 shows the maintenance of such a recce pod.

Fig. 15.16: Maintenance of the "Recce Pod" of the TORNADO

During the following years these recce pods were frequently mentioned in the newspapers, when they were used in civilian emergency cases such as investigating disasters or searching for missing people.

One of the main advantages of these reconnaissance cameras from ZEISS was their use for photogrammetric measurements. One might think that the slit shutter used within this design and the fast moving forward motion compensation would disturb the mathematical central perspective of the images. However, by 1979 Munich Technical University had demonstrated and attested that pictures from these cameras could deliver adequate basic photogrammetric measurements (EBNER et al. 1980a).

15.3 Remote sensing

In view of the increasing debate about remote sensing, especially for biological and agricultural applications, during the development of their first KRb 8/24 C reconnaissance camera the photogrammetrists in Oberkochen discussed designing a commercial camera version for interpretation purposes. As a result an evaluation model of the MUK 8/24 multispectral camera (Fig. 15.17) was presented at the International Congress for Photogrammetry in Ottawa in 1972, together with a KRb 8/24 C recce camera from series production. In the MUK 8/24 the three lenses were arranged parallel and vertical, and they could be equipped with three different filters.

Fig. 15.17: MUK 8/24 multispectral camera from ZEISS with adapter and AS II mount of the RMK (1972)

The main parameters of the MUK 8/24 multispectral camera were:

- *Lens: 3 x ZEISS TOPAR AS 2/80, parallel vertical looking,*
- *A-characteristics: corrected for the specification of panchromatic film, infrared film, colour film and colour infrared film,*
- *focal length: 80 mm,*
- *aperture range: 1 : 2 to 1 : 16,*
- *filter: green, yellow-orange, red, infrared as standard,*
- *field angle: 48° (64° diagonal),*
- *image format: 71.5 mm x 71.5 mm,*
- *shutter speed: 1/100 to 1/2 000 sec,*
- *cycling rate: 0.25 to 3 sec in steps, max. 4 frames/sec,*
- *film width: 9.5 " (240 mm),*
- *film capacity: 20 m at 0.1 mm base,*
- *dimensions: 340 x 270 x 250 mm,*
- *weight: 12 kg with film.*

With adequate longitudinal overlap consecutive images could be evaluated stereoscopically and used for basic measurements. With a ready-to-use prototype of the MUK 8/24 several tests were flown in the years 1972 to 1974, together with several customers, to optimise the functionality and the usefulness for various applications and filter combinations. This development was, as well as the development of the strip camera described below, sponsored by the German Federal Ministry for Research and Technology between November 1972 and December 1978 and documented in a final report (MEIER 1979).

Parallel with the MUK 8/24 tri-lens multispectral camera a functional model of the SK 2 strip camera was developed (Fig. 15.18). This camera with a narrow slit in front of the image plane and oriented perpendicular to the flight path took a continuous image of the overflown terrain on film. For this the film behind the slit had to be moved with a speed identical with the forward motion of the projected image.

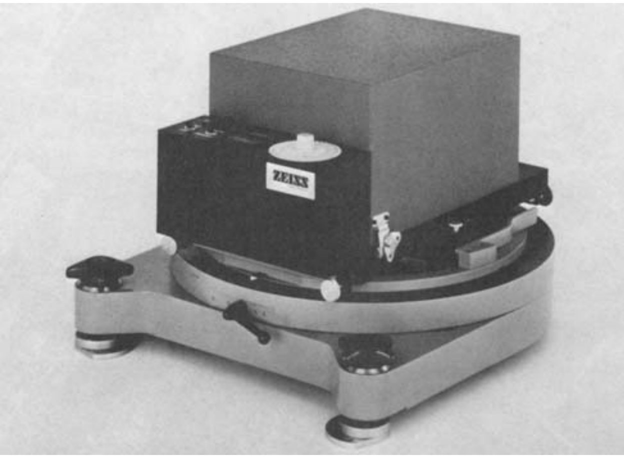


Fig. 15.18: SK 2 strip camera from ZEISS in AS II mount of the RMK (1973)

This design led to a relatively elementary mechanical principle for the forward motion compensation controlled by the v/h signal. Even with longer exposure times, e. g. of 1/15 sec, sharp images were obtained. Image geometry was identical to line scanners: a central perspective across the flight path and a parallel projection along the flight direction.

The main parameters of the SK 2 strip camera were:

- *Lens: ZEISS BIOGON 4,5/53, interchangeable, e. g. with ZEISS UV-SONNAR 4,3/105,*
- *focal length: 53 mm or 105 mm,*
- *aperture range: 1 : 4.5 (or 1 : 4.3) to 1 : 32,*
- *field angle: 95° or 57°,*
- *image width: 115 mm,*
- *shutter speed (width of slit shutter): 0.1, 0.2 or 0.4 mm,*
- *cycling rate: 0.25 to 3 sec in steps, max. 4 frame/sec,*
- *max. v/h rate: 0.019 to 0.70 rad/sec, [UV-SONNAR: 0.010 to 0.35 rad/sec],*
- *film speed: selectable within 2 ranges with each 24-steps, 1 to 10 mm/sec and 5 to 37 mm/sec,*
- *Film width: 5 " (127 mm),*
- *Film capacity: 60 m Estar Thin Base (3 mil base).*

As with the MUK 8/24, together with customers, between 1973 and 1976 several test flights were made with the functional model of the SK 2 strip camera in one case parallel to a microwave sensor. However, as with line scanners, there was no compensation for the aircraft roll and the deformation disturbed the interpretation for specific purposes. The roll could have been compensated by using a stabilised mount but the development of both the MUK 8/24 and the SK 2 for remote sensing was abandoned. This decision was made because on the one hand the R&D experts for aerial cameras were busy with other urgent and more promising projects, and on the other hand the market potential for photographic cameras optimised for remote sensing seemed not to be sufficient in view of the progress of opto-electronic sensors and satellite based services (FAUST 1977).

By 1971/1972 the R&D teams in Oberkochen had developed and tested by laboratory experiments an airborne laser scanner for terrain survey, nowadays known as airborne Lidar, (REICHE 1973, KÖHLER 1983), and around 1976 a study on infrared scanners called MIRAS was conducted. However, because the market did not seem ready these projects were also aborted. Only around 1990 did the development team for "Luftbild-Spezialsysteme" again address the remote sensing topic. At this time the RMK TOP had just gone into series production and electro-optical technology was making good progress and would soon invade the remote sensing field and later the metric aerial cameras (see DMC in chapter 7.8).

Therefore the "EO-study" was started, which in the autumn of 1991 was transferred to ZEO (ZEISS ELTRO OPTRONICS GmbH in Oberkochen, a daughter company of CARL ZEISS), together with the "abduction" of the project manager. The former long standing ZEISS division for optical systems for military use had been transferred to ZEO, which was temporarily a joint venture with other partners, but later came back as the 100%-subsidiary CARL ZEISS OPTRONICS GmbH. From that time, like the photogrammetry and geodesy product divisions, these military activities belonged to the business group OES-UB "Optisch-Elektronische Systeme".

Therefore the result from that EO-study, the VOS 60 electro-optical camera system, managed by a former photogrammetry scientist, shall be included in this documentation. The study and the camera were both reported at the Photogrammetric Week in 1995 (CLAUS 1995).

Fig. 15.19: VOS-60 digital colour video observation system

The VOS 60 electro-optical camera (Fig. 15.19) consisted of a ZEISS lens with 60 mm focal length, a CCD line sensor with 3 x 6 000 pixels for the three colours red, green and blue, the control electronics and a monitor for in-flight viewing. The VOS 60 (Video Sensor Open Skies) was first applied with the Treaty on Open Skies (signed in Helsinki in 1992) for the aerial surveillance of military activities and disarmament at the end of the Cold War. Under this agreement the German Airforce converted a TUPOLEV TU 154M aircraft, inherited from the DDR military, into a surveillance aircraft with the following special equipment:

- *3x LMK 2015 aerial cameras with special filters and stabilised mount from CARL ZEISS in Jena, with focal length 152 mm, image format 228 mm × 228 mm, field angle 90°, and with ground resolution reduced to 30 cm as required, vertical and oblique looking for photogrammetric use (recognise, identify and calibrate),*
- *3x VOS-60 electro-optical cameras from CARL ZEISS in Oberkochen with 3 x 6 000 pixels, field angle 60°, as primary sensor for low flying height (detect, observe in real time, viewfinder for the LMK and support evaluation),*
- *1x A 84 panoramic camera from ZENITH in Russia with focal length 300 mm, image size 118 mm × 748 mm, field angle 20° × 143°, ground resolution reduced to 30 cm as required, with automatic exposure control and rotating lens (supplement a line scanner, detect and map).*

Fig. 15.10 shows the TU 154M aircraft and the installation of the three LMK aerial metric cameras. The three not visible VOS 60 were looking parallel to the LMK. Unfortunately this aircraft was lost on September 13, 1997 after a tragic mid-air crash over the South Atlantic Ocean, and it was not replaced.

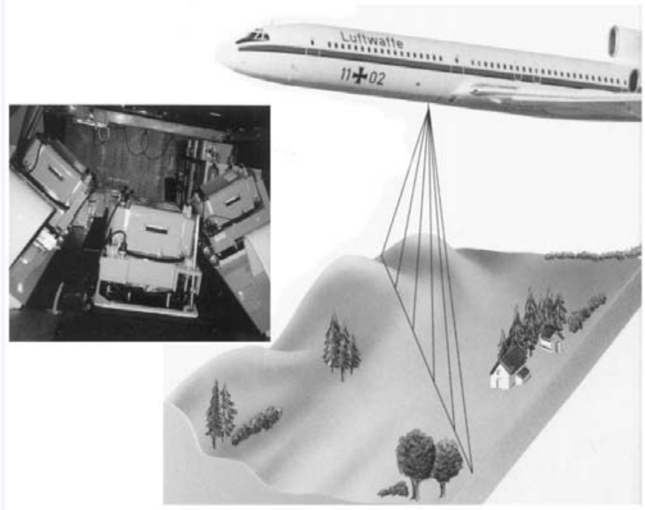


Fig. 15.20: Open Skies concept with VOS-60 / LMK (1994)

In 1996 ZEISS introduced the VOS 80 C for commercial use (Fig. 15.21). The only difference to the VOS 60 was the use of the ZEISS PLANAR 2.8/80 with 80 mm focal length (instead of 60 mm). Again the CCD detector from KODAK with 3 x 6000 pixels and 12 µm pixel size was used, thus generating an angular field of 48.5° across the flight path. If required other lenses could be used. Because this system was marketed by CARL ZEISS OPTRONICS GmbH, too, it shall not be further discussed here.

Fig. 15.21: System components of the VOS-80 C

16. Resumé of photogrammetric R & D in Oberkochen

To complete the documentation about the development of photogrammetric methods and instruments in Oberkochen a few additional comments shall be added here describing the R&D activity as such, as well as its general performance and results.

16.1 ZEISS Photogrammetry in numbers

Every year between 50 000 and 60 000 man hours were spent at CARL ZEISS in Oberkochen on research and development in photogrammetry. This figure was relatively constant from the start of recordings in the mid 1950s until the end of the 1980s. This equates to about 30 to 40 people working full-time. The effort for the contracted development of reconnaisance cameras is not included in this number. In the 1990s the number of man hours per year declined to about 30 000 due to the reduction in hardware activity.

In the early decades 80 % of the overall R&D costs were directly spent on creating the required hardware. Of this the mechanical design work was about 45 % the electronic design 10 % and the manufacturing of prototypes 25 %. In addition 15 % was spent by the staff in the photogrammetric laboratory for studies and conceptual work, project management and testing. On average between two and three scientists of the central mathematical department were engaged in optical design for photogrammetric instruments the major part of their work being the continuous improvement of the lenses for aerial cameras. With the beginning of the transition to analytic systems in the 1970s the share of the "Bildmess-Labor" and of the electronics laboratory rose due to the software programming and the increasing role of printed curcuit boards, and later microprocessors, while the effort required for the mechanical parts of the instruments declined. In the 1990s about 2/3 of all man hours spent were related to software and firmware programming.

During the first two decades after the restart in Oberkochen the technical management ("Technische Leitung") was fully responsible for all aspects of photogrammetric business and could decide without any restriction, together with the leading scientists, which instruments should be developed, how they should be designed and what they should look like. Around 1970 the executive board of ZEISS implemented the computer based planning system "Epla" (Entwicklungs-Planungs-System) for all development activities within the company. Now the required man hours for projects had to be budgeted a priori and allocated according to the required resources. The monthly account and a deviation from budget led to an increased cost awareness and work discipline not only in executing the projects, but also in selecting promising ideas. As a consequence the photogrammetric "brain" retreated periodically every three to four years to a strategic conclave, during which the collected project proposals of customers, marketing and sales colleagues and R&D employees were discussed and evaluated. The estimation of the development costs and the sales potential for drafted projects led to a ranking in potential of success. This procedure was in fact the main reason for the prosperity of Zeiss Oberkochen photogrammetry from the late 1970s.

Normally about 2 to 4 main projects and about 4 to 8 smaller development tasks were in the pipeline at any time. The smaller ones were studies and predevelopments for future instruments, but also smaller devices, accessories or improvements for items in series production. The duration of these smaller tasks ranged from a few months up to two years. The main projects, depending on complexity, took between four and, increasingly, only two years.

An example of the increasing cost conscious layout of instruments and the forceful use of new technologies is the development of 1st order stereoplotters during the 50 years. While in 1952 the C 8 STEREOPLANIGRAPH consisted of 2 600 different designed and 5 000 manufactured parts, the D 2 PLANIMAT (1967) was reduced to 650 designed and 1 700 manufactured parts. This led to a list price of only 1/3 compared to the C 8, with even higher accuracy and, for most applications, equal flexibility. Or saying it differently: producing the C 8 in 1975 would have required 3 times the cost of the D 2, or in spite of the inflation in living costs and salaries (+200 % since 1962) the D 2 in 1985 was no more expensive than the C 8 in 1962. So the price level of the photogrammetric "premium workhorse" could be kept even below the price-index of 150 % of the industry for optics and precision-mechanics (Fig. 16.1).

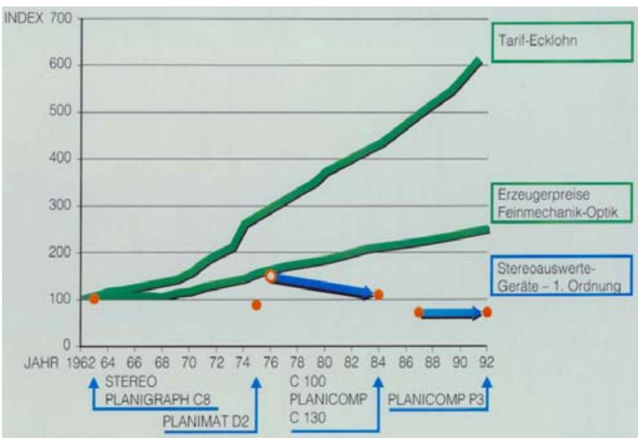


Fig. 16.1: Manufacturing costs of ZEISS stereoplotters

With the introduction of the analytical plotter Zeiss was able to keep this price level almost constant (the C 100 Planicomp consisted of only 460 manufactured parts), although at the beginning the minicomputers and its peripherals for the C 100 were very expensive. However, with falling computer prices the situation became more favourable. With the P 3 Planicomp in 1987 the base level was even undercut in spite of ongoing inflation and in relation to an extrapolated C 8 price would have reached a factor of 7.

16.2 Patents and publications

The development activity in Oberkochen required a remarkable amount of paperwork, too. The laboratory staff had to write functional specifications, project proposals, meeting and progress reports, manufacturing documentation and testing procedures and provide basic input for the user and service manuals. Sometimes a description for a patent application had to be prepared and, more often, technical and scientific publications had to be written for periodicals and congresses in form of papers and posters.

About 100 patents and registered designs were applied for and mostly accepted between 1949 and 2000 on behalf of the photogrammetric development at Carl Zeiss Oberkochen (15 % being registered designs). About 1/3 of these were related to stereoplottting and about 1/4 to aerial cameras. About 2/3 of the 100 ideas were really applied in instruments produced in series. To safeguard these inventions they were often also registered in the home countries of the main competitors (e. g. in Switzerland) and in important markets (usually at least in the USA). Including these applications the total number was over 300.

The printed technical papers as well as the registered patents have already been listed together with the related developments in the previous chapters. In addition several overviews, e. g. summarising complete product families, have been published over the years (inter alia Ahrend 1966a, 1967b & 1969, Meier 1966c, 1969, 1976a, 1976b, 1978b & 1989, Hobbie 1981a & 1984b, Schwebel 1980a). The photogrammetric scientists in Oberkochen also wrote contributions to general scientific and technical publications not directly related to specific instruments: e. g. regarding optical problems (Roos 1950 & 1952, Schwidefsky 1952b), application aspects in air survey, aerotriangulation, rectification or land consolidation (Brucklacher 1949, 1950, 1955, 1962 & 1967b, Meier 1958, 1964c, 1970a & 1972a), and about the general technical advancement (Hobbie 1977d & 1999, Meier 1970e, 1987 & 2002, Schwebel 1991 & 1999).

About 350 primary publications were printed during the five decades, most of which are listed under the references below, together with the patent and design applications. Several of these papers were also printed in English and in the first half of this period in Spanish and French as well. Some were published again (slightly modified or updated), which brings the total number of technical/scientific papers to about 700. Noteworthy is also the special edition of the periodical ZPF ("Zeitschrift für Photogrammetrie und Fernerkundung") in Chinese Mandarin for the Wuhan symposium of ISPRS Commission III in May 1990 with a contribution from Zeiss (Hobbie 1990).

The development staff often supplied technical and product related information for the brochures and catalogues. During the 50 years the sales and marketing group issued about 1 000 different printed items of which about 250 were before 1964 and were therefore from Zeiss-Aerotopograph and 750 were from Carl Zeiss. Most of these were also edited in English with the most important also in Spanish and French. In Japan the important papers and brochures were printed in Japanese, after translation by Nobuaki Horie, a photogrammetry expert and Zeiss veteran from the late 1960s. Last but not least display material was created which consisted of slides and posters in the beginning, and later overhead transparencies and more recently powerpoint presentations.

A further diversity in documentation and updates was caused by changing the company name or company logo. Because before 1964 photogrammetric marketing and sales was handled by Zeiss-Aerotopograph all outside paperwork carried their logo. Later all material, including the instruments, had to carry the Oberkochen logo, either Zeiss or Opton, depending on the country of destination. As a consequence of the name dispute with VEB Carl Zeiss Jena, Carl Zeiss Oberkochen had to use the label "Opton Feintechnik GmbH" in defined countries such as those in the Eastern bloc. With the political reunion "West Germany" was now "Germany" again, and with the reunion of Jena and Oberkochen as well as the growing globalisation of Zeiss with its worldwide production sites, finally the "Germany" was dropped (Fig. 16.2).

Fig. 16.2: Logos of Zeiss-Aerotopograph and Carl Zeiss

16.3 Other activities

Besides the previously mentioned product related paperwork the "ZEISS photogrammetrists" frequently gave technical presentations and poster contributions at national and international conferences although this goes beyond the scope of this documentation. Their involvement in ISPRS commissions (as a member of the German Society for Photogrammetry) as evaluators or consultants in external issues, and as lecturers for internal company skill enhancement and know how transfer shall be omitted, too. However, the involvement of individual scientists in universities e. g. in Stuttgart, Munich and Hanover, for many years should be mentioned. This resulted in MEIER, SCHWEBEL and HOBBIE being appointed honorary professors ("Honorarprofessor").

A few ZEISS employees, some after their retirement, actively supported and partly lead the photogrammetric standardisation work of the DIN German Institute for Standardization (MEIER 1977). This resulted in the following DIN standards: DIN 18716 "Photogrammetrie und Fernerkundung" (MEIER 1994 & 1995) and DIN 18740 "Photogrammetrische Produkte" (KRESSE et al. 2001, SCHWEBEL 2001, 2002a & 2002b).

More as a marginal note is the occasional work for associations such as participation in the geodesy group of the F&O organisation for precision mechanics and optics (today SPECTARIS the German industry associaton for hightech medium sized businesses). And participation in, and temporarily heading, GEOKART, the German association for private enterprises working in the field of geodesy, photogrammetry and cartography. The reason for this participation was to support international activities, e. g. as a member of the German delegation to the Regional Cartographic Conferences of the United Nations (HOBBIE 1993b, 1994 & 1997) Mention should also be made of commenting on the requirements for the professional education of surveying students, based on personal professional experience and the company internal skill enhancement program of CARL ZEISS in Oberkochen (Hobbie 1989, 1998 & 2002).

Last but not least, an important spin-off of the scientific photogrammetric and geodetic work in Oberkochen is the CARL-PULFRICH-PRIZE, which was established in 1968 by CARL ZEISS, Oberkochen (KÜHN 1969). Therewith outstanding scientific, technical or application oriented activities related to geodetic or photogrammetric instruments and methods continue to be honoured every other year. Organised by the general manager of the Surveying division ("GB Vermessung"), an independent council elects a young commendable professional with the intention to encourage him/her for continued excellence. Since 1969 this prize has been awarded to "photogrammetrists" and "surveyors" in almost equal parts (MEIER 1985a). Because the photogrammetric business went into the Z/I IMAGING joint venture with INTERGRAPH (and the surveying business was given to another partner), the CARL-PULFRICH-PRIZE is now managed by INTERGRAPH, and regularly awarded at the Photogrammetric Week.

16.4 People and organisation

Although this is primarily a record of the technical and scientific aspects of photogrammetric instruments and methods, the scientists and engineers who have created and shaped the photogrammetric solutions and were decisive for their success shall be mentioned here.

As desribed in detail in chapter 4, EDUARD OSKAR MESSTER and WALTER BAUERSFELD initiated the restart of photogrammetric activities in Oberkochen. From 1946 MESSTER re-established his pre-war contacts to international customers, revitalised ZEISS-AEROTOPOGRAPH in Munich, and in the winter of 1949/1950 placed an order for the STEREOPLANIGRAPH with ZEISS-OPTON in Oberkochen. Then BAUERSFELD, the "father" of the earlier Jena version of this stereoplotter from 1920, and one of four managing directors in Oberkochen guided the project. MESSTER and BAUERSFELD therefore were the drivers for the first reconstruction phase between 1948 and 1951.

In June 1951 KURT SCHWIDEFSKY returned from Wetzlar, where in 1947 he had been sent from Oberkochen as scientific director of the ZEISS owned HENSOLDT & SÖHNE AG, and took the newly established position of technical manager photogrammetry ("Technische Leitung Bildmess"). While in Wetzlar he had continued to spend part of his time on photogrammetric activities (e. g. for pre-developing a new rectifier). After a few months, in September 1951, he presented the C 7 STEREOPLANIGRAPH together with the SEG V, STEREOTOP and RADIALSECATOR at the first post-war Photogrammetric Week in Munich. Shortly before GÜNTER WEIMANN had joined Bildmess but left ZEISS after only 3 ½ years.

At ZEISS-AEROTOPOGRAPH immediately after the restart WALTER BRUCKLACHER promoted the technical affairs. ROLF HERMINGHAUS and HERMANN DEKER joined ZA in 1951 and 1952 and the former became technical manager in 1954. After the early death of HERMINGHAUS in 1959 DEKER took over the position. BRUCKLACHER and DEKER were located at the technical liaison office to Bildmess in a barracks in front of the company site in Oberkochen. Between 1954 and 1958 FRIEDRICH ACKERMANN was also a ZA scientist in the Oberkochen barracks. Innovative design contributions came from HEINRICH SONNBERGER, who in 1951 came from ZEISS in Jena to Oberkochen. Especially SCHWIDEFSKY, BRUCKLACHER and DEKER stand for the second phase of "new designs for pre-war ideas" between 1952 and 1956, described in chapter 5.

Between 1953 and 1957 three young surveying graduates came directly from their universities to Bildmess as staff members, who all later achieved managing positions: MARTIN AHREND (1953), HANS-KARSTEN MEIER (1955, after being a research assistant at Munich Technical University) and GÜNTER DREYER (1957). In 1956 HERBERT MONDON came from Jena and contributed interesting technical solutions especially to the GZ 1 development, but unfortunately he died in 1967.

With the number of new projects started in the mid 1960s this loss required the hiring of more young surveyors with knowledge of the practical requirements for photogrammetric development. HEINRICH EBNER had left for Stuttgart Technical University at the end of 1966 after only two years with Bildmess. Therefore in April 1968 DIERK HOBBIE and REINER SCHWEBEL started work in the photogrammetric development laboratories and were followed 12 months later by WINFRIED LORCH. The latter two initially worked as assistants and then received their doctoral degrees at Stuttgart Technical University. Whereas SCHWEBEL and HOBBIE joined the newly formed development labs "Bms-Labor 1" (head: MEIER) and "Bms-Lab 2" (head: BRUCKLACHER) for the aerial cameras and evaluation systems for civilian use. LORCH, and, from 1972, also HANS-WOLFGANG FAUST, belonged to "Bms-Lab 3" (head: DREYER), where the reconnaissance cameras were the main topic.

In April 1960 when SCHWIDEFSKY was appointed to a professorship at Karlsruhe Technical University, AHREND had become his successor as "TL-Bildmess", which in 1966 was extended to "TL Geo-Bms", the technical director of surveying and photogrammetric instruments. This position in fact had overall business responsibility. When in November 1968 AHREND was appointed first as a special delegate to the executive board and became a member a few months later MEIER became his successor as TL Geo-Bms.

It is to the predominate merit of AHREND and MEIER to have shaped the phase of the analogue stereoplotters, aerial and reconnaissance cameras in Oberkochen between the mid 1950s and mid 1970s. In the early 1970s with significant input from DREYER, SCHWEBEL and HOBBIE. ZEISS-AEROTOPOGRAPH had been steadily integrated into CARL ZEISS Oberkochen between 1963 and 1965. After the expiration of the agreement for 30-years of cooperation the Munich office had been closed. But even earlier ZA's impact on the Oberkochen projects was marginal, although OTTO HOFMANN was employed by ZA in Munich between 1962 and 1964.

During the first half of the 1970s the new possibilities of semi-conductor electronics, microprocessors and desktop computers initiated in Oberkochen the "analytical phase". With the termination of all development activities with respect to analogue and terrestrial equipment, and with the retirement of BRUCKLACHER in 1975, the development labs were restructured into development departments for "Photogrammetrie" (head: SCHWEBEL, who already had become head of Bms-Lab 1 soon after MEIER) and "Luftbild-Spezialsysteme" (head: DREYER).

The C 100 PLANICOMP with a wide range of software programs and with manifold computer equipment was a new world to the Zeiss staff as well as to the customers. For mastering the overwhelming success of the C 100 and the fast changing computer world, the need for a new department for system integration and technical customer care became obvious. This department needed to be a link between the development labs, the assembly shop, the service technicians, marketing and the customers. SCHWEBEL was appointed to oversee the implementation and management of such a new department, "Systemtechnik", within the photogrammetry division and to safeguard the transition of these new complex sytems into the still analogue customer world. HOBBIE took over the management position for photogrammetric development in March 1982.

The growing demand for software for the new analytical instruments and for supporting data acquisition at analogue plotters and comparators required the employment of more engineers graduated in surveying and with knowledge in computer programming. A few of these were still on board at the end of the period documented here. (2002). The names and their presence within photogrammetry in Oberkochen are: JOHANNES SAILE (1980-1993), JOSEF BRAUN (1981-1998), HELMUT RÜDENAUER (1981-1985), ENRICO CLERICI (1981-1983), KURT MENKE (1983-1994), MICHAEL CLAUS (1984-1991 later with the sensor-project in the special optics division, then with corporate R&D), VOLKER UFFENKAMP (1984-1990), WOLFGANG KRESSE (1985-1995), ERWIN KRUCK (1987-1993), CHRISTOPH DÖRSTEL (1989-), PHILIPP WILLKOMM (1989-1993), WERNER MAYR (1990-1997), ZOLTAN POTH (1990-). In addition graduated mathematicians and information scientists were members of the team: HEINZ SPRONGL (1975-1989), WALTER LEIDEL (1981-) and RASMUS DEBITSCH (1994-1998 & 2001-).

Since early 1980 HANS-KARSTEN MEIER and KARL-HEINZ VOGEL, who as a surveying engineer had served CARL ZEISS in various positions within the surveying division since 1961, shared the overall technical and economic responsibility of the business unit "Geodäsie und Photogrammetrie", which was renamed "Geschäftsbereich Vermessung" in 1981. When MEIER decided to take early retirement in 1986, VOGEL took the sole responsibility for the GB Vermessung (V-GB), which at the same time was structured into the product divisions (PB) "Geodäsie", "Photogrammetrie" and "Spezialsysteme". General manager of the PB Photogrammetrie became DIERK HOBBIE. The photogrammetric development was consigned to KURT MENKE the following year. With VOGEL being promoted to the general manager of the business group (UB) " Optisch-Elektronische Systeme" (OES-UB) in 1991, HOBBIE became his successor as head of V-GB. It is him who essentially guided the "analytical phase" in Oberkochen, with significant input from WINFRIED LORCH, HANS-WOLFGANG FAUST, JOHANNES SAILE and JOSEF BRAUN.

With this change in 1991 MENKE was appointed general manager of the PB Photogrammetrie, and WERNER MAYR became head of development during the following year. CHRISTOPH DÖRSTEL made an important contribution to the early steps into digital photogrammetry. From 1991 the PB Spezialsysteme was managed by RUDOLF SPILLER who already had responsibility as project manager in this field. His long standing predecessor DREYER had retired in 1988 with KARL-HEINZ FRIEDRICH filling the interim period.

After the difficult years of the reunion with Jena a new executive board of CARL ZEISS Oberkochen decided, in 1995, to merge the respective business fields of both locations. Afterwards the PB Photogrammetrie was concentrated in Oberkochen and the PB Geodäsie at the now fully owned subsidiary CARL ZEISS Jena GmbH. From December 1995 onward HOBBIE concentrated on managing the PB Photogrammetrie (Fig. 16.3), which now consisted of the evaluation and sensor departments (Phm-A "Auswertesysteme", head: MAYR and "Sensorsysteme", Phm-S, head: SPILLER) and the sales /marketing (Phm-V, head: HANS-JOACHIM HELLMEIER).

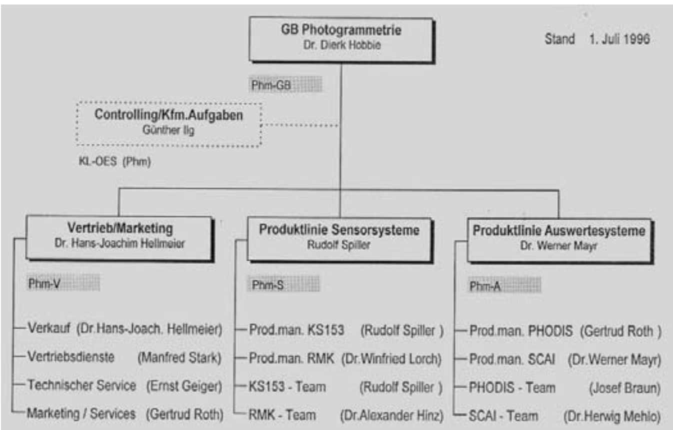


Fig. 16.3: Organisation chart of PB Photogrammetrie (1996)

Early in 1998 it became clear that the search for a partner for the PB Photogrammetrie (see next chapter) would be successful. That was the time, that the head position went to SPILLER, who then in the joint venture with INTERGRAPH became the manager of Z/I IMAGING GmbH in Oberkochen and, in addition, the chief operating officer (COO) as well as one of two general managers of Z/I IMAGING Corp. in Huntsville (until the exit of ZEISS).

The great success of photogrammetric product development at CARL ZEISS Oberkochen is due not only to the excellence of the aforementioned managers, scientists and engineers, but also to the many other engineers, technicians and workers within the photogrammetry lab and in other departments, particularly the following:

- ***the mathematial department for optical design***
  (after the death of ROBERT RICHTER in 1956 WOLFGANG ROOS, who had already worked with RICHTER in Jena since 1935, was responsible for the photogrammetric lenses and other optics, after his retirement in 1973 followed by first HANS LAHRES and since 1977 by HANNFRIED ZÜGGE),
- ***the mechanical design group***
  (this group, in the early years part of a corporate department, was later incorporated into the photogrammetry unit and was responsible for mechanical and electrical design, and was managed in the 1960s by HANS UTZ and since 1968 by HEINZ KRASTEL),
- ***the electronic design group and laboratory***
  (this group, in the early years also part of a corporate unit, was later incorporated into the photogrammetry unit and was responsible for electronic design and prototype building and testing, and firmware programming, and was managed since its establishment in 1961 by KARL FELLE and after his retirement in 1990 by HERWIG MEHLO),
- ***the assembly department for photogrammetry (MJ 6)***
  (this department, always a coporate unit except for the 1990s, was significant for the precision and reliability of the instruments it manufactured, and was managed from 1949 until his retirement in 1956 by KURT WOLF, who joined ZEISS in Jena in 1912 and photogrammetry in 1921, and since 1956 for 29 years by HANS STROBACH).

The "surveyors", scientists and technical managers, who have served photogrammetry for at least 25 years and thus accompanied more than half of the whole Oberkochen period, shall be named here again: BRUCKLACHER, DREYER, FAUST, FELLE, HOBBIE, KRASTEL, LORCH, MEIER, ROOS, SCHWEBEL, STROBACH and UTZ.

Even such a listing of departments and people remains incomplete. Many more ZEISS employees in service and sales/marketing, in other business and corporate units of ZEISS, and last but not least external partners and customers in academia, industry and private enterprises have contributed to the success of "50 years of photogrammetry in Oberkochen". Many thanks to all of them.

16.5 Outlook

This record of the photogrammetric development at Carl Zeiss in Oberkochen demonstrates the diversity and excellence of the instruments and solutions that were created. However, from the early 1990s the forthcoming advent of a digital future for image taking and image processing was obvious. Therfore it became clear, that in the future the optical and mechanical content in the instrumentation for photogrammetry, remote sensing and reconnaissance would be minimised, and that software and computer technology would dominate. For the coporate strategy of Carl Zeiss this implied that the photogrammetric business unit, like the geodetic business with its surveying instruments, should be transfered to a more flexible and appropriate environment with the help of an adequate partner.

The background for this corporate decision was the structural and economic difficulty that resulted from reunification. In October 1991 Oberkochen resumed full responsibility for the core business of Carl Zeiss Jena GmbH with most of the business units now duplicated while the previous eastern market was down. Therefore in 1995 Zeiss decided to concentrate only on the markets with a strong growth perspective. These were identified as the medical sector, microscopes, the huge lens systems for the semiconductor chip producers, industrial metrology and products for furthering public awareness such as planetaria, spectacle lenses, lenses for photographic and digital cameras, mobile phones and webcams. This implied that the few selected photogrammetric and geodetic activities in Jena should not proceed as intended in 1993 (Hobbie 1991a, 1991b, 1992, 1993a & Hobbie et al. 1993).

Firstly between 1994 and 1997 Intergraph, as the long standing partner since 1981, was confidentially contacted to ascertain their willingness for closer cooperation. Also other companies with expertise in photogrammetric software such as GDE Systems Inc., San Diego and Inpho, Stuttgart were contacted. However, these talks were not successful and negotiations with LH Systems, San Diego (a joint subsidiary of GDE Systems and Leica Geosystems AG, Heerbrugg) in February 1998 quickly led to a letter of intent (LOI). The goal was that Zeiss, after becoming a one-third owner of LH Systems, would bring in its business and would take over the common role as "camera competence center" and would manage and control further development of digital cameras (Walker 1998 & Zeiss 1998). This intention had to be abandoned in November 1998, because an objection of the anti-trust authorities of the European Union could not be rebuted.

Talks with Intergraph were immediately resumed and led in December 1998 to a LOI, and on May 15th 1999 to the foundation of Z/I Imaging Corp. in Huntsville, AL /USA, with Intergraph and Carl Zeiss as shareholders owning 60% and 40% of the shares respectively. On April 1st 1999 the photogrammetric business unit of Zeiss was almost completely transferred to Z/I Imaging GmbH in Oberkochen. Z/I Imaging GmbH was a 100%-daughter of Z/I Imaging Corp. but remained within the Zeiss compounds in Oberkochen until 2002 (Fig. 16.4). The GmbH remained responsible for the photogrammetric hardware, especially for the development of the digital aerial camera, and for sales and service concerned with the whole existing program for photogrammety and reconnaissance in Europe and other specified regions (Spiller 1999).

Fig. 16.4: Carl Zeiss compound in Oberkochen in 2000

Following the strategy of 1995 Zeiss sold its 40%-share of this joint venture to Intergraph on September 30th 2002 and thus left the field of photogrammetry. However, Zeiss continued to supply Z/I Imaging with high level components (e.g. lenses for aerial cameras), camera calibration services, and service support for the photogrammetric products from Zeiss still in use. At this time the Oberkochen based Z/I-teams moved into newly rented offices and workshops in a technology center in the neighbouring city of Aalen. With this the post-war period of "Photogrammetry in Oberkochen" came to an end after more than 50 successful years. Several former Zeiss employees are promisingly continuing this tradition, under the logo of Z/I Imaging (Fig. 16.5).

Fig. 16.5:

Logo of Z/I Imaging

17. References

<u>*List of abbreviations for German periodicals:*</u>

AVN *Allgemeine Vermessungs-Nachrichten.* Zeitschrift für alle Bereiche des Vermessungswesens, Herbert Wichmann Verlag, Karlsruhe.

BuL *Bildmessung und Luftbildwesen.* Organ der Deutschen Gesellschaft für Photogrammetrie, Herbert Wichmann Verlag, Karlsruhe.

DGK *Deutsche Geodätische Kommission*, Verlag der Bayerischen Akademie der Wissenschaften in Kommission beim Verlag C. H. Beck, München.

NaKaVerm *Nachrichten aus dem Karten- und Vermesungswesen,* Verlag des Instituts für Angewandte Geodäsie, Frankfurt a. M.

PFG *PFG - Photogrammetrie, Fernerkundung, Geoinformation.* Organ der Deutschen Gesellschaft für Photogrammetrie und Fernerkundung e. V., E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart, (former ZPF and BuL).

VR *Vermessungswesen und Raumordnung* (until 1972: *Vermessungstechnische Rundschau*). Ferd. Dümmlers Verlag, Bonn.

ZfV *ZfV - Zeitschrift für Geodäsie, Geoinformation und Landmanagement* (until 1972: *Zeitschrift für Vermessungswesen*), Wissner-Verlag, Augsburg.

ZPF *ZPF - Zeitschrift für Photogrammetrie und Fernerkundung (früher BuL).* Organ der Deutschen Gesellschaft für Photogrammetrie und Fernerkundung, Herbert Wichmann Verlag, Karlsruhe.

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