PHOTOGRAMMETRIC PLATE MEASURING FACILITIES AT NPL

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Abstract

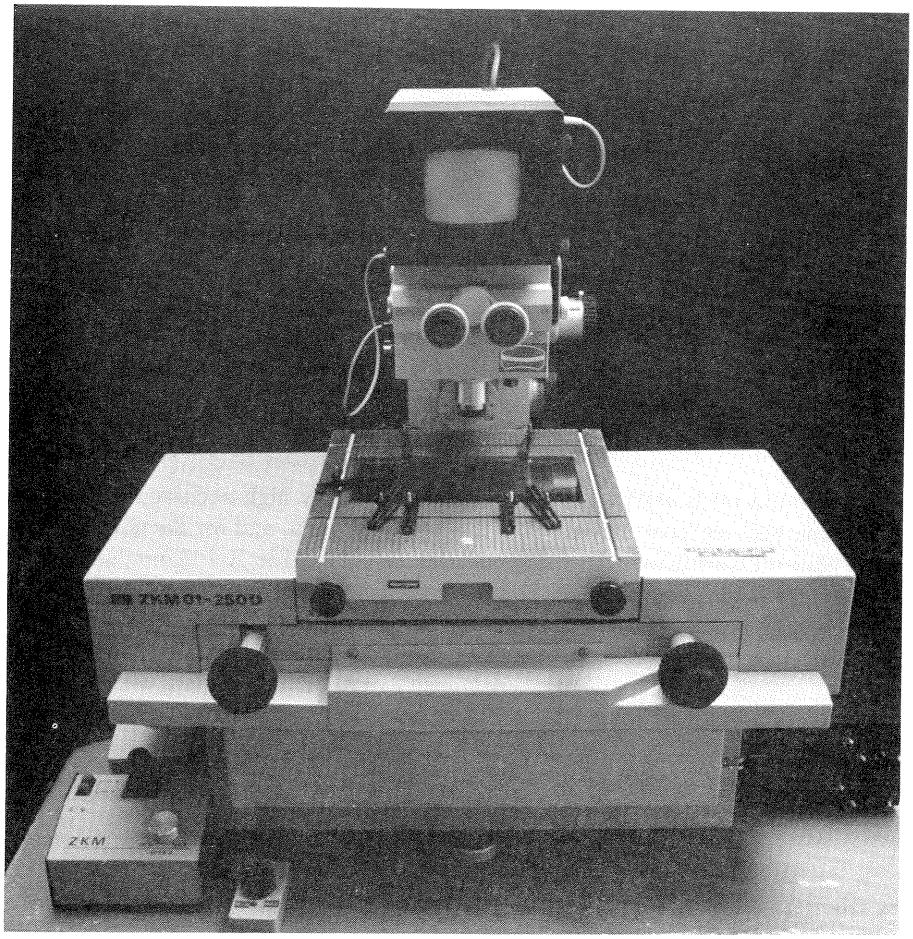
The National Physical Laboratory (NPL) has a requirement for very high accuracy plate measurements in the photogrammetry section, both for conventional (UMK10) photography, and for the new Centrax camera [1].
NPL has three main plate measuring machines, one covering an area of 130 X 250 mm, with an accuracy of about 0.5μm, and a resolution of 0.1μm is used under computer control for the measurement of UMK photography. A second machine covering an area of 100mm square, with an accuracy of 20nm ($^1/_{50}$μm) and a resolution of 10nm is used with a photoelectric setting system to measure Centrax plates. The third machine, which is still being developed, has a range of 265 X 230mm, with a repeatability of about 0.1μm, and will, when fully calibrated, be the most accurate machine of its type in the UK. This machine, working under full computer control, will be used to measure more than one UMK plate at the same time, and should eliminate most gross errors of measurement.

Introduction

Photogrammetry requires the position of images on photographs to be measured, and the accuracy with which this can be done greatly affects the final accuracy of the survey. Algorithms exist to take out lens distortion (provided it is regular) plate unflatness etc., but the final result relies on the measuring machine.
The measuring machine can, essentially, take one of two forms to achieve a high accuracy, either it can be very accurate as built, with measuring scales which are straight and orthogonal with uniform graduations, or it can be very rigid and repeatable and work with a correction algorithm or look-up table to give accurate results.
At the start of the photogrammetry project at NPL, the decision was taken to aim for the highest possible accuracy in the work, which meant using convergent photography, rather than stereo photography. At that time most of the photogrammetric plate measuring instruments were stereo machines, or stereo machines which had been modified to take only one plate. These machines were designed to produce the accuracy needed for general survey work using rather grainy photographic emulsions and fairly low viewing magnifications. Early work at NPL [2] showed that a change to high resolution emulsions would produce much better imagery and would allow much more accurate plate measurements to be made at high magnifications. Accordingly NPL bought a Zeiss Jena ZKM 01 250D measuring machine. This has a range of 130 x 250 mm, and can therefore cope with a UMK plate of 13 x 18 cms. It is designed as a general purpose measuring machine, and is therefore much more massive (and hopefully much more rigid) than a machine specifically for photogrammetry.

Zeiss Jena ZKM 01 250 D

As originally supplied this machine has Moire grating scales with a resolution of 0.1μm and an accuracy of about 0.5μm. The viewing system consists of a binocular microscope, with an overall magnification of between 10 and 100 depending on the objective, with a ground glass projection screen as an alternative. The stage is positioned by hand, and fine motion (with a range of about 5mm) is provided by hand wheels.
The machine was used in this form for several months, with the addition of a paper tape punch to record target coordinates, but is was felt that for large numbers of measurements the operator became fatigued too easily. Repositioning to a specified position was also found to be difficult as it relied on the operator watching two position displays to find the location. It was therefore decided to modify the machine with the addition of motor drives and a TV camera, so that the machine could be operated remotely under computer control.



The Zeiss ZKM

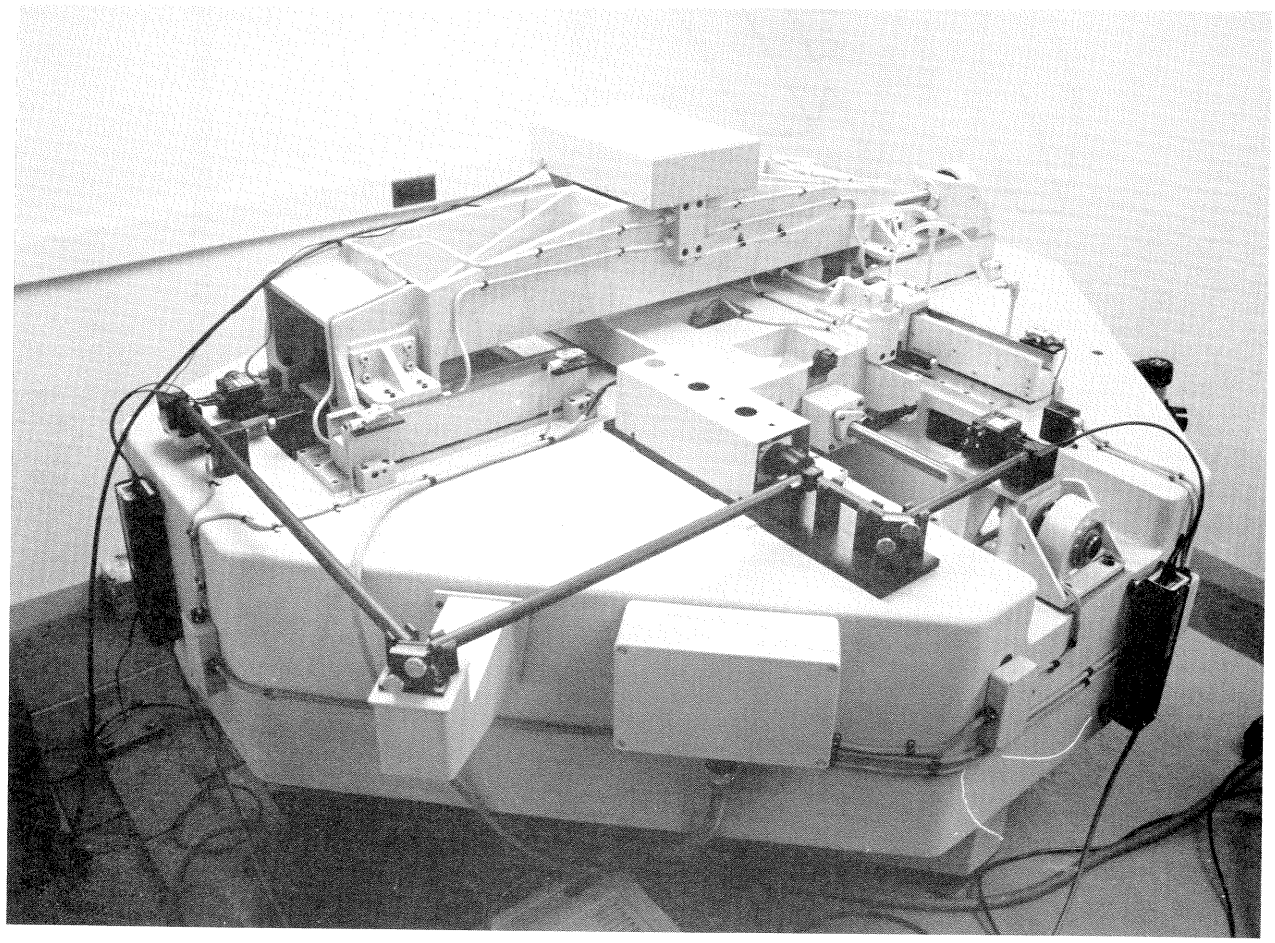
Because the machine is not fitted with full length lead screws, the motor drive system uses DC linear servo motors (made by Anorad), which give a positioning resolution of $^1/_{128}$ of the grating pitch (10μm in this case). These motors, and the position readout, are controlled by a small micro computer (BBC model B) so that the stage will move to any requested position, the operator can then centre the target on the graticule with a joystick, and record the target position directly onto computer disk. The data from this disk can then be transfered directly to the main frame computer at NPL for subsequent analysis. This process means that there cannot be any human error in recording coordinates. Also linked into the system is a digitising tablet, so that the operator can control the machine by positioning the cursor of the digitiser on a paper print of the plate being measured. This facility has proved very useful in the reading of plates at high magnification, in that positioning the digitiser cursor over the target on a paper print is very easily done, and always brings the target into the field of view of the microscope, whereas searching 'blind' on the plate is very tedious as the field of view may only be 0.5–1 mm across.
This machine has been the main one used to measure UMK photography at NPL to date, and has enabled NPL to offer a photogrammetry service to industry with an accuracy of 1 part in 10^5 of the camera field (e.g. for a 10m diameter antenna, photographed from 3 locations, an accuracy of 0.1mm can be realised. However, the introduction of the new Centrax lens has meant that to realise the full 1 part in 10^6 possible with the Centrax, a new measuring machine has had to be built.

The Centrax measuring machine

The NPL Centrax camera produces images unlike those of any other photogrammetric camera. The camera has a circular field of view, 50mm in diameter on the plate, with images of concentric circle form, with a ring spacing of about 2μm. These rings are sharply defined, and should be capable of being measured to about $^1/_{100}$ of a ring spacing (about 20nm) if a suitable measuring machine exists. Thus the problem was one of finding, and modifying, a machine or building a new machine from scratch.
The micro-electronics section at NPL have modified a Zeiss Jena ZKM 05–150 machine for their own use, to give

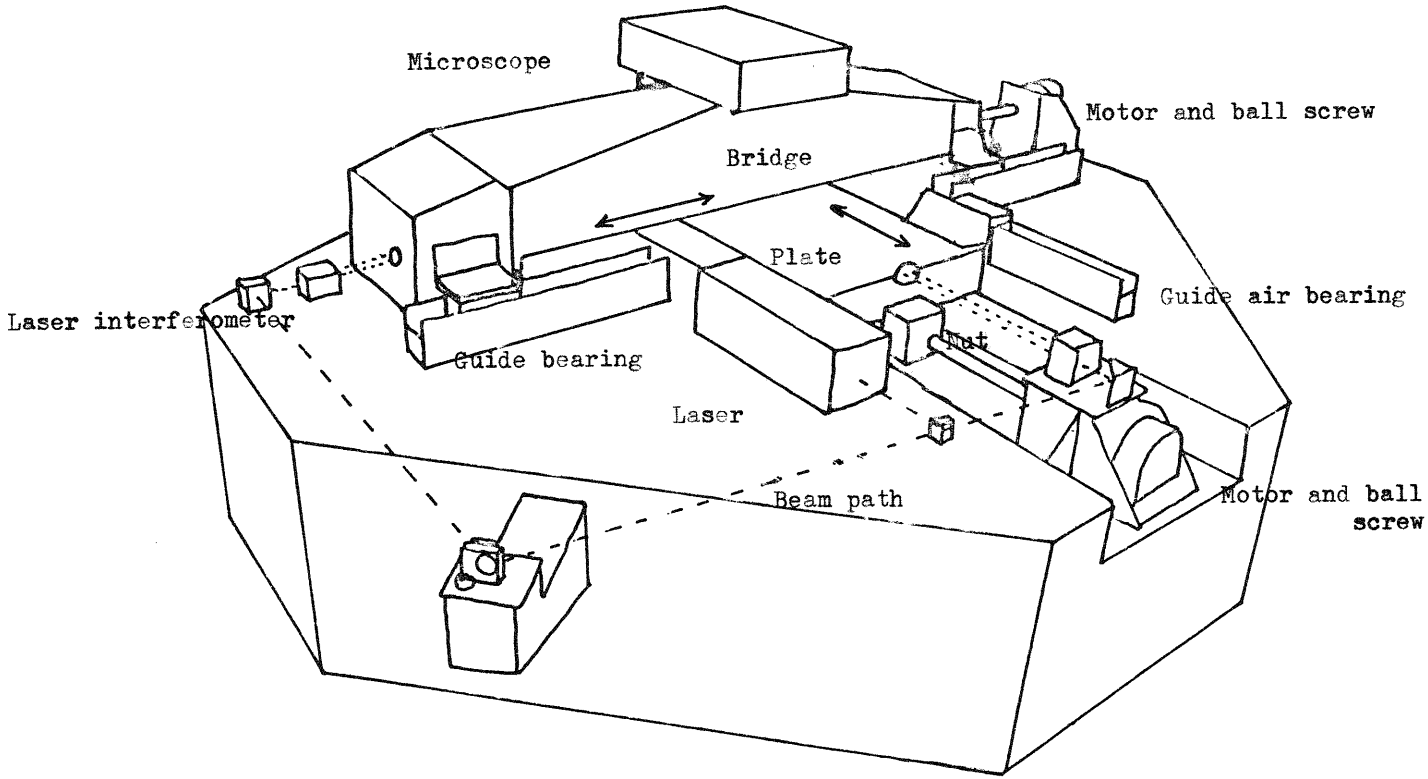
an accuracy of 20nm and a resolution of 10nm. This machine uses the basic Zeiss stage, to which has been added a Piezo-electric positioning system to give enhanced positioning capability, and a completely new optics and measurement system.
The measurement system consists of a square ring of fused silica, lapped flat and square to better than $\lambda/20$, which surrounds the plate to be measured, and forms the reflector for a plane mirror laser interferometer. Part of the measuring beam passes through the ring, and falls onto a position sensitive detector and provides correction for pitch, roll and yaw errors. The reference arm of the interferometer is linked to the microscope objective by fused silica rods, so that the measuring system is rigidly attached to the objective itself, and remains unaffected by small changes in temperature.
An air refractometer measures the refractive index of the air in the room in order to correct the wavelength of the laser.
A conventional form optical microscope views the plate, but for measuring Centrax plates this has been modified so that the illumination is in the form of a tightly focussed spot of light which tracks in a circle of radius equal to that of the first clear ring in the Centrax diffraction pattern. The transmitted light is then picked up by a photocell. The resulting signal will show fluctuations as an image tracks across the centre of the field, but will be uniform when the image is centred correctly. Thus the machine is able to measure Centrax plates (50mm in diameter) to better than 1 part in 10^6.
This machine has been used to prove the Centrax system to an accuracy of 2 parts in 10^6 (the main limitation on accuracy for this experiment was the thermal stability of the test object).

Large Plate Measuring Machine



The Large Plate Measuring Machine
(see also drawing)

In order to improve the accuracy of the photogrammetry still further, a more accurate plate measuring machine



LARGE PHOTOGRAPHIC PLATE MEASURING MACHINE AT THE NPL

than the Zeiss ZKM was required, and NPL contracted the Cranfield Unit for Precision Engineering (CUPE) to refurbish and upgrade an X-Y table in their possession to achieve a repeatability of better than 0.2μm.
The absolute accuracy of the stage was not specified in the original contract, and it is intended that the machine will be calibrated with an X-Y standard in order to produce a correction table within the control computer to enable the X-Y position to be determined with an accuracy of 0.2μm This machine has now been delivered to NPL, and is in the process of being commissioned.
The machine was built with stability and reproducability in mind, and consists of two separate air bearing slideways moving in orthogonal directions. The plate carrying stage is a simple plate with a glass platten capable of taking a 23cm square photograph, with a total movement of 235mm. This is lifted with four widely spaced air pads, and constrained to move in a straight line by air bearing pads running in 'U' shaped guides. The microscope is carried on a bridge structure which runs over the plate holder carriage, and is supported by air bearings at both ends, and has air bearing guides at both ends. The illumination system is carried by an inverted bridge below the plate holder, and attached to the microscope bridge through slots in the main base casting. The microscope/illumination assembly has a total movement of 260mm.
Both motions are driven by DC servo motor controlled ball screws, and position readout is by laser interferometers in the plane of the photograph.
The design of the machine is such that although the ways are not straight or orthogonal the repeatability of positioning is better than 0.1μm. This means that with suitable calibration the machine should achieve an accuracy of 0.2μm or better.
When complete this machine will be used to measure two UMK plate simultaneously (reading a point on one plate, then the other) so as to eliminate gross errors caused by point mis-identification (software in the control computer can perform an intersection to check).
Also fitted to the machine is a writing head, to enable grid plates etc. to be fabricated, again with an accuracy of 0.2μm over 235 x 260 mm.

Conclusion

The NPL has photographic plate measuring facilities that can cope with plates up to 23cm square, with a resolution of 0.1μm, or for smaller plates a resolution of 10nm (0.01μm). These machines are used in house for the measurement of plates from very high accuracy close range surveys, and are also available for use by outside groups when available.

References

1 Progress with the NPL Centrax camera system, J M Burch and C Forno International Archives of Photogrammetry, Vol 25/V

2 Factors defining precision in close range photogrammetry, J W C Gates, S Oldfield, C Forno, P J Scott and S A Kyle. International Archives of Photogrammetry, Vol 24/V1