EXPOSURE METERING AND CONTROL IN THE LMK AERIAL SURVEY CAMERA SYSTEM

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1. GENERAL

One of the main problems of aerial photographic technology and therewith of aerophotogrammetry is optimal exposure and processing of aerial negatives; because this is the first information for the total photogrammetric process. Shortcomings occurring in this connection can almost not be compensated.
Aerial photography represents an especially difficult case in the scope of applied photography due to different reasons. The already low brightness range of the objects to be photographed is differently diminished depending on the weather situation and flight hight. Small and low contrast details are especially concerned. This results in relatively high development gradations in opposition to the general pictorial photography, requiring again a very exact determination and observation of exposure parameters. A generally rapid change of the photographic scene has to be added, i. e. there are continuous changes of black-white distribution in consecutive photos.

An optimal exposure is then obtained if the total brightness range of the object has been represented in the density range of the photograph material having its highest resolution capability.
On the one side it is necessary to perceive the size of the object brightness range and to control film development in such a way that a gradation is obtained guaranteeing the above mentioned transformation. On the other side the intended development has to be considered already during taking photos because the effective film sensitivity which has to be applied for exposure measurement, can be highly influenced by the gradation, as is well known. A critical point always is underexposure, i. e. such a case that object details will not be represented in the range of the toe of the gradation curve or - in drastic cases - are not at all represented.

2. EXPOSURE MEASUREMENT AND CONTROL IN THE LMK AERIAL SURVEY CAMERA

With regard to the above mentioned problems high attention was paid to the questions of exposure measurement and control at the development of the aerial survey camera (5). It was the objective to develop a system which will cover the requirements mentioned and above all enabling even the unskilled operator with small practical experience to take air photos of highest quality. At first it had to be decided whether exposure measurement shall be made by a sensor with great acceptance angle on integral basis or by one with a small acceptance angle, that means on "differential" basis. The decision was made due to photographic reasons which will be explained hereinafter, in favour of the differential method. The realization of this measuring method was possible by the application of a microprocessor in the LMK in order to collect and process the necessarily incurring high data amount.

2.1. Factors for the selection of the differential measuring method

2.1.1. Determination of objective brightness range

The necessity to transfer the object brightness range by respectively selected exposure and development into a specified density range of the emulsion, is especially due to two reasons:

- Each emulsion has got optimum image forming qualities (1), (3), (4), (7) only in a certain medium density range. Position and size of this range is influenced by the object contrast (Fig. 1) as well as by the gradation (Fig. 2 and 3).

- It is necessary to fully utilize the available range in order to convert the generally very low object contrasts into possibly high image contrasts and to obtain therewith totally a high informative content of the aerial photo.

Consequently, depending on the object brightness range always a certain gradation shall be endeavoured at development (Fig. 3). The most favourable situation has to be found, so that, as shown in Fig. 2, the optimum, i. e. usable density range is enlarged with increasing gradation. The result is that the covered exposure range (object brightness range) is not decreasing with increasing gradation in such an extent as expected first of all due to the tangent ratio.[1)]

Due to the above, a well-founded knowledge of object brightness ratio is required in order to obtain an optimum result at aerial photography.

With regard to i n t e g r a t i n g exposure measurement only a medium brightness value is obtained, the size of which sonsiderably depends on incidental dark-white distribution on the object. Concerning the determination of brightness range you have to rely upon estimations requiring very high experience of the operator.

However, with regard to d i f f e r e n t i a l exposure measurement the object brightness range can be found with the required security by the determination of the brightest and darkest object details. Measuring possibilities can be even expanded if the same filter type is placed in front of the sensor of the exposure meter for the photo in case of intended use of antihaze filters. Then the contrast increase effected by the filter can be covered by the measurement, judged in its effect and considered in the gradation determination.

Presupposing that the sensor is sufficiently adjusted in its spectral sensitivity to that of the photographic material, furthermore the filter factor is simultaneously included in the result

1) It is desirable if the producers of aerial films specify density ranges which provide optimum image-forming qualities, in the same way as it is done for effective film sensitivity.

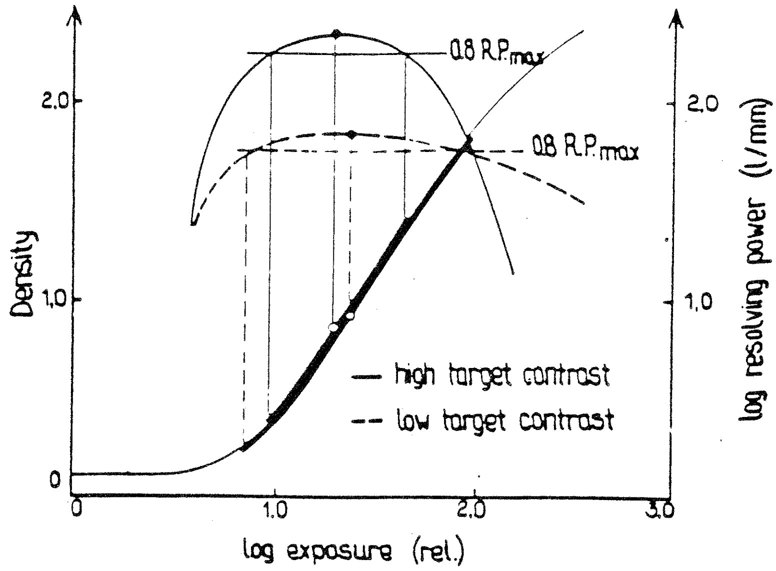

Fig. 1 Resolving power (RP) of emulsion for high and low object contrast in dependence on exposure. The optimum density range of emulsion is here determined by the RP > 80% of RP_{max}.

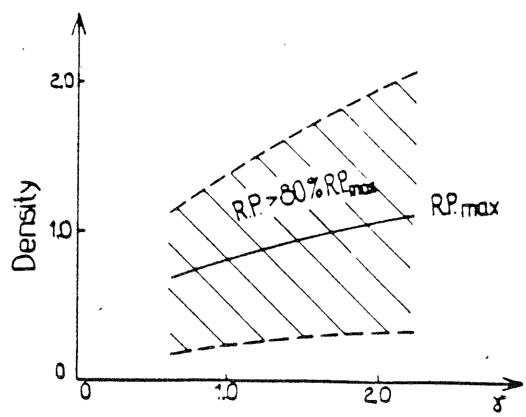

Fig. 2 Position of the maximum resolving power and the optical density range as a function of gradation (represented for low object contrast)

during measurement.

2.1.2. Determination of the exposure parameters

For the determination of the exposure parameters always the effective sensitivity of the film used has to be taken as basis in aerial photography.Effective sensitivity differs from the nominal sensitivity of a film in such a way that it cannot be determined under standardized conditions with a fixed low gradation adjusted to the requirements of general, pictoral photography but under practical conditions of gradations as usual in aerial photography, which, as we have seen above, are essentially steeper in general. However, steeper gradations mean in any case gain of sensitivity.
Todays customary sensitivity systems after DIN (9) and ASA (8) apply as sensitivity criterion a value of 0.1 density units above the fog, i. e. a value in the range of the lower toe of the gradation curve (Fig. 3); and here begins the difficulty for the integrating exposure measurement because it refers to a medium object brightness value which can be found in the medium range of the gradation curve depending on the black-white distribution appr. in the range of the maximum resolution capability. As shown in Fig. 3, this range has got an essentially greater dynamic with increasing steepness of the gradation than the DIN or ASA criteria. Therewith the integral exposure measurement is missing a true relation towards this system, considering, as we have seen above, that the object brightness range can only be estimated. Therewith underexposure is easily possible, unless right from the beginning sufficient safety factors are included. Therefore the Soviet GOST standard and the CSN standard of CSSR provides especially for aerial photography sensitivity criteria with 0.85 density units above the fog corresponding approximately with the position of maximum resolution capability, which includes this condition.

In differential exposure measurement one can easily orient oneself by DIN or ASA criteria with knowledge of the brightness minimum. In opposition to pictoral photography which only requires that "detail is still recognizable in shadow areas", however, the exposure metering system will be designed with an addition of appr. 0.2 to 0.3 density units, so that even the darkest details will be photographed in the optimum density range.

2.1.3. Practical exposure measurement

Even in the practical performance of exposure measurement the integral measuring method clearly differs from the differential. Furthermore both methods have got differences that depend on the intended use of the measured value i. e. for manual setting of the exposure parameters or for automatic control of exposure.

In integratin exposure measurement for manual setting it is reasonable to study the measured values for a certain period and, in order to avoid underexposure, to take the highest exposure value determined for setting. The automatic control of exposure on the basis of integrated measured values seems to be problematic. In general it is performed in such a way that for the exposure of each photo the measured value directly pertaining to it is used.

Necessarily this results in underexposure if single dark objects are distributed on a large ground area with a bright object structure, or if dark areas adjacent to bright areas are included, because they are registered by the sensor but only proportionately included in the measured result.

The d i f f e r e n t i a l exposure measurement as already explained, will orient itself on the darkest details, in any case. For measurement with manual exposure meter it is sufficient to check the actuality of the respective last measured value in certain periods as for the integrating measurement. For automatic exposure control it is necessary to process the measured values continuously collected in such a way that the respective minimum values, by appropriate evaluation remain determinative for the control process for a longer period. Basically it can be assumed that the minimum values are determined by certain, generally recurrent dark ground structures as wood, moorland, newly ploughed fields, dark elements in the settlements etc., whereas expecially on photos from low flight height the object shadow plays additionally a great role. The brightness of these minimum values is practically only changed due to a long-time change of the sun's altitude or appearance of high clouds, or in large areas due to differently compact high clouds or certain meteorological effects such as different haze distribution etc. Only these modifications have to be considered by the control system.

Figure 4 illustrates once again the essential differences between integrating and differential exposure measurement by a simple example.

A wooded area with a diffuse reflection factor of 0.04 to 0.06 (mean value 0.05) is followed during overflight, within sequential exposures, by bright fields with a diffuse reflection factor of 0.15 to 0.25 (mean value 0.20) (Fig. 4a). The illustrations below the photos (Fig. 4b and c) indicate in a sequence of gradation curves by expansions those areas, in which the contents of the respective photograph are images. The respective sensitivity criterion is marked with a point on the gradation curves, that is for the integrating exposure measurement at D = 0.95 (or 1.05 resp.) and for the differential exposure measurement at D = 0.04. The measured values applicable for the calculation of the exposure parameters are written to the respective gradation curves. To simplify matters, the diffuse reflection factors of the reference areas or the mean diffuse reflection factors resulting from integrating measurement were adopted as measured values. The diagrams of the gradation curves are furthermore supplemented by the position of the highest resolution capability of the emulsion (horizontal line at D = 0.95) and the best image range (between interrupted lines at D = 0.4 and D = 1.6).

A gradation of $\gamma = 1.5$ was selected for the mentioned example. It results from the best image range $\Delta D = 1.2$ and the exposure level resulting from the object brightness $\Delta \lg H = 0.8$ according to

$$\gamma = \frac{\Delta D}{\Delta \lg H} \qquad (1)$$

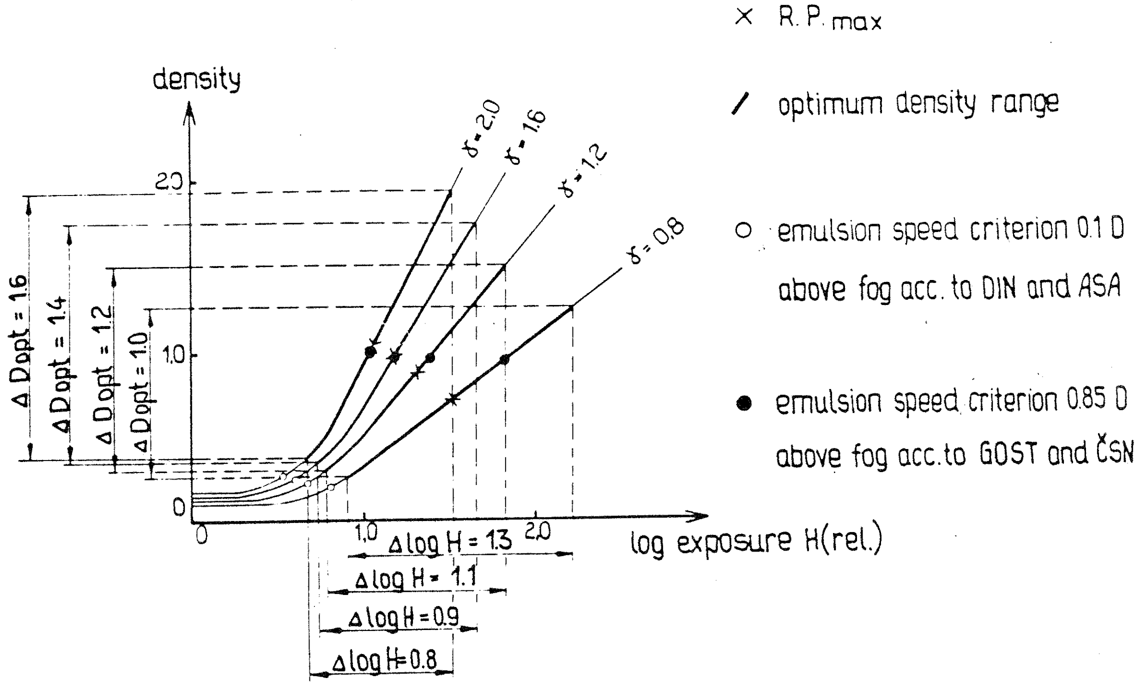

Fig.3 Conversion of different object brightness ranges (Δlog H) into the optimum imaging range (ΔD_{opt}) of an air-photo emulsion by varying the development in order to get different gradations (γ)

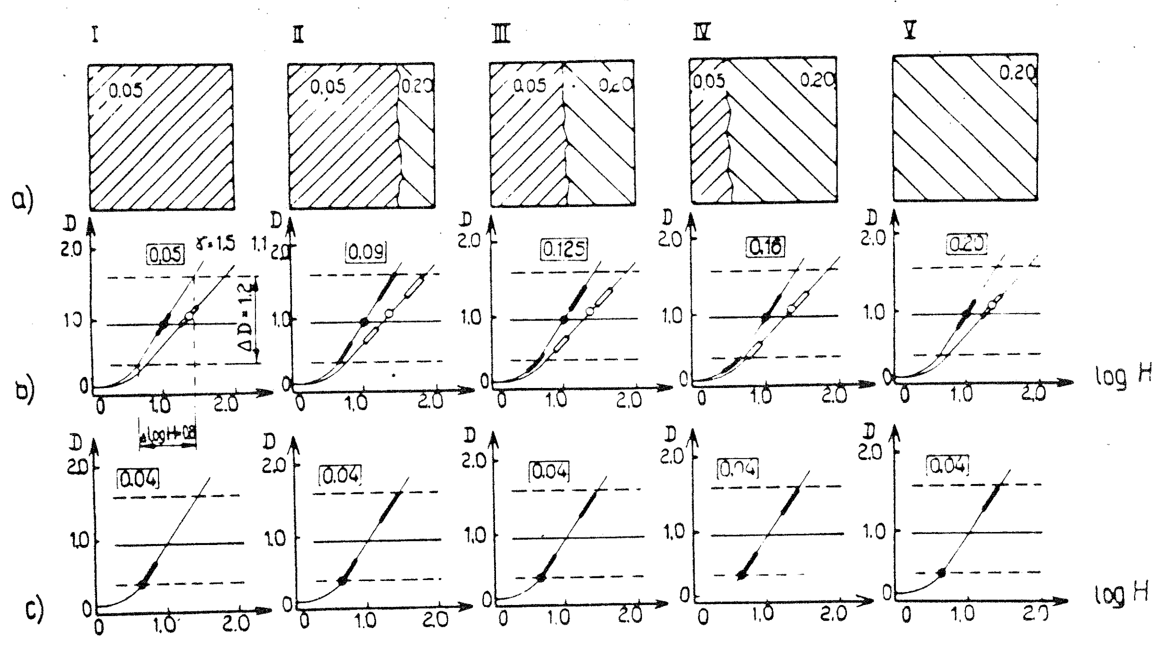

Fig. 4 Comparison of the integral and differential measuring methods regarding the acquisition and imaging of bright and dark terrain regions

a) representation of brightness-darkness distribution
b) integral measuring method
c) differential measuring method

As shown, for the integrating measurement images are within the optimum density range only for photos with a uniform object structure (I and V) as well as for photos where the dark proportion of wood is dominating (II). Already in photos of a bright-dark distribution with the ratio 1:1 (III) and especially those with a very small proportion of dark wood (IV) the wood areas are clearly underexposed. Due to the respectively different evaluation of the general image contents a continuous change of the density values occurs. The result is that the wood area covering the whole image (I) is imaged in the same medium density range as the bright field area covering the whole image (V). According to experience these density changes cause considerable difficulties in photographic processing, for instance for photo mapping.
In general the shifting of the density values results in an apparent increase of the object brightness range, which cannot be located in the optimum density range with the gradation used. It can only be improved by selection of a lower gradation and - due to the asymmetry of the density range - a displacement of the sensitivity criterion (example with $\gamma = 1.1$). This necessarily results in an image with lower detail contrast and moreover in a lower effective sensitivity.

These problems, as can be seen, do not exist for the differential measurement. Irrespectively of bright-dark distribution in the object, always the same object brightness is rendered in the same density range of the emulsion if it is ensured that the determined minimum value of the object brightness is stored in a suitable way during an appropriate period for the determination of the exposure parameters.

2.2. Instrumental realisation

2.2.1. The measuring system

The measuring system is located in the lens cone directly beside the lens. It consists of a photoelectronic sensor, on which the ground section is projected by a lens. A logarithmic amplifier with high input sensitivity and large work range directly follows the sensor, the output voltage values of which are fed to a microprocessor in the control unit of LMK after respective analogue-todigital conversion.

The acceptance angle of the measuring system is based on the diameter of the sensor (d = 1.2 mm) and the focal length of the lens (f = 55 mm). It amounts to 1.4 gon and is therefore small enough to take in the brightness of areas shadowed by buildings or trees in case of largescale projections from a low flight height. Visibility of detail in shadow ranges plays an important role especially in these scales.

In order to keep falsification of measured values by straylight as low as possible, special attention was paid in the conception of the optical measuring system to keeping this as low as possible.

Spectral sensitivity of the sensor has been largely adjusted to that of customary panchromatic air-photo emulsion

(Fig. 5). As the photodiode used (on silicium base) has got its sensitivity maximum at $\lambda = 800$ nm, i. e. it is sensitive up to the near infrared region, an absorbing filter is used limiting the sensitivity region at 700 nm and taking into consideration simultaneously the sensitivity reduction of the emulsion by the camera lens in the short-wave visible range. Due to the good balance obtained, it is possible to utilize completely the above advantages of differential exposure measurement with regard to the determination of contrast increase by filters and automatic consideration of the filter factor. According to the arrangement of the sensor system a second analogue filter has been assigned for the sensor (Fig. 6) to each colour filter for exposure in the same filter mounting in addition to the camera lens (Fig. 6).

2.2.2. Reduction of measured values

The measuring system has been developed in such a way that the brightness values are registered continuously in the flight route. The measuring values are interrogated with a frequency of 38 Hz and fed to the microprocessor. Frequency has been selected in such a way, that with the maximum travelling grid speed in the control unit, i. e. the highest v_g/h_g ratio produced by LMK[2] each object detail will be sensed at least 4 times during passing of the sensor face, i. e. it is scanned with a longitudinal overlap of appr. 75 %. With decreasing v_g/h_g ratio the longitudinal overlap increases and reaches a value above 99 % with the minimum travelling grid.

From the measured values obtained in such a way the microprocessor selects continuously the 5 lowest and 5 highest values each, from groups of at least 100 measured values and calculates the values $(E)_{min}$ and $(E)_{max}$ by averaging. These basic values calculated block-wise are subject to damping before further processing. Here the above mentioned requirement isconsidered that in the differential exposure control the respective minimum values determine the control process by respective evaluation during a longer period. This requirement is applicable in the same way for the respective maximum values with regard to the calculation of gradation performed in the LMK.

Damping is made in such a way that the values $(E)_{min}$ and $(E)_{max}$ obtained from each following block are only included in a certain percentage into the value E_n used for exposure control or gradation determination, resp., in proportion as they are greater or smaller than the preceeding value E_{n-1}. For exposure control,

$$E_{min_n} = E_{min_{n-1}} - 0.2 \; (E_{min_{n-1}} - (E)_{min_n}) \quad \text{for} \; (E)_{min_n} < E_{min_{n-1}}$$

$$E_{min} = E_{min_{n-1}} - 0.01 \; (E_{min_{n-1}} - (E)_{min_n}) \quad \text{for} \; (E)_{min_n} > E_{min_{n-1}} \qquad (2)$$

2) v_g = flight speed over ground
h_g = flight height over ground

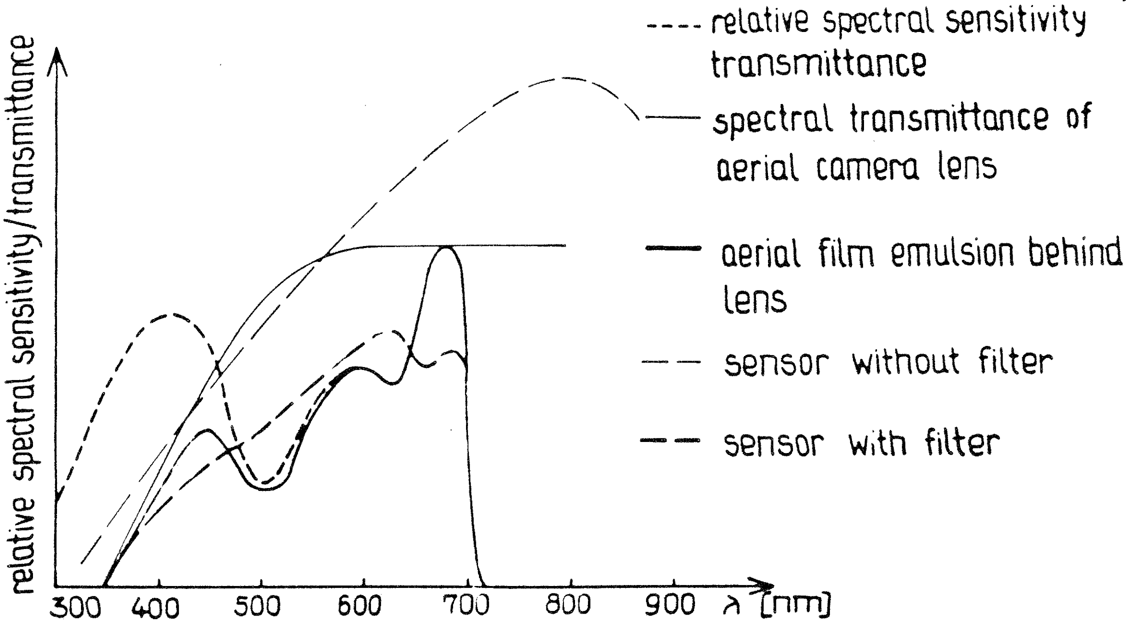

Fig. 5 Spectral sensitivity of the sensor in comparison to the typical spectral sensitivity of black and white aerial photo emulsions

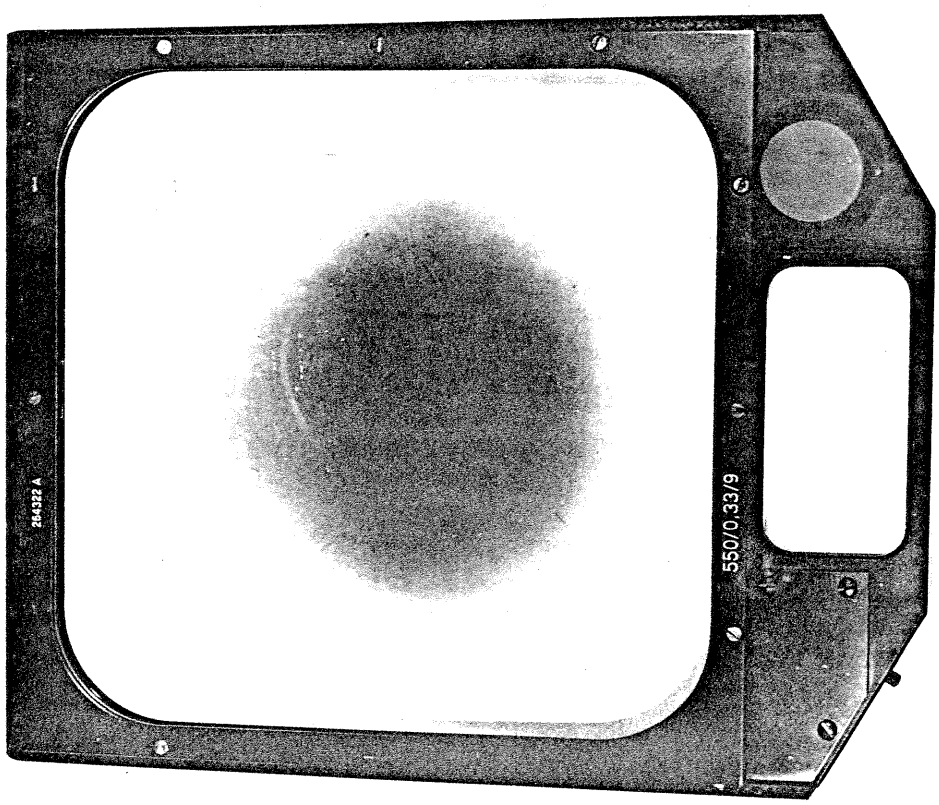

Fig. 6 Colour filter of an LMK lens cone with filter for the exposure metering system

and for gradation determination

$$E_{min_n} = (E)_{min_n} \qquad \text{for} \quad (E)_{min_n} < E_{min_{n-1}}$$

$$E_{min_n} = E_{min_{n-1}} = 0.01 \; (E_{min_{n-1}} - (E)_{min_n})$$

$$\text{for} \quad (E)_{min_n} > E_{min_{n-1}} \tag{3}$$

$$E_{max_n} = E_{max_{n-1}} = 0.01 \; (E_{max_{n-1}} - (E)_{max_n})$$

$$\text{for} \quad (E)_{max_n} < E_{max_{n-1}}$$

$$E_{max_n} = (E)_{max_n} \qquad \text{for} \quad (E)_{max_n} > E_{max_{n-1}}$$

Fig. 7 shows the effect of measured value damping in a schematic example. The block-by-block averaged values $(E)_{min}$ and $(E)_{max}$ as well as the sequences of the measured values E_{min} and E_{max} obtained according to above formulae are represented. As shown, the dominant minimum and maximum values determine calculation of the exposure parameters or gradation, resp. during an adequate period.

2.2.3. Determination and input of exposure parameters

The exposure parameters are determined in such a way that the value for the diaphragm (f-stop number k) and film sensitivity (x in DIN) are fed to the microprocessor by setting elements at the control unit. Including the values E_{min} it calculates the exposure time t_{nom} according to the following formula:

$$t_{nom} = \frac{k^2 \cdot c_R \cdot 10^{-\frac{x}{10}}}{E_{min}} \tag{4}$$

Figure c_R is a calibration constant which includes among others the medium transmittance τ_{MK} of the camera lens and τ_{BM} of the exposure meter lens as well as its f-stop k_{BM}.

$$c_R = H_o \frac{\tau_{BM}}{\tau_{MK} \cdot k^2_{BM}} \quad [lxs] \tag{5}$$

The value H_o corresponds to the sensitometric constant in the basic formula for sensitivity determination of photographic emulsion according to (9) or (10) resp. There it has the figure 1.0 (lxs) for negative material for pictorial use, but for the determination of the exposure value in the LMK exposure measuring system it was stipulated with 1.6. Therewith the sensitivity point was practi-

cally raised by appr. 0.2 density units to a value of $\Delta D = 0.3$ above the fog guaranteeing therewith that this value is not lower in the exposed negative.
The exposure time calculated by the microprocessor is indicated at the control unit as t_{nom}. With disconnected exposure automatic this value is manually supplied, but with connected automatic system the microprocessor directly controls. Exposure time as well as diaphragm are controlled. Based on the preset diaphragm the system switches over to the following smaller or larger diaphragm in case of exceeding the control range of the exposure time. In case of downward control movement the diaphragm preset by the operator will have priority. It is not necessary to consider a certain exposure time limit with regard to minimizing the image motion in the LMK system due to the existing image motion compensation. In case the controlling range of exposure time and diaphragm is not sufficient, then it is indicated to the operator by flickering of the exposure time figure.

2.2.4. Gradation determination

The reduction of measured values for the gradation determination has already been explained above. Including the values E_{min} and E_{max} as well as the value ΔD preset by the operator and set at the control unit, the microprocessor calculates the gradation value according to [3]

$$\gamma = \frac{\Delta D}{\lg E_{max} - \lg E_{min}} \qquad (6)$$

This value is subjected to additional attenuation and then indicated as gradation recommendation on the control unit.

2.3. <u>Practical handling</u>

Due to the specific character of the LMK exposure measuring system, some instructions are necessary for practical operation.
The described determination of measured values requires a continuous flight over the area to be photographed. Due to this reason exposure measurement is not possible from a "standing" position as it may be the case from a helicopter. In this case a representative exposure value should be determined by flying over a characteristic ground area, and exposure should be made by manual setting of this value. The same method will be applied for gradation determination.

If the sensor, due to certain reasons, for instance by changing filters or any other short-time closing of the bottom-hatch, is temporarily fully covered, then, due to the above measured value dampling, real figures will only occur after a relatively long delay. In this case it is reasonable to restart the programme by means of the release key mounted at the control unit.

[3] This formula corresponds with formula (1). Due to $H = E \cdot t$ and $t = const.$, $\Delta \lg E = \lg E_{max} - \lg E_{min}$ can be used instead of $\Delta \lg H$.

ABSTRACT

One of the main problems of aerial photography consists in optimum exposure and further processing of aerial negatives. An optimum exposure will be obtained if the total brightness range of the object is projected in the density range of the photographic material where it has got its highest resolving capability. The article describes the problems of solving these tasks. Integral and differential exposure measurement are compared. Practical operation of the LMK exposure measuring system from Jena is described.

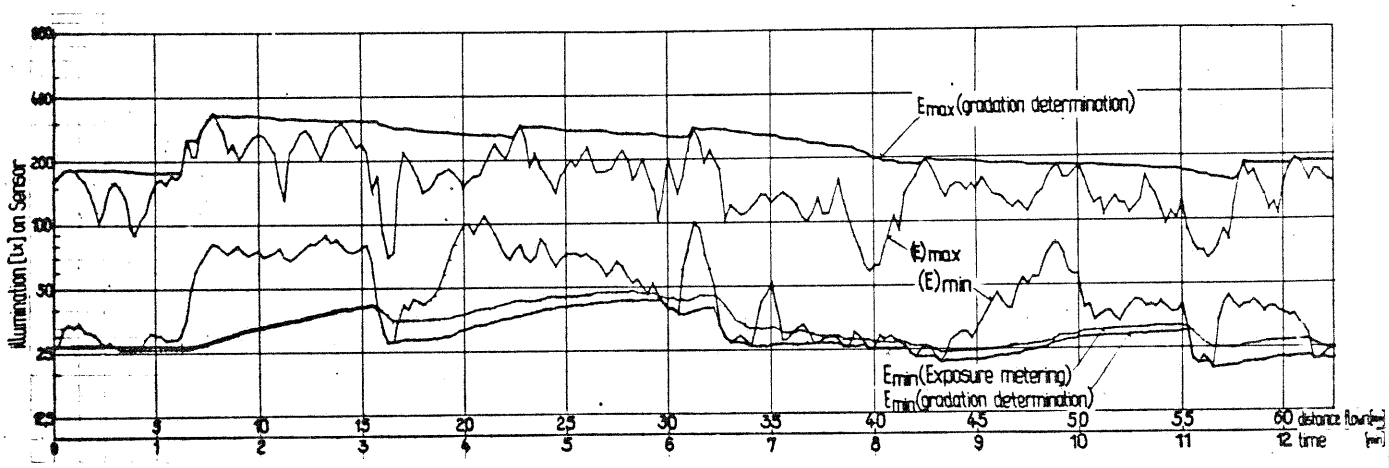

Fig. 7 Effect of smoothing the measured values

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(8) ASA PH 2.5-1960 American Standard Method for Determining Speed of Photographic Negative Materials (Monochrome, Continuous Tone)

(9) DIN 4512 Photographic Sensitometry, Determination of photosensitivity of Black-White-Negative Material for photographs

(10) TGL 143-408/12 Photosensitive Silver Halide Recording Material on Transparent Base, Determination of General Sensitivity