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Modelling of acutance dye influence on the image sharpness in heterogenic light-sensitive layers*

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In this paper, the results of theoretical examinations of the influence of acutance dyes contained in light-sensitive layers on the modulation transfer function and the image sharpness are presented. A significant increase of the photographic image quality was confirmed which resulted from diminishing the harmful influence of the scattered actinic radiation. The results obtained have been presented in the form of changes in both the modulation transfer function and the values of state indicators of image sharpness as dependent on the acutance dye concentration in the light sensitive layers.

1. Introduction

The exposure is one of the most important stages of the photographic recording influencing the quality of the images obtained. In the course of this process the light beam penetrates the silver halogen photographic layer which is composed of silver halogen crystals suspended in gelatin. In order to produce a photographic image in such a layer a part of radiation incident on the light sensitive layer must be absorbed by the crystals. On the other hand, the light which has not been absorbed is subject to scattering and reflection or passes through the layer without causing any effects. Depending on the sizes and spatial forms of the silver halogen crystals the light scattering can be caused by diffraction at the crystals or reflection from their surface. The scattered light penetrates the light sensitive layer in different directions interacting with the crystals located outside the place of light beam incidence which changes the topography of the photographic image (Fig. 1a).

Due to these effects the acutance and the resolving power of the image suffers from worsening. For the sake of comparison, the profile of the distribution function of the effective exposure inside the light sensitive layer has been presented at the border between strong and weak exposures in the cases of light scattering and without this effect (Figs. 1**a**, **b**). Thus, the lack of scattering of actinic radiation can be considered as an ideal one, though rarely occurring in the practice of

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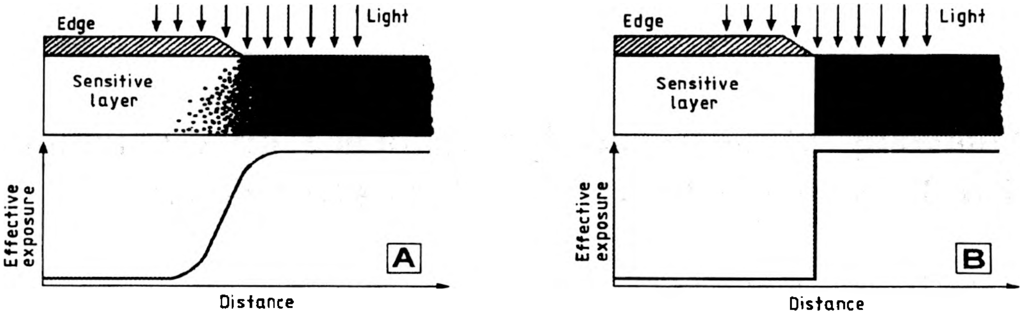

Fig. 1. Distribution of the effective exposure in the light sensitive layer at the image-background border (fields of strong and weak irradiation) shown for two cases: **a** — when light scattering effect occurs within the heterogeneous light sensitive layer, **b** — for the lack of light scattering effects.

exploiting the silver halogen light sensitive materials (Lippman materials exposed to the light or defectoscope materials expanded to the X-ray irradiation).

In order to limit the intensity and range of the light scattered inside the photographic layer the so-called acutance dye can be introduced [1]. The latter absorbs a part of radiation the silver halogen is sensitive to, thus changing the sensitometric properties of the light sensitive layer. The respective changes in contrast are especially essential from the point of view of sharpness which diminishes with an increase of acutance dye concentration.

The consequences of the scattered light diffusing within the light sensitive layer are described by the line spread function (LSF) first determined and described by Frieser [1], [2]. The systems of low light scattering can be described by the Frieser equation (below) and are called in this case the first approximation of the line spread function

$$L(x) = \frac{2.303}{K}\, 10^{-(2|x|)/K} \tag{1}$$

where: $L(x)$ — line spread functions, x — distances from the place of incidence, K — Frieser coefficient of the first approximation.

On the other hand, the case of strongly scattered light is described by the Frieser equation (2) called the second approximation of the line spread function

$$L(x) = \rho\, \frac{2.303}{K_1}\, 10^{-(2|x|)/K_1} + (1-\rho)\, \frac{2.303}{K_2}\, 10^{-(2|x|)/K_2} \tag{2}$$

where: K_1 and K_2 — Frieser coefficients of the second approximation.

The quality of the photographic image, depending on the needs, can be defined with the help of different functions and structurometric indicators. In the examinations concerning the light scattering in the photographic layers the modulation transfer functions and indicators of the acutance are the most important indicators of the image quality. The modulation transfer function expresses the dependence of the coefficient defined by ratio of the recorded optical signal modulation M' to the original signal modulation M as a function of spatial frequency (3). The increase of spatial frequency is inversely proportional to the size of the imaged detail in the photographic image

$$T(\nu) = \frac{M'(\nu)}{M(\nu)}. \tag{3}$$

The modulation transfer function is strictly connected with the line spread function. For the systems weakly scattering the light, for which the first Frieser approximation described by Eq. (1) is applicable, the modulation transfer function is described by the equation

$$T(\nu) = \frac{1}{1+\left(\frac{\pi K \nu}{2.303}\right)}. \tag{4}$$

On the other hand, for the strongly scattering systems consequently described by the second Frieser approximation the MTF is calculated from equation

$$T(\nu) = \frac{\rho}{1+\left(\frac{\pi K_1 \nu}{2.303}\right)} + \frac{1-\rho}{1+\left(\frac{\pi K_2 \nu}{2.303}\right)} \tag{5}$$

where: $T(\nu)$ – modulation transfer function, ν – spatial frequency, K, K_1, K_2 – Frieser coefficients consistent with the coefficients in Eqs. (1) and (2).

The simplest estimation procedure of the sharpness in the image is offered by the analysis of the so-called limiting curve which reflects the spatial distribution of the optical density as a function of the distance at the border between the weakly irradiated field and that strongly irradiated (the image-background border). From such curves the indicators of acutance can be determined which are strictly related to the subjective impression of sharpness registered by a human being. In our examinations the acutance indicators based on r.m.s. gradient of the limiting curve [3]–[5] expressed by Eq. (10) were used in addition to average gradient expressed by Eq. (6). The way the r.m.s. gradient was calculated is shown in Fig. 2. In the calculations, the following formulae are used:

$$G_{av} = \frac{D_B - D_A}{x_B - x_A}, \tag{6}$$

$$g = \frac{\bar{G}^2}{D_B - D_A}, \tag{7}$$

$$\sigma = \frac{\bar{G}^2}{x_B - x_A}, \tag{8}$$

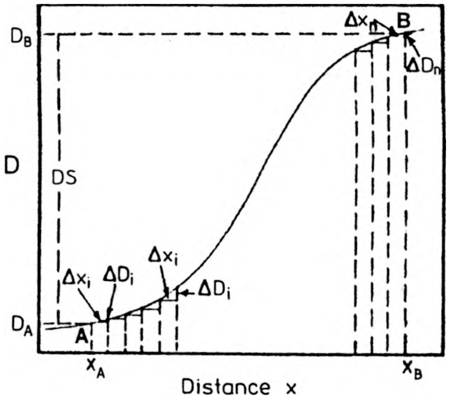

Fig. 2. Border curve for which the way of calculating the r.m.s. gradient was illustrated.

$$A = \frac{\bar{G}^2}{(D_B - D_A)(x_B - x_A)}, \tag{9}$$

$$\bar{G}^2 = \frac{\sum\limits_{i=1}^{n} (\Delta D_i/\Delta x_i)^2}{n}. \tag{10}$$

2. Model characteristics

In our examinations the model was used the functioning of which is shown in the scheme (Fig. 3). In the first stage the experimental line spread function ($\mathrm{LSF}_{\mathrm{exp}}$) was fitted to Frieser function represented by Eq. (2). This has been done by finding the optimal values of the coefficients ρ, K_1 and K_2. The optimization was carried out using the method of least-square method. As $\mathrm{LSF}_{\mathrm{exp}}$ the results obtained from the model based on Monte-Carlo method, described in [6], [7], were exploited. The

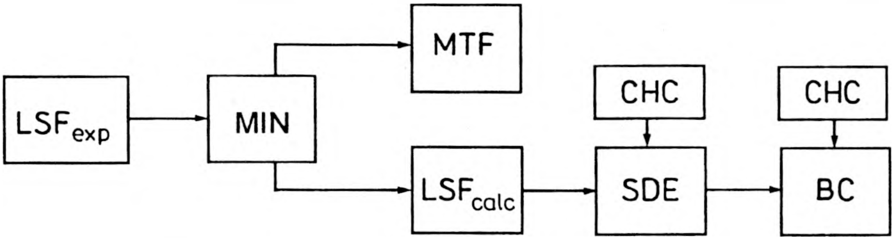

Fig. 3. Scheme illustrating the course of the model contour sharpness examinations for the photographic images. $\mathrm{LSF}_{\mathrm{exp}}$ — experimental line spread function obtained from the model, MIN — modulus calculating the optimal values of the coefficients: ρ, K_1, K_2 of the theoretical Frieser equations, MTF — modulus calculating modulation transfer function from the Frieser equation, $\mathrm{LSF}_{\mathrm{calc}}$ — modulus calculating the line spread function from Frieser equation, SDE — modulus calculating the spatial distribution of exposure inside the light sensitive layer, BC — modulus calculating the border curve taking account of the theoretical characteristic curve.

essential modelling parameters were:

1. The value of the ratio of the layer thickness (LT) to the free path of the photon (FPP). For typical real light sensitive films the value of LT/FPP was 1.0 to 10.0.
2. The value of the ratio of average free path of the photon to the average free "dye" path of the photon, *i.e.*, FPP/AFDP. This parameter is proportional to the dye concentration in the layer.

In the second stage the theoretical $\mathrm{LSF}_{\mathrm{calc}}$ and the MTF were calculated by substituting the coefficients ρ, K_1, K_2 to Eqs. (2) and (5). In the third stage the conditions of light field H_1 and dark field H_2 exposures for the limiting curve were defined. The exposure H_1 corresponds to normalized transmission $T = 0.9$, while the exposure H_2 was twice as great as H_1 ($H_2 = 2H_1$) [8]. In the fourth stage the spatial distribution of the exposure (SDE) was calculated by integrating the theoretical line spread function ($\mathrm{LSF}_{\mathrm{calc}}$) and normalizing the obtained values in the range from H_1 to H_2. In the last stage the value of optical density was calculated from the particular values of the spatial distribution of the exposure using the characteristic curve (ChC). In this way the function called the border curve (BC) was obtained from which the indicators of the acutance were determined.

The model described was exploited to calculate the influence of the acutance dye on the sharpness of the photographic image. The influence of the dye concentration on the shape of modulation transfer function and border curve was examined. In Figures 4 and 5, the MTF as well as the border curves were determined for three dye concentrations in the photographic layer. The light sensitive layer thickness is denoted as LT and expressed in micrometers. Besides, the changes of the static values of the image sharpness indicators are analysed as dependent on the acutance dye concentration in the layer while the results are presented in Fig. 6 where the dye concentration is denoted as the value of DC.

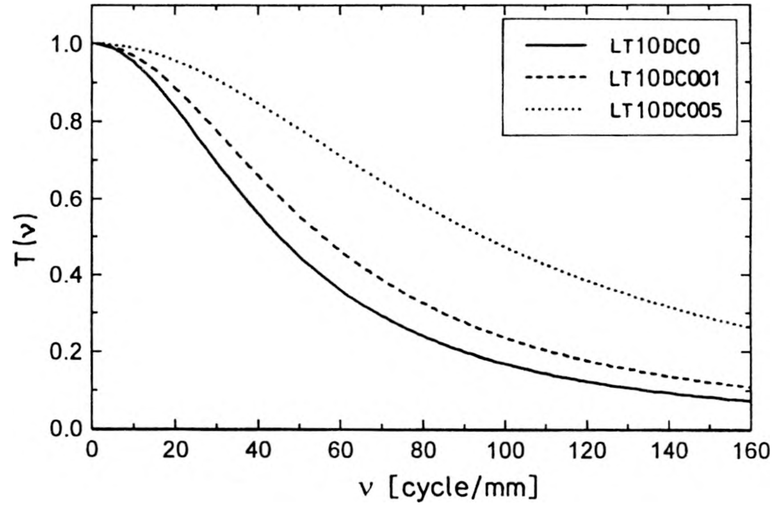

Fig. 4. Curves of the MTF obtained for the light sensitive layers of thickness equal to LT = 10 and the acutance dye concentration in the layer amounting to 0, 0.01, 0.05.

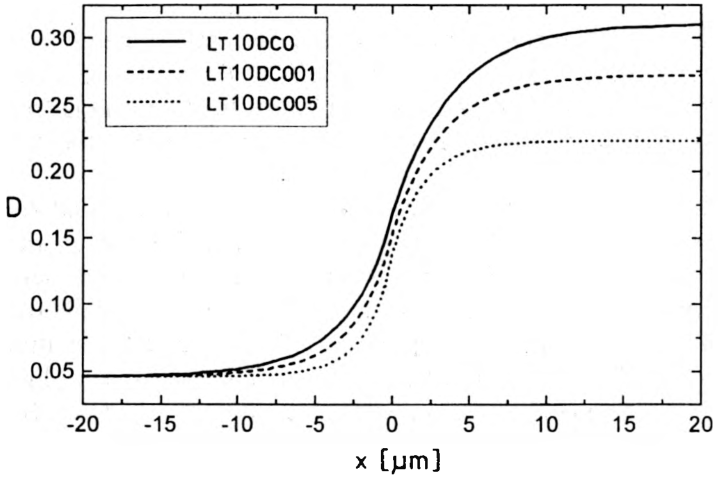

Fig. 5. Border curves obtained for the light sensitive layers of thickness equal to LT = 10 and for the acutance dye concentration in the layer amounting to 0, 0.01, 0.05.

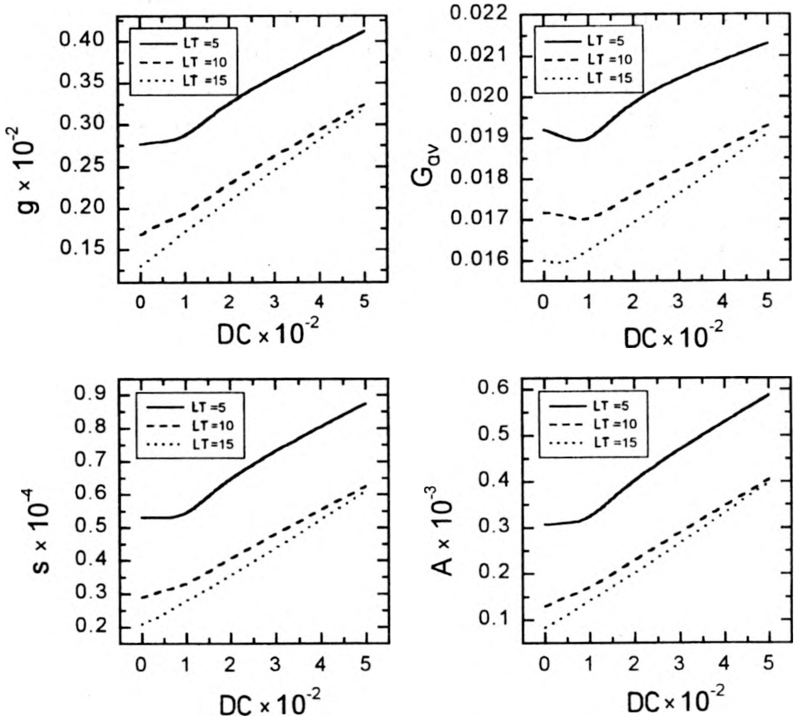

Fig. 6. Changes in the contour sharpness indicators as a function of acutance dye concentration in the light sensitive layer of thickness 5, 10, 15 μm. G_{av} denotes the average gradient of the border curve, g denotes the sharpness indicator suggested by Jones and Higgins, while s — that proposed by Müller and A — that proposed by Perrin.

3. Conclusions

On the basis of the results obtained, it can be concluded that the sharpness of the photographic image increases with the acutance dye concentration in the light sensitive layer. This is confirmed by the value of the MTF illustrated in Fig. 4 and the increase of the static indicators of the image sharpness shown in Fig. 6. The decrease of the average gradient of the border curve (B_{av}) for lower dye concentrations shown in Fig. 6 follows from the decrement of the average gradient of the characteristic curve which is used to calculate the optical density distribution in terms of exposure distribution. For the higher acutance dye concentrations the decrease of B_{av} caused by decrease of the average gradient of the characteristic curve is compensated by the increase of B_{av} following from the lower light scattering in the layer. The other indicators of the acutance have a similar distribution as that of B_{av} only for the thinnest layer.

The formation of the image in the photographic layers weakly scattering the light can be considered as being composed of two images, one of which is "perfectly sharp" being expressed the Dirac delta function normalized to unity while the other is diffused being expressed by the Frieser function. In the analysis carried out for the shape of the border curve and the corresponding static indicators of the acutance the contribution of the "perfectly sharp" image in the process of image creation were not encountered due to the difficulties in defining this case.

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