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Modelling of the modulation transfer function of silver halide light-sensitive layer including DIR and DAR dye couplers

PIOTR NOWAK

Institute of Physical and Theoretical Chemistry, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland.

A mathematical model of the modulation transfer function of silver halide light-sensitive layer which includes dye couplers of DIR (Development Inhibitor Releasing) and DAR (Development Accelerator Releasing) types is presented in this paper. Contemporary methods of the production of colour photographic materials purposely utilize adjacency effect based on the strong, but locally restrained, photographic development. As a result of such a mechanism of the photographic image formation from organic dyes, improved quality of the image, especially contour contour and the modulation transfer function were obtained. In order to study both qualitative and quantitative relationships between scattered lights within photographic layers, theoretical model simulating these processes has been developed. The above model enables the analysis of the influence of adjacency effects on the properties of photographic materials when inhibitors of the photographic development of dye components DIR and accelerators of the photographic development of components of DAR types are applied.

1. Introduction

Local reducing or local strengthening of the photographic image is connected with the restraining or accelerating action of some chemical substances on the process of photographic development. The action of these substances results in either local increase or local decrease of the optical density in the photographic image. The corresponding phenomena called adjacency effects or edge effects have first been noticed first by the astronomers: KOSTNISKI (Poland) in 1906 [1] and EBERHARD (Germany) in 1912 [2], but were described for the first time as late as in 1918 by MACKIE [3]. A detailed elaboration of these problems can be found in later works [4]–[13]. The most frequently met adjacency effects, occurring due to the restraining action of some products of the development process, exert in general harmful influence in most applications of the black-and-white photographic materials. However, the same effects play some positive role in the colour photography where their presence improves essentially the usability of these materials.

The mechanism of the edge effects creation is different in the black-and- white photographic materials from that in colour photographic materials but the consequences of its appearance are qualitatively identical though quantitatively highly disproportional. As is well known, the colour photographic materials are composed of minimum three basic layers which results in essential increment of the contribution of scattered actinic radiation to the creation of the photographic image. This increment in the scattered light causes some deterioration of both the contour acutance and the resolving power of the photographic images obtained with these materials. Some reduction of harmful effects caused by the light scattering has been achieved by applying special dye components liberating inhibitors restraining this process during the colour development [14]. Currently, the coupling components of this type are classified as those of DIR-type, while the components freeing the development accelerators are defined as those of DAR-type.

As a result of diffusion of either the slowing down or accelerating substances in the development process as well as that of both the developer components and the products of its oxidation, some local changes of the dye concentration occur, the spatial region of which depends mainly on the magnitude of the diffusion coefficients for those substances. The analysis of the edge effects influence on the usability of the colour photographic materials is, thus, very complex and requires that very sensitive and precise instruments be used in research, which consequently would render possible a complex estimation of all the effects determining the quality of the photographic images. Currently, one of the best ways of expressing the quality of the photographic images is the estimation of the modulation transfer function (MTF). This method is especially well developed in the field of silver halogen photographic materials coated on the transparent background and is now commonly used as a standard characteristic of all the photographic materials to be used in optical recording of the image information.

The MTF called also contrast transfer function expresses the ratio of the sinusoidal test modulation in the produced photographic image M' to the modulation of the original test M being considered as a function of the spatial frequency [12]. The value of this ratio for a concrete spatial frequency ($\nu = \text{const.}$) defines the modulation transfer coefficient C given by the equation

$$C = M'/M. \tag{1}$$

On the other hand, the contrast of the image and by the same means the value of the same coefficient C is a function of the magnitude of the photographic image element and this relation is described by the MTF

$$\mathrm{MTF} = C(\nu) = M'(\nu)/M(\nu) \tag{2}$$

where ν is the spatial frequency understood as a number of line pairs, alternatively white and black and of the same width, distributed along 1 mm of length (cycle/mm).

Under the conditions of photographic development where neither restraining nor accelerating substances appear or in the case when such substances occur but the diffusion forced by strong mixing renders difficult its efficient action the edge effects are not observed. In this case the contour acutance of the photographic materials is determined only by the actinic radiation scattering inside the light sensitive layer. The light scattering in an optically heterogeneous medium, which is the case for silver halides photographic layers, is described by the Frieser function [12] which in the simplest form is expressed by the following equation

$$L(x) = (2.303/K)10^{(-2|x|/K)} \tag{3}$$

where: x is the distance, while the constant K characterizes the estimated photographic material and is called the Frieser constant. The light spread function (LSF) is connected with the MTF via the Fourier transform operation the due relation being given in the form

$$\mathrm{MTF}(\nu) = \mathrm{FT}[L(x)], \tag{4}$$

the analytical form of which is expressed by

$$\mathrm{MTF}(\nu) = 1/[1+(K\pi\nu/2.303)^2]. \tag{5}$$

The operation mechanism for edge effects occurring during the chemical processing of the photographic material is similar in both its nature and consequences to the effects caused by the light scattering. This analogy allowed us to apply the LSF defined by (3) to the description of the edge effects action which, with reference to these phenomena, has been called chemical scattering function (ChSF), [13]. Depending on the direction of edge effect action the ChSF changes its sign and thus for the case of restraining the development processes it takes on a negative value, while for the case of acceleration – positive value. During exposure of the photographic material the light scattering occurs within the layer due to which some additional silver halides crystals are subject to irradiation which otherwise would not be irradiated. However, in order to visualize the fact of light scattering and the due exposure of the crystals the photographic layer should be developed and thus subject to a chemical process in which, as we already know, the edge effects appear. Thus, it should be concluded that in the process of photographic development there occurs a summing up of the effects following from the light scattering inside the

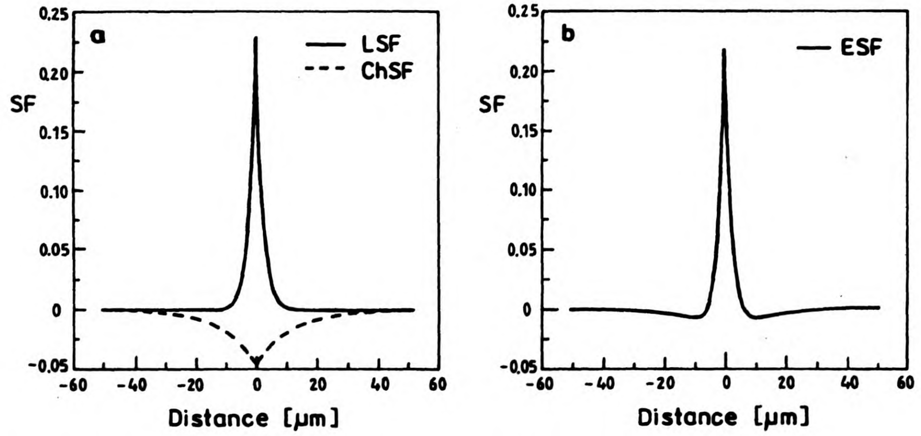

Fig. 1. Shaping of the ESF for the case of restraining down the development process: a – the LSF for $K = 10$ μm and ChSF for $K = 50$ μm, b – the ESF obtained according to Eq. (6) for coefficient $\alpha = 0.5$

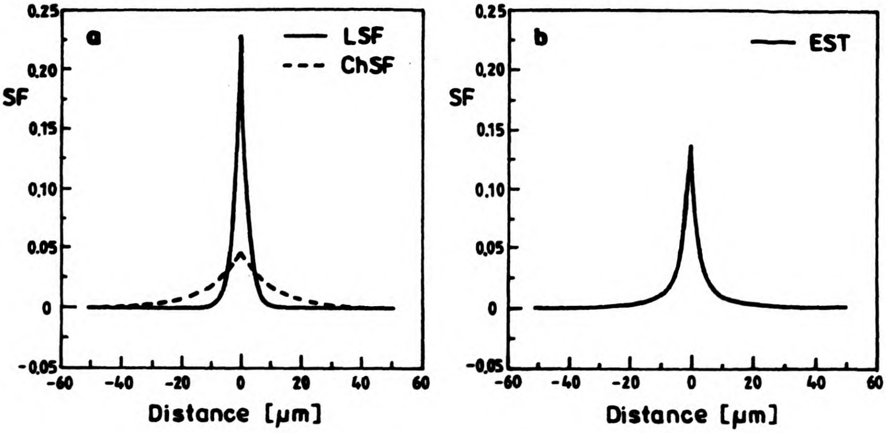

Fig. 2. Shaping of the ESF for the case of accelerating the development process: a — the LSF for $K = 10$ μm and ChSF for $K = 50$ μm, b — the ESF obtained from Eq. (6) for coefficient $\alpha = 0.5$

photographic layer with those evoked by diffusion of the developer components, the products of development and the chemical substances liberated during this process and influencing in a local way the kinetics of this process. In order to better illustrate the problems under consideration, in Figs. 1 and 2 the LSF, ChSF and effective scattering function (ESF) are presented. The latter results from the mutual interaction of these phenomena for the case of either restraining the photographic development (Fig. 1) or accelerating this process (Fig. 2).

Additionally, in Figure 3 a comparative study for the two directions of operation of the two edge effects has been presented together with the changes caused by these effects so far as the run of the edge curve, ESF and MTF are concerned. The contribution of the edge effects to the shaping of the ESF has been determined on the basis of normalized LSF and also the normalized ChSF taking the integral value of the LSF as a constant value with respect to which the contribution of the edge effects has been defined. Besides, taking account of the fact that the operation intensity of these phenomena depends on the physical and chemical parameters of the photographic development process it has been suggested that the degree of the edge effect contribution to the ESF should be defined according to the following equation

$$\mathrm{ESF}(x) = \alpha\,\mathrm{ChSF}(x) + \mathrm{LSF}(x) \tag{6}$$

where α is the coefficient responsible for the contribution of the ChSF compared to the LSF.

Normalization of both the scattering functions (ChSF and LSF) aims at simplification of the interpretation of their shapes and, in particular, at facilitating the estimation of the relative intensity and the operation range as well as the evaluation of the results of action of single phenomena. The normalization process has been carried out each time for all the scattering functions (ChSF, LSF and ESF) taking advantage of the general condition given by equation

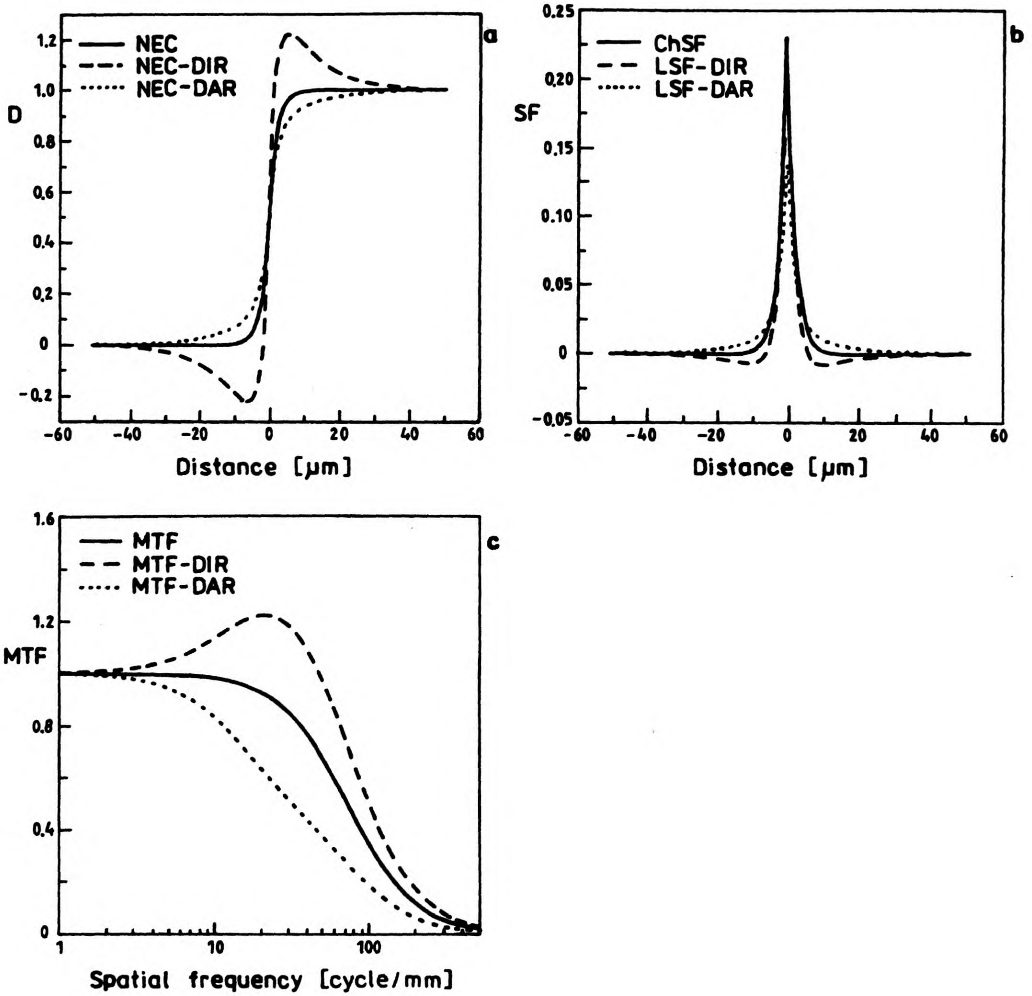

Fig. 3. Illustration of the influence of both direction and strength of the edge effects action on the run and properties connected with the light scattering inside the photographic layer. a — the normalized edge curves (NEC), b — the normalized LSF, c — the MTF. The solid line is used to plot the functions without edge effects for the values of constant K of the LSF amounting to 10 μm, the broken line — the same function for the case of restraining the development process with the constant K for ChSF equal to 50 μm and $\alpha = 0.5$ and the dotted line was used for the case of accelerating the development process with the constant K for ChSF equal to 50 μm and $\alpha = 0.5$

$$\int_{-\infty}^{+\infty} \mathrm{ESF}(x)dx = 1. \tag{7}$$

When analysing the run of the curves illustrated in Fig. 3, it should be noticed that the edge effects influence in an essential way the usefulness of the photographic materials. This fact is especially well exemplified when the case of MTF is considered which, as already mentioned before, connects in a simple way the utilisation properties of the photographic materials with their physical properties. This observation became a basis to elaborate a theoretical model enabling us to estimate the changes of the MTF occurring under the influence of the edge effects action. In addition to the plots of the calculated functions, the changes of some popular quality indicators connected with the MTF are presented. Since the spatial frequency determined from the MTF when the latter takes the value 0.3 corresponds well to the resolving power of the photographic material determined by resolvometric method [15]–[17], it has been decided to examine the changes of this magnitude as a function of edge effects. Besides, this magnitude allows us to approximate the Frieser constant according to the equation

$$K = 1119.6/\nu_{(\mathrm{MTF}=0.3)} \tag{8}$$

where: ν is expressed in terms of the number of line pairs (cycles) along 1 mm of the length (cycle/mm), K is expressed in μm. The subsequent magnitude which has been applied in the elaborated model is the integral quality factor (IQF) calculated as a integral value of the MTF within the range of values starting from MTF = 1.0 to MTF = 0.3, according to the equation

$$\int_{0.3}^{1.0} \mathrm{MTF} = \mathrm{IQF}. \tag{9}$$

2. Modelling the modulation transfer function

Practical value of the constant K of the LSF for negative colour materials fluctuates within the range from 10 to 50 μm, while the value of the constant K_c of the ChSF changes within the range from 50 to 100 μm [15]. The values of the constant K are usually known while the evaluation of the relative contribution of the ChSF compared to the scattering function has not been experimentally examined yet. Therefore, the following conditions for the model examination of the influence of the edge effects on the MTF as well as on some chosen quality factors connected with the latter have been assumed:

- range of change of the constant K of the LSF from 10 μm to 50 μm,
- range of change of the constant K_c of the ChSF from 20 μm to 100 μm,
- contribution of the ChSF as compared to the LSF changed from $\alpha = 0.0$ to $\alpha = 0.5$.

As a result of the simulations carried out a series of dependences have been obtained which are illustrated in Figs. 4–6. These plots allow us to qualitatively analyse the phenomena under study and to comparatively determine the influence of the particular constants of the scattering functions on the shape and properties of the MTF. Figure 4 illustrates the infleunce of the constant K_c of the ChSF on the shape of the MTF at a constant level of the edge effects contribution ($\alpha = 0.5$) and the constant K_c being two times and three times greater than the constant K, respectively. The analysis of the functions obtained allows us to conclude that the value of the integral factor defined by Eq. (9) changes linearly with the change of the

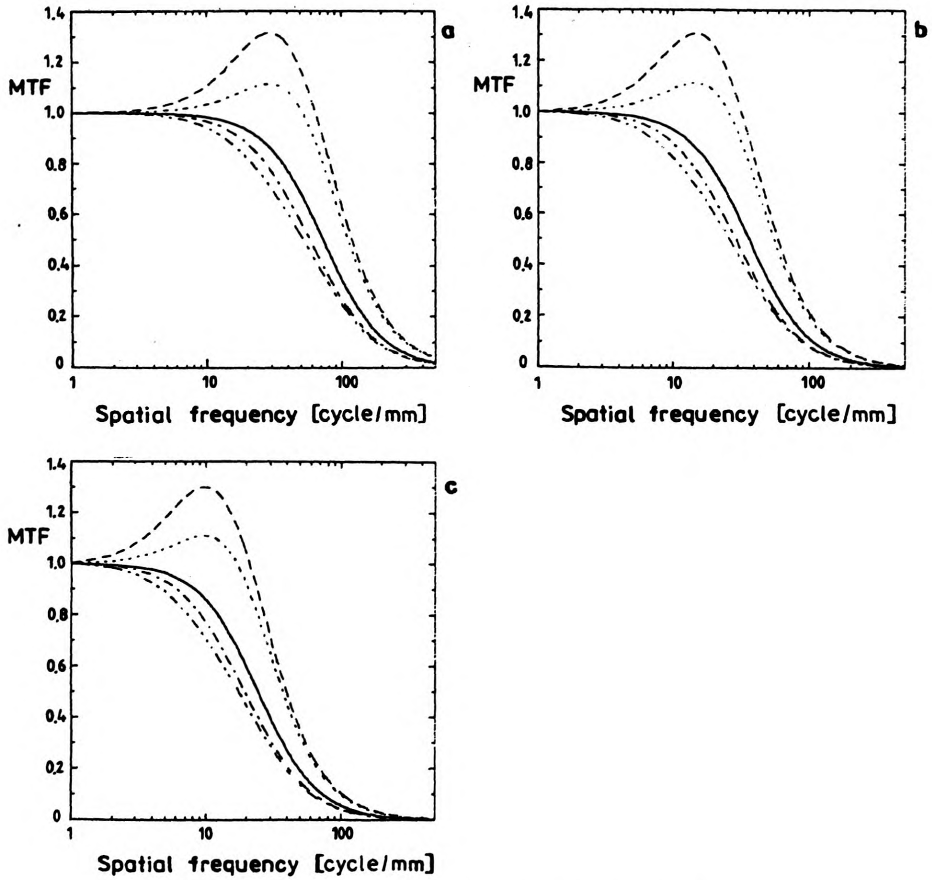

Fig. 4. Influence of the constant K_c of the ChSF for $\alpha = 0.5$ on the MTF for the constant $K = 10$ μm (a), $K = 20$ μm (b), and $K = 30$ μm (c). The solid lines are used to mark MTF calculated without taking account of the edge effects, the broken lines located above this function are used to represent the MTF calculated under the conditions of restraining the development process (components of DIR-type), and the broken lines situated below are used to mark MFT calculated under the conditions of accelerating the development process (components of DAR-type). The value of K_c is defined as the twofold or threefold value of the constant K. For: **a** – $K_c = 20$ and 30 μm, for **b** – $K_c = 40$ and 60 μm, and for **c** – $K_c = 60$ and 90 μm

K_c/K ratio. For the effects restraining the development process and for the factor $\alpha = 0.5$, the following equation has been derived:

$$\mathrm{IQF} = \mathrm{IQF}_0(1.1448 + 0.2413 K_c/K), \tag{10}$$

while for the effects accelerating the development process the corresponding relation is valid in the form

$$\mathrm{IQF} = \mathrm{IQF}_0(0.9582 - 0.0755 K_c/K) \tag{11}$$

where IQF_0 is the value of the integral quality factor for MTF calculated without the

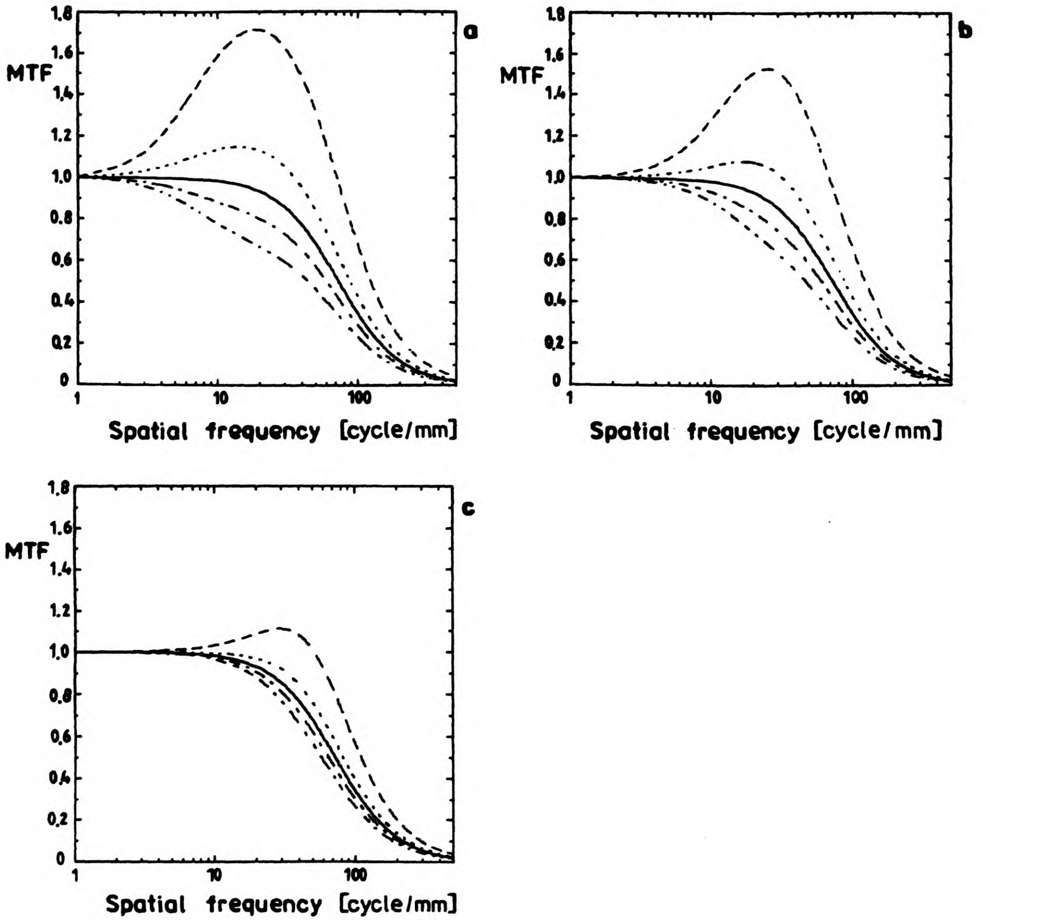

Fig. 5. Influence of both direction and strength of the edge effects on the shape of the MTF calculated for $K = 10$ μm and $K_\varepsilon = 100$ μm (a), $K = 10$ μm and $K_\varepsilon = 50$ μm (b), and $K = 10$ μm and $K_\varepsilon = 20$ μm (c). The solid lines are used to mark the MTF calculated without interaction of the edge effects, the broken lines situated above this function are used to mark the MTF calculated under the conditions of restraining the development process (components of DIR-type), and the broken lines situated below are used to mark the MTF calculated under the conditions of accelerating the photographic development

edge effects. The constants Eqs. (10) and (11) depend on the value of the contribution factor α and these magnitudes can be calculated within an arbitrary range, provided the physical measuring of the modelled phenomena is preserved. In a similar way the analysis of the influence of the edge effects for established values of the constants K and K_ε has been carried out. The results obtained are illustrated in Fig. 5.

When analysing the curves illustrated in Fig. 5, it must be stated that the greatest influence on the shape of the MTF is exerted by those edge effects for which the range of action expressed by the value of constant K_ε is much greater as compared to the range of light scattering inside the photographic layer expressed

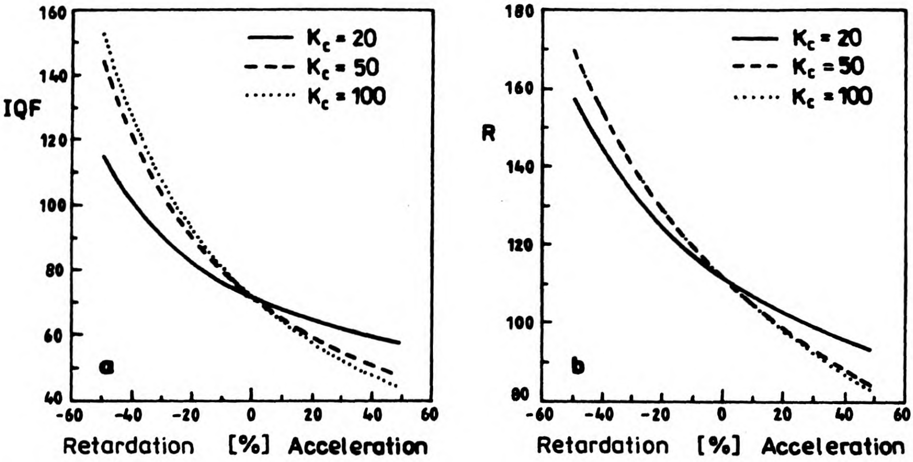

Fig. 6. Influence of both direction and strength of the edge effects on the value of the $\mathrm{IQF}_{\mathrm{MTF}=30\%}$ (a), and the spatial frequency factor $\nu_{\mathrm{MTF}=30\%}$ for the MTF calculated for the constants $K = 10$ µm and $K_c = 20$, 50 and 100 µm (b)

by the constant K. In Figure 5**a**, the MTF is shown for the ratio $K_c/K = 10$, in Fig. 5**b** the MTF is shown for $K_c/K = 5$, and finally, in Fig. 5**c** the same for $K_c/K = 2$. The essentially diminishing area below the presented functions indicates a significant lowering of acutance of the photographic image created under such conditions. The qualitative approach to these phenomena is represented by the curves illustrated in Fig. 6 and showing the changes of the integral quality factor and the effective constant K of the LSF defined by Eq. (8), as depending on the contribution of the edge effects. The contribution of these effects is expressed in percents, while the negative values have been assumed for the effects restraining the photographic development process and the positive values for the effects accelerating the photographic development process. In both cases the greatest gradient of the changes is shown by the function determined for the greatest ratio $K_c/K = 10$.

3. Summary

The obtained model of the influence of edge effects on the shape and properties of the MTF allows us to analyse easily the changes of the photographic material properties taking special account of the negative colour materials. As already mentioned before, in these materials the dye components of DIR-type are mainly applied the usage of which causes the appearance of strong edge effects essentially improves the usability of those materials. It is this fact that justifies the necessity of the modelling analysis of the influence of edge effects on the acutance of photographic images which, in turn, can be expressed in two ways: in terms of static indicators of the contour acutance calculated from the edge curves or in terms of the modulation transfer function and the factors connected with the latter.

The results of theoretical simulation obtained can be used not only in examination of the nature of these phenomena and their mutual interaction with the effects following from the light scattering but also can be useful for the technologists when forecasting the final usable features of the multilayer photographic materials. Besides, the designed model may be exploited in the teaching processes especially in the field of photographic structurometry.

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References

[1] JAMES T. H., *The Theory of the Photographic Process*, IV ed., Macmillan Pub. Co., New York 1977, Chapt. 21, p. 609.

[2] EBERHARD G., Physik. Z. **13** (1912), 288.

[3] MACKIE A., Br. J. Photogr. **64** (1918), 11.

[4] POWELL G. P., J. Photogr. Sci. **9** (1961), 167.

[5] FRIESER H., Kinotechnik **17** (1935), 167.

[6] WILCZYNSKI J. S., Proc. Phys. Soc. (London) **17** (1960), 17.

[7] WOLFE R. N., BARROWS R. S., Photogr. Sci. Tech. **13 B** (1947), 554.

[8] ROSS F. E., Astrophys. J. **52** (1920), 98; **53** (1921), 349.

[9] SMITH H. M., J. Opt. Soc. Am. **58** (1968), 533.

[10] LAMBERTS R. L., J. Opt. Soc. Am. **60** (1970), 1389.

[11] EHN D. C., SILEVITCH M. B., J. Opt. Soc. Am. **64** (1974), 667.

[12] FRIESER H., *Photographische Informationaufzeichnung*, Focal Press, London, New York 1975.

[13] NELSON C. N., Photogr. Sci. Eng. **15** (1971), 82.

[14] BARR C. R., THIRTLE J. R., VITTUM P. W., Photogr. Sci. Eng. **15** (1969), 74.

[15] NOWAK P., *Measuring the modulation transfer function of photographic materials* (in Polish), Report Institute of Organic Chemistry and Physics, Wrocław University of Technology, Wrocław 1991 (unpublished).

[16] LUX B., GÖRGENS E., BÖTTCHER H., Bild und Ton **40** (1987), 165.

[17] GÖRGENS E., J. Inf. Mater. **15** (1987), 305.

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