Václav Bumba

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Department of experimental physics and methodology of physics
The chairman of the department: Prof. Paed. Dr. Josef Fuka

THE OPTICAL TRANSFER FUNCTION OF PHOTOGRAPHIC FILMS

VÁCLAV BUMBA

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In our laboratories we observed the possibilities of gaining optical transfer functions of photographic films. How we obtained this function by means of analysis of the image edge which was copied direct on the photographic layer is described below.

The Edge Spread Function

The edge is copied on the film (Fig. 1). Let's consider that relation between jump illumination $I(x)$ and the optical density $D(v)$ is linear and integral, *i. e.*

$$D(v) = \int K(v - x)\, I(x)\, \mathrm{d}x\,.$$

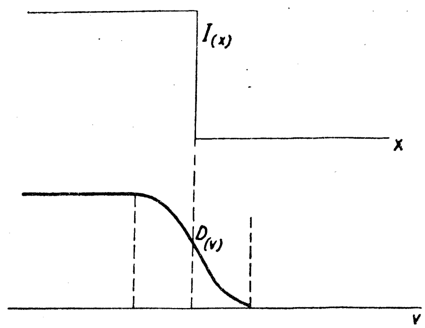

Fig. 1

By means of derivation of v and integration per partes we gain

$$D'(v) = \int \frac{\mathrm{d}}{\mathrm{d}v} K(v - x)\, I(x)\, \mathrm{d}x = - \int \frac{\mathrm{d}}{\mathrm{d}x} K(v - x)\, I(x)\, \mathrm{d}x =$$

$$= \int K(v - x) \frac{\mathrm{d}}{\mathrm{d}x} I(x)\, \mathrm{d}x = \int K(v - x)\, I'(x)\, \mathrm{d}x\,.$$

Because $I'(x) = \delta(x)$, $D'(v) = K(v)$.

It is obvious that in analogy to optical systems we can introduce „the spread function“ $K(v)$, which in our case equals derivation of optical density $D(v)$ and its Fourier's image is then optical transfer function (OTF).

The Optical Transfer Function

Let's designate the fotometrical course of the edge copied on the photographic film $E(v)$ to distinguish it from the designation of the optical density $D(v)$.

As usual at first we standardize the edge spread function by means of the relations

$$0 \leq E(v) \leq 1$$
$$E(-\infty) = 0$$
$$E(+\infty) = 1\,.$$

The course of this function is given in fig. 2.

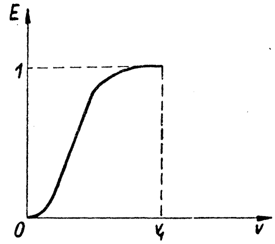

Fig. 2

If we consider definition of OTF [1] as Fourier's transformation of derivation of the intensity (analogy to electronic systems), then is

$$T(\omega) = \int_{-\infty}^{+\infty} \frac{\mathrm{d}E(v)}{\mathrm{d}v}\, e^{-iv\omega}\, \mathrm{d}v = \int_{-\infty}^{+\infty} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v\,, \tag{1}$$

where $T(\omega)$ is complied OTF amplitude and phase, ω is spacing frequency in lines per millimeter, where $\omega = 2\pi\nu$ and $\tau(v) = \dfrac{\mathrm{d}E(v)}{\mathrm{d}v}$.

In this case the origin of coordinates was given on the origin of the curve of the edge spread function $E(v)$. If the origin of the coordinates is in the middle of the curve of the edge spread function (Fig. 3), we come to more similar calculation. From eq. (1) is

$$T(\omega) = \int_{-\infty}^{+\infty} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v = \int_{-\infty}^{-a} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v + \int_{-a}^{+a} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v +$$

$$+ \int_{+a}^{+\infty} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v = \int_{0}^{a} \tau(-v)\, e^{iv\omega}\, \mathrm{d}v + \int_{0}^{a} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v = 2\int_{0}^{a} \tau(v) \cos v\omega\, \mathrm{d}v, \tag{2}$$

because $\tau(v)$ in intervals $\langle -a, -\infty)$ and $\langle +a, +\infty)$ equals zero.

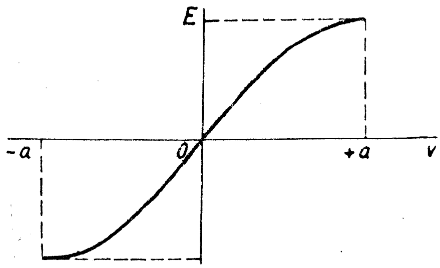

Fig. 3

From eq. (2) is obvious that OTF obtained on geometrical edge is determined only by integral real part of OTF under conditions that the edge spread function $E(v)$ can be considered as antisymmetrical function if the origin of coordinates is in the middle of the curve. As in the real case the edge spread function can't be used we have chosen the first way of calculation when the real and imaginary part of OTF are separate from each other.

Let's go back to eq. (1) and fig. 2. So we have

$$T(\omega) = \int_{-\infty}^{+\infty} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v = \int_{-\infty}^{0} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v + \int_{0}^{v_1} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v + $$

$$+ \int_{v_1}^{+\infty} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v = \int_{0}^{v_1} \tau(v)\, e^{-iv\omega}\, \mathrm{d}v\,, \tag{3}$$

because $\tau(v)$ in intervals $(-\infty, 0\rangle$ and $\langle v_1, +\infty)$ equals zero. Eq. (3) can be written

$$T(\omega) = \int_{0}^{v_1} \frac{\Delta E(v)}{\Delta v} [\cos v\omega - i \sin v\omega]\, \mathrm{d}v\,. \tag{4}$$

The calculation of integral (4) can be obtained by means of Simpsone method, *i. e.*

$$\int_a^b f(x)\, \mathrm{d}x = \frac{h}{3} (y_0 + 4y_1 + 2y_2 + 4y_3 + \ldots + 4y_{n-1} + y_n), \tag{5}$$

where step $h = \frac{b-a}{n}$, n is a even and $y_k = f(a + kh)$, $y_0 = f(a)$, $y_n = f(b)$.

In our case Δv is the step of the measuring. The real calculation then can be obtained when we convert the established nonstandardized edge spread function $E(v)$ with step Δv to the spectrum densities $D(v)$. By means of characteristic curve of the photographic material we obtain the real exposure spectrum $H(v)$ with step Δv. After that we standardize this course by relations

$$0 \leq H(v) \leq 1$$
$$H(-\infty) = 1$$
$$H(+\infty) = 0\,.$$

The calculation is simpler when we substitute this to the eq. (5) because we can calculate only with increases $\Delta H(v)$.

OTF $T(\omega)$ is

$$T(\omega) = |T(\omega)|\, e^{i\vartheta(\omega)}$$

where

$$|T(\omega)| = \sqrt{[\mathrm{Re}\; T(\omega)]^2 + [\mathrm{Im}\; T(\omega)]^2}\;,$$

while Re $T(\omega)$ and Im $T(\omega)$ is the real and imaginary part of OTF and $\vartheta(\omega)$ is a phase defined as

$$\vartheta(\omega) = \mathrm{arc\;tg}\,\frac{\mathrm{Im}\; T(\omega)}{\mathrm{Re}\; T(\omega)}\,.$$

The Objections Against Calculation of Optical Transfer Function from the Edge Spread Function

The objections against calculation of OTF from the edge spread function have been mainly concentrated in the work [2]. We have these objections in mind:

a) The measuring is difficult to be done with satisfying precision.
b) The light can reflect from the edge.
c) The light diffraction.

These objections are right and we agree with them if we form the image of the edge by the lens.

Let's take these objections against our case:

ad a) We always obtain the OTF by measuring of the testing object and so error occurs during measuring of every testing object.

ad b) In our case the light is reflected from the edge. F. Perrin [2] notices that in some laboratories thea tried to cover the edge by black lacquer. It is difficult to say if the lacquer and photographic layer do not effect each other. When covering the edge by black lacquer we can disturb the sharpness of the edge. If we consider the light reflection from anti-halation layer (a row of materials have absorbing colouring substance in emulsion) we always deal with the black beam which eventually can cause the latent blackening of the emulsion. But when using the normal exposures we find it too academical to consider the beam reflected from the edge which can cause the blackening of the emulsion on its way through the sensitive layer.

ad c) It is obvious that by contact copying we can observe the diffraction of light which can be partly eliminated. But it is known that by any other image forming we obtain the light diffraction in greater or smaller quantity.

The great advantage of the edge is that it can be obtained easily as well as the whole spectrum of spacing frequencies. The other advantage is in the edge itself. The object tests we use are to imitate dark and light spots on various objects in the nature. In the nature we find only random changing of dark and light spots less we can find in on the edge and the sine changing does not exist. From this point of view we find the usage of edge more suitable than the usage of the sine object tests.

The problems and results of measuring are given in work [4].

Conclusions

The suggested method of measuring of OTF of photographic films by analysing of the edge imaged on the sensitive layer needs a very good microphotometer and a computer to calculate the results. The whole methodology of gaining OTF of emulsions has been adapted and can be used by evaluation of colour films where the traditional method can't be relied on and the improvement of films is difficult.

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SHRNUTÍ

OPTICKÁ PŘENOSOVÁ FUNKCE FOTOGRAFICKÝCH FILMŮ

VÁCLAV BUMBA

Je popsána metodika získání optické přenosové funkce (OTF) fotografických filmů analýzou obrazu hrany. Získaný mikrofotometrický průběh byl přizpůsoben a normován a OTF byla vypočítána na počítači. Jsou diskutovány námitky uváděné v literatuře proti získání OTF tímto způsobem.

ZUSAMMENFASSUNG

DIE KONTRASTÜBERTRAGUNGSFUNKTION DER PHOTOGRAPHISCHEN FILMEN

VÁCLAV BUMBA

In der Abhandlung wird die Kontrastübertragungsfunktion (KÜF) der photographischen Filme mittels der Kantenbildanalyse beschrieben. Der gewonnene mikrophotometrische Verlauf wird adaptiert und genormt und die KÜF wird vom Computer errechnet. Die in der Literatur erhobenen Einwände gegen die Auswertung der KÜF auf diese Weise, werden begutachtet und diskutiert.