A New Type Test Chart for Measuring Radiographic Image Quality and its Application

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Abstract

For the purpose of measuring the sharpness of a radiographic image, we have recently manufactured a metallic test chart consisting of lead and aluminum foils. As a result of testing of this chart, it was found that this chart gave a very large contrast, being as large as 0.9 compared to the value of about 0.5 for conventional test chart of evaporation-type. It was also confirmed that the incident angle characteristic for an oblique incident radiation of this new test chart was superior to that of the conventional evaporation-type test chart. Further, using this newly-made test chart, the image quality for several kinds of the X-ray films was evaluated.

From the results obtained we were able to find quantitatively how the MTF, that is, an evaluating measure of sharpness would be affected when the thickness of film base, the f-value of film, the velocity of developing treatment, the granularity, etc., were changed.

§ 1. Introduction

In general the main factors that determine the image quality of a black and white photograph are the tone reproduction, the granularity and the sharpness, etc. This is also the same in an X-ray photographic image. For evaluating the tone reproduction of an X-ray photographic image, a characteristic curve (H-D curve) is used.

To obtain the H-D curve, our object can be easily achieved either by performing an exposure of the time scale by use of a slit of metallic plate, or by performing an exposure of the intensity scale by use of metallic step wedge. To evaluate the granularity of an X-ray photographic image, the evaluation scales of R.M.S. (Root Mean Square), A.C.F. (Auto-correlation Function), W.S. (Wiener Spectrum), etc., are commonly used.

In order to carry out these measurements, the overall surface of the X-ray film is uniformly exposed and after developing and fixing it, the variation of photographic density at a small portion of the film piece is measured, then a mathematical treatment is applied to the data obtained.

On the other hand, for the purpose of evaluating the sharpness of an X-ray photographic image, it is most effective to use the Modulation Transfer Function (M.T.F.). However, in the case of an X-ray photographic image, there occurs a new type difficulty in the measurement of MTF that has not been encountered in the case of a general black and white photographic image.

In other words, the incident radiation under discussion is an X-ray radiation that is different from a light beam in its strong penetrative power, so that the various measuring techniques applied in the field of optics can hardly be used.

Therefore, other special techniques for the measurement of MTF of an X-ray photographic image are being devised in various ways. These are divided into the following two method:

1) Method in which the intensity distribu-
tion of an edge image or a slit image obtained by using a material impenetrable by X-rays is Fourier-transformed mathematically\(^\text{1,2}\).

(2) Method in which a test chart made of a special material, of which the contrast is definite and the frequency varies spatially, is employed.

The former method is frequently used in research laboratories, but it cannot be a convenient method because of the necessity of a considerable amount of calculation.

On the contrary, the latter method has so many advantages that the operation is simple, the accuracy of measurements is stable, and it is possible to observe not only MTF but also the marginal resolving power directly by naked eyes or by a microscope.

However, this method has a disadvantage that the manufacturing process of the test chart is far difficult compared to that of the test chart used in optical field.

Now, we were able to make a special test chart of high contrast (to be called KR-chart hereafter) successfully by using lead foils and aluminum foils of highly accurate thickness, which is used for the measurement of the image quality of radiographic image.

In the following the manufacturing method and the characteristics of the chart, and the results of actual measurements about the sharpness and granularity of four kinds of X-ray films obtained by use of the chart, will be presented and discussed in detail.

§ 2. Manufacturing Method of KR-Chart

The KR-chart trially made at this time is a metallic chart consisting of parallel rectangular wave patterns, in which lead foils are used as the absorbing material for radiographic ray and aluminum foils as the transmitting material for it. Fig. 1 is a photograph showing the outline of the KR-chart. The manufacturing process can be divided into 7 steps as shown in the flow-chart of Fig. 2. In the steps 1~3, the selection and cleaning of manufacturing materials, and coating of adhesive to the materials are performed respectively, being the preliminary steps for the manufacturing. The steps 4~6 are the main parts showing the special features in these steps, so that detailed explanation of parts is given in Fig. 3.

In the step 4, the aluminum foils and the lead foils are at first sectioned into blocks \(Bn\) of the same thickness \(D\) mm. Next, each one piece of these blocks is cut at \(Z\) mm in width. In the present experiment we took \(Z=3.0\) mm.

In the step 5, by using a setting machine the aluminum foils and the lead foils are ar-
ranged alternatively in each block, and further by compounding each of these blocks the rectangular wave pattern is formed as shown in the figure. After heating and adhering, the step 6 follows.

The spatial frequency $\nu_n \text{ lines/mm}$ is determined by the thickness of metallic foil $D_n \text{ mm}$, and a relation $\nu_n = 1/(2D_n)$ is always held between the spatial frequency and the thickness of metallic foil. The number of repetitions of the same frequency is determined by the number of pairs in the block concerned.

In the step 6, plain shaping is applied to make it thinner than the minimum cutting width 3.0 mm limited by the cutting machine.

In the course of this step the part shown by the broken lines is shaved off and the part of frequency pattern of the KR-chart is completed. In this case the finished thickness amounts to 1.0 mm.

At present the marginal minimum limit of this finished thickness is 1.0 mm, and it is difficult to obtain a more thinner KR-chart from the point of working accuracy.

In the finish working step 7, the frequency pattern is stucked on a base plate of acryl resin 1.0 mm thick, and further a transparent acryl resin solution is sprayed on the surface of pattern to make a protective layer, then the KR-chart required has been accomplished.

The above is an outline of the manufacturing method of KR-chart. According to this method, by changing the arrangement of each block in the step 5 of Fig. 3, we are able to set up an arbitrary ordered frequency pattern desired by the user.

The X-ray photographs (A), (B) in Fig. 4 show two kinds of KR-chart having different frequency arrangements. The photograph (A) shows a KR-chart (RP-type KR-chart) used for measuring the resolving power, in which bold lines of aluminum 3.0 mm wide are inserted for the purpose of sectioning (black lines in the photograph), and (B) shows a KR-chart (MTF-type KR-chart) for measuring MTF, in which the number of repetitions at the same frequency pattern is less compared to (A) and on the whole, the frequencies are arranged symmetrically left to right.

This symmetrical arrangement of frequencies serves to reduce, the adjacency effect, an effect coming from the neighbors at the time of development, and the end effect that comes from the finite length of chart as far as possible, in other words, it is devised so as to moderate the variation of frequencies arranged side by side.
Furthermore, such a symmetrical arrangement of frequencies enable us to check the spatial non-uniformity of the incident radiation, for the reason that, if the incident radiation is uniform, the results of left and right measurements would be equal, so that it is possible to obtain the degree of non-uniformity of the incident radiation from the difference of results of left and right measurements.

Table 1 shows the aspect of arrangement of frequency in the RP-type chart and MTF-type chart and the dimensions of each part of the charts.

Table 1

<table>
<thead>
<tr>
<th>Type</th>
<th>Spatial Frequency (lines/mm)</th>
<th>X</th>
<th>Y</th>
<th>Z1</th>
<th>Z2</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTF-type KR-chart</td>
<td>0.0, 0.05, 0.05, 0.05, 0.1, 0.3, 0.3, 0.3, 0.3, 0.5, 0.5, 0.5</td>
<td>80</td>
<td>40</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>and 10.0, 5.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RP-type KR-chart</td>
<td>0.0, 0.025, 0.025, 0.025, 0.3, 0.3, 0.3, 0.3, 0.4, 0.4, 0.4</td>
<td>220</td>
<td>60</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>and 10.0, 10.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

§3. Characteristics of Chart (I) Incident Angle Characteristic

The KR-chart is so constructed that the thickness of the spatial frequency pattern is taken at 1.0mm to bring about the high contrast characteristic. Therefore, the thickness of chart becomes as thick as 20 times compared with the line width at the position of maximum frequency \( \nu_{\text{max}} = 10 \text{lines/mm} \). When this ratio is large the behavior of the radiation beam incident to the test chart seems to resemble the state of sunlight coming into a space between high buildings; namely, depending on the incident angle of light beam there appears a part corresponding to the shade, resulting in the impossibility of sending a correct rectangular signal waveform to the measured system, or the X-ray film emulsion, being incapable of attaining the role as test chart.

In order to examine such an effect, the change of MFT of an X-ray film for the rectangular wave according to the incident angles of X-ray is considered in the following.

3.1 Experimental Method

The experiments for testing the incident angle characteristic were carried out in such a way that, as shown in Fig. 5 (a), a KR-chart was closely attached to an X-ray film and exposed to X-rays at different incident angles, and after developing the film the MTF corresponding to the respective incident angles were obtained.

In this case the procedure of measuring the MTF followed the method to be described latter in section 5.1. At the same time an
evaporation-type test chart (to be called SR-chart hereafter) was selected from among the radiographic charts on the market and taken as reference for our KR-chart.

Generally the influence of incident angle is remarkable at a position of high frequency in the chart. Accordingly in the present experiments the intersection between the chart and the main axis of radiation cone of the incident X-ray was always fixed at the position of the maximum frequency 10 lines/mm, and the X-ray exposure was carried out with moving the X-ray source along the circumference of 200 cm radius.

Under these conditions it is sufficient to consider the influence of incident angle of radiation on the test chart, taking account of only the effect due to the main part of incident X-ray along the main axis of radiation cone which is understood from Fig. 5(a).

In Fig. 5(b), let us denote the ratio of the width of the shady part $S$ to that of X-ray transmitting metallic foil $X/2$ by the coefficient $\eta$.

Neglecting the difference of receiving radiation ray intensity at the shady part due to the difference of the path within X-ray absorbing metallic foil shown by the broken line and assuming that the shady part $S$ is perfectly interrupted from X-ray, the coefficient $\eta$ can be expressed simply by the following formula:

$$\eta = 2h \tan \theta \cdot \nu$$

where $h$ is the thickness of chart, $\theta$ the incident angle and $\nu$ the frequency of chart.

The case of $\eta=0$ corresponds to the perpendicular incidence and the case of $\eta=1.0$ to the perfect interruption of X-ray. In Fig. 6 are shown the results of measurement obtained by changing the value of $\eta$ in value of $\eta$ in various ways.

3.2 Experimental Results and Considerations

The results of measurement of the change of MTF against the change of incident angle obtained by the method mentioned above are
given in Fig. 6.

The measurements were done at three points of $\theta=0^\circ$, $\theta=2.9^\circ$ and $\theta=5.7^\circ$. The full line represents the MTF of KR-chart and the broken line that of SR-chart.

In the incident angle of X-ray for the KR-chart of 1 mm thick, is equal to that for the SR-chart of about 50 $\mu$ thick, the fraction of the shady part $S$ becomes different among these charts as shown in Fig. 5(b). This difference is shown as the difference of value of the coefficient $\gamma$.

Generally it is expected that the MTF takes a lower value as the value of $\gamma$ becomes larger, but in our KR-chart the MTF is lowered less relative to its large value of $\gamma$ and large incident angle of X-ray, so that we have confirmed the fact that our KR-chart has a desirable angle characteristic compared to the conventional evaporation type test charts.

This remarkable characteristic may be probably due to the difference of manufacturing method of test pattern, namely, the thin layer of metallic lead deposited on the supporter (made of glass or synthetic resin) of the SR-chart has a more porous structure compared to the lead foils of the KR-chart, and it may be suspected that in the SR-chart the absorbing effect for X-ray does not act so effectively. This may probably be a reason to degrade the incidence angle characteristic of the SR-chart.

§ 4. Characteristic of Chart (II) Chart Contrast

In order to know the contrast in the KR-chart, experiment was made by the X-ray photographic method. In this case comparative experiments with the SR-chart were performed.

Generally in an evaporation type test chart, a lead layer is deposited on a base plate of synthetic resin and the arrangement of spatial frequency pattern is formed by the photographic etching method or the mechanical working method. The thickness of the lead layer in this case is usually of the order of 50 $\mu$.

4.1 Experimental Method

To measure the chart contrast $C_E$ the KR-chart and the SR-chart are simultaneously photographed by placing them on an X-ray film side by side, and the photographic density at the position of zero frequency of each image obtained is measured and then, the value of $C_E$ is obtained by the following formula:

$$C_E = (E_{\text{max}} - E_{\text{min}})/(E_{\text{max}} + E_{\text{min}})$$  \hspace{1cm} (2)

where $E_{\text{max}}$ and $E_{\text{min}}$ are the converted values of the photographic density of X-ray transmitting part at $\nu=0$, $D_{\text{max}}$ and that of X-ray absorbing part at $\nu=0$, $D_{\text{min}}$ respectively, to the relative X-ray intensities by use of the characteristic curve. As the $E_{\text{max}}$ and $E_{\text{min}}$ do not take negative values, the maximum of $C_E$ is 1.0. Therefore, if $E_{\text{max}}$ is definite, $C_E$ tends to zero as the value of $E_{\text{min}}$ becomes large, or as the photographic density of the background is increased. The range of the chart contrast testing was limited to that used in the actual diagnosis, where the X-ray tube voltage is taken 50~100 kVp and $D_{\text{max}}$ is taken 0.5~2.0. The films used were SAKURA X-ray films of new Y-type for medical use and the X-ray source was a TOSHIBA X-ray generating apparatus of KXO-15-2A type for medical use. In taking photographs the distance between the X-ray source and the film was fixed at 200 cm, and the KR-chart and the SR-chart were placed side by side closely attaching to the X-ray film to carry out the comparison test. At first, under a certain X-ray tube voltage the exposure was varied as a parameter, and photographs was taken for different exposure exchanging the films successively one by one. Next, similar photographings were performed by changing the tube voltage, obtaining a series of images of the samples for various X-ray tube voltages and the X-ray doses. In this case the development was carried out by use of a SAKURA high-speed automatic developing apparatus of model QX-200 and the photographic density measurement was done by use of a SAKURA photoelectric densitometer, PD-9R type.
4.2 Experimental Results and Considerations

The results of photographic density measurement are shown in Figs. 7–9. Fig. 7 and Fig. 8 show the measured values of photographic density which cover the whole region of discussion on chart contrast, and show the characteristics of density variation against the tube voltage and exposure of the KR and SR-chart respectively. Difference of the both charts is clearly observed from the $D_{\text{min}}$ curves shown by the broken lines in the figures. This aspect is clearly seen also in the photographs of Fig. 9.

As the exposure of X-ray is increased, $D_{\text{min}}$ of the SR-chart, that is, the photographic density of background, is increased remarkably compared to that of the KR-chart, lowering of contrast of the chart being noticed to a large amount. To support this fact quantitatively, the measuring results of chart contrast $C_E$ obtained by the formula (2) are shown in Fig. 10. According to these results, the value of $C_E$ for the SR-chart is below 0.7, hence it is considered that this chart should be used as a low contrast chart rather than as a
high contrast chart.

On the other hand, as evidently seen from that figure, the KR-chat gives the values of $C_e$ larger than 0.9 throughout the whole region of the experiments from which it has been confirmed that the KR-chart is available as a chart that gives a sufficiently high contrast for the measurement of sharpness of X-ray photographic image in the overall diagnostic region.

§ 5. Applications of KR-chart

As described in detail in sections 3 and 4, the KR-chart can be satisfactorily used in practice as a high contrast chart. Then, we have made some tests on the image quality of several kinds of X-ray films for medical use by using the KR-chart.

In the present experiments we used the imaging system as shown in Fig. 11, which is the most general imaging system applied in the direct photographing method in the medical treatment.

In using such a system it is necessary to consider not only the image quality of X-ray film but also the effects of the X-ray source, photographic object, fluorescent intensifying paper, etc., on a quality of the final image.

Firstly, as for the effects of X-ray source on the image quality, a kind of "obscur image" is appeared from the finite size of focus of X-ray tube. Secondly, it should also be noticed that a kind of "blur" is appeared from the temporal or spatial variation of X-ray quantum$^{(1), (2)}$.

Thirdly, as for the effects of photographic object (the KR and SR-chart are meant here) on the image quality, a certain kind of "unsharpness" is caused on the image due to the contrast, the incident angle characteristic, and the secondary scattering effect of X-ray, etc. in the test chart.

Furthermore, the graininess of fluorescent material in the fluorescent intensifying paper and the extent of blurred emission light affect the final image by being directly transmitted to the X-ray film.

In the present experiments the final images containing all of these effects were treated as the subjects of our study.

5.1 Experimental Method

The KR-chart was set at the position of the photographic object $O$, of the system shown in Fig. 11 and it was closely attached to the cassette $C$, and the exposure was carried out.

The experimental conditions in this case were as follows: X-ray source of TOSHIBA KXO-15-2A type with the size of focus of $1 \times 1$ mm and fluorescent intensifying paper of KYOKKO FS of JAPAN PAINT Co., Ltd. were used.

The photographic conditions were: distance from X-ray source to film = 180 cm, X-ray tube voltage = 65 kVp, X-ray tube current = 200 mA, and exposure time = 0.1 sec.

The films were developed under the conditions specified for each film using the SA-KURA automatic developing apparatus.

Measurements were made using the SA-KURA micro-densitometer of PDM-4 type.
The MTF was measured by the following procedure: Each sample was scanned by the micro-densitometer to obtain the waveform $D(\nu)$ of the photographic density distribution on a recording paper. On the other hand, separately from the above, the sample on which an aluminum wedge had been exposed by X-ray was scanned by the same micro-densitometer to obtain the H-D curve, and by using this the above-obtained waveform $D(\nu)$ of the photographic density distribution was converted to the relative X-ray intensity waveform $E(\nu)$, then the MTF, $R(\nu)$, for rectangular waves was calculated by the formula:

$$R(\nu) = \frac{E(\nu)_{\text{max}} - E(\nu)_{\text{min}}}{E(\nu)_{\text{max}} + E(\nu)_{\text{min}}}$$

where $\nu$ is the spatial frequency (lines/mm), $E(\nu)_{\text{max}}$ and $E(\nu)_{\text{min}}$ are the maximum and minimum values of X-ray intensity distribution waveform at each spatial frequency, respectively.

Remark: The MTF's we obtained in this study were all those of rectangular waves, but for simplicity they were called MTF in the following sections. The MTF is given by normalizing the value of each $R(\nu)$ with the value of $R(0)$, and our MTF curves are obtained from the mean values of measurements three times.

5.2 Experimental Results and Considerations

Fig. 12 shows the results of measurements of the direct photographing X-ray films of A and B types for medical use and Fig. 13 the results of the films of C and D types. Along the $D$-axis of the three-dimensional coordinates shown in these figures the values of diffuse density of MTF at zero frequency measured by the SAKURA photoelectric densitometer of PD-9R type are plotted.

From these figures it is understood that the MTF of the X-ray films and their marginal resolving power vary according to the density of $R(0)$. To consider this fact in more detail, the density dependence of MTF of the X-ray films or the MTF-D representation was rewritten to the $\nu_{n/m}-D$ representation. Here, $\nu_{n/m}$ means the frequency that the normalized value of MTF becomes $n/m$. Fig. 14 and Fig. 15 show the aspects of variation of $\nu_{n/m}-D$ for $m=4$ and $n=1, 2, 3$. According to these figures the changing behavior of MTF when the density varies can be understood accurately. For instance, on the $\nu_{n/m}$ vs. photographic density curve in
Fig. 15 a peak is observed distinctly, which, however, cannot be found in the group of MTF curves of Fig. 13.

Recently, the automatic developing apparatus has been remarkably popularized for the purpose of shortening the developing time.

In a high-speed automatic developing apparatus, a series of processes of developing, fixing, washing and drying is finished in a short time such as about 90 sec, of which the developing time is about 30 sec. The X-ray films for such a short time development are designed so as to make the characteristics of emulsion and the properties of film satisfy the high-speed treatment of automatic developing apparatus more adequately than the conventional X-ray films (to be used in manual or low-speed automatic developing apparatus) do.

For example, the material of film base has been improved from TAC (triacetate) to PET (polyester), and the film base has become thinner by increasing the mechanical strength.

Moreover, various processes have been devised such as reduction of emulsion thickness for improving the permeation effect of developing agent.

In order to express quantitatively the difference between the image quality of the quick treatment X-ray films designed as above and that of the conventional X-ray films (to be used in manual or low-speed automatic developing apparatus) do.

For example, the material of film base has been improved from TAC (triacetate) to PET (polyester), and the film base has become thinner by increasing the mechanical strength.

In the case of X-ray film, as the emulsion layers are coated on both surfaces of film with the film base sandwiched, it may be expected for the reduction of base thickness to bring about a good effect on the sharpness of film.

In fact the enhancement of sharpness due to the reduction of base thickness is clearly observed from the experimental results shown in Fig. 14 in the high-frequency region of more than 2.0 (lines/mm). From this fact our expectation concerning the relation between the base thickness and the sharpness is quantitatively justified.

Discussion of $\nu_{m/n} - D$ characteristic based on the difference of H-D curve

The two kinds of films for high-speed treatment, C-type and D-type are treated by the same development conditions and the thickness of emulsion layer and that of base are also the same, the only difference being presented in their H-D characteristic curves as shown in Fig. 16.

In the C-type film almost the same slope of curve is extended linearly up to the high density region, whereas in the D-type film a reduction of slope is noticed in the density region higher than $D_{1.5}$. It is said from experience that, in the high density region (of more than $D_{1.5}$), a film with low $\gamma$ characteristic such as the D-type film allows to make the “details” of its image more easily observable.

On the other hand, a microscope sharpness characteristic, that is, an MTF characteristic, taking consideration of the frequency, is shown in Fig. 15 against a macroscopic easily-observable characteristic mentioned above. As understood form this, the MTF of image in the high density region is not always better, which does not essentially coincide with the empirical observation that the detail of image is more easily seen as the $\gamma$ becomes small in the high density region.
Discussion of $\nu_{m/n} \sim D$ characteristic due to the difference of high-speed and low-speed treatments of films

Further, the difference of image quality (sharpness) of low-speed and high-speed treatments of films is comparatively discussed referring to Fig. 14 and Fig. 15. The difference is clearly shown in the $\nu_{m/n} \sim D$ characteristics in these figures.

Namely, in the A-type and B-type films of low-speed treatments, the sharpness gradually raises up to $D \approx 2.0$ and saturates above $D \approx 2.5$.

In the C-type and D-type films of high-speed treatments, a peak appears at $D \approx 1.5$ differently from the above case, and the degradation of the characteristics are observed almost symmetrically for the both regions of high and low density. This is a characteristic difference between the high-speed treatment film and the low-speed treatment film.

Let us consider this point further. As shown in Table 2, in the high-speed treatment films, both the emulsion layer and the base are thinner than those of the low-speed treatment films for raising the sharpness and reducing the disturbance due to diffusion of light in the layer. From this fact it is expected for the high-speed treatment films that the $\nu_{m/n} \sim D$ characteristics will be generally improved, provided that the development is done under the same conditions. It is, however, noticed from the results of Fig. 15 that the characteristics are lowered with the increase of density in the region above $D \approx 1.5$. Firstly, it can be judged from the results for the low-speed treatment film in Fig. 14 that the effect of improving the sharpness is slight in this density region, even though the film base is thinned. Secondary, it is necessary to remind of the fact that the high-speed treatment film is subjected to fairly severe conditions regarding the time and temperature of treatment as shown in Table 2.

So, from these reasons it is suspected that in the high density region the good effect of thin film does hardly act, and only the bad effect in the development tends to lower the MTF characteristic of image.

On the other hand, in the low density region below $D \approx 1.5$, both the high-speed and low-speed treatment films show almost the same characteristic.

This fact seems to imply that, considering the high-speed treatment film, the enhancement of sharpness due to lessening of the thickness of emulsion layer and that of base, and the degradation of sharpness due to the severe conditions of development would result in cancelling each other.

Table 2

<table>
<thead>
<tr>
<th>Film Type</th>
<th>Processing</th>
<th>Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 16–17μ</td>
<td>200μ</td>
<td>TAG</td>
</tr>
<tr>
<td>B 16–17μ</td>
<td>175μ</td>
<td>ESTER</td>
</tr>
<tr>
<td>C 11–12μ</td>
<td>175μ</td>
<td>ESTER</td>
</tr>
<tr>
<td>D 11–12μ</td>
<td>175μ</td>
<td>ESTER</td>
</tr>
</tbody>
</table>
It has been made clear by the facts mentioned above that the high-temperature and high-speed treatment in the development gives a inferior effect on the X-ray image in the high spatial frequency region, especially in the high density region this effect becomes prominent.

For comparison we carried out the measurement of MTF using the SR-chart for B-type film by the same procedure. The results obtained are shown in Fig. 17.

The values of MTF obtained by use of the SR-chart are extremely low on the whole and any strong correlation for the density is hardly observable.

It has been thus confirmed that, in the case where the composition and the thickness of emulsion, and the conditions of development, etc., are varied, the KR-chart is more sensitive than the SR-chart in the detection of the change of sharpness corresponding to these variations.

5.3 Measurement of Graduality (RMS)

Further, in order to find out the relation between the results of measurement of MTF using the KR-chart and the graininess, we made measurement of granularity.

As the scale of granularity, we adopted the RMS (Root Mean Square) that shows a relatively good correlation with the psychological “roughness”.

The measurement was carried out in such a way that the position, or the part of $D_{\text{max}}$, of $R(0)$ of a sample for measuring the MTF was scanned by a micro-densitometer, and from the density waveform obtained the RMS was calculated by a digital computer.

The measuring conditions in this case are as follows:
- Scanning aperture: $\phi=10\mu$, $\phi=20\mu$
- Total scanning distance: $X=5.5\text{ mm}$
- Interval of sampling: $\Delta t=1.09\mu$
- Number of sampling points: $N=5,000$

The results of measurement are shown in Fig. 18 and Fig. 19.
The points in the figures represent the mean value obtained by the three-time measurements for the same sample.

From these results it has been clarified that there is no difference in the variation of granularity among the films for high-speed treatments and those of low-speed treatments. Namely, in either case the value of RMS increases gradually and attains the saturated state in the density region over \( D \approx 2.0 \). This fact holds even though the scanning aperture size varies, and for the aperture of 20 \( \mu \) and 10 \( \mu \) there is only a difference of about 0.1 in the value of RMS, retaining the whole granularity characteristic with the same tendency.

From the present experiments we obtained the following results for both of the films of high- and low-treatments:

1. In the low density region (0.3–1.5), the changes of granularity and sharpness are in the opposite tendency.
2. In the high density region (0.3–1.5), the changes of granularity and sharpness are in the same tendency.

According to these results, it seems that, in so far as the RMS is used as the scale of granularity, the present experiments do not necessarily support for the conventional opinion that the sharpness is improved when the granularity becomes good.

§ 6. Summary

In order to measure the sharpness of radiographic image, a metallic rectangular wave test chart with a pattern of 1 mm in thickness and 10 lines/mm in maximum frequency consisting of aluminum and lead foils was trially made. The contrast of this chart was found to be as high as more than 0.9 compared to about 0.5 in an evaporation-type test chart.

It was also found from the results of investigation of the incident angle characteristic of our chart that, considering the value of coefficient \( \eta \) which indicates the rate of interrupting the obliquely incident X-ray is as high as about 20 times that of the evaporation-type test chart, the reduction of MTF is slight and the incident angle characteristic is excellent.

Further, we examined the image quality performance of several kinds of X-ray films, obtaining the following results:

1. The aspect of improvement of sharpness associated with the reduction of thickness of film base could be detected quantitatively by using the MTF.
2. It was found that, in the high density region, as the value of \( \gamma \) of X-ray film become little, the MTF is decreased.
3. The MTF characteristic for the density of film for low-speed treatment (Fig. 14) has an increasing value with the increase of density up to \( D \approx 2.0 \), and shows a saturating effect in the high density region, on the other hand in the MTF characteristic for the density of film for high-speed treatment (Fig. 15), a peak is observed at \( D \approx 1.5 \) while in the other density region, the characteristic is degraded as the value of \( D \) is departed from 1.5.
4. In the experiments performed by using a conventional evaporation-type test chart, a remarkable correlation between the density of X-ray film and the MTF which had been found when the KR-chart was used was hardly found (Fig. 17).
5. It was found that the granularity (RMS) has a tendency of showing larger values as the density of X-ray film becomes high, and in the low density region (0.3–1.5) the variations of granularity and sharpness show opposite tendencies, while in the high density region (1.5–3.0) those variations are almost in the same tendency.

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References