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Measurement of Focal Spot sizes of X-ray Radiographic Units by Digitisation of Slit Image and Generation of MTF

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ABSTRACT

The focal spot size of Radiographic Unit has an influence on the resolution of a system and hence influences the Modular Transfer Function (MTF) of the system. MTF has been used for estimation of focal spots of radiographic units. Although a focal spot pinhole radiogram is the popular method for determination of focal spot size of conventional radiographic unit, it is not suitable for measurement of focal spot size of microfocus radiographic units. This limitation comes from the requirement of the pinhole size, which should be an order of magnitude lower than the expected focal spot size. The requirement of pinhole size makes it difficult for focal spot measurement of minifocus units by pinhole method. Vernier slits are radiographed at low KV for two different focal spot sizes (mini and conventional) of two X-ray radiographic units at AFFF. The slit images were digitised using high resolution scanner and the standard optical density curve. The digitised images were spatially calibrated. The line profile generated across the slit gives line spread function, which represents the radiation intensity distribution in the image of a relatively infinitely narrow and long slit. MTF curves are drawn by Fast Fourier Transformation (FFT) of LSF and for the derivatives of Edge Spread Function. The results were compared with Resolution (Star) Pattern method. This paper highlights the use of MTF generated from the digitised image stored in computer for measurement of markedly varying focal spot sizes of the radiographic units, in the absence of a suitable pinhole camera. Standardisation of the MTF method will make it possible to determine focal spots of industrial radiographic units.

1. Introduction

The focal spot size of a radiographic unit is an important design parameter as it influences the resolution of the system. Although focal spot pin-hole radiogram is the popular method for determination of focal spot size of conventional radiographic unit, it has certain limitations. Larger pin-hole blurs the image and introduces large inaccuracies. Resolution test chart has been successfully used for determination of focal spot size of microfocal radiography unit [1]. Modular transfer function (MTF) shows the frequency response of the imaging system. Since the focal spot dimension is closely linked with the frequency response, there exists a relationship between the focal spot dimension and the MTF of a radiography system. The first minima or the first zero of the MTF curve has been used to determine focal spot size of industrial radiography units [2]. In absence of a suitable pin-hole camera, vernier slit radiographs were taken with each focal spot of the two dual focus x-ray radiography units at ADVANCED FUEL FABRICATION FACILITY(AFFF),BARC,TARAPUR. The radiographs were taken at magnification and at low voltage. High-resolution scanner was employed for grabbing the slit images which were subsequently digitised using standard optical density curve. Contrast transfer characteristic or MTF curves were generated by fast fourier transformation (FFT) of the line spread function (LSF) of digitised slit images. In the present work an attempt has been made to use the MTF generated, using image analysis software on the scanned slit radiographs, for determination of focal spot sizes of industrial radiography units. The results obtained through digitisation of slit radiographs in some cases are compared with that obtained from their microdensitometer scanning.

2. Principle

When an input signal is transmitted through an imaging system, the system parameters change the input signal and give a modified output image. In this case vernier slit is the input signal, the x-ray radiography unit along with entire imaging set-up is the system and the radiographic image of the slit is the output response. The ratio of image contrast to that of the object gives the quality of retransmission of information by the system. This is called contrast transfer function (CTF) or MTF. A MTF graph plots the percentage of transferred contrast versus the spatial frequency (cycles/mm)[3]. One of the ways to obtain MTF is to take FFT of the LSF. The LSF is the property of an imaging system and it characterises the way the system operates on a signal. In the present case the LSF is generated from the optical density profile across the slit radiograph. For edge radiograph, LSF was generated from derivatives of its edge spread function (ESF). It has been reported that a sinusoidal function will remain sinusoidal with the same frequency even after going through the system . For magnified images the spatial frequency changes according to the reciprocal of magnification [3]. Fourier transformation of LSF gives its sinusoidal component signals of different amplitudes and frequencies. MTF is related mathematically by fourier transformation to LSF [2].

For radiographic imaging system Morgan [4] showed that CTF(same as MTF) for sinusoidal varying object as

CTF = Sin[pf0a{d2/(d1+d2)}]/[pf0a{d1/(d1+d2)}] ..eqn(1)

Where d1 & d2 are respectively the source to object distance and object to film distance.
f0 = Spatial fr4equency of the sinusoidal object.
a = Focal spot size.
Use of resolution test patterns for focal spot size determination using equation (1) has been reported earlier [1]. Value of MTF will be zero where frequency is such that argument of sine function is equal to p or its multiple.

Hence focal spot size a = n*[(d1+d2)/d2]*1/f0 ..eqn(2)

The frequency at which FFT of LSF becomes zero is the same for which MTF is zero. Using that frequency in equation (2) one can find out focal spot size. In the present case, since the amplitude spectrum (FFT of LSF) of the image plane frequency is used, the equation (2) gets modified [2].

Focal spot size = 1/fi*d1/d2 ..eqn(3) for n=1(First harmonic).

At 2X magnification d1 equals d2 and equation(3) becomes:
Focal spot size = 1/fi ...eqn(4)

In absence of a distinct zero on MTF curve the frequency of the first minima gives satisfactory result. Although the MTF of the scanner and other system affects the result, their effect is neglected for the present work.

3. Experimental

Vernier slits of 50 um width were radiographed at 2x magnification,with both mini and conventional foci of two different dual focused X-ray radiography units at AFFF,BARC. In all cases Agfa D2 films were used. The radiographs were scanned under identical parameter settings using high resolution scanner having transmission facility for use with radiograph. The scanned images were digitised with respect to standard optical density curve using image analysis software. The line profile of optical density generated across the spatially calibrated slit image gives its LSF.

The amplitude spectrum for the component frequencies, which is similar to MTF were generated by FFT of LSF data with the help of a standard software. The frequencies for which the amplitude becomes zero is noted for each plot, and the same is used for calculating the respective focal spot size using eqn(4).

The radiograph of star resolution test pattern is taken with each focal spot of both the X-ray radiography units. The first circle of null contrast is used for calculating focal spot size [5]. The values were compared with that obtained using MTF plots.

The comparison of resultant MTF plots obtained from microdensitometer scanning of slit radiographs, with that obtained from digitisation of scanned radiographs, has been done. For this, the slit radiographs of X-ray units at ATOMIC FUEL DIVISION, for which focal spot sizes were calculated from FFT of LSF data obtained by microdensitometer scanning, were scanned by high-resolution scanner and digitised. The value of the focal spot size obtained from MTF of digitised image is compared with that from microdensitometer scanned data, to understand the effect of scanner and digitisation with image analysis.

4. Results and Discussion

A typical graph of line spread function for the smaller focus of one of the dual focus x-ray units is shown in Fig(1a). The MTF derived from it is shown in Fig(1b). The curve falls to zero at the spatial frequency of 0.00113(cycles/um). By using equation (4) the focal spot size works out to be 884um. The catalogue value of the focal spot is 800um and the dimension measured by the star pattern is 995um. The remaining focal spot sizes of both the dual focus x-ray units were measured similarly. The focal spot sizes measured by MTF method are shown in table 1 along with their respective catalogue values and that measured by star pattern.

TABLE 1

	XRT Unit-1 Focal Spot Size (um)		XRT Unit-2 Focal Spot Size (um)	
Catalogue Value	400	1500	800	1500
MTF Method	435	1162	884	1712
Star Pattern	373	1651	995	1185

It is seen that the focal spot measured by the MTF method, for smaller focus of both the units are in close agreement with their catalogue value and that measured by star pattern. Their MTF plots drops sharply to zero level amplitude giving distinct frequencies at which corresponding amplitude becomes zero. However in case of larger focus of both the units, there is a marked difference in the focal spot size measured with MTF method from that of the respective catalogue value and that measured with star pattern. Fig 2(a) &(b) show respectively the LSF and the MTF derived from it for the larger focus of one of x-ray radiography units. For larger focus, the MTF plot gradually flattens after a sharp drop to a lower amplitude level. There exists no distinct frequency for which amplitude is zero. The focal spot sizes for such case are calculated with frequencies at which there is a sudden change in slope in the respective

MTF plots. The flattening of MTF may be due to high frequency noise components in the LSF obtained with larger focus. This aspect of MTF flattening with larger focus and absence of a distinct frequency for which the amplitude is zero needs further study.

MTF curves obtained from LSF of 100um slit using microdensitometer is shown in Fig(3a). The same radiograph was digitised directly by the scanner and the resultant MTF is shown in Fig (3b). Table 2 shows the focal spot sizes measured from resultant MTF plots of scanned radiographs against that obtained from the MTF curves generated using microdensitometer, for the two different units at AFD, BARC. Their catalogue value is also given side by side for comparison.

TABLE 2

	Focal Spot Size (um)		
	XRT Unit-3	XRT Unit-4	
	Slit RT	Slit RT	Edge RT
Catalogue Value	2500	400	400
MTF Method Scanned Radiograph	2183	636	694
MTF Method Microdensitometer Data	2480	740	616

It can be seen that the focal spot sizes obtained from MTF of scanned radiographs and that of microdensitometer data do not deviate much,except for the larger focus unit. The deviation may be the result of different procedure adopted for generation of LSF and resultant MTF.

5. Conclusion

The method of obtaining focal spot size of industrial radiographic unit by scanning and digitising the slit radiographs and generation of MTF works satisfactorily for focal spot size upto 800um(catalogue value). For larger focus (>1000um) the MTF curves generated for scanned radiographs flattens and does not show a minimum or zero amplitude at any frequency. This aspect needs further investigation.

The focal spot size obtained for MTF of slit radiographs are affected by the following parameters:

(1) Noise in LSF obtained. Use of exposure profile instead of optical density profile for LSF may reduce noise.

(2) Portion of LSF included for generation of MTF.

(3) The interval selected for Hanning window for FFT of LSF. It has been observed that the selection of same interval in the Hanning window, as that of optical density data for the scanned radiograph at a particular dpi, gives value of focal spot close to their catalogue value.

(4) Alignment of the slit with the X-ray radiography unit.

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