APPLICATIONS OF FILM TOMOGRAPHY TECHNIQUE FOR NDE

A. Notea

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INTRODUCTION

Tomography with X- and gamma-rays provides three-dimensional radiographic information on the examined object. The film-based tomography (1,2) generates a summation-image of a surface within the object by continuously combining back projections directly on the film. This method has many attractive features for industrial applications in which cost and simplicity are of primary importance. Some of the features are:

(a) The absence of post processing allows this method to yield an image immediately on development of the film.

(b) Conventional radiologists need a short training time to master the technique as most components and concepts are familiar to them: e.g. radiation sources, films, screens, collimators, filters, processing units, viewers, exposure, contrast, resolution.

(c) Purpose oriented system optimized for a certain range of products, may be built with costs much less than digital computing transaxial tomography (CT).

(d) Tomographic images of surfaces of critical areas within the examined object are directly recorded on films curved to match the required shape.

(e) Tomographs on film may be digitized and image-processed by commercial system developed for conventional radiographs.

(f) The slice thickness of the recorded surface may be in the order of magnitude of the thickness of the film-emulsion.

(g) The quality of the tomograph is high especially for high-contrast objects (2) and whenever the noise and the dynamic-range of the film do not impose a limitation on the information to be extracted.

In the present study the possibility to record images of surfaces within the object was studied and the response function was modeled.
The method is based on synchronous rotation of the object and the film holder. Both axes of rotation are in the same plane as well as the radiation source. The radiation beam is perpendicular to the rotation axis. The radiation fan beam covers the full width of the object. The thickness of the slice covered by the beam can be varied according to the area of interest in the object. The source-object distance is adjusted so that the cone beam geometry does not introduce significant distortions in the volume under inspection. This method in principle was suggested over forty years ago (3).

In this system every point in the inspected volume of the object corresponds to a point in the generated three-dimensional tomographic image and both points remain relatively stationary. Each point to be imaged is passed by the radiation from all directions (0 to π). A film placed within the 3D tomographic image records the corresponding surface within the object.

The analytical approach for noise-free continuous summation on the film is given by the following transforms. The spatial distribution of the radiation attenuation in the examined volume may be expressed by

\[ g(x,y,z) = \mu(x,y,z)\rho(x,y,z) \]  

(1)

where \( \mu \) is the mass attenuation coefficient (cm\(^2\)/g) for a given energy, and \( \rho \) is the material density (g/cm\(^3\)) at \( x,y,z \). The interoqate radiation passes the \( x-y \) planes in the examined volume and the \( z \) axis is parallel to the symmetric axis of rotation.

The \( g \) function may be expressed in coordinates defined by the penetrating radiation \( s,u,z \) (see Fig. 1). The projection \( P \) along the \( u \) direction for a certain \( \theta \) is solely a function of \( s \), and is given by the Radon transform (4) \([Rg]\) (5).

\[ P(s,\theta,z) = \int_{0}^{E_{\text{max}}} S(E)\exp\{-(Rg)(s,\theta,z,E)\}dE = \]  

(2)

\[ = \int_{0}^{E_{\text{max}}} S(E)\exp\{\int_{-\infty}^{\infty} g(s\cos\theta-u\sin\theta, s\sin\theta+u\cos\theta,z,E)du\}dE \]

\[ s \geq 0, \ 0 \leq \theta < 2\pi \]

Fig.1. Coordinate Systems.
where \( S(E) \) describes the X-ray energy spectrum and the film spectral response.

The image generated by the continuous summation on the film is expressed by the unfiltered integration over \( \theta \), i.e. by the back-projection transform \([\mathcal{R}]\) \((5)\),

\[
I(x,y,z) = \mathcal{R}(x,y,z) = \int_{0}^{\pi} p(s,\theta,z) \, d\theta .
\]

The tomographic image \( I \) differs from that obtained by the CT, as in the later method the \( \mathcal{R} \) transform is performed on \([Rg]\) after applying an appropriate filter. The film placed within the the 3D image along a surface \( F(x,y,z) = C \) will record a two-dimensional image representing the intersection of \( I \) with \( F \).

MEASURED IMAGES

The object used for the demonstration was a ceramic hand-made jar with a defect in the neck area (see fig.2). The tomographic images were generated on Agfa-Gevaert Structurix D7 films with industrial X-ray unit (Andrex, 2.9 mm. focus) at 150 KV and source to jar distance of 310 cm.

The following "cuts" are presented:

i) horizontal planar tomogram at the neck through the damaged area (location P in fig.3) is presented in fig.4.

ii) planar tomograms at 45° in the neck area (location A and B of fig.3) are presented in fig.5.

iii) vertical planar tomograms (parallel to the symmetric axis of the jar) along the diameter and off-center (see fig.6).

iv) vertical cylindrical tomograms generated by two concentric film cylinders whose symmetric axis coincides with that of the jar. The smaller cylinder (C in fig.4) cuts within the neck's wall where the defected area is observed, and through the base (see fig.7a). The larger cylinder (D in fig.3) cuts through the walls of the spherical volume (see fig.7b). As is seen the two bands of the intersections with wall are not parallel i.e. the perimeter of the jar is not circular. Both films were exposed simultaneously.

The resolution was measured using a perspex block 20 by 45 by 200 mm. with fifteen slits of 10 mm. depth and widths: 10;5;3;2;1.5;1.2;1;0.8;0.6;0.5;0.4;0.3;0.2;0.1 and 0.05 mm. The tomogram reveals the slits down to 0.2 mm., but as is expected (6,7), the image contrast reduces with the width. The limit is achieved with 2.9 mm. focus and 1.19 magnification i.e. about 0.5 mm. geometric unsharpness.
Fig. 2. The examined jar

Fig. 3. Locations of films.

Fig. 4. Horizontal planar tomogram at P, fig. 3.
Fig. 5. Planar tomograms at 45° in the neck area

(a) at A, fig. 3.  

(b) at B, fig. 3.
Fig. 6. Vertical planar tomograms

(a) along the diameter          (b) off-center
Fig. 7. Vertical cylindrical tomograms

(a) Cylinder at C in fig. 3

(b) Cylinder at D in fig. 3.
CONCLUSIONS

The study has shown that it is possible to obtain 2D tomographic images of planar and curved surfaces within the object under investigation. Thus critical areas may be examined with films exposed simultaneously to the X-ray beam.

The film tomograph method can yield satisfactory geometrical resolution using X-ray units of small focus and relatively accurate motion mechanism.

In applying digitization and image enhancement techniques, the advantage of photographic film as a detector becomes apparent due to the spatial resolution achieved, which is far better than with CT systems.

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REFERENCES