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放射線 寫眞術에서 自動化技術로서의 放射能試驗

Radioscopy as Automated Technique in Radiography+

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I) INTRODUCTION

Radiography by x-ray or gamma radiation belongs to one of the oldest methods of nondestructive material testing and has developed to a reliable technique as it is applied today.

Radiography, as it presents itself to us nowadays, is classified and evaluated in Fig. 1. This schematic illustration has been taken from a publication by E. Mundry [1]. As can clearly be seen radiography comes off relatively well, particularly for information on defects which do not occur directly on the surface or do not extend as far as the surface.

Based on this evaluation it can be stated that great importance must be attributed to the further development of the technique of nondestructive testing. However, the question arises in view of this positive evaluation, is there any motive for further developing the technique, i.e. which are its weak points and disadvantages, and are there any possibilities of improving radiography with x-ray films. Particularly in nuclear engineering, e.g. in-service testing in nuclear power plants, problems are encountered in radiography which necessitate tha further development of the latter, as can clearly be gathered from the following evaluation.

II) ADVANTAGES AND DISADVANTAGES OF RADIOGRAPHY

The radiation detection systems in radiography can be valuated by the following aspects:

- Radiation detection efficiency
- Internal spatial resolution of the system
- Contrast resolution
- Possibility of automation
- Sensitivity to scattered or background radiation
- Possibility of energy discrimination
- Exposure time

+) This work was furthered with means by the Ministry of Economics, Small Business and Trade of North-Rhine Westfalia.

1) E. Mundry Schweisstechnik 6/82.

- Real time representation
- Handling ease (size, reliability, requirments of the control)
- Costs

When examining the radiation detection system of x-ray film under the aforesaid aspects, the following results are obtained.

- The detection efficiency for high-energetic radiation (e.g. Co-60) is relatively low, so that long exposure times and high doserates are required for greater material thicknesses, even when using intensifying screens which, in turn, decrease the internal spatial resolution.
- A few typical values for the internal lack of definition of x-ray films are approx. 0.1-0.2mm for x-rays of 100 KV, and approx. 0.2-0.3mm for gamma rays (Ir-192, Co-60); this, of course, being very good values against which other detection systems will have to be measured.
- The contrast resolutions obtained with x-ray films are the basis of the image quality values for image quality class I postulated in the DIN-regulations (54 109). Depending on the material thickness irradiated (3mm to 150mm) they amount to 2.4% to 0.7%. Thus, for x-ray films very good contrast resolutions are obtained which are ultimately reflected in the evaluation of Fig. 1.
- However, the x-ray film cannot or can only be used indirectly for quick and automated radiography.
- Background or scattered radiation contribute to a blackening of the film which can hardly be avoided as an energetic separation of the scattered radiation from the direct radiation is not possible. On the contrary, based on the lower energy of the scattered radiation the latter is absorbed more strongly in the film. Though spaced exposures, wobble filter or film screen combinations contribute to relieve this problem, however, they cannot remedy the latter.
- On the other hand, handling ease of the film is excellent; it requires only little space, can be cut to adapted size, and is reliable; however, it takes a relatively long time to have the film developed, and the quality of the exposure cannot readily be examined.
- Costs for film exposures have considerably increased lately. When comparing prices, in addition to the investment costs also the costs for the testing personnel in view of the long exposure and film-developing times must be considered.

In summary, the following can be stated considering the significance of a further development in radiography:

- Radiography is a valuable technique in nondestructive material testing.

- There are a number of disadvantages in the radiation detection system x-ray film that would justify the request for a further development while considering the presently available technological possibilities.

In the in-service testing of installations vital for safety reasons in nuclear power plants, it is, above all, the request for automation, reduction in the exposure time and the possibility of real time operation for quick inspections, e.g. valve settings, that necessitate new techniques and methods in radiography.

III) RADIATION DETECTION SYSTFMS IN RADIOGRAPHY

Radiography can be classified into various fields which are closely related to the respective radiation detection system:

1) Projected images
   - A) Radiography (x-ray films)
   - B) Radioscopy (fluorescent screen)
   - C) Radiometry (radiation detectors, e.g. scintillation crystal, semi-conductor crystal)

2) Tomographic images
   - D) Computer tomography (radiation detectors)
   - E) Tomosynthesis (x-ray film).

In this classification, the computer tomography actually belongs to radiometry and the tomosynthesis to radiography. However, since they supply a tomographic image and not a projected image, in contrast to the otherwise conventional radiographic techniques, a further sub-division has been made here. In our research section we are engaged in the development of the technique as stated under A-D, for which we have devised testing systems. In this paper, however, we shall restrict ourselves to radioscopy with Co-60. At the Conference on Nuclear Engineering '83-also here in Seoul we shall report on the development of a gammametric system.

IV) RADIOSCOPY WITH HIGH-ENERGETIC RAYS

Radioscopy is a technique well-known as such which has gained a predominant significance since long particularly in the medical field.

In this connection it should be mentioned that it is well worth while for the designers of nondestructive testing techniques to have an eye on the medical field, because in this latter field a few methods are already prior art which are still in their initial stages in the material testing field.

An important reason for this, most certainly, is that the costs of some of the medical systems are relatively high (how much may health cost?!), on the other hand, in most cases the demands of material testing operators differ widely, frequently more far-reaching. This conversion of medical systems to material testing, therefore, represents the actual problem in development. In nondestructive material testing much greater absorption coefficients are involved, different radiation energies, different contrast resolutions and, generally, considerably higher requirements of spatial resolution.

In two respects, however, we are much better off than the physicians: our objects under examination are not likely to resent high radiation doses, and in most cases readily endure any examination times. The radioscopic systems including x-ray image converter tube according to the present prior art in the medical field are illustrated in Fig. 4[2,3,4]. However, for reasons of costs and principal reflections, the application of the arrangement shown in 4a is selected as suited best for radiography.

By means of Fig. 5 the eseential problem of development shall be explained which occurs in the conversion of the radioscopic system from the medical to the material testing field. A Co-60 radioactive source having 10 Ci generates $6 \, . \, 10^4$ photons/mm^2/sec at 1 m distance (1.1 and 1.3 MeV). The intensity of this radiation is attenuated by a factor 15 when passing through a 100 mm thick workpiece of steel so that subsequently, only $4 \, . \, 10^3$ photons/mm^2/sec are still existing. The detection efficiency of a relatively thick CsJ-input screen, optimized to Co-60 radiation, is approximately 1%. This reduces the number of photons/mm^2/sec which provide the whole information on the radiation image to 40/mm^2/sec, meaning a noise-to-signal ratio according to the laws of statistics of 16%.

This value, off-hand, limits the contrast resolution which cannot be improved by any further signal processing. The absorbed or scattered radiation quanta generate electrons producing light on the input screen (approx. 150 photons per absorbed gamma quantum). They impinge upon a directly contacted photo cathode which, in turn, emits photo electrons. By means of an electron optics the electron image produced by the cathode is reduced by a factor 10 and amplified via an accelerating voltage so that the phosphorus output screen presents a relatively bright image caused by the impinging electrons, which is imaged on the TV-pickup tube by means of a so-called tandem optics. The tandem optics comprises two fast lenses having an aperture ratio of approx. 1 : 1 in whose respective focal points the phosphorus output screen, respectively the light-sensitive layer of the TV-pickup tube are located. Between these two lenses the light is parallel. This fact can be used to project the image, for instance, on an additional camera by a partially-transmitting mirror arranged in the parallel path of rays. By means of the TV-pickup tube the radiation image is presented on a monitor.

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2) A. Gebauer, J. Lissner, O. Schott: Das Rontgenfernsehen Georg Thieme Verlag, Stuttgart, 1974.
3) Siemens Med. Technik: Bildgebende Systeme fur die medizinische Diagnostik, E. Krestel Hrsg., 1980.
4) R. Halmshaw: Industrial Radiology, Applied Science Publishers, London, New Jersey, 1982.

From this schematic drawing it will become apparent that the critical factor, resp. the determining element for the contrast resolution is the relatively low detection efficiency of the input screen for the respective radiation, from which it follows that the input screen should be made as thick as possible, however while considering the desired local resolution, two requirements which are diametrally opposite to each other.

V) DESIGN OF THE GAMMASCOPIC SYSTEM GS 220

The principal design of the radioscopic system GS 220 for the energy range up to 8 MeV, which we have devised, is shown in Fig. 6. It comprises an image converter tube as it is used in modern medical x-ray TV-systems. However, the thickness of the CsJ-input screen has been increased substantially so that for instance, the gamma radiation of Co-60 yields a detection efficiency of 2-3%. This considerable increase in thickness over against medical instruments without a deterioration in the spatial resolution of the image coverter has been rendered possible by providing that the CsJ-input screen is applied to the photo cathode such that indicidual CsJ-crystal needles of 10 - 20 μm diameter are produced closely adjacent each other. This needle structure acts like an optical fiber so that even for greater crystal thicknesses the point of origin of the light is well defined and therefore a good spatial resolution can be obtained.

Despite this thick input screen of the image converter, however, the image on the phosphorus output screen suffers from relatively high background noise. A further improvement in the contrast resolution is therefore obtained by an integration of several TV-images in so-called real time, i.e. 25 integrated images per second. Integration is carried out by means of an image-processing system, 65,000 digitalized TV-images of 512 x 512 image points, each having a contrast resolution of 256 gray values (corresponding to 0.4%) can be summed up with in 45 min.

The image-processing system permits manipulations of the images, such as, for instance, frequency filtering, pseudoplastic representations, accentuation of contrast etc. Also, by subtraction of two images, one of which is taken prior to operation of the system, the other after a certain time of operation, it permits a substantial simplification in fault recognition, as now, only the changes will be imaged.

The images can be presented on a color or b+w- TV-monitor. A documentation is possible by digital storage on a magnetic tape or magnetic plate or via a so-called "hard-copy"-unit on a film (slide, polaroid).

The following (two) Figures 5a, b illustrate the Gammscope GS 220 (5a) as well as the computer unit including operator console and color and b+w -monitor (5b) showing a test image.

The specifications as related to spatial and contrast resolution which can be obtained with this system will now be explained and discussed more fully.

1) Spatial resolution

The spatial resolution of a radioscopic system is substantially defined by the image converter, the TV-system and the image-processing system, and for quantum-statistical reasons also by the doserate at the input of the CsJ-screen.

These dependencies of the system GS 220 are plotted in Fig. 8 for Co-60 as radioactive source. The values on the abscissa (doserate) depend on the energy of the radiation via the detection efficiency of the input screen. It can be seen that above a doserate of 1 R/h the spatial resolution is determined by the number of lines of the television system, the limit value of approx. 1.2 line pairs (LP) per mm being linearly dependent on the diameter of the input screen, in this case 220 mm. 1.2 LP/mm correspond to a spatial resolution of 0.8 mm.

In our system the effective image diameter can be reduced down to by a factor 2 so that a spatial resolution of 0.4 mm for 100 mm image diameter can be obtained on the input screen. This resolution limit can easily be calculated when considering, that for a 625-line televison system k. 625/2 line pairs are available which must be distributed over the size of the input screen, k being the so-called "Kell-factor" which describes the loss of information by the TV-scan (K = 0.75). Thus, 235 line pairs are obtained as resolution limit for a 625-line TV-imaging system.

As the transfer of information of a composite system is always worse than its individual components, the composite system of image converter including TV-imaging system can be represented by the lower curve in Fig. 8. This is described by the conception of modulation transfer functions to which, however, no further reference can be made here.

2) Relationship between spatial and contrast resolution

The contrast resolution similarly to the spatial resolution depends on the doserate, i.e. on the number of absorbed radiation quanta. Therefore, by means of the quantum statistics the relationship between spatial and contrast resolution can readily be established.

Assuming N is the number of detected and counted radiation quanto. Then, the quantum noise δ in the input screen is given by

$$\delta = \sqrt{N}$$

When defining the contrast C still recognizable as the ratio of the k-fold noise to level of signal N, then

$$C = \frac{k\delta}{N} = \frac{k}{\sqrt{N}}$$

is obtained. N results from the number of particles n_e impinging per mm^2 and per sec, the integration time t_{Int}, the diameter d of the smallest object still to be recognized and the detection efficiency ϵ_a of the screen to

$$N = n_e \cdot t_{Int} \cdot \pi d^2 \cdot \epsilon_a$$

Thus, as relation between spatial and contrast resolution for the ideal image converter

$$C = \frac{k}{\sqrt{d \quad \pi n_e \epsilon_a t_{Int}}}$$

is obtained, Herein, only the noise of the incident photons has been considered; the internal partly correlated noise portions of the overall system will, however, strongly deteriorate these values.

In Fig. 10, the connection given by the above relation for an integration time of 0.2 sec (integration time of the eye) and for a detection efficiency of the input screen of 3% with different doserates has been plotted as parameter (k = 2).

When using, for instance, a 100 Ci Co-60 source (3% detection efficiency) at 1 m distance from the input screen and a workpiece with 15-fold attenuation of the intensity, this corresponds to a curve of the doserate 7 R/h. For a diameter of the smallest object still to be recognized of 1 mm a contrast resolution of approx. 7% is obtained. If a contrast resolution of 2% shall be achieved under these conditions, the integration will have to be carried out for 2.45 sec for an ideal arrangement.

When considering the other noise portions of the system, especially correlated noise, under the above conditions and for a contrast resolution of 2% a necessary integration time of t_{Int} = 162 sec will be obtained.

3) GS 220: Specifications

The contrast resolution obtained with the Gammascope GS 220 has been determined with image quality indicators according to DIN standards 54 109 for Ir-192, Co-60 and an x-ray tube (60 - 225 kV, 5 mA). The results are plotted as a function of the wall thicknees for iron in Fig. 11.

For the gamma sources Co-60 and Ir-192, contrast resolutions of about 1.9% can be observed, while the x-ray tube yields image quality class I in the range of wall thickness of iron of 6-60mm.

Fig. 12 illustrates the irradiation image of an image quality test specimen of high-grade steel (10 mm thickness) made by us and which is provided with a number of recesses for determination of spatial and contrast resolution. This image (integration time 10 sec) which has been taken with the x-ray tube, readily shows a local resolution of 0.3 mm; this being the distance of the closest line pattern (5 line pairs).

In the following Fig. 13 the irradiation image of a test specimen of Pb (Fe-equivalent 35 mm) taken with 50 Ci Ir-192 can be seen. The upper image has been made without integration, the lower after an integration time of 30 sec.

On main purpose of application of the gammascopic system shall be the macroscopic fault recognition, i.e. the inspection of structural parts as to completeness or physical state. Fig. 14 illustrates an example thereof. The question to be answered was whether the proper functioning of a check valve having been exposed to external damaging, was still ensured. The specimen was irradiated with 100 Ci Co-60 (integration time 15 sec, wall thickness approx. 5 cm).

VI) FUTURE DEVELOPMENTS

From the reflections so far the following possibilities of further development of the radioscopic system in future ensue:

- Further or new development of the image converter tube with a view to an improved detection efficiency for high-energetic radiation.
- Application of high-resolution TV-systems and image-processing equipment with 1024 x 1024 image points
- Establishment of program systems permitting an automatic fault recognition