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Radiography – Radioscopy … a technology comparison

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Abstract

More and more typical Radiographic applications get converted into digital solutions. On the forefront of technology are Flat panel digital detectors and systems with Image Intensifier solutions. The quality of these systems and the comparability to radiographic exposures have long been discussed, and ground in the essential difference of the detector properties and the resulting difference of the inspection conditions for radioscopic applications.
GE InspectionTechnologies has driven the digital conversion from the start, and is as a leader in this process sharing its experience, progress, recommendation and outlook. This Abstract is making the effort to promote and explain the factors influencing and dominating radioscopic X-Ray.

1. Introduction

Standardization of X-ray applications in the traditional field of Film technology has made this technology the dominant modality for Non Destructive Testing in many areas.

Clear defined procedures for setup, execution and interpretation of radiographic images, along with an unmatched repeatability of the inspection result, have hold the technology on the upfront of today's inspection.
Nevertheless, constraints of the film technology such as time consuming image - retake, development of the exposed films and chemistry handling, make it a lengthy process.

Digital solutions have developed in the market, and have proven their strong capability to replace film technology with outstanding performance values in many application-fields.

In order to find out the key performance factors of each technology, we have to compare the relevant factors influencing the image quality, and have to evaluate the necessary actions to achieve this desired quality.

2. Radiography – Radioscopy

The essential differences between radiography and radioscopy lie in the different detector properties and the resulting inspection conditions (see Tab.1).

We can group detector properties into 3 major sections:

A) Exposure related differences
B) Physical detector differences
C) Mechanical differences

A)
The key performance value here is the quantum noise of X-Ray. Because exposure times on films often exceed several minutes, there is virtually no noise detectable on film images. Not so in Radioscopy, where the exposure times are limited to 40ms, as specified in the video standard. Here the live image will show up with a distinct "graininess", and image enhancement tools will be needed to perform frame integration of a number of static digital images, to achieve noise reduction.

B)
The spatial resolution of common detectors in radioscopy is distinctly lower than the spatial resolution of film. (see table 1)
To compensate for the difference, the application setup in radioscopy has to work with a geometric magnification with magnification factors being around approx. 1.5 - 2.5 in casting examinations. Geometric magnification compensates for low spatial resolution or higher inherent unsharpness in comparison to X-ray film

C)
Mechanical differences are best described through the flexibility of the examination perspective. Because of the arrangement of the film, only a fixed, rigid examination perspective directly behind the test

subject is possible in radiography. However, very few restrictions exist in radioscopy, depending on the handling system and the geometry of the casting.

	Film Radiograph	**Conventional RTR**	**RTR with Image Processing**	**Microfocus RTR with Image Processing**
Resolution	0.1 to 0.06 mm (0.004 to 0.002 inch)	0.5 to 0.25 mm (0.02 to 0.01 inch)	0.5 to 0.25 mm (0.02 to 0.01 inch)	Up to 0.05 mm (0.002 inch)
Contrast Sensitivity	1 to 2%	3 to 4%	0.5 to 1%	0.5 to 1%
Speed	5 to 15 min/image	Real time	1 to 30 sec/image	1 to 30 sec/image
Test perspective	Fixed	Flexible	Flexible	Flexible
Imaging Geometry	1:1 geom. mag. aprox.1 low influence of focal spot size	1:1.5 or higher geom.. mag. Larger than 1 high influence of focal spot size	1:1.5 or higher geom. mag. Larger than 1 high influence of focal spot size	1:1.5 or higher geom.. mag. Larger than 1 high influence of focal spot size

Table 1. Performance comparison between film and various Radioscopy system configurations.

Digital image enhancement & evaluation tools, along with geometrical magnification, have made it possible for radioscopic images, to achieve an imaging quality equivalent to that of film.

When magnification is used in an RTR system, the geometric unsharpness of the inspection setup needs to be taken into consideration. The size of the X-ray tube focal-spot and the magnification factors, namely the source-to-specimen and specimen-to-detector distances, are used to calculate the geometric unsharpness of the inspection setup.

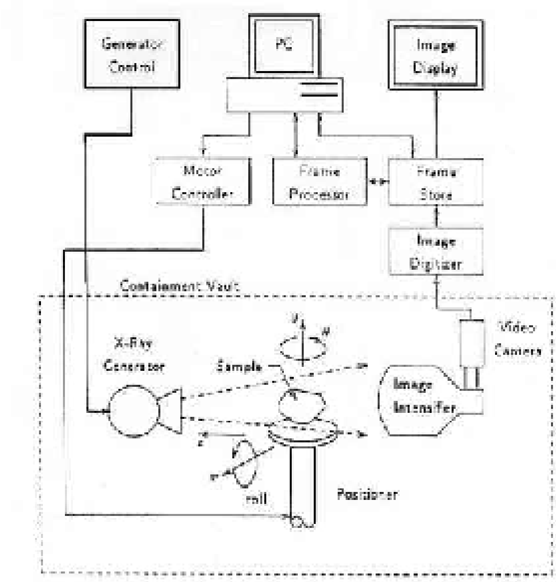
Conclusion: Radioscopic solutions can be used to achieve film equivalent defect detectability, if the application is prepared with sufficient geometrical magnification and the appropriate focal spot size needed.

2.1 Radioscopic system component setup

The schematic design of a radioscopy system is shown in workflow 1. The radiation image is generated in a procedure of two main tasks: the conversion of the X-ray image into a visual image and the subsequent image transfer. All Imaging systems used in radioscopy produce a positive Image of the attenuation profile (low attenuation equals high intensity in radiation image).

Most important for the system setup is the validation of the inspection task. Type and size of detectable defects, correspond to unique system properties. The previously discussed application requirements need to get translated into appropriate component features in the system.

The x-ray source with its focal spot, the geometric necessary enlargement and the dynamic range of the detector system are the most basic variables to control. The following image transfer and processing technology enhances the functionality of the system, and digitally improves image quality and defect detectability.



Workflow 1: radioscopic system set-up and imaging system

A consequence of the geometric magnification of test objects is, that the properties of the X-ray focal spot have a decisive influence on the image quality. We have to understand the influence of the focal spot, as it is illustrated below.

2.1.1 Ideal case with point shaped focal spot

Figure 1 shows what happens in a setup with the ideal imaging geometry of a point-shaped (infinite small) X-ray focal spot. The optical display of the test subject is dependent only on its position between X-ray focal spot position and detector. This way, in theory endless magnification would be possible, and any small defect detail could be displayed. The magnification factor M is only dependent upon the ratio of the focus-detector distance (FDD) to the focus-object distance (FOD):

Geometric or direct magnification factor:

$$M = \frac{FDD}{FOD}$$

- Therefore, $M \rightarrow 1$ for $FOD \rightarrow FDD$ (Corresponds to the radiographic imaging situation)
- M= max for FOD=max
- M=2 for FOD=1/2 FDD

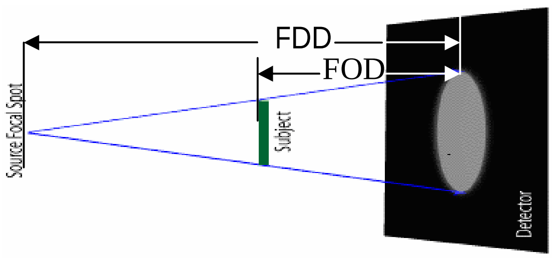


Fig. 1: ideal imaging geometry

2.1.2 Imaging reality with defined focal spot

The practical imaging situation differs from the ideal, as the X-ray focus size cannot be a point with no dimensions. (see Fig. 2). The focal spot size d causes a geometric unsharpness u_g that is additionally dependent upon the geometric magnification M.
The geometric unsharpness is calculated as:

Geometric unsharpness

$$u_g = d \cdot \frac{(FDD - FOD)}{FOD}$$

or

$$u_g = d \cdot \left(\frac{FDD}{FOD} - 1 \right)$$

or

$$u_g = d \cdot (M - 1)$$

With d being the dimension of the focal spot.

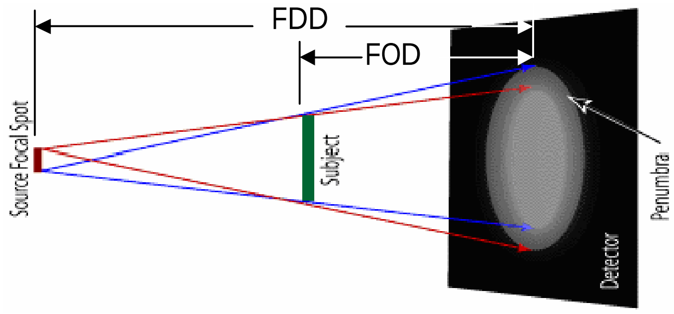


Fig. 2: real imaging geometry

Geometric unsharpness influences the radiographic definition of the x-Ray image. Radiographic definition is the abruptness of change in going from one area of a given radiographic density to another. Like contrast, definition also makes it easier to see features of interest, such as defects, but in a totally different way.

In the image Fig.3, the upper radiograph has a high level of definition and the lower radiograph has a lower level of definition. In the high definition radiograph it can be seen that change in thickness of the stepwedge, translates to an abrupt change in radiographic density. It can be seen that the details, particularly the small circle, are much easier to see in the high definition radiograph. It can be said that the detail portrayed in the radiograph is equivalent to physical change present in the stepwedge. In other words, a faithful visual reproduction of the stepwedge was produced. In the lower image, the radiographic setup did not produce a faithful visual reproduction. The edge line between the steps is blurred. This is evidenced by the gradual transition between the high and low-density areas on the radiograph. For a small object detail, this means that the loss of image resolution due to blurring can lead to the detail being drowned out by noise. It is then no longer detectable on the image.

The geometric unsharpness caused by the focal spot and the chosen magnification, leads to a limited resolution of the whole radioscopy system, regardless of the detector used. The larger the focal point, and the larger the geometrical magnification M, the more distinct this effect becomes.

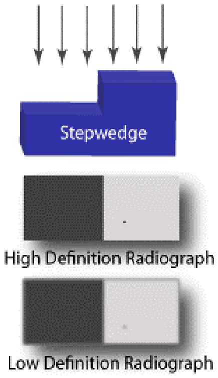


Fig. 3: Radiograph definition

Generally, the unfaithful spatial resolution of up to date digital detectors in comparison to the excellent values achievable with film, (see table1) require geometric magnification to be used in order to compensate for this low detector resolution. This circumstance inherits the need of distinct smaller focal spot sizes for the use in radioscopic applications, than usually needed in radiography. Focal spots in radioscopy are approximately 0.4 to 1.5 mm maximum, while in radiography focal spots are up to several millimeters in size. This condition implies the need to minimize geometric magnification in film applications, in order to achieve a certain minimum imaging quality on film, in accordance to (EN1435/EN444)

Another important consideration for the achievement of optimum radioscopic imaging conditions is the proper adjustment of the Focus to Detector Distance. Increasing this FDD would automatically lead to a decrease in geometric magnification. Furthermore, the intensity conditions on the application setup will change significantly.

The inverse square law states, that any point source spreads its influence equally in all directions without a limit to its range. This comes from strictly geometrical considerations. The intensity of the influence at any given radius (r) is the source strength divided by the area of the sphere. (Fig.: 4) Being strictly geometric in its origin, the inverse square law applies to diverse phenomena. Point sources of gravitational force, electric field, light, sound, or radiation obey the inverse square law.

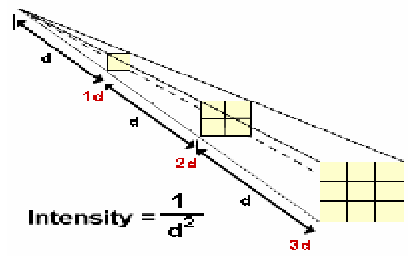


Fig.4: illustration of the inverse square law

Conclusion: Since, due to the thermal conditions of the focal spot, a compromise must always be found between required intensity and focal spot size, it is always necessary to set up a usage-specific system that has a fixed minimum detectability value.

2.2 MTF as a quantitative measure of the imaging system quality

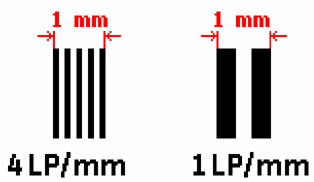
Modulation Transfer Function (MTF) is the approach of evaluating the spatial resolution performance of an entire imaging system, as well as the measurement of each component being part of that system.

In order to measure the change that a defect detail is displayed with, after passing each step of the imaging chain, the sinusoidal signal response of this imaging detail is measured before and after each component of the imaging system.

This way the resulting losses of detail resolution can be measured.

A limit or threshold resolution can then be calculated with a procedure where the imaging detail recognition has faded to 10% of its original value.

This maximum achievable resolution is the limiting frequency under which a detail can still be recognized on the output device of the imaging system. It is measured in Line-pairs per Millimeter (Lp/mm). (see Fig. 5)



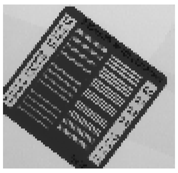
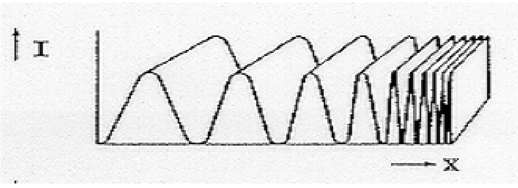


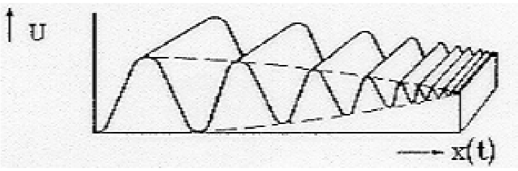
Fig. 5: linepair diagram

2.2.1 How is MTF generated ?



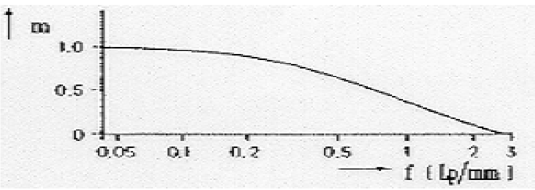
Graph 1:sinusoidal intensity distribution with increasing spatial frequency

A sinusoidal intensity distribution of increasing spatial frequency is displayed, as it would appear on the input screen of an X-ray image intensifier.



Graph 2: Intensity distribution from Graph1, with decreasing contrast resolution

The optical image of the intensity distribution, just as it would appear in the video signal on the output of the imaging system is shown above. The more the spatial frequency increases, the more the contrast decreases until the threshold resolution is reached.



Graph 3: MTF Plot from Graph 1 & 2

Graph 3 shows the MTF for each special frequency, calculated through,

$$MTF = \frac{modulation_{output}}{modulation_{input}}$$

and displayed as spatial resolution in Lp/mm.
The schematic diagram in Figure 6 shows a description of the individual MTF's of each component in the imaging system. However, for the practical user, only the MTF of the entire system is important in the end.
It is thereby to see that the output MTF of a component in the imaging chain is giving the input MTF for the following component. Using above formula it becomes obvious, that the resulting MTF of a system is always worse than the MTF of the worst component in this chain.

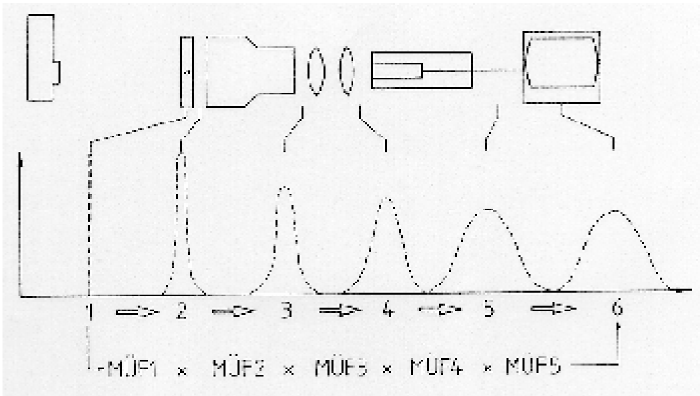
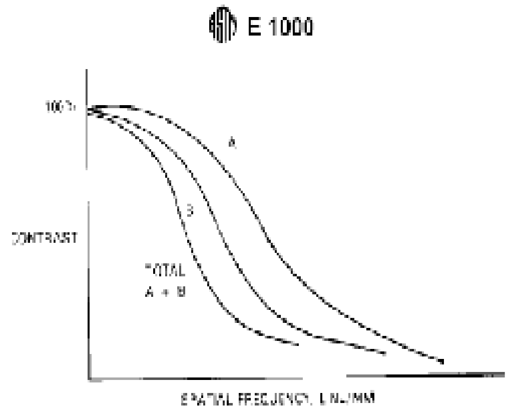


Fig.6: schematic diagram of the optical imaging process

Graph 4 gives a plot of the transfer functions of individual components of the imaging chain, and is then plotting the output MTF of the complete system. It is thereby to see that the output MTF is the product of the component MTF's A & B.



Graph 4: total MTF as product of individual MTF'S

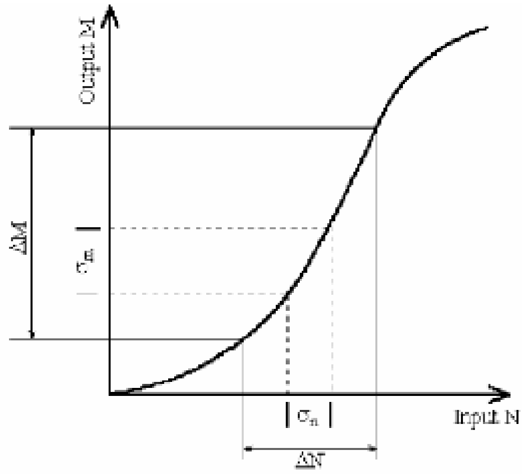
2.3 Detective Quantum Efficiency for the final Image quality estimation.

While the MTF of a system is giving sufficient response to the question of limiting frequency or contrast resolution, it is not describing the overall quality of the imaging system, and does not assure defect detectability of a certain minimum detectable defect.
The sensibility of a detector plays a vital role when determining effects like signal contrast, resolution and noise, as these values change with the x-ray spectrum and the internal system-component performance over this spectrum.
Only by viewing all of these factors, we can make an assumption of the imaging performance of the complete system.
Detective Quantum Efficiency (DQE), is the tool to describe the performance of a system with all influencing relevant variables, at a given frequency.

Graph 5 explains the mathematical approach:

$$\boxed{SNR_{in} = \frac{\Delta N}{\sigma_n}} \qquad \boxed{SNR_{out} = \frac{\Delta M}{\sigma_m}}$$

$$DQE(f) = \frac{(SNR_{out})^2}{(SNR_{in})^2}$$



Graph 5: Signal to noise ratio for a given spatial frequency

Conclusion:

The image quality of a radioscopic solution is dependent upon many factors. DQE will be the tool helping the most, when evaluating the setup for a given application, as it is the tool covering most of the individually influencing parameters of image quality. This is mainly due to the fact that DQE is giving a frequency dependent response to a specific setup, rather than a general value that is still subject to influencing environment and specimen- specific variables.
Probability of detection (POD) is therefore described best, when using DQE as the relevant performance objective.
The best estimate for the final output image quality of a radioscopic system is given as:

$$SNR_{out} = \sqrt{DQE(f)} \cdot SNR_{in}$$

Generally, the selection of an appropriate imaging system to a specific application task, involves as well component specific characteristics as also setup and application specific considerations, should the system be the solution of choice, and the resulting image performance comparable to that of the excellent detector performance of radiographic film.
Nevertheless, due to popper evaluation of the equipment involved, many Radioscopic applications today have exceeded film performance, and will continue to do so in the future, as digital components improve.

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