Development and application of a high energy X-ray digital radiography nondestructive testing system for a driving mechanism

Bailin Zheng* and Kai Zhang

*School of Aerospace Engineering and Applied Mechanics
Tongji University, 1239 Siping Road, Shanghai 200092, P. R. China
blzheng@tongji.edu.cn

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A high energy X-ray digital radiography (DR) nondestructive testing (NDT) system has been developed to detect the operating state of a driving mechanism. The system consists of five main subsystems, namely, X-ray generator, image intensifier, image processor, mechanical platform and control subsystem. Owing to the mechanical platform, the X-ray generator and image intensifier are able to rotate around the vertical axis from 0° to 360° in 35 s and move along vertical axis within the range of 500 mm in 20 s. The 450 kV X-ray generator provides a maximum 100 mm penetration depth and a coverage angle of 40°, and the resolution of the scanned image is 66 lp/cm. As is indicated by its applications, the system is featured with fast scanning speed, wide detection range and high imaging quality. It can be applied to inspect the defects in the driving mechanism as well.

Keywords: High energy X-ray; digital radiography (DR); nondestructive testing (NDT).

1. Introduction

Nowadays, it is hard to detect the operating state of a driving mechanism working in a sealed container. The acoustic emission (AE) method, commonly defined as transient elastic waves within a material caused by the release of localized stress energy,¹ is one of the solutions to the problem. But the disadvantage of AE that the signal is easy to be interfered by noise limits the use of it under noisy circumstances. The high energy X-ray digital radiography (DR) technology can penetrate into the sealed container and detect the operating state directly, and it can be widely used in many conditions including noisy situation. DR is a filmless X-ray image capture technique, in which a digital image capture device or sensor records the X-ray image in place of the standard X-ray film. In the standard screen and film radiography technique, the film serves a dual function, both of a detector and storage media. In contrast, in DR, the digital detectors only generate the images, following which the images are processed, archived and finally stored on a separate digital medium.² It is significantly valuable to develop a high energy X-ray DR nondestructive testing (NDT) system for a driving mechanism.

2. Principles of DR Imaging

According to the Beer–Lambert law,³ the transmissivity of light through a substance can be expressed by Eq. (1)

$$T = \frac{I}{I_0} = 10^{-\sum_{i=0}^N \alpha_i l_i}, \quad (1)$$

where T is the transmissivity of light; I and I_0 are the intensity of the transmitted light and incident light, respectively; α is the absorption coefficient and l is the path length.

As is shown in Fig. 1, the attenuations of the incident lights are detected, and the DR images are presented in the form of grayscale, which is obtained from the processing of the attenuations.

3. Development of the DR System

3.1. Testing of penetration depth

A scroll wheel was taken as an example and was put into a small vessel. The total thickness was thickened with several metal plates to 90 mm. DR images of it were taken with different voltage X-rays. As shown in Fig. 2, the DR image became clear after the voltage of X-ray being higher than 430 kV. So the maximum penetration depth is about 100 mm.

3.2. Components of the DR system

The DR system consists of five main subsystems, including X-ray generator, image intensifier, image processor, mechanical platform and control subsystem, which are shown in Fig. 3.

3.2.1. X-ray generator

The X-ray generator is made up of a X-ray tube, two high voltage generators (HVGs) and an oil cooler. The two HVGs provide the X-ray tube with 250 kV voltages, respectively, and the oil cooler lower the temperature of the X-ray tube.

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Fig. 1. Principles of DR imaging.

3.2.2. Image intensifier

The image intensifier contains a low absorptency/scatter input window, input fluorescent screen, photocathode, electron optics, output fluorescent screen and output window. These parts are mounted in a high vacuum environment within metal/ceramic.

3.2.3. Image processor

The image processor can correct, repair, restore and enhance the DR images obtained from image intensifier. All the modified images are stored and managed by the processor.

Fig. 2. DR images of a scroll wheel.

Fig. 3. Constitution of the DR system.

Fig. 4. Diagram of the mechanical platform.

3.2.4. Mechanical platform

The X-ray generator and image intensifier were installed on the mechanical platform, as shown in Fig. 4. Owing to the mechanical platform, the X-ray generator and image intensifier can rotate around the vertical axis from 0° to 360° in 35 s and move along vertical axis within the range of 500 mm in 20 s.

3.2.5. Control subsystem

The control subsystem takes control of the X-ray generator and the mechanical platform, thus the operating personnel can adjust both the voltage/current of the X-ray tube and the movement of the mechanical platform.

3.3. Main performance indexes of DR system

The main performance indexes of the DR system are as follows.

- (1) The maximum voltage and current of the X-ray tube is 450 kV and 10 mA, respectively, and the variable step size is 1 kV and 0.1 mA.
- (2) The maximum penetration depth is 100 mm.
- (3) The coverage angle is 40° .
- (4) The resolution and contrast of scanned images are 66 lp/cm and 25:1, respectively.
- (5) The mechanical platform can finish the rotation around the vertical axis from 0° to 360° in 35 s and the translation along the vertical axis from 0 to 500 mm in 20 s.

4. Application of the DR System

Figure 5 shows the DR images of a driving mechanism. The two operating states of the driving mechanism are presented clearly, and the operating personnel can troubleshoot problems with the help of DR images if the driving mechanism breaks down.

(a)

(b)

Fig. 5. DR image of the driving mechanism. (a) Driving mechanism in the closed state and (b) driving mechanism in the open state.

5. Conclusion

A high energy X-ray DR NDT system, which features with fast scanning speed, wide detection range and high imaging quality, has been developed to detect the operating state of a driving mechanism. This system provides strong guarantees, ensuring the smooth operation and rapid maintenance of the driving mechanism. Furthermore, this system can also be applied to the NDT of other large-sized structural components.

References

- ¹R. K. Miller, *Nondestructive Testing Handbook: Volume 5 Acoustic Emission Testing* (American Society for Nondestructive Testing, Columbus, 1987).
- ²J. Brennan, An introduction to digital radiography in dentistry, *J. Orthod.* **29**, 66 (2002).
- ³A. Beer, Bestimmung der Absorption des rothen Lichts in farbigen Flüssigkeiten, *Ann. Phys. Chem.* **86**, 78 (1852).