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Digital Radiography Using Flat Panel Detector for the Non-Destructive Evaluation of Space Vehicle Components

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Abstract

Digital technology has been introduced into radiography very recently but the conventional film based technique will be totally out of the arena in no time as what has happened in the photography field. The state-of-art technology is direct digital X-ray imaging based on Flat Panel Detector technology in which the X-ray image is displayed on the computer without the intermediate optics or mechanical scanning. The flat panel detector (FPD) system is very compact and provides high quality digital images with better signal to noise ratio, high spatial resolution and wide dynamic range. The application of Real-time DR system for the NDE of space vehicle components is presented in this paper. The salient features of the studies on digital radiography of solid rocket motors with respect to defect sizing, spatial location and quantitative analysis are briefly described in this paper. Details of digital projection radiography technique with a mini-focus X-ray machine applied for the NDE of small pyrodevices are also discussed.

Keywords: *Digital radiography, Flat panel detector, Solid propellant grain, Pyrodevices*

1. Introduction

Radiography is more than a century old imaging technique, began in 1895 with the invention of X-rays by Sir. W.C.Roentgen, serendipity. The first historical radiograph of Lady Roentgen’s hand revolutionized the medical diagnosis and in no time the technology was woven into medical field. In the last two decades we have experienced the invasion of digital technology into the photography field and film has been totally replaced with digital detectors. The entry of digital technology into the field of radiography is very recent, mostly because of lack of suitable X-ray optics and requirement of large area imaging devices which are harder and more expensive to make. Various devices have been in serious development for the last decade and are now becoming available for digital application. The evolution of radiography from the conventional film based technique to the latest Digital technology is through a few generations of developments. Computed Radiography (CR) system with imaging plates based on photo-stimulable phosphor technology has been emerged in the recent past. But the image readout of the exposed plate using a laser scanner system introduces noise and the quality of image is just comparable to that of film radiography. The plate is reusable but the two step process doesn’t give much attraction to the technique for real-time inspection and automation in industrial radiography. Radiography has been extensively used in the NDE of space vehicle components especially for solid rocket motors, solid propellant grains, composite nozzles and pyrodevices. In this paper the application of digital radiography for the NDT of solid rocket propellant and other components are presented. The digital projection radiography and its use in the NDT of small size components like pyrodevices and ceramic discs are also presented.

2. Flat Panel Detectors

The state of art technology is direct digital X-ray imaging based on flat panel detector (FPD) systems in which the image is displayed directly on a computer without intermediate imaging optics or mechanical scanning. The incident x-rays are converted into electric charge and then to digital image through a large area panel sensor. Compared to earlier technologies the FPD provides high quality digital images better than film radiography with better signal to noise ratio. Two distinct technologies are available for flat panel detectors: “direct conversion” and “indirect conversion”. In the direct conversion detectors X-ray energy is converted directly into electric charge and in the indirect conversion detectors X-ray energy is first converted to light photons by a scintillator and subsequently into electric charge by adjacent semiconductor layers. Amorphous selenium based flat panels are direct conversion type and amorphous silicon as well as CMOS based flat panels are the presently available indirect conversion detectors. With advanced chip technology FPD detectors are commercially available with pixel size varying from 400 microns to as low as 39 microns and sensor area 20cm x 20cm to 35cm x 43cm. There is a one to one correspondence between the size of the individual sensor and the out put image pixel. The spatial resolution of the electronic image depends on the captured signal profile and pixel size. Also the resulting digital image has a gray level dynamic range of 12 to 16 bit which provides high sensitivity for radiography application.

3. Real-Time DR System

The FPD based real-time digital radiography system based on a-Si FPD used for the study is shown in (Fig. 1). It consists of a 450kV X-ray machine and an indigenously developed four-axis object manipulator. A 225 kV mini-focus X-ray machine of focal spot size 0.2mm is also attached to the system for high resolution radiography and projection radiographic inspection of small components like electronic devices.

Fig.1: Real-Time DR System consists of X-ray machine, FPD and 4-axis object manipulator

This FPD is the first generation type with sensor size 400 microns and sensor area 20cm × 20cm. The output image is of 512 × 512 pixel with a gray level dynamic range of 16-bit. The scintillator coating used in this FPD is $Gd_2O_2S:Tb$, so that it can be used for X-rays upto 450KV. A shutter system with remote control is provided for the X-ray machine to protect the FPD from direct X-ray exposure. Necessary software is incorporated for image processing and analysis. It is also linked with an indigenously developed Relational Data Base Management System for NDE (RDBMS), so that the inspection results of the large number of components routinely tested are easily handled. The linearity of the detector response with respect to the incident X-ray provides wide dynamic range for radiography (Fig. 2). The MTF studies showed that this FPD gives a spatial resolution of 2.5 line pairs per mm (Fig. 3) which is sufficient for practical radiographic NDT of solid propellant grains and other rocket components.

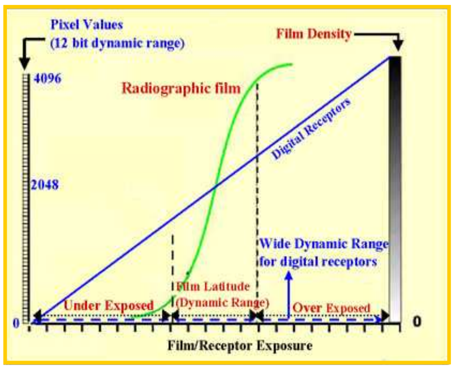


Fig 2: Comparison of response curve for film and FPD

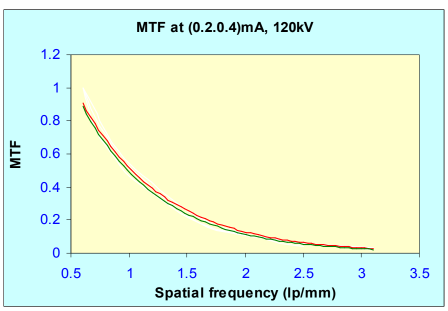


Fig 3: MTF curve of the FPD showing spatial resolution of 2.5 lp/mm

4. Application of Real time DR System

The advantages of real-time digital radiography are high POD due to 100% scanning, fast and cost effective inspection. Defect characterization and sizing in solid propellant grains were effectively carried out by scanning the object under rotation and linear motion using the object manipulator. In a typical case of a solid propellant grain the void and crack nature of a defect could be identified as shown in Fig 4. Since the detection of crack depends on its orientation with respect to the x-ray beam, the scanning capability under object rotation provides very high probability of defect detection compared to film radiography.

DR technique has been successfully applied to inspect the cirseam weld in a component having complex geometry developed for space vehicle application. Cracks and lack of penetration were easily detected in the DR setup with very high through put. A typical case showing cracks in the weld is given in Fig 5. The 100% scanning scheme adopted with all angular orientations using the object manipulator ensure the structural integrity of the weld and assembly.

4.1 Digital Projection Radiography

The projection radiography is used to generate magnified X-ray images of small objects to study internal defects. Distortion free projection images can be obtained with micro focus or to some extend mini focus X-ray machines. The DPR technique using FPD system is a new approach for the NDT of very small components like pyrodevices and electronic components. The projection imaging can considerably improve the flaw detection in smaller objects. Image magnification produces improved spatial resolution and increased image contrast, which enables detection of minor details.

The effect of magnification on the image of a resolution strip using a mini-focus X-ray machine of focal spot size 0.2mm has been studied. The higher spatial frequency lines were visible at 4x magnification. Fig 6 shows the comparison of the normal radiographic image without magnification and 8x magnification. The digital projection radiograph recorded for a 10 mm diameter squib is shown in Fig.7. Here the first image shows the bridge wire and the second image shows the burnout of the wire after testing.

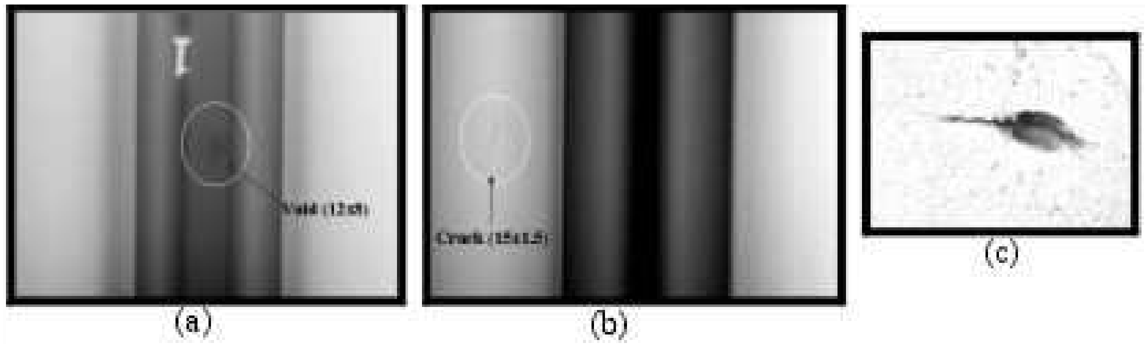
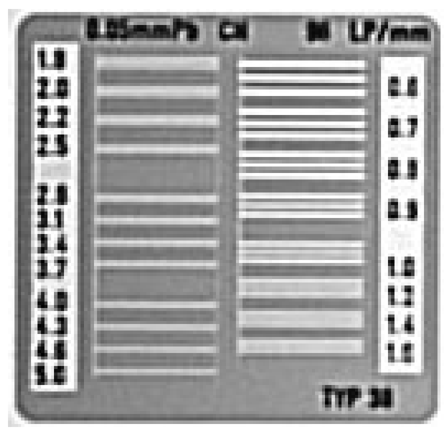


Fig.4: Digital radiographs at two orientations showing (a) void (b) crack and (c) photograph of the Cut cut section showing the real nature of the defect

Fig.5: Digital radiograph showing weld crack in a space vehicle component



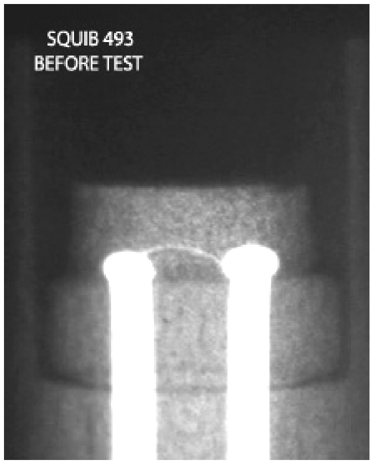
(a)

(b)

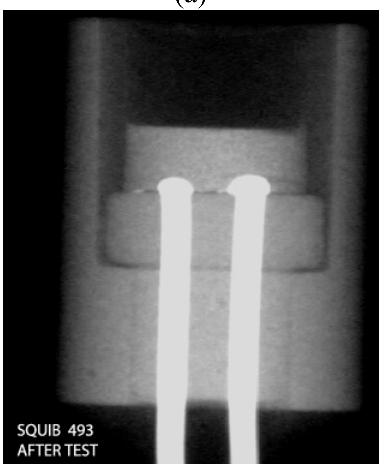
Fig 6: Image of the resolution strip (a) original image(b) 8 x magnification for the area marked in (a)

5. Conclusion

A perspective of digital radiography technology and the performance of the system operationalised are presented here. The flat panel detector based real time digital radiography system is the best alternative presently available to replace the conventional film radiography. The system provides a very fast and cost effective inspection for the critical components. The system with its digital image processing support provides a very good tool for quantitative NDE.



(a)



(b)

Fig. 7: Projection radiographs of a squib before(a) and after(b) test showing the bridge wire performance

6. References

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