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Development of a Manipulator System for X-ray Imaging Laminography

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Abstract: X-ray imaging laminography is a well-known non-destructive testing (NDT) technique well suited for non-destructive examination of large and flat structures of which traditional computed tomography (CT) is impractical. This technique allows for precise characterisation of welding defects, including its depth information, in welded components, ensuring component quality meets the standard criteria and safety purposes. This work highlights an approach to develop and establish a new manipulator system for the x-ray imaging laminography to characterise the welding defects in high-quality radiographed images. The mechanical hardware and programmed software system are developed with synchronisation to well established Radiographic Testing – Digital (RT-D) software in acquiring the image. To ensure compliance with industry standards, the exposure conditions, image sensitivity, and quality are analysed according to ISO 17636-2.

Keywords: Laminography, Radiographic Testing – Digital (RT-D), X-ray manipulator.

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1. INTRODUCTION

Radiographic Testing (RT) is a method of non-destructive testing (NDT) that was extensively used to assess and examine the integrity of welded components to detect discontinuities that could affect the strength, durability, and service life of the components. RT penetrates a specimen with an X-ray or gamma-ray and records the results on a viewing media, such as photographic film or digital electronic detector [1].

Traditionally, RT was implemented on film radiography systems. The digital imaging technology was first introduced in medical applications and is now widely used throughout non-destructive testing. The technology significantly eliminated the use of chemicals for film processing, resulting in reduced inspection time. Moreover, the service providers benefit significantly from digital technology and image processing since they are faster, more accurate, and efficient [2]. As a result, digital radiography technology, i.e. Radiographic Testing – Digital (RT-D), has been developed as a critical tool and has emerged as one of the most potential solutions and techniques for NDT.

Over the last three decades, many researchers have suggested the suitability of the laminography technique in measuring the depth of welding defects. The Laminography technique was used initially for healthcare medical testing in 1916 [3]. Later, the technique was introduced to RT-D for visualising and depth measurement in a three-dimensional (3D) image volume, gradually replacing stereo radiography techniques in various applications [4][5][6][7].

Figure 1 depicts the fundamental mechanism and principle of laminography, which employs the relative motion of the X-ray source and detector. Due to the synchronous movements of the X-ray source and detector, the internal structure in the focus plane will be projected onto the detector at the same position [8]. Several scan trajectories or scan geometries for the laminography system have been studied [9][10][11].

This research will study the linear movement of X-ray source with a fixed position of object and detector, known as co-planar translational laminography. Unlike traditional computed tomography (CT), this system requires the X-ray source to be moved linearly at a known distance and parallel to the detector and object plane.

2. RESEARCH APPROACH

A laminography system can be considered as comprising four components: (1) X-ray tube, (2) detector, (3) manipulator system, and (4) image processing (acquisition, visualisation, and reconstruction system). This research will focus on designing and developing a manipulator system to move the X-ray tube and parallel to the detector, as shown in Figure 2. The manipulator was modelled using Computer-Aided Design (CAD) software based on the co-planar translational laminography configuration. As discussed, the detector and object will be fixed in the opening beam area to acquire a set of image projections.

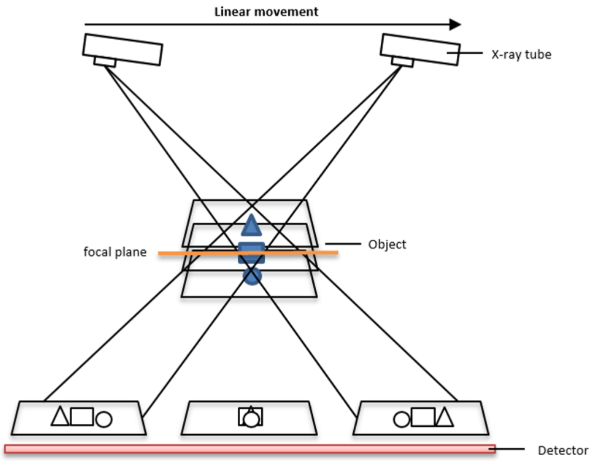

Figure 1. Principle of laminography [12].

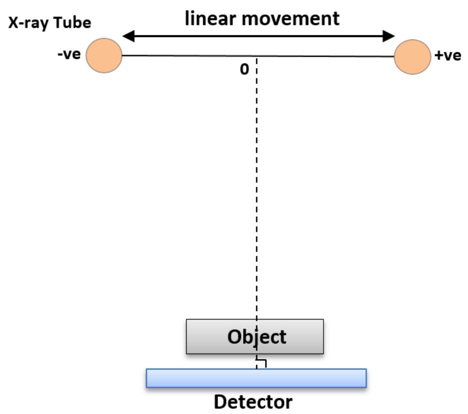

Figure 2. Geometric configuration of co-planar translational laminography.

The experimental setup used an X-ray tube with a maximum of 225kV X-ray source with 3 mm focal spot size, while the detector is a flat panel digital detector array (DDAs) with amorphous silicon plates (Si-A) and a scintillator sensor. In laminography, appropriate precautions and calibrations of the detector are required for the best image quality with contrast sensitivity. The specifications of the detector are illustrated in Table 1. For image acquisition, display, and analysis, Isee! and public ImageJ software were used to interpret, inspect, segment, and measure the 2D and 3D images data. As image reconstruction, the possible technique will be addressed and discussed in future work. Prior to image reconstruction into a 3D image volume, the 2D image was assessed for contrast sensitivity and basic spatial resolution according to ISO 17636-2 [13].

Table 1. Specifications of the detector [14]

Manufacturer	Perkin Elmer
Model	XRD 1611xp
Pixel size	100 µm
Active area	409.6 mm × 409.6 mm
Scintillator	Gd_2O_2S:Tb
Scintillator thickness	Approx. 200 µm

3. RESULT AND DISCUSSION

3.1 Manipulator system

A manipulator was specially designed to carry and move the X-ray tube. Based on Figure 2, a conceptual schematic diagram of the laminography system is modelled and shown in Figure 3. The maximum distance in scan angle range up to 40° depending on the X-ray tube specification.

A linear guide with an open linear bush, case hardened shaft, and rail was installed to support the weight and linear motion of the X-ray tube. In order to move the X-ray tube axis with absolute minimum drag torque, a lead screw with precision rolled ball screws was attached at the frame's centre with connections to a stepper motor. A NEMA34 motor was used with maximum torque and speed up to 12 N.m and 2000rpm. This motor has a step angle of 1.8 degrees and 200 steps per revolution for excellent reliability and accuracy.

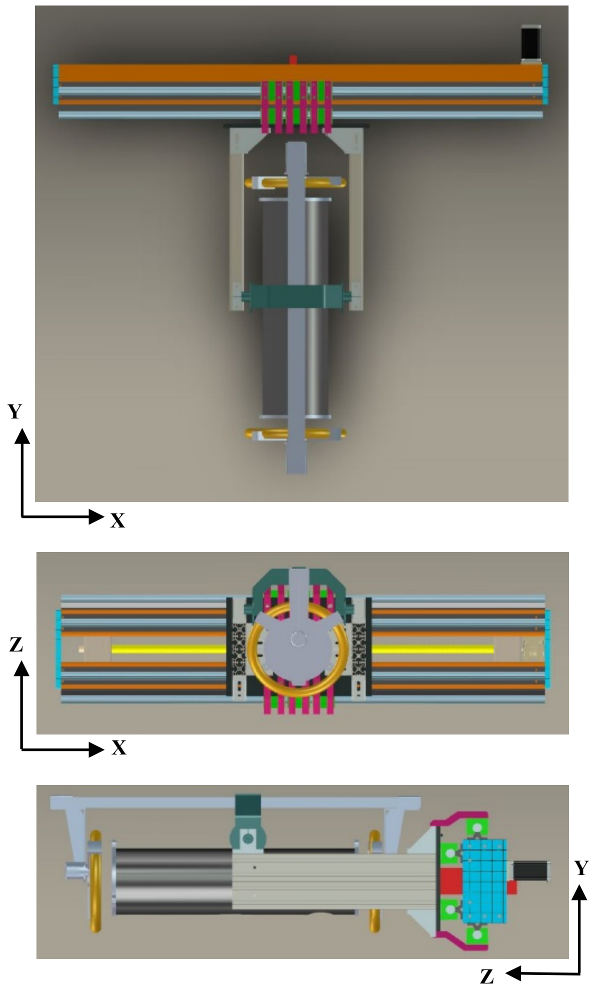

Figure 3. The manipulator system is displayed in the top view (upper), front view (centre), and side view (bottom).

During the image acquisition, a driving motor was programmed to obtain multiple projections of images with a minimum speed of less than 1.0 mm/sec. The movement can be configured to acquire up to 1000 projection images, depending on the X-ray tube's capability. For this purpose, the system used open-source Arduino IDE and Grbl firmware to control and program the motion. To communicate the programmed code to the Arduino, an interface or controller software is necessary. There are various options offered for that purpose, both open source and commercial.

In this study, the open-source Universal G-code Sender (UGS) was chosen for the Grbl controller program. It is a self-contained Java application with highly optimised features that can be operated in small RAM and CPU. Figure 4 illustrates the UGS interface and Grbl system setting.

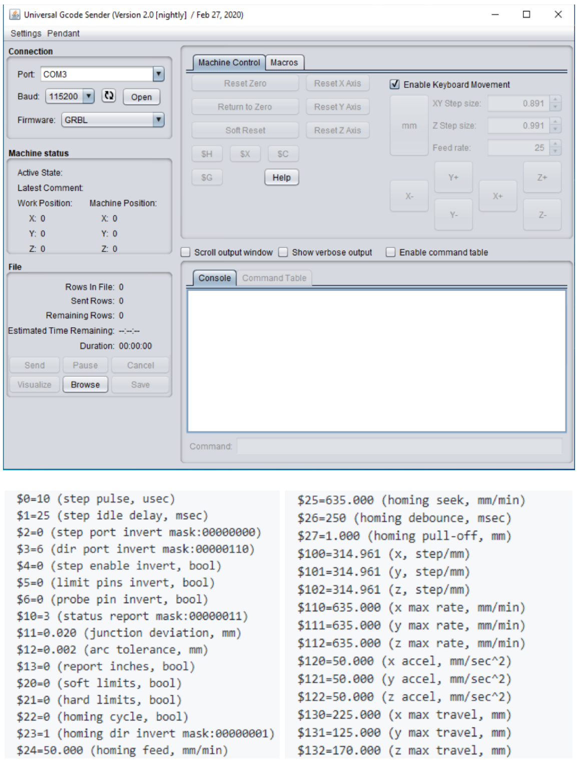

Figure 4. UGS interface (top) and GRBL system setting (bottom) [15]

4. CONCLUSION

The present study was designed to develop a manipulator system of X-ray imaging laminography for depth information of welded components under inspection. Considering specific objects where CT is inadequate, this technique offers an efficient and reliable solution. The hardware and software that developed could be used for scanning mechanism and data acquisition. The system indicated consistent and reliable accuracy to evaluate the depth of defects within the minimum requirement of the standard practices. Further study will be conducted on the spatial resolution and image reconstruction in producing a high resolution of the image.

Laminography is commonly employed in medical application. Despite its numerous advantages, it is rarely seen in industrial applications. This technique would be a beneficial endeavour for future research in various material composites, aircraft, electrical components, and other engineering applications.

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