EARLY STUDY ON RADIOGRAPHIC EXAMINATION OF SOFT ALLOY CASTING MATERIAL USING DIGITAL FLUOROSCOPY

Studi Pendahuluan tentang Pengujian Radiografi pada Material Coran Campuran Logam Lunak menggunakan Fluoroskopi Digital

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ABSTRACT

Radiographic experiment has been conducted to examinine the product quality of the ignition house of motorbike made of soft alloy casting material using digital fluoroscopy. In today's industrial radiographic technology, the digitally radiographic examination - including digital fluoroscopy – are considered as new emerging technology in radiography which offer simpler in image processing. In this experiment, the radiographic examination to the specimen was carried out using established radiographic examniation standards such as ASTM or ASME for metallic casting. The specimen thickness as main parameter was used for determination of source to object distance (s.o.d), x-ray energy and image quality inidicator (IQI). In this experiment, the predetermined s.o.d was 1.2 m; the x-ray generator was set at voltages of 250 kV and 270 kV respectively, and electric current of 5 mA. The IQI and radiographic marking were prepared for source-side exposure. Radiograph generated from this experiment showed that radiograph's density, sensitivity and image quality are excellent. None defects were found in examined specimen.

Keywords: soft alloy casting, digital fluoroscopy, radiograph, image, defects

ABSTRAK

Eksperimen radiografi telah dilakukan untuk menentukan kualitas produk rumah kunci sepeda motor yang terbuat dari material coran campuran logam lunak menggunakan digital fluoroskopi. Di dalam teknologi radiografi industri saat ini, pengujian radiografi secara digital - termasuk fluroskopi digital – yang kemunculannya dianggap sebagai teknologi baru dalam radiografi yang menawarkan pengolahan bayangan lebih sederhana. Di dalam eksperimen ini, pengujian radiografi pada spesimen dilaksanakan menggunakan standar pengujian radiografi yang sudah diakui, seperti ASTM atau ASME untuk coran logam. Tebal spesimen sebagai parameter utama telah digunakan untuk menentukan jarak sumber radiasi ke spesimen (s.o.d-*source to object distance*), energi sinar-x dan indikator kualitas bayangan (IQI – *image quality indicator*). Di dalam eksperimen ini, jarak sumber ke spesimen ditetapkan 1,2 m; mesin pembangkit sinar-x di set pada tegangan masing-masing sebesar 250 kV dan 270 kV serta arus istrik sebesar 5 mA. IQI dan perangkat penanda radiografi disusun menghadap penyinaran. Radiograf yang dihasilkan dari expereimen ini memperlihatkan bahwa densitas, sensitivitas and kualitas bayangan sangat baik. Tidak ada cacat yang ditemukan di dalam spesimen yang diuji.

Kata kunci: coran campuran logam lunak, fluoroskopi digital, radiograf, bayangan, cacat

INTRODUCTION

Fluoroscopy is one of imaging modalities of using x-rays photon to obtain real time radiograph of interior exposed object [1]. Fluoroscopy was developed just after being of invention of x-ray by Roentgen in 1895 [2, 3]. He noticed that barium platinocyanide screen fluorescent showing an image when being exposed to x-ray. Since then, various x-ray machines were produced and manufactured for imaging purpose. Early fluoroscopy imaging was simple, made of cardboard goggle funnel with open window at narrow end for eyes of observer and cardboard window coated with a layer of fluorescent metal salt at wide end for observed object. The fluoroscopic image obtained in this way was directly and was rather faint.

Development of x-ray image intensifier (XRII) in 1950's revolutionized fluoroscopic systems. The goggle funnel become obsolete and replaced by XRII. The light produced by the fluorescent screen is able to be amplified, allowing it to be seen even in a lighted room. Moreover, development of dedicated digital camera at the

same decade, which further as integral part of the fluoroscopic system, enabled radiologist to view the image on a monitor screen from separate room. In such situation the radiologist is away from the risk of radiation exposure. Recent fluoroscopic system no longer use a separate fluorescent screen, instead of use deposited cesium iodide phosphor on photocathode of the intensifier tube. Subsequent improvement were made, including the coupling cameras which later replaced by CCTV cameras to permit recording of moving object and storage electronic images [4]

Since designated as IAEA Collaborating Center (CC) in 2015 in Non-Destructive Testing (NDT) theme sector, Indonesia's National Nuclear Energy Agency (BATAN) has assigned NDT group of Center for Isotopes and Radiation Application (CIRA) to organize relevant activities to support successful implementation of the CC program, including to increase its capacity building in this sector. One of challenging and demanding interests is to use radiographic digital imaging, including fluoroscopy, for radiographic examination of welding, forging and casting products. [5-7]. It has been known that the NDT group of CIRA has long engaged with conventional x-ray and gamma ray radiographic methods for both research activities and services. This conventional film-based radiographic method was very established and mature, and research of using this technology is almost saturated. Although it has similarity with film-screen radiography, the digital radiography offers several advantages, among of them are: wide range of exposure dynamic, faster processing, image storage in digital format and economic benefit [8,9].

Availability of fluoroscopic system in the NDT group of CIRA was started at the middle of 2017. Human resources and experiences of using this technology is very limited and almost none. It is therefore that the purpose of the current study is to familiarize with the fluoroscopic system by doing an experiment to generate digital image of fluoroscopic radiographs. As the standard of examination for digital fluoroscopy is not available yet, the experiment was carried out by referring to the available standard of radiographic examination for metallic casting that one is commonly used in film-screen radiography [10, 11]. The experiment was focused to compare quality of fluoroscopic images generated from different x-ray voltage (kV). Due to lack of

appropriate tools for image diagnostics, some basic image quality parameters are highlighted to give additional information about image quality.

EXPERIMENTAL METHOD
Materials and equipment.
The materials and the essential equipment components used in current expereiment were: the specimen of ignition house of motorbike made of soft alloy casting material, as shown in Figure 1, portable x-ray machine (Rigaku RF-300EGM2, Japan), IQI wire DIN 62 FE-10 ISO 16 and duplex, lead numbers and letters, x-ray image intensifier screen, digital fluoroscopic system and desktop computer.


Figure 1. Specimen for fluoroscopic examination is a ignition house of motor bike made of soft-alloy casting material.

Experiments
The image formation in digital fluoroscopy is created through the following processes, as shown in Figure 2. The incoming x-ray photon interact with specimen. During the interaction, x-ray photon energy is attenuated through the three interaction processes: photoelectric, Compton scattering and pair production leading to part of the x-ray photon is absorbed by the specimen and the rest is transmitted. The transmitted x-ray photon hit the input phosphor layer of sodium activated cesium iodide and releases light photon. Input phosphor is image intensifier which absorb the x-ray photon and emit light photon. After being reflected by a mirror, light photons is detected by photochatode tube which convert it into electron. Photocathode is a layer which prevent the divergence of the light. In the tube, electrons are accelerated from cathode to anode by a potential difference. When these high-energy electron strike the output phosphor, a considerable amount of light is produced. Becauase the electron

are greatly accelerated in the tube, more light photon is emitted in the output phosphor than those produced in input phosphor. These light photon is the fluoroscopic image that can be viewed directly by observer or indirectly through closed-circuit television (CCTV) [12,13]
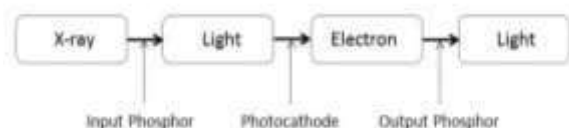
Figure 2. Shematic diagram of image formation process in a digital fluorocopy

In this experiment, the specimen of steel composite is exposed by x-ray photon generated from x-ray machine. To fulfill the requirement of geometrical unsharpness, U_g, the source to object distance (s.o.d) was calculated using following equation [14]

$$U_g = \frac{F.t}{d_0} \qquad (1)$$

where F is the maximum projection dimension of radiation sourece or focal spot (mm), t is material thickness (mm) and d_0 is source to object distance (mm). As mentioned in the standard, the maximum $U_{g,max}$ for material thickness under 50 mm is 0.51 mm. According to equatin (2), the minimum souce to object distance, $d_{0,min}$, for the specimen thickness of 18 mm and x-ray machine focal spot size of of 3 mm is 106 mm [15]. Exposure the specimen with the source to object distance at 1,200 mm is therefore fulfilled the standard requirement. The image quality indicator (IQI) used were wire types of DIN 62 FE - 10 ISO 16 and duplex, whereas the recording media used was x-ray image intensifier screen (XRII). The x-ray generator was set at voltages of 250 kV and 270 kV respectively, and electric current was fixed at 5 mA. The detaild exposure parameters is summarized in Table. 1.

Table 1. Setting parameters of fluoroscopic xperiment

Exposure parameters	Fluoroscopy
Material	Soft metal
Thickness	18 mm
Amperage	5 mA
voltage	250 and 270 kV
Recording medium	Image Intensifier
S.0.D	1200 mm
IQI	10 ISO 16, Duplex
Exposure time	60 s
Processing:	Electronic, CCTV

RESULTS AND DISCUSSION

Radiograph images produced by digital fluoroscopy for machine voltage of 250 kV and 270 kV are shown in Figures 3 and 4 respectively. If we are familiar with film-screen radiography, it is immediately found that the darkness or brightness, commonly known as grey-scale, of the film-screen radiography is opposite with that produced from digital fluoroscopy. The different appearance of the images are due to different recording materials used in these different imaging modalities. When the film receives more photoelectron the film becomes darker. In opposite, if the fluoroscopic image intensifier receives more photoelectron, the image is brighter. Moreovere, the analog image produced is permanent on film sheet and there is almost no chance to manipulate the analogue image except it is converted into digital format using digitalizer. Fluoroscopic image, on the other hand, is in digital format as a result of conversion analogue signal of photoelectron by analogue to digital converter (ADC) device or by CCTV camera. This digital image can be manipulated by image processing software algrorithm. As mention previously that due to lack of image analysis tools some parameters for image quality analysis are highlighted as per definitions.

Figure 3. Fluoroscopic image generated from x-ray voltage of 250 kV and current of 5 mA.

Figure 4. Fluoroscopic image generated from x-ray voltage 0f 270 kV and curent 5 mA.

Evaluation of image quality

By image quality we mean the quality of fluoroscopic image that can be clearly visualized by naked eyes of observer on computer monitor. There ara many factors that can be used for evaluation of image quality. These factors can be divided into two main categories: the primary factors and secondary factors. The secondary factors are as consequence of apllied the primary factors to the imaging system. Among the relevant primary factors that contribute to the formation image are miliamperage (mAs), electric potential (kV), exposure time and source to object distance (s.o.d). The secondary factors include pixel size, resolution, modulation transfer function, dynamic range, detective quantum efficiency (DQE) and noise.

For film-based radiography and digital fluoroscopy, the kV, mAs and exposure time are selected simultaneously to produce proper film darkening with maximum image contrast. These factors are controlled through x-ray machine. Miliamperage (mA) controls the number of electric current at the cathode filament. More current more x-rays are produced at the target. Miliamperage and the time of exposure always work together as a single parameter. It controls the amount of current flowing for a given period of time and thus controls the quantity of photon in the x-ray beam but not the penetrating power of the beam. The electric current of the x-ray machine used in this experiment is fixed at 5 mA, based on the manufacture setting. The mAs is controlling factor of film density [16, 17].

Density is the overall darkness of the radiograph. Although the adequate density is a matter of personal choice, however, the background around the image should be clearly distinguished. The next variable that controls the production of images is the electrical potential applied across the x-ray tube, which measured in kV. Adjusting the kV setting on the x-ray machine

changes the speed of electrons that travel from the cathode to the anode. The kV controls the quality of the x-ray beam. Higher voltage applied to the x-ray machine higher penetrating power. Unlike the fixed miliamperage, the elctric voltage in x-ray machine used in this experiment is a variable [16, 17].

Source to object distance (s.o.d) may probably be the most important factor for the criteria of acceptable radiograph. Source to object distance is related to the thickness of an exposed objet and the focal spot size of x-ray machine target. The object and focal spot size determine the geometric unsharpness of image and its maximum size is listed in radiographic standard [14]

Once the image, analog or digital, has been formed based on primary factors setting, the image can be evaluated to obtain some parameters that describe its quality. Although the image of film radiography can be digitized, the film digitizer often introduce additional noise in the digitized image. It is therefore, film should not be digitized although it is intended as an effort to improve poor film image quality [18].

Although a digital image is seen on computer monitor as a collection of brighter and darker (gray-scale) area, but its apparance is very much resembles the traditional film-based image. However, the nature of a digital image is completely different compared to analogue one. A film-based radiographic image is composed of radiolucent of dark areas and radiopaque of bright areas due to distribution of silver grain in the film emulsion after being washed out during the film processing. A digital image, on the other hand, is composed of a set of cells that are ordered in rows and columns. The rows and columns form a matrix which represent the size of digital image. Each cell is characterized by three numbers: the x-ray coordinate, the y-coordinate and the gray value (shades). The gray value is a number that corresponds to the x-ray intensity at that location during image formation. Individual cells are called picture element or pixel for short [19].

The gray-scale of an image is strongly depend on the imaging system used. For the fluoroscopic system used in this experiment, the 8-bit ADC device samples the analogue video signal at dicrete time points and converts its value of the signal into a digital binary number. Digital binary number or binary digits (bits) is used to represent 2^n shade levels, where n is number of digit. The maximum and minimum analog video

signal values are scaled to the maximum and minimum digital values according to the bit depth (gray-scale or pixel value) of the ADC. An 8-bit ADC converts the video signal to a maximum of 256 (calculated from 2^8) different values of shade level, from 0 to 255. As a convention, the lowest value of gray-scale, e.g., 0, represents black color (the darkest), whereas the higest value of grey-scale represent white color (the brightest). Figure 5 shown an example of representatiion of gray-scale of digital image that is corresponding to its pixel value. In general, increases bit depth of the ADC increases the image quality which in turn increases the ability of imaging system to resolve image in detail [19].
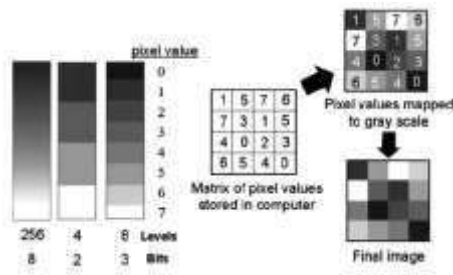

Figure 5. An illustration of gray-scale of digital image and its corresponding pixel value [19].

Resolution describes the abillity of imaging system to distinguish adjacent structure of the object being examined. Ideally, the recorded signal from detected x-ray photon should be able to produce digital image with sufficient resolution in space. Resolution falls into three main categories, namely spatial resolution, contrast resolution and temporal resolution [18]. The temporal resolution, however, is more convenient for exposed moving object and it is not included in this discussion.

Spatial resolution is defined as the ability of imaging system to detect and discriminate small object that are close together. Spatial resolution is determined by the pixel size, the space between adjacent pixels (pitch) and blur. Smaller the pixel size gives higher the spatial resolution. According to the Nyquist theorem, for pixel size a, the maximum achievable spatial resolution is $a/2$. However, increasing the radiation applied to detector will not improve the maximum spatial resolution [18]. On the other hand, scatter of x-ray photon and light photons influences spatial resolution.

Contrast resolution expalins how well the image system to show substle structure of an object being imaged, so it refers to the ability of imaging system to distinguish small density difference of an object or small attenuation variety of the image. Contrast resolution is sometimes called tissue resolution. If there are two small objects wiht large different densities, the areas between them is considered as high frequency or high contrast region. Conversely, if the areas have small difference in densities, the area between them is considered as low cotrast region. Contrast resolution is affected by number factors such as the tube collimation, number of photons received by recording media, noise, scatter radiation, beam filtratiion, detector properties and algorithmic resconstruction used [18].

Modulation transfer function (MTF) is the measure of capability of the detecor or imaging system to transfer the modulation of the input signal at given spatial frequancy to its output. In radiography, objects of different size and opacity have to able to displayed in form of an image with different gray scale value. In this regards, the MTF is responsible to convert object contrast into image contrast which is described by intensity levels in image or contrast resolution. To get a useful understanding, the measured MTF for three images is presented in Figure 6 [20].
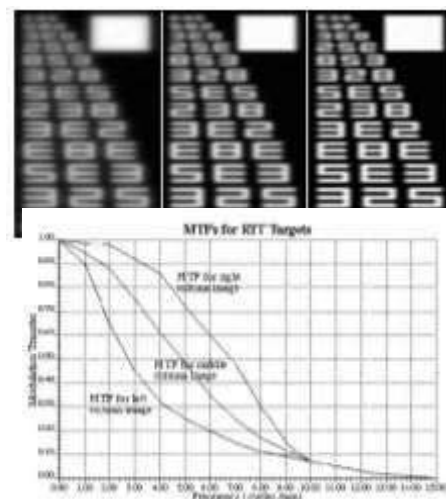
Figure 6. Measurement of modulation transfer function (MTF) for three digital image [20]

Figure 6 shows that the spatial image quality of the right image is superior compared its two neighbors. The spatial image quality of the

middle image is superior to its left neighbor. The corresponding MTF of these three image is also shown in the figure. From this discussion if is recognized that the MTF is a useful measure of true or effective resolution of imaging system because it takes into account the amount of blur and contrast object over the range of spatial frequency.

Dynamic range is a measure capability of detector or imaging system to response the minimal and the maximum number of x-ray photon exposed to it. In conventional film radiography, the dynamic range of the film is called latitude and is shown as S – shaped curve with narrow exposure range for optimal film blackening. As it has narrow range, the film has a low tolerance in the sense that when it receive too low or too high x-ray photon exposure, the resulted image produced is too bright (under-exposed) or too dark (over-exposed). When these two extreme is occur, retake should be performed because the under and over exposed film is fixed and no chance to be modified or manipulated.

Unlike the film radiography, the dynamic range of digital radiography-including fluoroscopy is wider and linear. By wider and linear dynamic range, digital imaging system is more tolerance in responding the x-ray photon exposed to the system. This is one of the most advantages of digital imaging system compared to conventional film radiography. Another positive effect of wide dynamic range is that the exposed object with different materials' type, size and thickness can be displayaed on one image without additional images. Moreover, with wider dynamic range the possibility to retake due to under or over exposure could be minimized [18].

Detective quantum efficiency (DQE) is one of the fundamental physical variables which related to image quality analysis in radiography. DQE refers to the efficiency of a recording media in converting incident x-ray energy into an image signal. DQE is calculated by comparing the signal-to-noise ratio (SNR) at the detector output to the SNR at the detector input as function of spatial frequency. DQE is dependent on radiation exposure, spatial frequency, MTF, and detector material. The applied voltage (kV) and the current (mAs) of the x-ray machine is also important factors that influence DQE. High DQE values indicate the capability of recording media to transfer less incident x-ray radiation to achieve identical image quality compared to the racording

media with low DQE value which needs more incident x-ray. Increasing the DQE and keeping radiation exposure constant will improve image quality. The ideal detector would have a DQE value is equal to 1, meaning that all the absorbed radiation energy is 100 % converted into image. In practice, the DQE of digital detector is limited to about 0.45 at 0.5 cycles/mm. [21, 22].

In radiographic imaging, noise is unwanted signal both in film image and in digital image. Noise produces undesirable effect such as artifact, unrealistic edges, unseen lines, corners, blurred object and an disturbs background scenes. The noise in the image detail falls into two categories, anatomic noise and radiographic noise. The former refers to normal unwanted anatomic variations within an image and it is not directly related to the intrinsic performance of recording media. The second type of noise refer to unwanted variations within an image that do not originated within the imaged subject. Radiographic noise is also directly related to resolution because it affects the ability of imaging system to resolve distinct features of an image. Although it is often quantified in term of variance or standar deviation, radiographic noise is best characterized by its Noise Power Spectrum (NPS). The NPS is the variance of noise within image divided among various spatial frequancy component of the image [24, 25].

The noise level is explained by the standard deviation, a measure of spread out the pixel's value. The lower standard deviation, the higher the accuracy of the average pixel value. Noise image is related to the number of x-ray photons that are logged in each pixel or in each small area of the image. Noise is also produced by scatter radiation which reduces subject contrast and decrease signal-to-noise ratio (SNR) and consequently degrades image quality [25].

Radiographic sensitivity

Radiographic sensitivity is a measure of imaging system to detect the smallest defects or discontinuities in a examined specimen. The smallest defect size is measured by the appearance the smallest diameter of wire IQI among the other visible wires on the radiograph. For wire IQI, the radiographic sensitivity is calculated using followeing equation [10, 14]

$$S = \frac{smalles\ wire\ diameter}{specimen\ thickness}\ x\ 100\ \% \qquad (2)$$

Recall the Figures 3 adn 4, the fluoroscopic images show 5 visible wires in the group of DIN 62 FE - 10 ISO 16 which contains 7 wires, as shown in Figure 7. The correspoding diameter for each wire is listed in Table 2. The most visible wires should be the wire with largest diameter followed by the large, small and smaller and so on. The smallest wire of the five visible wires on the fluoroscopic images is the wire no. 3 of having 0.16 mm in diameter. For specimen thickness of 18 mm, the sensitivity of radiograph calculated using Eqn. (2) is less than 1%, showing that the sensitivity of fluroscopic imaging system is high. It can be said that the fluoroscopic imaging of the current work can detect the defect size at order of 1% of the specimen thickness.

Figure 7. Image Quality Indicator (IQI) DIN 62 FE – 10 ISO 16 which contains 7 wires [14].

Table 2. Wire diam. of IQI DIN 62 FE 10 ISO 16 [12]

Wire No.	Diameter (mm)
1	0.25
2	0.20
3	0.16
4	0.13
5	0.1
6	0.08
7	0.032

Two fluoroscopic imaging produced from the current experiment, Fig. 3 and 4 show excellent image quality based on observation on computer monitor. The detailed parts of the exposed specimen is considerable clearly observed especially for the thinner parts. Higher density or thicker parts of the specimen are represented by darker image whereas thinner parts are brighter visible in fluoroscopic image.

In this experiment, the voltage (kV), current (mA) and exposure time applied to the x − ray machine was able to produce high quality fluroscopic image. It is justified by considerable high contrast of the fluoroscopic images and ability of fluoroscopic imaging system to detect defect size down to less than 1% of the specimen thickness. Visual observation on fluoroscopic image showed that the specimen is free from defects. In-depth observation on computer monitor, the applied voltage of 270 kV gives better image quality of fluoroscopic image than that the image produced using 250 kV.

CONCLUSION

Fluoroscopic imaging system, that is usually used for medical purpose, has succesfully been applied radiographically to detect internal defects in specimen made of soft alloy casting materilal. From the observation it is found that radiograph density in term of its contrast, image quality and sensitivity is excellent. The voltage, current and exposure time applied to x-ray machine was abe to produce high sensitivity fluoroscopic images that able to detect the defect size down to 1% of the specimen thickness. In-depth observation, no defects were observed in the examined specimen. The quality of fluoroscopic image generated of using 270 kV is better that the one generated of using 250 kV.

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PERTANYAAN SAAT PRESENTASI

1. Pertanyaan (Fajar Lukitowati (PAIR, BATAN)):
1) Kelebihan dan kekurangan digital fluoroscopy dibanding rontgen sinar-x konvensional (biasa)
Jawaban:

1) Kelebihan digital fluoroscopy:
   1. fluoroscopy hasil pencitraannya secara real time bisa langsung dievaluasi/interpretasi
   2. Low cost/murah harganya atau pembuatannya

   Kekurangan digital fluoroscopy:
   1. Hasilnya/kualitas gambarnya masih belum sebagus radiografi konvensional maupun CR
   2. Saat ini hanya bisa untuk pemeriksaan cacat secara makro/cacat-cacat yang besar saja, misal porosity pada pengecoran velg mobil.
   3. masih dalam tahap pengembangan (R&D)