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PUSPIPTEK - Serpong, 21 - 23 November 2017

Nuclear Technology Utilization
in the fields of Food, Health, Industry and Environment
through strengthening regional collaboration

batan

FNCA

Forum for Nuclear Cooperation in Asia

KATA PENGANTAR

Puji syukur kami panjatkan kehadirat Tuhan Yang Maha Esa atas petunjuk dan karunia-Nya **Prosiding Seminar Nasional Pendayagunaan Teknologi Nuklir (SENPATEN) 2017** dapat diterbitkan. Prosiding ini merupakan dokumentasi yang memuat karya tulis ilmiah para peserta SENPATEN 2017 yang diselenggarakan bersamaan dengan *FY2017 FNCA Workshop on Research Reactor Utilization Project*. Kegiatan tersebut diselenggarakan di Gedung 720 Auditorium Pusat Inovasi dan Bisnis Teknologi, Kawasan PUSPIPTEK Serpong, Tangerang Selatan, pada tanggal 21-23 November 2017, dengan mengambil tema "*Pendayagunaan teknologi nuklir di bidang pangan, kesehatan, industri dan lingkungan melalui penguatan kerjasama regional*".

Pada Seminar Pendayagunaan Teknologi Nuklir 2017 panitia menerima sebanyak 81 makalah dari BAPETEN, BATAN, BPFK-Jakarta, ITB, STIKES Guna Bangsa Yogyakarta, Universitas Indonesia, Universitas Nasional, Universitas Pamulang, dan setelah dilakukan seleksi serta evaluasi, diputuskan 30 makalah dipresentasikan secara *oral,* dan sisanya disajikan dalam bentuk poster.

Setelah melalui proses penyuntingan, dalam Prosiding Seminar Nasional Pendayagunaan Teknologi Nuklir 2017 ini, sebanyak 77 makalah dicantumkan sebagai makalah lengkap yang diklasifikasikan kedalam beberapa bidang yaitu pangan, kesehatan, industri, lingkungan, energi, keselamatan dan keamanan, metrologi serta bidang lainnya yang terkait dengan pedayagunaan teknologi nuklir. Semoga prosiding ini dapat dimanfaatkan sebagai sumber informasi untuk memacu kegiatan penelitian, pengembangan serta pendayagunaan teknologi nuklir di Indonesia. Akhir kata, kami mengucapkan terima kasih kepada semua pihak yang telah membantu penerbitan Prosiding ini.

Serpong, Maret 2018

Dewan Editor

DAFTAR ISI

RADIOGRAPH OF SOFT METALLIC CASTING USING COMPUTED RADIOGRAPHY

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ABSTRACT

Radiograph of soft metallic casting using computed tomography. *BATAN has long time employed conventional radiography modality using film-screen (F/S) for examination of discontinuities or flaws in metallic materials produced from welding, casting and forging. The standard examinations used were based established international standards such as ASTM or ASME. In order to increase capacity building, capability and demanding on digital technology, BATAN's NDT laboratory has recently been equipped with new variant of digital radiography equipment namely computed radiography set. As a newcomer in industrial NDT's world, the established examination standards of computed radiography were very limited and were not accepted worldwide yet. Only several advanced countries were used this technology. In this study, radiographs generated using computed radiography was compared with conventional film-screen radiography. A soft metallic casting test piece has been exposed using X-ray generated from the machine. Expose preparation was based on ASTM standard for radiographic examination of metallic casting. Source to film distance (sfd) was determined based on maximum projection of unsharpness geometry of the test piece. Exposed time was determined based on existing exposure chart for the X-ray energy of 130 kV and current of 5 mA. The placements of IQI and material's marking were prepared for source side exposure. The image density and image sensitivity in radiograph, as a measure of the image quality, were analyzed both conventionally and digitally. Based on examination, the conventional film-screen radiograph revealed better image quality compared to those of digital radiograph. It was understood that the exposure preparation was based on the established standards for conventional film-screen radiography.*

Keywords: conventional radiography, film-screen, computed radiography, soft metallic casting.

ABSTRAK

BATAN telah lama menggunakan modalitas radiografi konvensional film-skrin (F/S) untuk mendeteksi cacat-cacat atau diskontinuitas yang ada di dalam material logam hasil pengelasan, pengecoran dan penempaan. Standar pengujian yang digunakan didasarkan pada standar internasional yang ada seperti ASTM atau ASME. Untuk meningkatkan kapasitas, kemampuan dan permintaan tekonolgi digital, laboratorium investigasi tak rusak dan diagnosis BATAN baru-baru ini dilengkapi dengan varian baru perangkat radiografi digital yaitu computed radiografi. Sebagai varian pendatang baru di dalam dunia NDT, standar pengujian untuk computed radiografi sangat terbatas dan belum dapat diterima di seluruh dunia. Hanya beberapa Negara maju yang telah menggunakan teknologi ini. Dalam makalah ini, radiograf yang dihasilkan dari computed radiografi dibandingkan dengan radiograf yang dihasilkan dari radiografi konvensional film-skrin. Benda uji berupa logam lunak telah disinari menggunakan sinar-X. Persiapan penyinaran dilakukan berdasarkan standar ASTM untuk pengujian radiografi coran logam. Jarak antara sumber dan film (sfd) ditentukan berdasarkan proyeksi maksimum dari ketidaktajaman geometri benda uji. Waktu penyinaran ditentukan berdasarkan grafik paparan sinar-X untuk energy 130 kV dan arus 5 mA. Penempatan IQI dan material penanda didasarkan pada penyinaran arah sumber. Densitas bayangan dan sensitivitas bayangan radiograf, sebagai ukuran kualitas bayangan dianalisis secara konvensional dan secara digital. Berdasarkan hasil pengujian, radiografi konvensional film-skrin *memperlihatkan kualitas bayangan yang lebih baik dibandingkan dengan yang dihasilkan dari radiografi digital. Hasil ini dapat dimengerti karena penyinaran didasarkan pada standar yang ada untuk radiografi konvensional film-skrin.*

Kata kunci : radiografi konvensional, film-skrin, computed radiografi, coran logam lunak

INTRODUCTION

Shortly after invention of X-ray by Roentgen in 1895, he was able to show a radiograph of left hand of his wife, Martha, on photographic film [1]. Since then, various X-rays machines were produced and manufactured for diagnose and treatment purposes in medicine through radiographic examination [2]. Invention of radioactivity by Becquerel in 1896, followed by capability of nuclear reactor in producing gamma rays sources, especially Co-60, was open new era of imaging to complement of X-ray invention [3]. X-rays and gamma rays are always associated with high energy photon of short wavelength which capable of penetrating materials they are passing through. X-rays are generated by bombarding high-atomic number metallic target, usually tungsten, with high kinetic energy of electron in X-ray tube. The gamma rays, however, are produced by disintegrating processes of unstable nuclei [4]. X-rays are mostly used in nuclear medicine, whereas gamma rays are used in industry [3,5].

In conventional methods, image is produced on recording media such as film-screen (F/S) materials. The classical examples of these imaging modalities are photography and radiography. In modern society, however, images are produced electronically and it appearance especially after advent of computer technology in the 1960s [6,7]. The first form of digital imaging was angiography which was introduced in 1977 and put to clinical use in 1980. Today, the term of digital radiography comprises computed radiography (CR) and digital direct radiography (DDR). CR is radiographic system that replaced film-screen (F/S) in conventional radiography with storage phosphor plate as the image receptor. In practical society the term storage phosphor plate is interchangeable with image plate (IP). The latent image on the exposed IP is scanned by a laser beam and converted into digital data to produce an image. The storage phosphor image plates of CR were first used to record general radiograph in 1980. DDR, on the other hand, acquire image data in digital format without laser scanning to extract the latent image. DDR using charged-coupled device (CCD) was introduced in 1990 for producing digital image from direct capturing X – ray [8-16]

BATAN has long used conventional film-screen (F/S) technique for radiographic examination. New investment by establishment of computed radiography (CR) equipment is to fulfill demand on digital radiography for materials testing which offering fast and more economic services [17,18]. The purpose of this current study is therefore to demonstrate of producing a radiograph using image modalities of conventional and computed radiography. The test object is a motorbike key house made of soft metallic casting material. The set up measurement of parameters are based on ASTM standards for radiographic examination [19,20]. Two modes of image processing were carried out manually and using CR reader. The discontinuities or defect in the test object were examined by observing the corresponding radiographs

THEORY

The underlying theory of radiography is related to absorption of photon by material. As photon has no charge, the absorption of photon is commonly termed as attenuation of photon. The attenuation is contributed from three mode processes of interactions: photoelectric, Compton scattering and pair production. In photoelectric mode, the incident X–ray photon is completely absorbed by an inner shell electron which is then ejected from the atom as photoelectron. In Compton effect, the energy of the incident photon is partially absorbed by an outer shell electron, which is then ejected from the atom as a recoil electron. The remaining photon is reemitted as a Compton scatter photon which may penetrate to reach the image receptor. Pair production can only be occurred when the photon energy is at least 1,02 MeV. In pair production high energy photon travelling close to the nucleus of high atomic number is converted into a pair of particles: an electron and a positron.

The total attenuation coefficient per atom, σ, is expressed as [21]

$$\sigma = \sigma_{pe} + \sigma_{cs} + \sigma_{pp} \quad (1)$$

Where σ_{pe} , σ_{cs} and σ_{pp} are respectively absorption coefficient for photoelectric, Compton scattering and pair production interaction per atom. If there are any other modes of interaction they will contribute to total attenuation coefficient. The incident photon when passing through a material of thickness x is expressed as [21,22]

$$I = I_0 e^{-n\sigma x} \quad (2)$$

where I is transmitted intensity of photon, I_0 is intensity of incident photon, n is number of atoms per cubic centimeter, σ is total atomic cross-section (cm^2) per atom and x is thickness of material.

METODOLOGI

The purpose in radiography is for material examination through analysis of image on radiograph. In this study, two methods are described, each for conventional film-screen (F/S) radiography and computed radiography (CR). Conventional (F/S) radiographic consists of transparent, bluish plastic substrate coated on both sides with an emulsion of radiation sensitive silver halide crystal such as silver bromide and silver chloride in micro size. When incident X–rays or gamma rays or light rays strike the emulsion crystal or grain, some of bromide ion, Br^- are liberated and captured by the silver ion, Ag^+. In such situation, the radiograph contains a latent image because the changes in the grains are virtually undetectable. The exposed grains are more sensitive to react with the developing solution. When the film is processed in dark-room, the exposed film will react with solution to develop latent image on radiograph.

Film processing basically involves five steps, as follows [21-23]: (1) development of latent image by developing solution. Electrons in developing solution convert the silver halide grain to metallic silver in the exposed film. To obtain an optimum result, the temperature of the developing solution should properly be controlled, (2) stopping development of latent image by diluting and washing the remnant of developing solution away with water in stop bath, (3) fixing the latent image using fixing solution. Unexposed silver halide crystals are removed by the fixing bath and leaving the silver metallic crystal in the radiograph. In this stage the latent image is fixed, (4) washing the radiograph contained fixed image by removal all the processing chemicals, and (5) drying the film for viewing. Processing film is governed by rigid rules in the sense that the quality of the film on the radiograph depends on chemical concentration, temperature, time of processing and physical movement [22]

Image formation for computed radiography (CR) in digital format differs from conventional F/S radiography. CR system use image plate (IP) having a detective layer of photostimulable phosphor (PSP) crystal that contain different halogenides such as bromine, chlorine or iodine (e.g., $BaFBr:Eu^{2+}$) [24]. The phosphor crystals are usually coated into plastic substrate of resin materials in an unstructured way. The IP is commonly termed as storage-phosphor image plate. The image formation on the IP is illustrated in Figure 1. When the IP is exposed to X – rays or gamma rays, the photon energy of X – rays or gamma rays is absorbed and temporarily stored by the phosphor crystals in the manner that the electrons of the crystals are excited to higher energy levels. In this way, X – rays or gamma rays photon energy can be stored for several hours in the higher energy level, depending on the specific physical properties of the phosphor crystals [8]. If it is done, the stored energy will decrease over time. It is therefore, the readout process should be started immediately after exposure the IP. The read out process is conducted by scanning the exposed crystal using high energy laser beam of a specific wavelength (flying-spot scanner). During the scanning process, the stored energy is set to free returning to the ground state energy by emitting light having a wavelength different from the laser beam. These lights are collected by photodiode and converted into an image using A/D converter for further analysis.

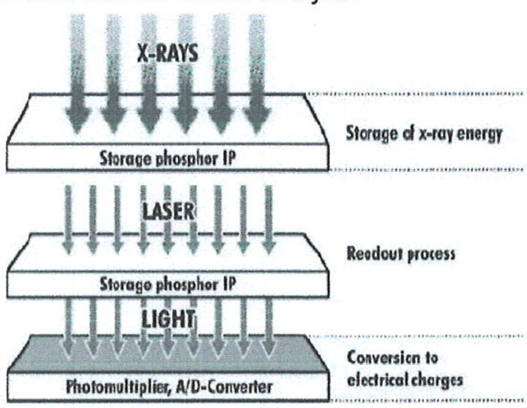

Figure 1. Illustration of digital image formation on storage phosphor image plate of CR [8]

The experiment was carried out by exposing key-house of motorbike made of soft metallic casting materials of the thickness 18 mm using X – rays beam generated from the X – ray machine. The amperage and electrical voltage of the machine were set at 5 mA and 130 kV respectively. The source to film distance (sfd) was set at 1 m. The image quality indicator (IQI) used was wire type10ISO16. For conventional F/S radiography, the medium speed of Agfa D7 radiographic film of the size 4 inch x 10 inch was used as recording media to record a latent image that become visible after chemical processing.

The film was sandwiched by pair of intensifying screens of the thickness 0.125 mm each. For CR, the recording media used was storage phosphor image plate (IP) and the latent image is processed by CR reader [25]. The detail exposure parametersare shown in Table. 1.

Table 1. Exposure parameters of the radiographic experiment

Parameters	Imaging modalities	
	F/S	**CR**
Material	Soft metal	Soft metal
Thickness	18 mm	18 mm
Amperage, voltage	5 mA, 130 kV	5 mA,130 kV
Film speed	Medium,Agfa D7	IP, blue type
Intensifying screen	0.125 mm	--
sfd	1 m	1 m
IQI	DIN10ISO16	DIN10ISO16
Exposure time	90 s	60 s, 90 s
Processing:		
Developer	5 minutes	
Stop bath	7 minutes	
Fixer	15 minutes	CR reader
Washing	20 minutes	

RESULTS AND DISCUSSION

A digital image is a two dimensional matrix of pixel (picture element) in length dimension. Each pixel contains a number. The value of number in each pixel representing grey scale value corresponds to the intensity of that point in image. The radiographs produced by conventional film-screen (F/S) radiography is shown in Fig. 2, whereas those produced using computed radiography (CR) technique are shown in Fig. 3 and 4 respectively. As can be seen from the figures, conventionalF/S radiography shows better visual appearance of radiograph compared that processed by CR. As its nature, the radiograph produced from conventional F/S radiography is analogue, therefore there are no chance to manipulate such radiograph except if it is converted into digital format in advance for further analysis.

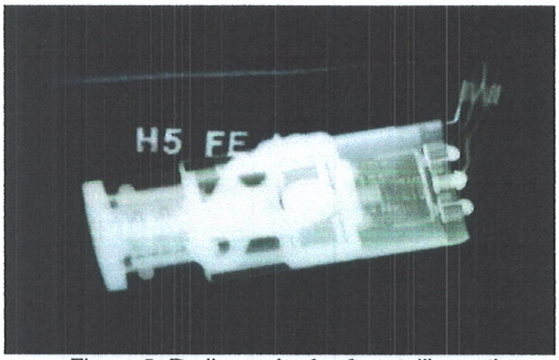

Figure 2. Radiograph of soft metallic casting material developed using conventional F/S radiography. The object was exposed by X – rays beam for 90 s and processed manually in chemical solution.

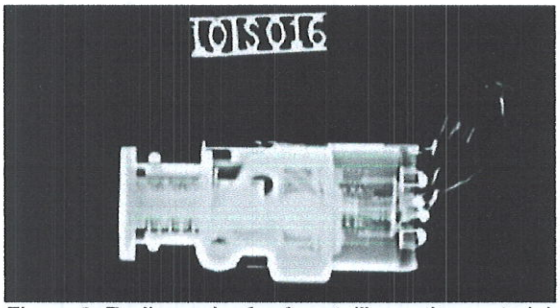

Figure 3. Radiograph of soft metallic casting material developed using CR. The material was exposed by X – rays beam for 90 s and processed using CR reader

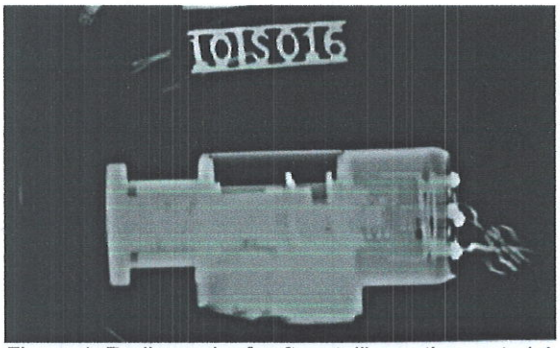

Figure 4. Radiograph of soft metallic casting material developed using CR. The material was exposed by X– rays beam for 60 s and processed using CR reader

As in conventional F/S radiography, there are many factors that affecting the quality of an image. Three factors that give major contribution to image quality are radiographic contrast, detail and noise. They play major role in CR imaging quality. Some other factors are result of the digital nature of the process [8,23].

Radiographic contrast is expressed as the difference of optical density between two adjacent areas on conventional F/S radiography or as the relative difference of brightness between the adjacent areas in a digital image displayed on monitor. For both F/S and CR, radiographic contrast is influenced by subject contrast and receptor sensitivity. In CR, radiographic contrast can also be altered by adjustment of display parameters which is independent to acquisition parameters. Subject contrast is proportional to the relative difference of transmitted x-ray on exit side of object and it is the result of the attenuation properties of the object being exposed. Attenuation is strongly dependent on the X – rays energy and it is determined by density and thickness of the object properties and voltage and amperage applied in the X – rays tube. Subject contrast is reduced by the presence of radiation scattering.

Receptor sensitivity in conventional F/S radiography is defined as changes of the amount of optical density in receptor due to change of exposure. In CR, however, receptor sensitivity is defined as changes of analog-to-digital due to change in exposure to the receptor. In principle, the sensitivity of the IP can be gained to certain extent by appropriate phosphor blending formula that make its dynamic range can cover wide range of radiation intensities.

The signal stored in digital form is directly or logarithmically proportional to the amount of radiation transmitted through the object. For this reason, the stored signal for processing image reflects the inherent subject contrast provided that the image receptor is operated in the linier portion of its response curves. In CR, image processing is used to determine display contrast which is expressed by pixel values or gray scale levels.

Detective quantum efficiency (DQE).

The DQE is useful factor for description of performance of image receptor because it takes into account detection efficiency, spatial resolution, and noise. The DQE describes the relative efficiency of the IP and it is defined as SNR_{out}^2/SNR_{in}^2, where SNR stand for signal to noise ratio. SNR_{in}^2 is the SNR of the exposure incident on the IP which numerically equal to input fluence, whereas SNR_{out}^2 is the ratio of the relative magnitude of the image signal to the noise. From the definition, DQE represents the SNR transfer efficiency and it is energy-dependence quantity. The efficient SNR is important because the image quality is better with increasing SNR [8, 10, 14,16]

The DQE is generally related to spatial frequency, DQE(f). A perfect system has DQE(f) equal unity at all spatial frequencies. At higher spatial frequency the noise increase results in decrease transfer efficiency. A system with higher DQE requires less exposure for a given image quality than the system with lower DQE. The DQE concept in CR is important for improvement of image quality compared with FS system. From reported studies [8,10] that DQE of the CR decrease compared with that of F/S with increasing beam energy. This fact suggests that beam energy applied for FS system is not always appropriate for digital system. In most cases, for a given energy the digital system shows over exposed than for FS system.

From the three figures, the components of the object are seen visible quite clear; however, the wires of IQI were not clearly visible. The parts electrical cables were also visible and can be seen by naked eye. As the wire of the IQI was not seen clearly, it means that any defects in the casting object cannot be determined precisely. From visual view on the object, it immediately found that the defect was not observed in object. It also found that the densities of the radiographs are too high as indicated by dark color of image background. It was due to over exposed applied to the object [20]. Although the contrast of the image is good and parts of object are visible, but none of the wire of the IQI are visible. This result indicated that the defects or discontinuity in the object cannot be determined precisely. A further radiographic examination on the same object is recommended with reducing the exposure time.

CONCLUSION

The radiographs produced from conventional F/S radiography and computed radiography (CR) have been successfully realized experimentally using X – rays beam. The contrast of the radiograph is considerable excellent and detail parts of object were visible on it. The density of the radiograph is high due to over - exposed. Although discontinuities or defect cannot be determined precisely, however none defects are identified from visual point of view. The appearance of radiograph visually shows that conventional F/S radiography produce better radiograph than that processed be CR system.

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REFERENCES

1. **HANNAH WATERS, (2011),** "The First X-ray, 1985", *The Scientist Magazine*, Vol 2, issue 7, July

2. **WILLI A. KALENDER, (2006),** "X-ray computed tomography", Phys. Med. Biol. Vol.51, R29-R43.
3. **ROBERT ADAMS, ROBERT ZBORAY, (2017),** " Gamma radiography and tomography with a CCD camera and Co-60 source", Applied Radiation and Isotopes, Vol.127, 82-86.
4. **IAEA, (2008),** "Industial process gamma tomography", Vienna
5. **JENS ALS-NIELSEN, DES McMORROW, (2011),** "Elements of Modern X-Ray Physics", 2 ed, John Wiley & Sons, Chichester.
6. **MARK B. WILLIAM, ELIZABETH A. KRUPINSKI, KEITH J. STRAUSS, WILLIAM K. BREEDEN, MARK S. RZESZOTARSKI, KIMBERLY APPLEGATE, MARGARET WYATT, SANDRA BJORK, J. ANTHONY SEIBERT, (2007),** "Digital radiography image quality: Image acquisition", J. Am. Coll. Radiol, Vol.4, 371-388.
7. **ELIZABETH A. KRUPINSKI, MARK B. WILLIAM, KATHERINE ANDRIOLE, KEITH J. STRAUSS, KIMBERLY APPLEGATE, MARGARET WYATT, SANDRA BJORK, J. ANTHONY SEIBERT, (2007),** "Digital radiography image quality: Image processing and display", J. Am. Coll. Radiol, Vol.4 389-400
8. **MARKUS KORNER, CHRISTOF H. WEBER, STEFAN WIRTH, KLAUS-JURGEN PFEIFER, MAXIMILIAN F. REISER AND MARCUS TREITL, (2007),** "Advances in digital radiography: Physical principles and system overview", RadioGraphics, Vol. 27, 675 – 686.
9. **B.S. VERMA AND I.K. INDRAJIT, (2008),** "Advent of digital radiography: Part 1", Indian J. Radiol. Imaging, Vol.18, No.2, 113-116
10. **TRACY L. HERMANN, TERRI L. FAUBER, JULIE GILL, COLLEEN HOFFMAN, DENISE K. ORTH, PAULETTE A. PETERSON, RANDY R. PROUTY, ANDREW P. WOODWARD, TERESA G. ODLE, (2012),** "Best practice in digital radiography", American Society of Radiologic Technologists, White Paper, 1-26
11. **I.K. INDRAJIT AND B.S. VERMA, (2007),** "Digital imaging in radiology practice: An introduction to few fundamental concepts", Indian J. Radiol. Imaging, Vol.17, No.4, 230-236.
12. **LUIS LANCA, AUGUSTO SILVA, (2009),** "Digital radiography detectors – A technical overview: Part 1", Radiology Vol.15, 58-62.
13. **LUIS LANCA, AUGUSTO SILVA, (2009),** "Digital radiography detectors – A technical overview: Part 2", Radiography, Vol.15, 134-138.
14. **A.R. COWEN, S.M. KENGYELICS, A.G. DAVIES, (2007),** "Solid-state, flat panel, digital radiography detectors and their physical imaging characteristics", Clinical Radiology, Vol.62, 487-498.
15. **B.S. VERMA, I,K. INDRAJIT (2008),** "Impact of computer in radiography: The advent of digital radiography, Part-2", Indian J Radiol. Imaging, Vol.18, No.3, 204-209.
16. **HO KYUNG KIM, IAN ALEXANDER CUNNINGHAM, ZHYE YIN, GYUSEONG CHO, (2008),** "On the development of digital radiography detectors: A review", International Journal of Precision Engineering and Manufacturing, Vol.9, 86-100.
17. **N. SHERIDAN, J.P. MCNULTY, (2016),** "Computed radiography versus indirect digital radiography for the detection of glass soft-tissue foreign bodies", Radiography, 1-5.
18. **A.L.M PAVAN, A.F.F. ALVES, S.B. DUARTE, G. GIACOMINI, T. SARDENBERG, J.R. A. MIRANDA, D.R. PINA, (2015),** "Quality and dose optimization in hand computed radiography", Physica Medica, 1-5
19. ASTM E 1030-00., Standard test method for radiographic examination of metallic castings.
20. ASTM E 94-00., Standard guide for radiographic examination.
21. **C. ROBERT EMIGH AND FRANK A. IDDINGS, (2002),** "Radiation and particle physics, in Nondestructive testing handbook, volume 4: Radiographic Testing, 3rd ed., American Society for Nondestructive Testing, Inc. Columbus, Ohio, cp. 2
22. **QUINN B. CARROLL, (2011),** "Radiography in the digital age: physics, exposure, radiation biology", Springfield, IL: Charles C. Thomas Publisher, Ltd.
23. **K. AL KHALIFAH, A. BRINDHABAN (2004),** "Comparison between conventional radiography and digital radiography for various kVp and mAs setting using a pelvic phantom", Radiography, Vol.10, 119-125
24. **A.R. COWEN, A.G. DAVIES, S.M. KENGYELICS, (2007),** "Advances in computed radiography systems and their physical imaging characteristics", Clinical Radiology, Vol.62, 1132-1141.
25. **DUR-NDT**., HD-CR 35 NDT/CR 35 NDT, Manual.