APPLICATION OF MEDICAL IMAGING COMPUTED RADIOGRAPHY (CR) SYSTEM IN INDUSTRIAL IMAGING: LEAD ACID BATTERY INSPECTION

NURUL HIDAYAH ZULKIFLI
DEPARTMENT OF DIAGNOSTIC IMAGING AND RADIOTHERAPY, KULLIYYAH OF ALLIED HEALTH SCIENCES, INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA, JLN SULTAN AHMAD SHAH BANDAR INDERA MAHKOTA 25200 KUANTAN, PAHANG, MALAYSIA
nurulhidayahzulkifli94@gmail.com

MOHD SYAHRIMAN MOHD AZMI
DEPARTMENT OF PHYSICS, FACULTY OF SCIENCE AND MATHEMATICS, UNIVERSITI PENDIDIKAN SULTAN IDRIS 35900 TANJONG MALIM, PERAK, MALAYSIA
syah_0602@yahoo.co.uk

ZAFRI AZRAN ABDUL MAJID (CORRESPONDING AUTHOR)
DEPARTMENT OF DIAGNOSTIC IMAGING AND RADIOTHERAPY, KULLIYYAH OF ALLIED HEALTH SCIENCES, INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA, JLN SULTAN AHMAD SHAH BANDAR INDERA MAHKOTA 25200 KUANTAN, PAHANG, MALAYSIA
amzafri@iium.edu.my

ABSTRACT

Introduction: Non destructive testing (NDT) is a procedure to assess the internal components without disassembling the outer components. Industrial imaging uses high energy x-rays to penetrate materials while x-rays used in medical imaging has exposure limitation. The purpose of this paper is to determine the optimum technical factors (kVp, mAs, and SID) used in medical imaging Computed Radiography (CR) system suitable for industrial imaging application to inspect lead acid battery. **Methods:** Lead acid battery is exposed to radiation with predetermined technical factors utilized in medical imaging. The kVp, mAs, and SID are varied throughout the experiment. The optimum technical factors obtained are further used to expose the battery at six different angles for inspection of lead plates. The sizes of lead plates are measured using imageJ software and the measured length is compared to the actual sizes of lead plates**. Results**: At 15 mAs, two values with the smallest difference to the original size of the lead plates are produced which is at 75 kVp and 125 kVp. Based on the technical factors used in this experiment, it is concluded that 15 mAs is the optimal mAs that can be used to provide the measurement with the least difference when compared to the original size of the lead plates. All measurement with the smallest difference when compared to the original sizes of lead plates are obtained at 125 kVp which is 4.19 cm (plate C when mAs at 5), 4.23 cm (plate C when mAs at 10), and 4.23 cm (plate C when mAs at 15). This indicates that 125 kVp is suitable to be used for inspection. The accurate measurement of lead plates is achieved when 100 cm SID is used. When exposed, white lead sulphate is seen coating the lead plates. **Conclusion:** X-rays used in medical imaging can be applied in industrial imaging for lead acid battery inspection as it also possess high energy and penetrating power.

KEYWORDS: Computed Radiography (CR) System, Lead Acid Battery, Industrial Imaging, sulfation, kilovoltage peak (kVp), source to image distance (SID), miliampere seconds (mAs).

INTRODUCTION

Industrial imaging application for non destructive evaluation can be dated back in 1913 when the high vacuum X-ray tubes with intense and reliable x-ray source became available. Non destructive testing (NDT) is a method commonly used in industrial imaging to evaluate internal components without destructing the outer components of the material. It utilizes x-rays and gamma rays to produce radiograph of the test object and commonly used to evaluate internal and external defects and show any changes in thickness or content of the test object and assembly. Lambert et al. (2017) highlighted that any process of non-destructive testing and failure analysis must be developed in such a way that the QC test can be performed without any possibility of contributing towards the failure of the product.

Radiographic testing works by placing the subject with the internal voids between the source of radiation and the film. Industrial imaging uses high energy x-rays because the type of materials to be exposed are usually made of thick materials causing the rays to be absorbed rather than penetrating the materials (Willcox & Downes, 2000). Because of variations in density and thickness of the part, or differences in absorption characteristics caused by variations in composition, different portions of a test piece will absorb different amounts of radiation. This utilizes the concept of attenuation coefficient. The advantage of this technique is that the battery does not need to be cut opened, making the process easier while acquiring reliable result. It is not practical to disassemble the sealed outer parts for the purpose of determining the number of lead plates, sizes and the thickness of the plates. The inspection can be done through a non destructive testing procedure which will allow for the internal parts of the battery to be viewed without destroying the outer layer of the material (Roberge et al., 1990).

Computed tomography, which is adapted from the medical computerized axial tomography (CAT) scanner is among the procedure that is commonly used in non destructive testing (NDT) and is also considered as a highly valuable nondestructive testing tool in various fields. However, the major disadvantage of this method comprises its high operating costs (Rosc et al., 2016). Hence, as x-rays that is used in medical imaging also posses high energy and penetrating power eventhough for selected materials only, it could be used in industrial imaging application for inspection of lead plates in sealed items specifically lead acid batteries because the outer casing of the battery is made up from thin plastic polypropylene (Carlton & Adler, 2006). Lead acid battery is one of the oldest types of rechargeable battery that are able to supply high power surge. The causes of defect can be from various factors such as misalignments of lead plates and related components, wrong placement of the components and external factors such as exposed to high temperatures or short circuiting (Wang et al., 2012). Sulfation also could lead to degradation of performance.

Computed radiography (CR) system has been adopted in industrial imaging for the purpose of producing images through non destructive testing. A CR system possess post processing algorithm that enables the researchers to manipulate the digital images taken (Deprins, 2004). The system was adopted in industrial imaging due to the post-processing elements such as panning, zooming, and contrast enhancement that able to assist in image evaluation. Technical factors such as kVp, mAs and SID are also important for producing images with optimum resolution to aid in image analysis. Hence, this research intends to study if the technical factors (kVp, mAs, and SID) applied in medical imaging that are used for human studies can be employed in industrial imaging application for the purposes of inspecting the internal lead plates within sealed lead acid battery.

METHODS

Study design

This research is an experimental quantitative study. This study is conducted in two stages which are during pilot stage and experimental stage. Pilot stage is conducted to ensure all the equipments needed in this experiment are available and correct methodology is used later in the experiment. The data are collected only at the experimental stage.

Pilot stage

The type of lead acid battery used in this experiment was CSB GP 1272 (12V 8.0AH. The objective of pilot study was to evaluate the best method to be used in the experiment. This is to ensure the data collected will be useful for further data analysis and to detect potential problems that may arise during the experiment. Then, the battery is exposed to predetermined technical factors and the images are assessed in the CR system. All images are evaluated and the procedures are approved by the supervisor. All the equipments are set up according to Figure 1.

Figure 1. The arrangements of the image receptor and lead acid battery to the x-ray tube during exposure to the radiation

Experimental stage

1. X-ray tube was centered to the table bucky with fixed source to image distance (SID) 75 cm.
2. Lead acid battery (12 volt) was placed at the center of the imaging plate and centered with both imaging plate and x-ray tube and exposed to technical factors as below.

Table 1. The varied kVp used to expose the battery when mAs is fixed at 5

kVp	mAs	SID (cm)
75	5	75
100	5	75
125	5	75

Table 2. The varied kVp used to expose the battery when mAs is fixed at 10

kVp	mAs	SID
75	10	75
100	10	75
125	10	75

Table 3. The varied kVp used to expose the battery when mAs is fixed at 15

kVp	mAs	SID
75	15	75
100	15	75
125	15	75

3. All images obtained were evaluated for any defects of the lead plates by using the tools provided in the CR system. Technical factor (kVp and mAs) that produce good contrast of the lead plates is selected.
4. The experiment was repeated with fixed kVp and mAs but varying SID as followed.

Table 4 The varied SID used to expose the battery when kVp fixed at 125 and mAs at 15

SID (cm)	kVp	mAs
50	125	15
75	125	15
100	125	15

5. Three lead plates located at the front of the lead acid battery labeled as A, B, and C were measured by using imageJ software and the measurement were compared with the actual size of the lead plates to identify the correct SID that would produce the correct measurement of the lead plates.
6. All measurements were recorded to determine the measurement with the least difference compared to the original size of lead plates. The condition of lead plates were evaluated and discussed.

Modality Used

CR system used in this experiment was model CR-IR348CI from FUJI Corporation. The CR console used Application Software v7.0. for the x-ray system, the type of x-ray tube used was ceiling suspended Siemens Multix Top General radiography system and the model of the x-ray tube is OPTITOP 150/40/80.

Data Analysis

The images were analyzed by using imageJ software. The post processing capabilities of the CR system such as panning, zooming and brightness manipulation were also utilized in evaluating the images. In this phase, the appropriate technical factors that provide correct measurement of lead plates within the lead acid battery is determined. The condition of lead plates within lead acid battery is also evaluated and discussed.

RESULTS AND DISCUSSION

Technical Factors (kVp and mAs)

In Table 5, the battery is exposed with varying kVp but the mAs is fixed at 5. With 75 kVp, the values of plate A, B, and C are 4.12 cm, 4. 04 cm, and 4.19 cm respectively. When kVp is changed to 100 kVp, the values of plate A and B remains the same which is 4.12 cm and 4. 04 cm, while the value for plate C reduces to 4.16 cm. Meanwhile when kVp is changed to 125 kVp, the values of plate A, B, and C are 4.08 cm, 4. 01 cm, and 4.19 cm respectively.

Table 5. The measured values of lead plates A, B, and C when mAs is fixed at 5

Variable (kVp)	mAs	Measured length (cm)			Original length (cm)			Difference (cm)		
		A	B	C	A	B	C	A	B	C
75	5	4.12	4.04	4.19	4.3	4.3	4.3	0.18	0.26	0.11
100	5	4.12	4.04	4.16	4.3	4.3	4.3	0.18	0.26	0.14
125	5	4.08	4.01	4.19	4.3	4.3	4.3	0.22	0.29	0.11

In Table 6, the battery is exposed with varying kVp but the mAs is fixed at 10. With 75 kVp, the values of plate A, B, and C are 4.08 cm, 4. 01 cm, and 4.16 cm respectively. When kVp is changed to 100, the values of plate A, B, and C are 4.04 cm, 4. 04 cm, and 4.19 cm respectively. However, when kVp is changed to 125, the values of plate A, B, and C changes to 4.08 cm, 4.16 cm, and 4.23 cm respectively.

Table 6. The measured values of lead plates A, B, and C when mAs is fixed at 10

Variable (kVp)	mAs	Measured length (cm)			Original length (cm)			Difference (cm)		
		A	B	C	A	B	C	A	B	C
75	10	4.08	4.01	4.16	4.3	4.3	4.3	0.22	0.29	0.14
100	10	4.04	4.04	4.19	4.3	4.3	4.3	0.26	0.26	0.11
125	10	4.08	4.16	4.23	4.3	4.3	4.3	0.22	0.14	0.07

In Table 7, the battery is exposed with varying kVp as stated in the table but the mAs is fixed at 15. With 75 kVp, the values of plate A, B, and C are 4.08 cm, 4. 01 cm, and 4.23 cm respectively. When kVp is changed to 100, the values of plate A, B, and C are 4.08 cm, 4. 08 cm, and 4.19 cm respectively. Meanwhile when kVp is changed to 125 kvp, the values of A, B, and C are 4.12 cm, 4.08 cm, and 4.23 cm respectively.

Table 7. The measured values of lead plates A, B, and C when mAs is fixed at 15

Variable (kVp)	mAs	Measured length (cm)			Original length (cm)			Difference (cm)		
		A	B	C	A	B	C	A	B	C
75	15	4.08	4.01	4.23	4.3	4.3	4.3	0.22	0.29	0.07
100	15	4.08	4.08	4.19	4.3	4.3	4.3	0.22	0.22	0.11
125	15	4.12	4.08	4.23	4.3	4.3	4.3	0.18	0.22	0.07

Based on the results obtained in the experiments, it is noted when the highest kVp is used which is 125, the highest measurement of lead plate is obtained. The value obtained is 4.23 cm which only differ 0.07 cm when compared with the original size which is 4.3 cm. Based on all measurement tabulated, it is determined that all measurement with the smallest difference when compared to the original sizes of lead plates are obtained when using kVp at 125 which is 4.19 cm (plate C when mAs at 5), 4.23 cm (plate C when mAs at 10), and 4.23 cm (plate C when mAs at 15). This indicates that kVp 125 is the optimal kVp to inspect lead acid battery. This is because 125 kVp is able to produce images with measurement closest to the actual sizes of lead plates.

Based on the three tables above, it is noted that when using 15 mAs, there are two values with the least difference from the original size of the lead plates are produced which is at 75 kVp and 125 kVp. When using 10 mAs as the fixed variable, there is only one measurement that is almost near the actual measurement which is 4.23 cm at plate C when 125 kVp is used. When 5 mAsis used, all measurement of lead plate A, B, and C obtained by image J is reduced. Thus, it is concluded that 15 mAsis the optimal mAs that can be used to provide the measurement with the least difference when compared to the original size of the lead plates.

Source to Image Distance (SID)

Based on table 8 for source to image distance (SID), lead acid battery is exposed to a fixed kVp 125 and fixed mAs 15. In this step, the source to image distance (SID) used is varied to 50 cm, 75 cm, and 100 cm. Values with smallest difference to the original sizes of lead plates are obtained when SID is at 100 cm.

Table 8. The measured values of lead plates A, B, and C when varying SID is used

Source to image distance (SID)	Fixed kVp	Fixed mAs	Measured length (cm)			Original length (cm)		
			A	B	C	A	B	C
50	125	15	4.19	4.12	4.12	4.3	4.3	4.3
75	125	15	4.08	3.93	4.12	4.3	4.3	4.3
100	125	15	4.08	4.01	4.23	4.3	4.3	4.3

For source to image distance (SID), lead acid battery is exposed to a fixed kVp 125 and fixed mAs 15. Both kVp and mAs above are chosen as the fixed technical factors because they are capable of showing good image resolution and able to provide measurements of lead plates that are almost identical with the original sizes of the plates. Determining the accurate SID that should be used when exposing the material subjected to inspection is crucial because according to Bontrager and Lampignano (2010), magnification and distortion of images would occur when varied SID is used. When 100 cm is used, the edges of all three lead plates are well defined and the image high in contrast. This enables to easily measure the lead plate using image J and the value obtained is 4.23 cm which almost reaching the original size (4.3 cm). Hence, it is safe to conclude that the optimal technical factors that can be used for lead acid battery inspection is 125 kVp, 15 mAs, and 100 cm source to image distance (SID).

The measurement with the least difference to the original size is obtained only when the highest exposure factor is used which is 125 kVp and 15 mAs. This indicates that the exposure factors used also depends on the materials that are subjected to the ionizing radiation. Although the outer plastic layer can be easily penetrated, high exposure factor is needed to produce high contrast images that will assist in the image analysis process later. Highest kVp and mAs are able to provide the highest accuracy when measuring the width of the lead plates

Condition of Lead Plates

Figure 2 and 3 show when the battery is exposed to ionizing radiation at six different angles, foreign material is seen coating the lead plates.

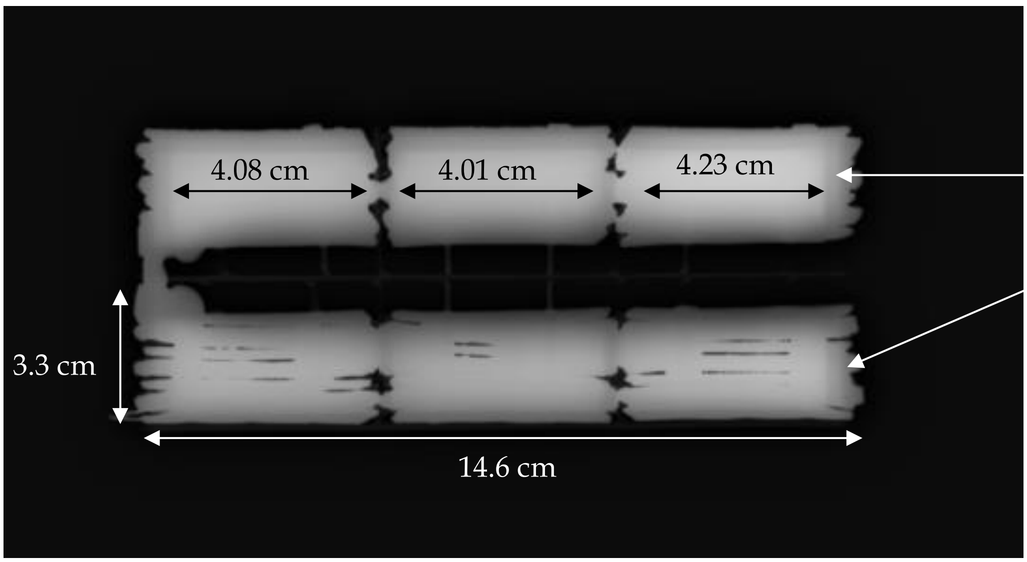

Figure 2. Top view of lead acid battery exposed at 125 kVp, 15 mAs

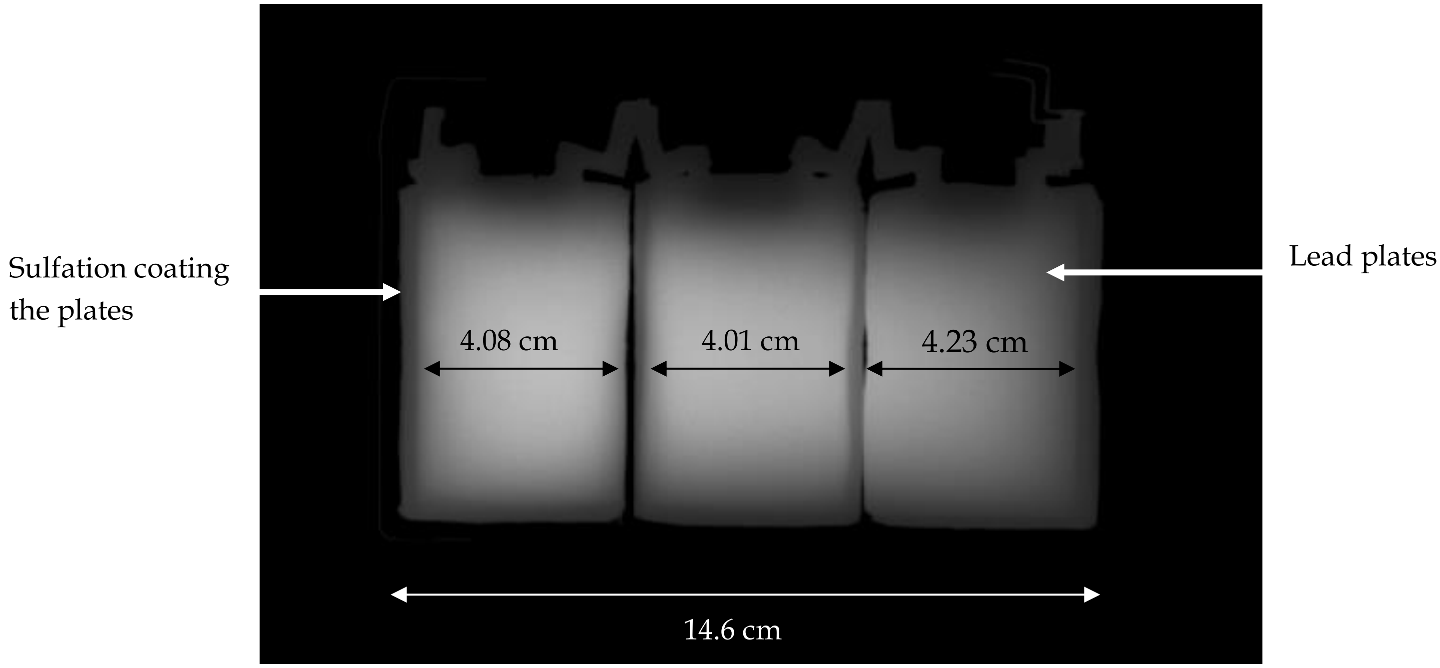

Figure 3. Front view of lead acid batter exposed at 125 kVp and 15 mAs

As noted in tables above, it can be seen that some of the measured values between plate A, B, and C are identical while some show a significant difference. This is due to the condition of the plates which were coated by white crystallized matter. Based on the image, each lead plates are unable to distinguish due to occupied spaces between the plates. A new lead acid battery should consist of lead plates with spaces in between However, it is proven that the white matter is solid lead sulphate that are developed during the process of charging and discharging of the battery through chemical reaction. During discharge of lead acid battery, the lead oxide reacted with sulphuric acid present in the battery. If the battery is left discharged for too long or not recharged fully, the lead sulphate will crystallize and deposited on the lead plates. According to Catherino et al. (2004), lead sulphate is non conductive materials. Thus, chemical reaction could not take place as the materials has become passive.

CONCLUSION

In conclusion, medical computed radiography (CR) system that is used in human studies could be applied in industrial imaging for lead acid battery inspection. All objectives introduced have been met in this study. The optimal technical factors (kVp, mAs, and SID) that could produce good quality images are determined. This is achieved by measuring the sizes of lead plates through imageJ software. The condition of plates are also evaluated. The x-rays used in medical imaging is high in energy and penetrating power thus enabling visualization of lead plates within the battery. Hence, the hypothesis of this study is accepted.

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