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An industrial radiography exposure device based on measurement of transmitted gamma-ray intensity

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Abstract. In film radiography, underexposure and overexposure may happen particularly when lacking information of specimen material and hollowness. This paper describes a method and a device for determining exposure in industrial gamma-ray radiography based on quick measurement of transmitted gamma-ray intensity with a small detector. Application software was developed for Android mobile phone to remotely control the device and to display counting data via Bluetooth communication. Prior to film exposure, the device is placed behind a specimen to measure transmitted intensity which is inversely proportional to the exposure. Unlike in using the conventional exposure curve, correction factors for source decay, source-to-film distance, specimen thickness and kind of material are not needed. The developed technique and device make radiographic process economic, convenient and more reliable.

1. Introduction

Industrial radiography is widely used for the nondestructive testing (NDT) of materials. Film is still the most popular image recorder due to economic, technical and practical reasons. In general practice, exposure is obtained from the exposure curve at the thickness of specimen equivalent to steel. Correction factors for kind of specimen material, source-to-film distance and source decay are required [1-4]. In case of lack of information of specimen material and hollowness, film density may be out of range resulting in waste of time and money. In this research, a technique and a device were developed for determination of the optimum exposure by measurement of the transmitted gamma-ray intensity. The appropriate exposure can then be determined without information of the specimen thickness and specimen material. Moreover, it is independent on source activity and source distance, which makes radiographic process economical, convenient and more reliable. The gamma-ray detector is essentially small so that the transmitted intensity can be measured at the desired parts of the specimen. This research, therefore, selected PIN photodiode which is small and sensitive to x-rays and gamma-rays particularly at high dose [5-8]. The device is remotely controlled using an Android mobile phone making the procedure even more convenient and safer [8]. Bluetooth communication allows up to 10 meters to control the device and to send counting data to the phone. Upon appropriate calibration, the device can also be used to monitor dose rate for safety purpose in industrial radiography and any other radiation practices.

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2. Experimental

2.1. Radiation counting device using PIN photodiode

The Si Positive-Intrinsic-Negative or PIN photodiode is a semiconductor detector type, which creates electron-hole pairs from interaction of an incident gamma-ray with P-N junction. By supplying the reverse-biasing voltage, charges can be then collected [5]. The basic structure of the PIN photodiode is shown in figure 1. The PIN photodiode is widely used in the radiation measurement [9, 10] due to the above mentioned properties [6] as well as its high-speed response, high sensitivity, low noise and compactness.

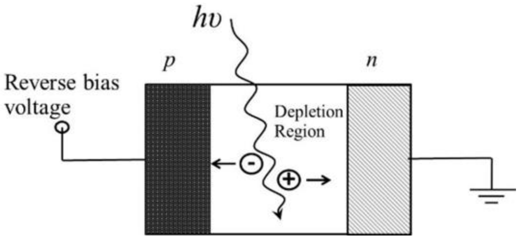


Figure 1. Basic structure of PIN photodiode.

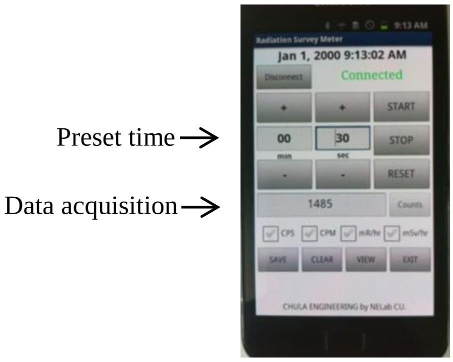


Figure 2. Developed interface.

The in-house developed radiation counting device is composed of four main parts; a PIN photodiode radiation detector, a pulse shaping circuit, a microcontroller board and a Bluetooth module. The developed counting system can be used for a maximum counting rate of 1×10^5 cps and an exposure rate is up to 300 mR/hr [8]. The android interface software was also developed to control the counting process and data communication as well as to display the counting results.

The software was designed to be simple and user-friendly and its interface is shown in figure 2. The preset time can be set by touching screen on the menu + and - for increasing and decreasing time, respectively. For the menu START, STOP and RESET, user can remotely controlled to start, to stop and to reset the system via Bluetooth technology. Then the acquisition data will be displayed on the screen. Note that the interface is not only designed for this purpose but also for other applications.

To investigate the relationship between the transmitted gamma-ray intensity and the thickness of specimen, a steel step wedge was used as a standard sample. The thicknesses of a steel step wedge are 5.48, 6.98, 8.14, 10.72, 11.55, 12.79, 14.30, 16.60, 18.10, 20.00, 21.06, 22.56, 24.00 and 25.33 mm. The PIN photodiode detector Hamamatsu model S3590-08 with an active area of 1 cm × 1 cm was set behind a steel step wedge and far from the 10 Ci Ir-192 radiation source of 80 cm-distance. Small size of the detector enables detection at high dose, and increase the precision of the inspection in a small area. The obtained signals from the PIN photodiode were counted by the pulse shaping circuit and the results were then delivered to a smartphone. The experimental setup and the schematic diagram of the developed counting device are shown in figure 3 (a) and (b), respectively. The relationship between the steel thicknesses and the transmitted counts was carried out.

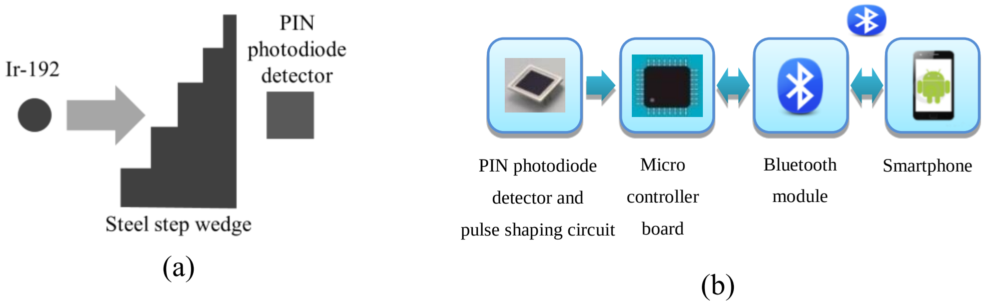


Figure 3. The experimental setup (a) and the schematic diagram of the developed counting device (b).

2.2. Film optical density (OD) for various steel thicknesses

For the industrial x-ray and gamma-ray radiography with film technique, the film optical density or OD is a conventional factor which indicates image darkness. The OD is defined as the logarithm of inverse of light transmittance. In practice, the OD of the radiographic image should fall in the range of 1 – 3 to keep the image contrast at maximum value [3].

To determine the film OD as a function of the specimen thickness and the exposure time, a steel step wedge was radiographed using Kodak AA 400 x-ray film at exposure times of 5, 10, 15 and 20 minutes, respectively. The experimental setup is shown in figure 4. After film processing, the film OD at each steel thickness was measured by a densitometer of X-rite model 301. The relationship between the exposure time and the film OD were then plotted for each steel thickness. Subsequently, the film OD calibration chart was created for determination of the appropriated exposure time.

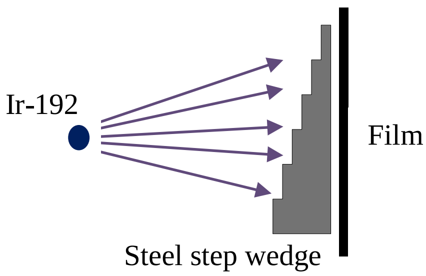


Figure 4. Schematic diagram of the experimental setup for determining the film OD.

2.3. Testing the developed device for determination of exposure time

To test the developed device and method, various types of specimen including a welded steel plate, a cast iron and a lock were radiographed. For the preliminary testing, we aimed to obtain the film OD to be 2.0. The developed device was set behind a specimen to measure the transmitted gamma-ray intensity. The investigated areas of the samples were indicated in figure 8. The obtained counting data were used to determine the appropriated exposure time of each specimen from the calibration chart. The three specimens were finally radiographed using the obtained exposure times. After the film chemical processing, the OD was measured at the position where the transmitted gamma-ray intensity was counted to compare with the expected OD of 2.0.

3. Results and discussions

3.1. Transmitted gamma-ray intensity versus steel thickness

The transmitted gamma-ray intensity was successfully measured by the developed device. The obtained transmitted gamma-ray intensity versus steel thickness could be plotted as shown in figure 5.

From the results, the transmitted gamma-ray intensity decreased with increasing steel thickness. The minimum count of all obtained counting data was found to be approximately 37,000 counts per 30 second. The standard deviation was therefore predicted from the square root of 37,000 which was approximately 192. The precision (3σ) was about 577 which was better than 2% at 99.7% confidence. The results showed that the uncertainty of gamma-ray counting is lower than 2%. However, it can be decreased with increasing of the counting time.

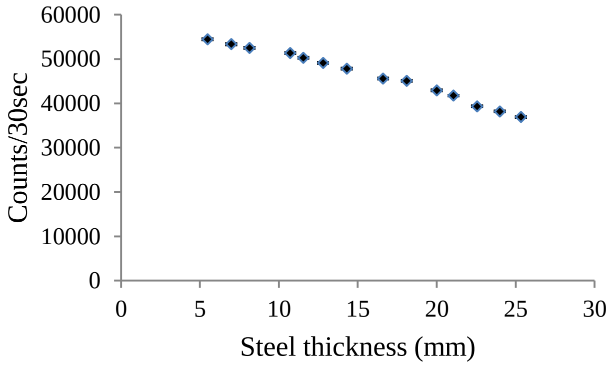


Figure 5. Relationship between the gamma-ray intensity measured by the developed counting device and the steel thickness.

3.2. Film optical density versus steel thickness

By varying the exposure times, the film OD increased with increasing the exposure time whereas it decreased with increasing the steel thickness. The obtained data were fitted with the linear function as shown in figure 6. To avoid overlapping of the fitted curves as shown in figure 6, only 10 out of 14 data sets from our experiments were selected to present.

The relationships of the transmitted gamma-ray count rates and the calculated exposure times at various thicknesses were created by fitting the logarithmic function. Finally, the calibration chart from the developed method was achieved as shown in figure 7. The calibration chart obviously shows that the impact of counting uncertainty from the in-house developed device is small in determining the exposure time. The obtained calibration chart was then employed to determine the appropriate exposure time using the transmitted gamma-ray intensity of and the test specimens, regardless of the thickness and kind of material.

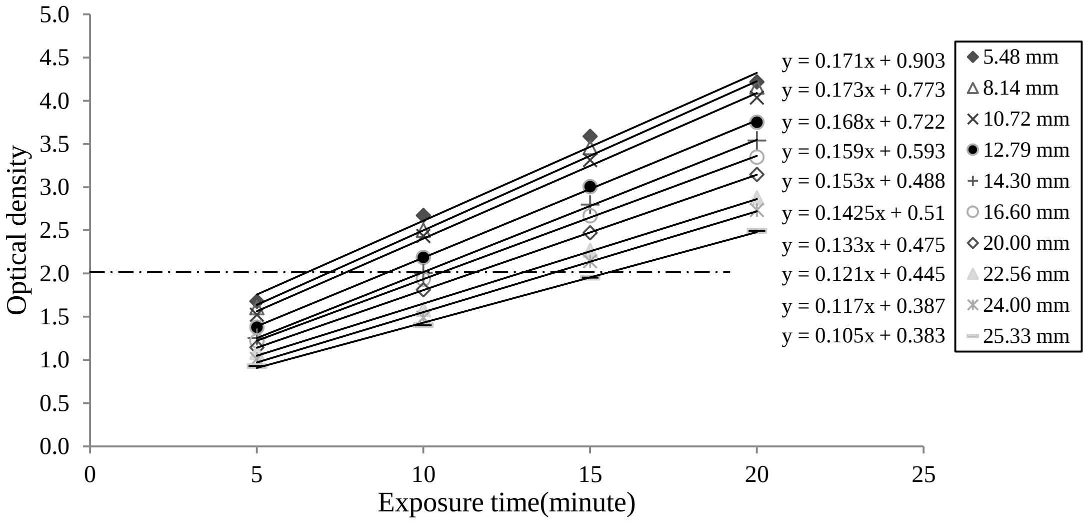


Figure 6. Relationships between the exposure times and the ODs at various thicknesses.

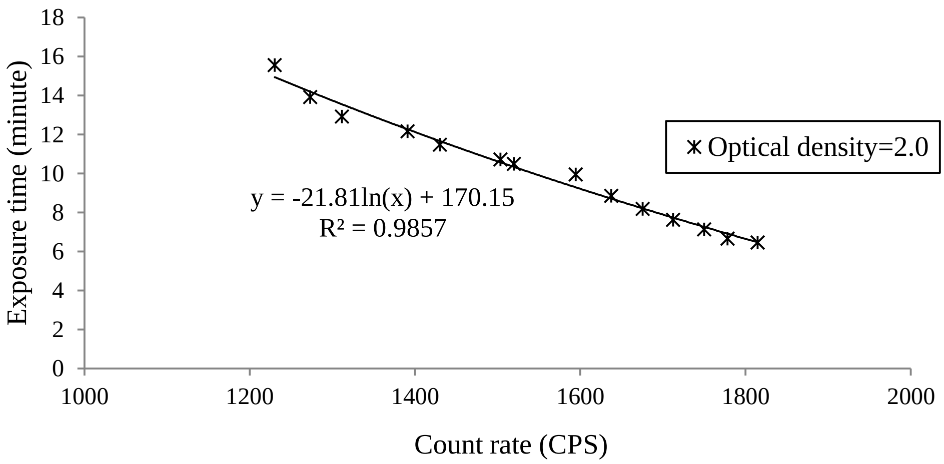
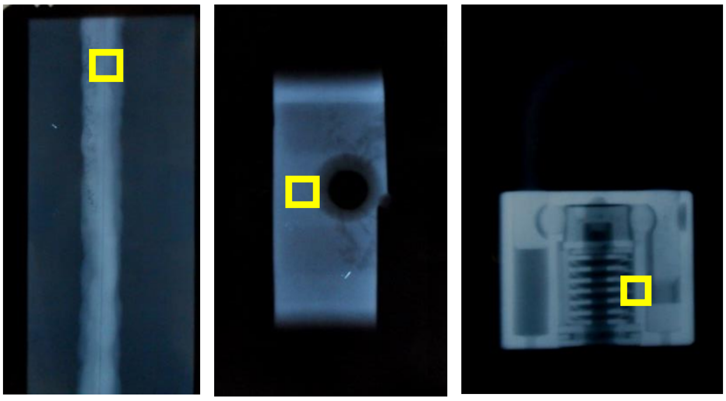


Figure 7. The calibration chart for the film OD at 2.0**.**

3.3. Determination of exposure using the developed technique and device

By applying the developed method, the appropriate exposure time for the OD is 2.0 could be successfully determined using the measurement of the transmitted gamma-ray intensity. The radiographic images were shown in figure 8. The film ODs were measured at the positions indicated by the squares in figure 8 where the PIN photodiode was placed to measure transmitted gamma-ray intensity. The film ODs of a welded steel plate, a cast iron and a lock radiograph were found to be 2.05, 1.98 and 1.92, respectively, as shown in table 1. The discrepancies of the film OD were found to be very small compared to the expected film OD of 2.0. The obtained ODs were still in the acceptable range. Furthermore, the results indicated that the developed counting system and the calibration method could give appropriate exposure time without specimen information and any correction factor. However, film chemical quality of film processing should be strictly controlled.



Steel welded seam Cast iron Lock

Figure 8. Radiographic image of the test specimens.

Table 1. The film OD of the radiographic testing.

Sample	Thickness (cm)	Gamma-ray intensity (cps)	Exposure time (min)	Optical density (OD)	Discrepancy
Welded steel plate	0.8	1713	7.68	2.05	+0.05
Cast iron	1.5	1530	10.14	1.98	- 0.02
Lock	2.0	1355	12.78	1.92	- 0.08

4. Conclusions

Nowadays, industrial radiography is actually not only used to radiograph industrial specimens. It is also widely used to inspect ancient objects and other large specimens like concrete structures and large animals. The latter is due to too low energy medical x-rays. Radiographers often have difficulty in determining appropriate exposures due to lack of appropriate calibration and specimen information The in-house developed gamma-ray counting device combining with a smartphone and Bluetooth technology was successfully tested in this work. It can facilitates the experiment is more convenient and safer. The calibration chart for the gamma-ray radiography using film with Ir-192 source was successfully created by the development method. The new technique based on measurement of transmitted gamma-ray intensity accompany with the calibration method could provide the appropriate exposure time with an expected optical density. Therefore, the method can help the radiographer to reduce time and cost loss from the trial and error of unknown specimen.

Acknowledgments

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