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Performance Qualifications for the Beam in a 10 MeV Electron Accelerator

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Abstract - The Advanced Radiation Technology Institute (ARTI) introduced an electron beam accelerator capable of continuous radiation processing in 2018. The instrument can be used for empirical research to industrialize already developed radiation technologies. Radiation processing has minimum absorbed dose requirements and maximum absorbed dose limits. It is important for radiation accelerators to maintain constant values for the device's operating parameters to meet the absorbed dose required by the product (AAPM 1998). Therefore, an inspection (Performance Qualification) of the accelerator performance is required, and the operation values of all processes need to be set so that the absorption dose requirements can be met (ISO/ASTM International 2015). To maintain dose requirements during the process, the processing variables need to be controlled: electronic energy, beam current, and parameters according to material handling (transfer vehicle speed or survey time), beam width, and characteristics of the processing process and conditions of investigation (Chilkulwar 2012). In this study, the performance test of the electron-ray accelerators presented by the international standards of ISO/ASTM was carried out. Assessments include Electron Beam Energy, Average Beam Current, Beam Size (Beam Spot Size), Spoken Size and Homogeneity (Scan Size and Uniformity of Unit), and Moving Dose Assessment (Uniformity). This allowed individual measurements to be obtained within the allowable range for each item specified in ISO/ASTM 51649. Periodic inspection procedures will need to be established to maintain a constant dose for the devices (Zofia and Slawomir 2008) .

Key words : Performance qualifications, Dosimetry, E-beam, Accelerator, CTA film, B3, Dose distribution

INTRODUCTION

Since the radiation generator was developed by Roentgen in 1895, its use has continued to increase day by day. Linear accelerators evolved significantly with RF technology developed during World War II after the initial attempts by Wideröe and Lawrence and Sloan (Wideröe 1928; Lawrence and Sloan 1931; Martins *et al*. 2014).

X-ray generators are routinely used in the medical field. Recently, electronic accelerators have been used in various ways to improve product quality (Lawrence *et al*. 1931).

The Advanced Radiation Technology Institute (ARTI) in the Korea Atomic Energy Research Institute (KERI) intends to conduct empirical research to industrialize radiation application technologies already developed at the laboratory scale. An electron beam accelerator capable of continuous radiation treatment was installed at the Advanced Radiation Research Institute in 2018. The accelerator is a 10 MeV energy electronic accelerator manufactured by Mevex of Canada with a current rating of 3 mA. The accelerator is equipped with a

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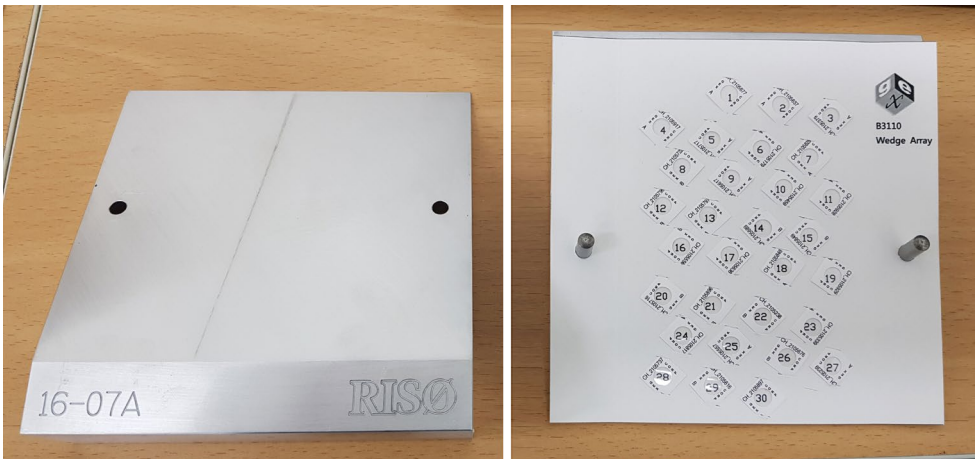

Fig. 1. RIS0 wedge (left), B3110 Dosimeter (right).

large conveyor 2 m wide and 20 m long to enable radiation treatment of large objects.

Electrons, unlike photons, have unique characteristics in their interaction with matter as particles. The electrons have mass, and energy is transferred to the material through two interactions with the material: collisions and radiation. The radiation treatment process using these electron beams has a minimum absorbed dose requirement and a maximum absorbed dose limit. It is important to keep the device operating parameter values constant so that the radiation accelerator can meet the absorbed dose required by the product (AAPM 1998; Soares 2007).

Therefore, after the accelerator installation was completed, performance qualification of the device should be performed (Meissner 1999). The process parameters obtained through this operating qualification should be set so that the absorbed dose requirements can be met (IAEA 2000; Miller *et al*. 2019).

The processing parameters that need to be controlled for the absorbed dose during radiation processing are as follows: electron energy, beam current, parameters (conveyor speed or irradiation time), beam width, process load characteristics and irradiation conditions.

MATERIALS AND METHODS

This study was conducted on a 10 Mev electron radiation accelerator installed in a building in the ARTI. The model name of the device is MB10-30, and was manufactured by Canada's MEVEX; the installation was completed in October 2018. The evaluation was carried out in accordance with the procedure described in ISO/ASTM 51649 to obtain the results of the characterization of the electron beam.

A total of eight items were evaluated: Electron Beam Energy, Average Beam Current, Beam Spot Size, Scan Size, Scan Uniformity, and Travel Uniformity, Dose-Speed Linearity Characterization, and Process Interruption for measuring the continuity of the dose due to beam downtime.

R_p and R_{50} were measured using film dosimeters (B3) provided by Riso and GEX as shown in Fig. 1 (Butson *et al*. 2003). The operating conditions of the accelerator were a PRF of 618 Hz, a beam average current of 3022 μA, and a scan speed of 4 Hz. The driving values did not change during the measurement. R_p and R_{50} values obtained using aluminum wedges were calculated using eq. 1 and eq. 2. At least three measurements of E_A were made.

$$E_p = (5.09 \times R_p) + 0.20 \quad \text{(eq. 1)}$$

$$E_A = 6.20 \times (R_{50}) \quad \text{(eq. 2)}$$

An aluminum beam stop under the accelerator window was used to obtain the average amount of current in the beam. The resistor value of the aluminum block was measured and a beam pulse signal was obtained through the oscilloscope from the beam stop to the ground through the load resistor. The amplitude of the beam pulse V_B was measured, and the peak beam current I_B (A) was calculated by substituting eq. 3.

$$I_B = \frac{V_B}{R_L} \quad \text{(eq. 3)}$$

To measure the beam spot size, CTA film was attached as

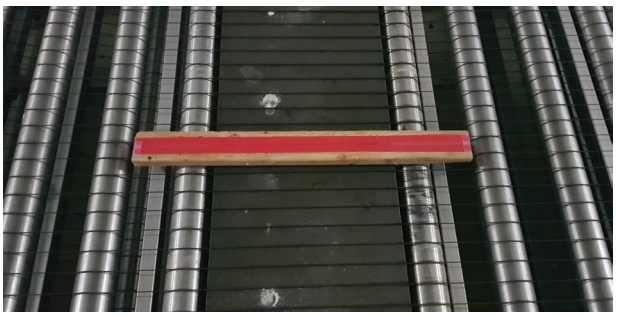

Fig. 2. A picture for the beam spot size measurement.

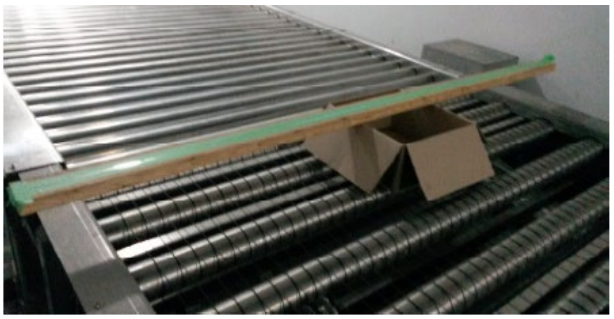

Fig. 3. Photograph of a scan quality experiment on the surface of a conveyor.

shown in Fig. 2 and 25 kGy was irradiated on the film. The beam spot size is usually defined as the width with half the value (FWHM) of the dose maximum, and the beam spot is rotationally symmetric.

The scan width of the accelerator electron beam should be at least 2300 mm for large products, as shown in Fig. 4. and typically at 2000 mm or greater on the conveyor surface, as shown in Fig. 3. The uniformity of the beam scan was tested to satisfy more than 90% of the maximum dose measured at the scan width. The measurement was repeated several times.

Dose uniformity during product movement was measured at the bottom of the accelerator window. The average dose absorbed during travel should be within a range of ±5%. In this experiment, a CTA film was used. The film was allowed to pass in a direction perpendicular to the beam (Teixeira and Caldas 2002).

For the relationship between the conveyor speed and dose below the beam, the rate of the transfer vehicle was measured in a range of 0.3 $m \cdot min^{-1}$ to 7.5 $m \cdot min^{-1}$ to derive the function between the speed and the dose. As shown in Fig. 4, the test was conducted using a 10 MeV phantom and a B3 dosimeter specified in ISO/ASTM 51261.

Sudden interruption of the accelerator beam may lead to

Fig. 4. Photograph experimenting with scan quality of large products.

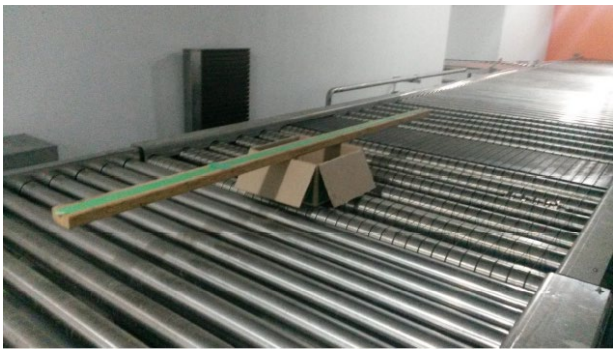

Fig. 5. Photograph to evaluate the travel uniformity of the dose during the movement of the product.

Table 1. Measurement of continuity variation of dose according to process interference

Measurement position	Conveyor surface
Measurement position	Conveyor surface
Method of interruption or parameter tripped	Beam clamp
Persist counts of parameter tripped	0.2 s
Distance of test surface from scan horn	2050

failure to meet the product's intended absorbed dose. The accelerator consists of an interlocked system between beam irradiation and conveyor movement speed, and the dose change due to the change of the conveyor speed during stop and restart was measured. In this test, the dose range was over 50 cm. The measurement surface was determined to be the one with the greatest effect of process interruption. The CTA film was attached to the product and placed at the centerline where the beam was drawn out. The emergency stop was performed

Table 2. Test equipment used in the test and each specification

Equipment type	Model number	Serial number	Calibration due date
Oscilloscope	Tektronix MDO3014	C01-0059	24 Feb 2018
DVM	Fluke 87	C02-0061	29 Jan 2017
Spectrophotometer	Aerial, Dos'ASAP	190022	N/A
Dosimeter type and batch	Fujifilm, FTR-125	4581806-L03	N/A
Wedge	RIS0 wedge	16-01A/03-03A	N/A
Spectrophotometer	Genesys 20	3SGU068007	02-Sep-2017
Dosimeters	B3 Batch CH	N/A	N/A

Fig. 6. Picture of 10 MeV calibration phantom allowing alanine dosimeters and thin-film routine dosimetry system dosimeters to be irradiated at the same position on the depth-dose curve.

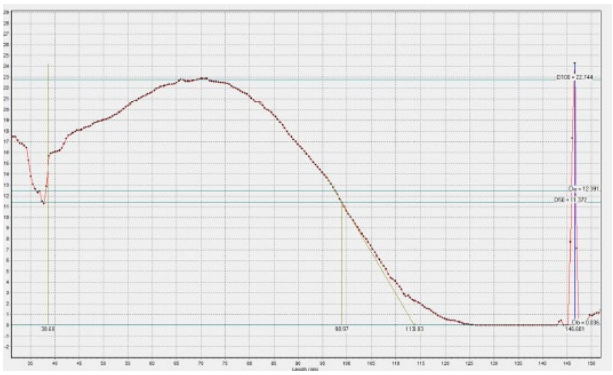

Fig. 7. Dose distribution curve by depth of aluminum wedge.

after half of the total length was determined in consideration of the conveyor speed, and then the dose was measured by restarting the accelerator again. The accelerator was operated under the conditions shown in Table 1 to see the change in dose continuity due to process interruption.

A 24-hour endurance test was performed with the accelerator running at 95% or higher. The accelerator conveyor system was also operated for 24 hours. Possible stop situations

Table 3. Experimental results of average beam current

Items	Results
Beam stop distance (mm)	50
Measured load resistor RL (Ω)	9.9
Beam pulse amplitude VB (V)	3.15
Calculate I_B eq. 5 (A)	0.318
PRF (Hz)	617.8
Beam pulse width (μs) (PW)	15.44
Calculate $\bar{I}$ (μA) eq. 4	3033

Table 4. Experimental values for obtaining beam spot size

Position	Conveyor surface	Large product surface
Distance from scan horn to dosimeter (mm)	2000	300
10 MeV Cross-plane spot dimension (mm)	340.7	44.2

and their delay times were measured. Operation variable values during operation were BEAM_CLAMP_1, BEAM_I_AVERAGE, PRF, PFN_V, KLY_PUL_I, RF_FWD, RF_REF, RF_FREQ, which were recorded. To measure all these variables, measuring instruments were used as shown in Table 2.

RESULTS AND DISCUSSION

1. Beam energy

The beam energy was measured at 10.14, 10.14 and 10.13, using the film dosimeter (Model B3000) provided by Riso and GEX. The average was calculated at 10.14 MeV. This value met the acceptance criteria of 10 MeV ± 0.5 MeV.

2. Average beam current

In this test, the distance between the beam window and the beam stop was 5 cm. The RL value obtained through the oscilloscope was 9.9 Ω, and the V_B value, the beam pulse amplitude, was measured at 3.15 V. The calculated results by

substituting these values for eq. 3 were 3,033 μA. This met the evaluation conditions.

3. Beam spot size

The beam spot size was measured on the conveyor in the direction of intersection with the 10 MeV beam. The beam spot size on the conveyor surface located 2 m from the beam window was measured at 340.7 mm and the beam spot size at the top of the product at a distance of 30 cm from the beam window was measured at 44.2 mm. Experimental conditions and results are given in Table 4.

Table 5. Experimental results on the scan size and uniformity of the beam

Measurement position	Product height	Conveyor surface
Scan current (A)	5.6	3.5
Distance from window to dosimeters (mm)	300	2050
Measured scan size (mm)	2312	2004
Note the position of the Kepco P.S. capacitor switch	6	6
Maximum dose (kGy)	35.96	38.20
Minimum dose (kGy)	32.48	34.59
Scan uniformity (%) (Min dose w.r.t. max dose)	>90%	>90%

Table 6. The results of an assessment of the travel uniformity of the dose during the movement of the product

Dosimeter position	Conveyor surface
Distance from window to dosimeters (mm)	2050
Conveyor speed ($m \cdot min^{-1}$)	0.3
Maximum dose along travel direction (kGy)	37.53
Minimum dose along travel direction (kGy)	35.91
Average dose along travel direction (kGy)	34.57
Travel uniformity (%)	+4.5/−4.7

4. Scan size and uniformity

After placing the CTA film on a flat wooden surface, the beam irradiation uniformity test was carried out on the conveyor surface. A 30 kGy dose was irradiated, and the result of the measurement was that the beam scan width was 2004 mm and the beam width at the top of the larger product was 2,312 mm. In both cases, the beam uniformity was measured at over 90%. The experimental conditions and results for the scan size and uniformity of the beam are given in Table 5.

5. Dose uniformity during product movement

The purpose of this test was to check dose uniformity on the surface of the product according to product motion while the beam was irradiating. After attaching the CTA film to the top of the product, the experiment was carried out. As a result of reading the CTA film, satisfactory results were obtained within ±5% as shown in Table 6.

6. Dose-speed linearity characterization

Tests were conducted for 0.3, 1.0, 3.0 and 5.0 $m \cdot min^{-1}$ at typical UBC speeds used in daily operation. Three measurements were taken and the average values were calculat-

Table 7. Results of dose-speed linearity characterization

UBC speed ($m \cdot min^{-1}$)	Inverse UBC speed ($min \cdot m^{-1}$)	Trials and dose (kGy)			Average dose (kGy)
		1	2	3	
0.3	3.333	38.625	36.375	37.225	37.41
1.0	1.000	10.300	10.475	10.225	10.33
3.0	0.333	3.500	3.450	3.400	3.45
5.0	0.200	2.300	2.400	2.350	2.35
7.5	0.133	No readings - Dose was below calibration curve minimum			

Table 8. Process interruption data for interruption at conveyor surface

UBC speed ($m \cdot min^{-1}$)	Trial 1		Trial 2		Average	
	% U.D.	% O.D.	% U.D.	% O.D.	Ave % U.D.	Ave % O.D.
0.3	8.5	7.5	5.9	8.1	7.2	7.8
0.6	7.0	7.3	9.4	9.3	8.2	8.3
1.0	12.7	11.7	9.3	10.5	11.0	11.1

ed. The results of the experiment are shown in Table 7. The linearity of the two variables was examined by plotting the reverse graph of the UBC average velocity and the measured dose. In addition the R^2 coefficients were calculated for the trend line in Excel. The R^2 value for this function was 0.9993.

7. Process interruption

The Process Interruption test was performed twice for each conveyor speed. After stopping the process, the conveyor was restarted without changing the position of the measuring device on the conveyor. The Maximum Over Dose (% O.D.) and the Under Dose (% U.D.) were calculated to determine the deviation from the reference dose in each test to distinguish the effects of beam irradiation interruption from other variables.

$$\% \text{ O.D.} = \frac{100 \times (\text{Max dose} - \text{Reference dose})}{\text{Reference dose}} \quad \text{(eq. 4)}$$

$$\% \text{ U.D.} = \frac{100 \times (-\text{Min dose} + \text{Reference dose})}{\text{Reference dose}} \quad \text{(eq. 5)}$$

8. Endurance test

Accelerator endurance tests were performed to determine if the instrument was able to operate normally at more than 95% over 24 hours. The results of tests indicated that, the system operated for 24 hours without interruption, so there was no device off or delay time.

CONCLUSION

Through this study, all eight of the verification items were satisfied. To ensure the stable operation of the accelerator, it is necessary to continuously evaluate the eight items. In addition, other test methods specified in ISO/ASTM 51649 need to be performed periodically. In particular, it was concluded that Dose-Speed Linearity Characterization should be conducted at least once a week to ensure that the performance of the equipment is stable. In the future, the Beam Spot Size will be measured for each height from the beam extraction window to the conveyor surface, and dose assessment according to the beam extraction direction will be performed.

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