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Research Article

EXPERIMENTAL DETERMINATION OF SOME OF SPECIAL CHARACTERISTICS FOR X-RAY MACHINE

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ABSTRACT

In this report, some of the special characteristics such as machine factor (MF), half-value layer (HVL) and homogeneity factor (HF) for the X-ray machine "RF-200EGM" *applied in industrial radiography testing were determined by the experimental measurements of exposure dose-rate using the X-ray inspective machine* "Victoreen 8000".

The research results were as follows: Determination of MF in range of high voltages from 70 kV to 200 kV and values of MF depend on high voltages and distances from the center of X-ray generating target; determination of HF in range of high voltages from 70 kV to 200 kV with using aluminum filters to measure HVL. Besides, calculation of MF for some of the diagnostic X-ray machines at the medical installations in Ho Chi Minh City was also implemented to compare them with the results of the X-ray machine "RF-200EGM".

Keywords: X-ray machine; machine factor; half-value layer; homogeneity factor; exposure dose-rate

1. Introduction

As known, X-ray machines have many advantages as follows: Their high voltages could be changed to create different X-ray energies, and they have no security risks. Therefore, in the world as well as in Vietnam, they have been widely applied in society-economy such as medicine, industry, customs, biology, etc. Depending on an aim of use (particularly, use of X-ray in medicine, namely as radiology with the aims of diagnosis and treatment), X-ray machines have been manufactured with different structures on generating tube, range of high voltage, current of generating tube, anode target, additional and inherent filters, collimator for X-ray beam, etc. When an X-ray machine is fitted up for commission with an aim of use, at the first, it should be known about structures and

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characteristics of the machine such as high voltage, current and exposure field, etc. So, other than some of the known general characteristics in catalogues of the machines, determination of some of special characteristics such as machine factor (MF), half-value layer (HVL), homogeneity factor (HF) for them has been very necessary to ensure radiation safety, quality and control (beam quality specification).

In fact in Vietnam, when an X-ray machine is imported by an institution, the machine will be verified at once by a related authority on some of its general characteristics. For example, some of the general characteristics are needed to verify to be HV (accuracy, reproducibility), accuracy for the time of X-ray generation, reproducibility and linearization of output dose, HVL of primary X-ray beam (namely as HVL_1), level of change for focal spot, etc. for medical purpose, but it is not necessary to verify the characteristics for X-ray machines for industrial purpose. On the other hand, some of the special characteristics for an X-ray machine have not still been verified such as MF, HVL of secondary X-ray beam (namely as HVL_2) and HF. The special characteristics have also been very necessary for the field of medicine related to the health of patients and machine operators because radiation doses should be kept following the rule of As Low As Reasonably Achievable signed as ALARA (Ayad, Bakazi, & Elharby, 2001). On the other hand, when having no any portable meter of radiation dose-rate, if the value of MF for an X-ray machine is known, we could determine dose-rate field (at different positions and distances) around the machine at the value of the high voltage to ensure radiation safety for machine operators as well as patients.

Therefore, the research object of this paper is to determine some of the special characteristics for an X-ray machine (such as MF, HVL, and HF) to ensure radiation safety and beam quality specification.

2. Material and method

2.1. Research subject and method

The research subject is the X-ray machine "RF-200EGM" applied in industrial radiography testing using the X-ray inspective machine "Victoreen 8000" for measuring exposure dose-rate and aluminum filters (signed as Al filters) for measuring values of HVL.

The research method is implemented for direct measurements of exposure dose-rate to determine MF and HF for the X-ray machine.

The formula for calculating MF is as (Ayad et al., 2001):

$$MF = [P.L^2]/[I.(HV)^2] \quad (1)$$

where, P (in mR/sec) is exposure dose-rate, L (in cm) is the distance from anode target to a studied point, I (in mA) is current of generating tube, and HV (in kV) is peak high voltage. Ranges of MF for X-ray machines are from 5 up to 30 (Ayad et al., 2001).

The formula for calculating HF is as (IAEA, 2007; Godfrey, Adeyemo, Sadiq, & Onoja, 2015):

$$HF = HVL_1/HVL_2 \quad (2)$$

where, HVL_1 is the first half-value layer, HVL_2 is the second half-value layer. HVL_2 is determined as:

$$HVL_2 = d_{1/4} - HVL_1 \quad (3)$$

where, $d_{1/4}$ is one-quarter half-value layer.

For heterogeneous low energy X-ray beams, $HVL_2 > HVL_1$, resulting in $HF < 1$. For monochromatic beams, $HVL_2 = HVL_1$ and HF = 1 (Godfrey, 2015; Podgorsak, 2005). The value of HF gives a certain indication about the hardening of the X-ray spectrum. Its value lies between 0 and 1 with higher values indicating a narrower spectrum. Typical values of HF for beams used in diagnostic radiology are between 0.7 and 0.9 (Ayad et al., 2001).

2.2. Experimental equipment and tools

The X-ray machine has the characteristics as follows (Rigaku, 2004): Company of Rigaku, Model of Radioflex-200EGM, Series No. TJ 42196-1, made in Japan in 2006; Generating tube by Ceramic with Beryllium window of 1 mm thickness, Al filter with a circle having 2 mm thickness and 10 cm diameter; a range of peak high voltage HV = (70–200 kV) ± 2 kV, fixed current of I = 5 mA, size of the focal spot of 2x2 mm^2. The image of the machine, including the generating tube (left side) placed at the irradiation room and panel and the control panel (right side) placed at the control room, is shown in Figure 1.

The X-ray inspective machine has the characteristics as follows (Fluke Biomedical, 2006): Company of Fluke, Model of Victoreen 8000, Series No. 106051, made in the USA in 2006; ionization chamber No. 16-47 with an active volume of 30 cm^3 (measuring range of up to 999 R/min) for measuring exposure dose; accuracy on exposure dose is ± 5%, reproducibility of ± 2% or 2 mR; measured minimum exposure dose of 1 mR. This machine is yearly calibrated at the Secondary Standard Dosimetry Laboratory (signed as SSDL) of the Institute for Nuclear Science and Technology (signed as INST) in Hanoi. The image of the machine, including the display block (left side) placed at the control room and the measuring block (right side) placed at the irradiation room, is shown in Figure 2. Besides, Al filters (square shape with a size of 10x10 cm^2) having a purity level of 99.99% and different thicknesses (0.1; 0.5, 1 and 5 mm) are used for measuring absorbed layers. The image of the Al filters is shown in Figure 3.

Fig. 1. *X-ray machine* "RF-200EGM"

Fig. 2. *Inspective machine* "Victoreen 8000"

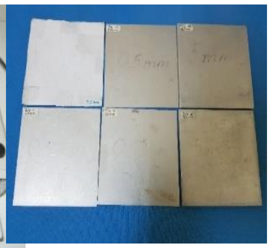

Fig. 3. *Aluminium filters*

2.3. Steps for measuring exposure dose-rate

Steps for measuring exposure dose-rates of the X-ray machine are as follows:

(1) Adjust X-ray beam of the X-ray machine parallel with the surface of the calibration table;

(2) Adjust the central axis of the X-ray beam;

(3) Determine a distance from the center of X-ray generating target (focal spot) to a point placed the ionization chamber of the inspective machine;

(4) Place the ionization chamber of the inspective machine to perpendicular to the calibration table (parallel with the X-ray beam) at the determined distance;

(5) Put exposure regime (exposure dose-rate) on the display block of the inspective machine;

(6) Put high voltage and measuring time on the display block of the X-ray machine;

(7) Place the Al filters with determined thicknesses closing to the head of the X-ray tube and perpendicular to the calibration table;

(8) Shut the lead door (separated between the irradiation room and control one) by hand;

(9) Switch on the measuring buttons on the display blocks of the X-ray machine and the inspective one;

(10) Read directly results of exposure dose-rates (in R/min) on the display block of the inspective machine.

3. Results and discussion

3.1. Experimental results

1. Determination of MF in range of high voltages from 70 kV to 160 kV (No filter: 0mmAl; measuring position: 4 distances of L = 50, 100, 150 and 200 cm; measuring time: 30 sec/time): Measured results and calculating average MF ($\overline{MF}$) depending on high voltages and distances are shown in Table 1 (SD is signed as standard deviation).

Table 1. *Average MF ($\overline{MF}$) depending on high voltages (kV)*

HV (kV)	MF ± SD				$\overline{MF}$ ± SD
	L = 50 cm	**L = 100 cm**	**L = 150 cm**	**L = 200 cm**	
70	30.977 ± 0.019	30.177 ± 0.076	29.388 ± 0.183	30.367 ± 0.298	30.23 ± 0.36
80	23.813 ± 0.017	23.865 ± 0.040	23.262 ± 0.059	24.000 ± 0.167	23.74 ± 0.18
90	19.914 ± 0.005	20.436 ± 0.045	19.583 ± 0.046	20.280 ± 0.131	20.05 ± 0.15
100	16.798 ± 0.007	17.527 ± 0.026	16.665 ± 0.052	16.987 ± 0.146	16.99 ± 0.16
110	14.325 ± 0.006	14.876 ± 0.017	14.213 ± 0.031	14.501 ± 0.088	14.48 ± 0.10
120	12.966 ± 0.006	13.565 ± 0.018	12.906 ± 0.042	13.185 ± 0.102	13.16 ± 0.11
130	11.817 ± 0.004	12.130 ± 0.016	11.552 ± 0.178	11.929 ± 0.063	11.86 ± 0.19
140	10.780 ± 0.005	10.980 ± 0.032	10.561 ± 0.031	10.612 ± 0.053	10.81 ± 0.07
150	10.135 ± 0.004	10.385 ± 0.021	9.967 ± 0.017	10.216 ± 0.065	10.18 ± 0.07
160	9.730 ± 0.003	9.948 ± 0.001	9.522 ± 0.026	9.781 ± 0.042	9.74 ± 0.05

2. Determination of MF in range of high voltages from 170 kV to 200 kV: Because the inspective machine could not measure exposure dose-rate with high voltages from 170 kV to 200 kV, it is necessary to use extrapolation as follows: From Table 1, extrapolation of MF with high voltages of 170, 180, 190 and 200 kV by drawing graphs in the type of excel with the horizontal axis being the values in column (1) and vertical axis being ones in column (6) of Table 1. So, fitting equation of MF = 10101x(kV)$^{-1.382}$ with R^2 = 0.9897 is received. From that, it is found out MF shown in Table 2.

Table 2. *Results of calculating MF depending on the high voltages (170-200 kV) by extrapolation*

HV (kV)	170	180	190	200
MF	8.35	7.72	7.16	6.67

3. Determination of HF in range of high voltages from 70 kV to 160 kV (Filters: 0, 1,…, 16 mmAl; measuring position: 4 distances of L = 50, 100, 150 and 200 cm; measuring time: 30 sec/time): Measured results and calculating HVL_1, $d_{1/4}$, HVL_2 and HF depending on high voltages at L = 50, 100 cm and L = 150, 200 cm are shown in Table 3 and 4, respectively.

Table 3. *Measured results and calculating HF depending on high voltages at L = 50, 100 cm*

HV (kV)	L = 50 cm				L = 100 cm			
	HVL_1 (mm)	**$d_{1/4}$ (mm)**	**HVL_2 (mm)**	**HF**	**HVL_1 (mm)**	**$d_{1/4}$ (mm)**	**HVL_2 (mm)**	**HF**
70	18.7	37.5	18.7	1	14.4	28.9	14.4	1
100	20.9	40.8	20.9	1	18.2	36.5	18.2	1
130	23.9	47.8	23.9	1	21.0	42.0	21.0	1
160	26.7	53.3	26.7	1	24.8	49.5	24.8	1

Table 4. *Measured results and calculating HF depending on high voltages at L = 150, 200 cm*

HV (kV)	L = 150 cm				L = 200 cm			
	HVL_1 (mm)	$d_{1/4}$ (mm)	HVL_2 (mm)	HF	HVL_1 (mm)	$d_{1/4}$ (mm)	HVL_2 (mm)	HF
70	13.9	27.7	13.9	1	8.2	16.5	8.2	1
100	16.5	33.0	16.5	1	11.0	22.0	11.0	1
130	19.2	38.5	19.2	1	13.9	27.2	13.6	1
160	23.4	44.7	23.4	1	17.3	34.6	17.3	1

4. Determination of HF in range of high voltages from 170 kV to 200 kV: Because the inspective machine could not measure exposure dose-rate with high voltages from 170 kV to 200 kV, it is necessary to use extrapolation as follows: Measuring exposure dose-rates with high voltages from 70 kV to 160 kV and with different thicknesses of the filters at L = 150 cm. From that, extrapolating exposure dose-rates with high voltages from 170 kV to 200 kV. From the extrapolation, drawing fitting graphs. From the fitting equations ($HVL_1 = 9.5549xe^{(0.0054xkV)}$ with $R^2 = 0.9859$; $d_{1/4} = 19.556xe^{(0.0051xkV)}$ with $R^2 = 0.9938$), calculating values of HVL_1, $d_{1/4}$, HVL_2 and HF depending on the high voltages, that are shown in Table 5.

Table 5. *Results of calculating HF depending on the high voltages by extrapolation*

HV (kV)	HVL_1 (mm)	$d_{1/4}$ (mm)	HVL_2 (mm)	HF
170	23.9	46.5	22.6	1.06
180	25.3	49.0	23.7	1.07
190	26.7	51.5	24.9	1.07
200	28.1	54.2	26.1	1.08

5. Calculation of MF for some of the diagnostic X-ray machines: According to the results of measuring the exposure doses (in mR) and the other parameters (such as high voltage in kV, exposure time in ms, current in mA) at the same distance of 75 cm for some of the diagnostic X-ray machines at the medical installations in Ho Chi Minh City (Tran, 2019), it could be calculated values of MF based on formula (1) that are shown in column (7) of Table 6.

Table 6. *Calculation of MF for some of the diagnostic X-ray machines at the medical installations in Ho Chi Minh City*

No.	Medical installation	kV	ms	mA	mR	MF
1	Nhi Dong Hospital 1 (Room 1)	69.93	100.30	200	261.10	15.02
2	Nhi Dong Hospital 1 (Room 2)	77.00	95.34	84	55.87	6.62
3	Sai Gon ITO Hospital	92.00	125.00	200	364.10	9.68
4	Nguyen Trai Hospital (Toshiba)	86.81	160.43	200	285.97	6.67
5	Nguyen Trai Hospital (Dell)	74.49	100.40	250	328.80	13.33
6	An Binh Hospital (Room 2)	90.03	84.80	47	51.77	8.98
7	An Binh Hospital (Room 3)	91.30	40.65	100	135.60	22.88
8	Dai Phuoc Consulting Room	69.18	298.10	100	366.20	14.35
9	Community Health Center CHAC	82.37	723.20	10	97.49	11.55
10	Traditional Medicine Hospital in Ho Chi Minh City (Room 1)	77.10	95.86	105	97.68	9.24
11	Traditional Medicine Hospital in Ho Chi Minh city (Room 2)	89.26	1000.00	80	1520	13.41
12	Hospital of Binh Tan District	120.00	123.40	100	419.90	13.67
13	Hospital of Binh Thanh District (Branch 2)	52.75	104.80	100	30.08	6.08
14	Nhi Dong Hospital 2 (Room 2)	69.21	25.09	160	32.40	9.51
15	Nhi Dong Hospital 2 (Room 3)	70.08	27.58	160	38.67	11.07
16	Nhi Dong Hospital 2 (Room 4)	58.99	7.01	71	5.71	18.46
17	Ear-Nose-Throat Hospital (Room 1)	72.62	137.00	85	101.20	9.00

3.2. Discussion

- From Table 1 and 2, it is seen that MF at a value of high voltage has the same value and does not depend on positions (distances from anode target). Therefore, MF is characteristic of an X-ray machine at a value of high voltage. Besides, MF depends on high voltages and in inverse proportion to high voltages. The values of MF are in the range of from 9 to 30 in proportion to the range of high voltages from 200 kV to 70 kV, that are in accordance with the results of other authors in the world (Ayad et al., 2001).

- From Table 3 and 4, it is seen that HF at high voltages from 70 kV to 160 kV and different distances is the same (equal to 1), which means that X-ray field is homogeneous, does not depend on high voltages and positions. From Table 5 for high voltages from 170 kV to 200 kV, it could commit a systematic error in the extrapolation (but rather little, HF $\geq$ 1). Besides, it is known that values of HVL and $d_{1/4}$ increase in proportion to high voltages and linearly decrease with distances from anode target. Therefore, for different X-ray machines (with different structures), HVL for a type of filter will be different and determining it by experiments in detail is necessary.

- Measurements of exposure dose-rate using the inspective machine were carried out with the procedure shown in (Fluke Biomedical, 2006). Besides, time for each measurement was short (30 sec), each value of exposure dose-rate was averaged at least for 5 of measuring times. Therefore, the experimental results above were shown that the measuring values had high accuracy and good reproducibility (less than 2%).
- From column (7) of Table 6, it is seen that the results of calculation of MF (range of from 6.62 to 22.88) for some of the diagnostic X-ray machines at the medical installations in Ho Chi Minh city are following those of MF measured for the X-ray machine "RF-200EGM" (range of from 6.67 to 30.23) as well as for X-ray machines (range of from 6 to 30) shown in (Ayad et al., 2001).

4. Conclusion

- This is an important result of the experiment for the determination of some of the special characteristics for X-ray machines in Vietnam, namely "RF-200EGM".
- The research results are basic to determine the special characteristics of types of other X-ray machines (having different structures and characteristics) to ensure radiation safety and quality applied in industry, customs, biology, and agriculture, especially in medicine, which is a field related to the health of the human (from the information of HF, it could be calculated dose with more accuracy for patients).

❖ ***Conflict of Interest:*** *Authors have no conflict of interest to declare.*

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XÁC ĐỊNH THỰC NGHIỆM MỘT SỐ ĐẶC TRƯNG RIÊNG CỦA MÁY TIA-X

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TÓM TẮT

Trong báo cáo này, một số đặc trưng riêng như hệ số máy (MF), lớp hấp thụ một nửa (HVL), hệ số đồng nhất (HF) của máy tia-X "RF-200EGM" *ứng dụng trong chụp ảnh phóng xạ công nghiệp được xác định bằng việc đo thực nghiệm suất liều chiếu dùng máy kiểm định tia-X* "Victoreen 8000".

Kết quả nghiên cứu là: *Xác định MF trong dải cao thế từ 70 kV đến 200 kV và các giá trị MF phụ thuộc vào cao thế và khoảng cách tính từ tâm bia phát tia-X; xác định HF trong dải cao thế từ 70 kV đến 200 kV sử dụng các phin lọc nhôm để đo HVL. Ngoài ra, việc tính toán MF cũng được thực hiện cho một số máy tia-X chẩn đoán tại một số cơ sở y tế ở Thành phố Hồ Chí Minh để so sánh với kết quả nghiên cứu đối với máy* "RF-200EGM".

Từ khóa: máy tia-X; hệ số máy; lớp hấp thụ một nửa; hệ số đồng nhất; suất liều chiếu