Electron Beam Output Measurement of aMedical Linear Accelerator

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Medical Physics Laboratory - I

Name: Souvik Das

Roll No: 241126007

National Institute of Science Education and Research
Jatani, Odisha, India

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Contents

1 | Objective

To measure the Electron Beam output of a Medical Linear Accelerator.

2 | Apparatus

BEAMSCAN Water Phantom System

The BEAMSCAN system (PTW, Freiburg) is a modern, fully motorized three-dimensional water phantom designed for beam data acquisition in radiotherapy. It is widely used for commissioning, quality assurance, and beam characterization of linear accelerators.

- **Purpose:** High-precision scanning of photon and electron beams for dosimetric measurements.
- **Design:** Large-volume water tank with three orthogonal motorized axes (X, Y, Z) for detector positioning.
- **Automation:** Fully computer-controlled scanning with high reproducibility and sub-millimeter positioning accuracy.
- **Detectors:** Compatible with ionization chambers, diodes, and other field detectors for depth-dose and profile measurements.
- **Applications:** Beam commissioning, reference dosimetry, treatment planning system (TPS) data input, and periodic QA of radiotherapy machines.
- **Advantages:** High mechanical stability, waterproof detector holders, automated setup, and integration with dedicated software for data analysis.

3 | Theory

4 | Observation

5 | Observation in Acharya Harihar Post Graduate Institute of Cancer

5.1 | Tabulation for 6MeV electron

Bias Voltage	M_{Q1}	M_{Q2}	M_{Q3}	Average (M_{Qunc})
+300 V	1.831 nC	1.834 nC	1.836 nC	1.8336 nC
+150 V	1.821 nC	1.824 nC	1.829 nC	1.8246 nC
-300 V	-1.847 nC	-1.851 nC	-1.853 nC	-1.8503 nC

Table 5.1: Tabulation for 6 MeV

Correction for Temperature, Pressure, and Humidity

$$k_{T,P} = \left(\frac{273.15 + T}{273.15 + T_0}\right)\left(\frac{P_0}{P}\right) \tag{5.1}$$

where $T = 21.2^o$C, $T_0 = 20^o$C, $P_o = 101.3$ kPa and $P = 100.3$ kPa.
So, After putting in the value, $\boxed{k_{TP} = 1.014}$.

Correction for Ion Recombination/ Saturation:

$$k_s = a_0 + a_1 \left(\frac{M_1}{M_2}\right) + a_3 \left(\frac{M_1}{M_2}\right)^2 \tag{5.2}$$

where $a_0 = 2.79977$, $a_1 = -4.50337$, $a_2 = 2.70513$ for a voltage ratio of 2, and the values for M_1 and M_2 are the averages of the meter readings for +300 volts and +150 volts, respectively. So, $M_1 = 1.8336$ and $M_2 = 1.8246$.
After calculating , $\boxed{k_s = 1.00606}$.

Polarity Correction:

$$K_{pol} = \frac{|M_+| + |M_-|}{2|M|} \tag{5.3}$$

Putting the values $|M_+| = |M|$ and $|M_-|$ the K_{Pol} calculation, we get $\boxed{K_{Pol} = 1.005}$.

Corrected meter reading:

$$\begin{aligned} M_Q &= M' \times k_{pol} \times k_{sat} \times k_{TP} \\ &= 1.8336 \times 1.005 \times 1.006 \times 1.014 \\ &= \boxed{1.8797 \text{ nC}} \end{aligned}$$

Absorbed does to water at $Z_{ref} = 1.4$ cm depth:

Given, $k_{Q,Q_0} = 0.919$ and $N_{D,w} = 5.734 \times 10^8$ Gy/C

$$\begin{aligned} D'_{w,Q} &= M_Q \times N_{D,w} \times k_{Q,Q_0} \\ &= 1.8797 \text{ nC} \times 5.734 \times 10^8 \text{ Gy/C} \times 0.919 \\ &= \boxed{0.99055 \text{ cGy}} \end{aligned}$$

Dose at the depth of dose maxima, 100 cm SSD set up:

PDD at $Z_{ref} = 1.4$ cm for a 10 cm $\times$ 10 cm field size for a 6 MeV beam is *99.166* %.
Absorbed dose rate calibration at Z_{max}

$$\begin{aligned} D_{w,Q} &= \frac{0.99055 \times 100}{99.166} \\ &= \boxed{0.9988 \text{ cGy/MU}} \end{aligned}$$

Error calculation

- Output measured: 0.9988 cGy/MU
- Standard output: 1.0000 cGy/MU

$$\begin{aligned} \text{Error } (\%) &= \left(\frac{\text{Measured} - \text{Standard}}{\text{Standard}}\right) \times 100 \\ &= \left|\frac{0.9988 - 1.0000}{1.0000}\right| \times 100 \\ &= 0.12\% \text{ (Tolerance} = 2\%) \end{aligned}$$

5.2 | Tabulation for 12 MeV electron

Bias Voltage	M_{Q1}	M_{Q2}	M_{Q3}	Average (M_{Qunc})
+300 V	1.865 nC	1.869 nC	1.870 nC	1.868 nC
+150 V	1.851 nC	1.856 nC	1.86 nC	1.8556 nC
-300 V	-1.869 nC	-1.872 nC	-1.874 nC	-1.8716 nC

Table 5.2: Tabulation for 12 MeV

Correction for Temperature, Pressure, and Humidity

$$k_{T,P} = \left(\frac{273.15+T}{273.15+T_0}\right)\left(\frac{P_0}{P}\right) \tag{5.4}$$

where $T = 21.2^oC$, $T_0 = 20^oC$, $P_o = 101.3$ kPa and $P = 100.3$ kPa.
So, After putting in the value, $\boxed{k_{TP} = 1.014}$.

Correction for Ion Recombination/ Saturation:

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_3\left(\frac{M_1}{M_2}\right)^2 \tag{5.5}$$

where $a_0 = 2.79977$, $a_1 = -4.50337$, $a_2 = 2.70513$ for a voltage ratio of 2, and the values for M_1 and M_2 are the averages of the meter readings for +300 volts and +150 volts, respectively. So, $M_1 = 1.868$ and $M_2 = 1.8556$.
After calculating , $\boxed{k_s = 1.0077}$.

Polarity Correction:

$$K_{pol} = \frac{|M_+| + |M_-|}{2|M|} \tag{5.6}$$

Putting the values $|M_+| = |M|$ and $|M_-|$ the K_{Pol} calculation, we get $\boxed{K_{Pol} = 1.001}$.

Corrected meter reading:

$$\begin{aligned} M_Q &= M' \times k_{pol} \times k_{sat} \times k_{TP} \\ &= 1.868 \times 1.001 \times 1.007 \times 1.014 \\ &= \boxed{1.9093 \text{ nC}} \end{aligned}$$

Absorbed does to water at $Z_{ref} = 2.7$ cm depth:

Given, $k_{Q,Q_0} = 0.919$ and $N_{D,w} = 5.734 \times 10^8$ Gy/C

$$\begin{aligned} D'_{w,Q} &= M_Q \times N_{D,w} \times k_{Q,Q_0} \\ &= 1.9093 \text{ nC} \times 5.734 \times 10^8 \text{ Gy/C} \times 0.919 \\ &= \boxed{1.0061 \text{ cGy}} \end{aligned}$$

Dose at the depth of dose maxima, 100 cm SSD set up:

PDD at $Z_{ref} = 2.7$ cm for a 10 cm $\times$ 10 cm field size for a 6 MeV beam is *98.963* %.
Absorbed dose rate calibration at Z_{max}

$$\begin{aligned} D_{w,Q} &= \frac{1.0061 \times 100}{98.963} \\ &= \boxed{1.0166 \text{ cGy/MU}} \end{aligned}$$

Error calculation

- Output measured: 1.0166 cGy/MU
- Standard output: 1.0000 cGy/MU

$$
\begin{aligned}
\text{Error (\%)} &= \left(\frac{\text{Measured} - \text{Standard}}{\text{Standard}}\right) \times 100 \\
&= \left|\frac{1.0166 - 1.0000}{1.0000}\right| \times 100 \\
&= 1.66\% \text{ (Tolerance} = 2\%)
\end{aligned}
$$

6 | Observation in AIIMS

6.1 | Tabulation for 6 MeV electron beam

Bias Voltage	M_{Q1}	M_{Q2}	M_{Q3}	Average (M_{Qunc})
+300 V	683 pC	682 pC	681.5 pC	682.17 pC
+150 V	680 pC	679.5 pC	680.5 pC	680 pC
-300 V	-692.5 pC	-692.5 pC	-691.5 pC	-692.17 pC

Table 6.1: Tabulation for 6 MeV

Correction for Temperature, Pressure, and Humidity

$$
k_{T,P} = \left(\frac{273.15 + T}{273.15 + T_0}\right)\left(\frac{P_0}{P}\right) \tag{6.1}
$$

where $T = 23^oC$, $T_0 = 20^oC$, $P_o = 101.3$ kPa and $P = 101.1$ kPa.
So, After putting in the value, $\boxed{k_{TP} = 1.0122}$.

Correction for Ion Recombination/ Saturation:

$$
k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_3\left(\frac{M_1}{M_2}\right)^2 \tag{6.2}
$$

where $a_0 = 2.79977$, $a_1 = -4.50337$, $a_2 = 2.70513$ for a voltage ratio of 2, and the values for M_1 and M_2 are the averages of the meter readings for +300 volts and +150 volts, respectively. So, $M_1 = 682.17$ and $M_2 = 680$.
After calculating , $\boxed{k_s = 1.0044}$.

Polarity Correction:

$$
K_{pol} = \frac{|M_+| + |M_-|}{2|M|} \tag{6.3}
$$

Putting the values $|M_+| = |M|$ and $|M_-|$ the K_{Pol} calculation, we get $\boxed{K_{Pol} = 1.0073}$.

Corrected meter reading:

$$
\begin{aligned}
M_Q &= M' \times k_{pol} \times k_{sat} \times k_{TP} \\
&= 682.17 \times 1.0073 \times 1.0044 \times 1.0122 \\
&= \boxed{698.593 \text{ pC}}
\end{aligned}
$$

Absorbed does to water at $Z_{ref} = 1.4$ cm depth:

Given, $k_{Q,Q_0} = 0.939$ and $N_{D,w} = 150.7$ cGy/nC

$$\begin{aligned} D'_{w,Q} &= M_Q \times N_{D,w} \times k_{Q,Q_0} \\ &= 698.593 \text{ pC} \times 150.7 \text{ cGy/nC} \times 0.939 \\ &= \boxed{98.856 \text{ cGy}} \end{aligned}$$

Dose at the depth of dose maxima, 100 cm SSD set up:

PDD at $Z_{ref} = 2.7$ cm for a 10 cm $\times$ 10 cm field size for a 6 MeV beam is *98.963 %*.
Absorbed dose rate calibration at Z_{max}

$$\begin{aligned} D_{w,Q} &= \frac{98.856}{98.963} \\ &= \boxed{1.0166 \text{ cGy/MU}} \end{aligned}$$

Error calculation

- Output measured: 1.0166 cGy/MU
- Standard output: 1.0000 cGy/MU

$$\begin{aligned} \text{Error } (\%) &= \left(\frac{\text{Measured} - \text{Standard}}{\text{Standard}}\right) \times 100 \\ &= \left|\frac{1.0166 - 1.0000}{1.0000}\right| \times 100 \\ &= 1.66\% \text{ (Tolerance } = 2\%) \end{aligned}$$

6.2 | Tabulation for 12 MeV electron

Bias Voltage	M_{Q1}	M_{Q2}	M_{Q3}	Average (M_{Qunc})
+300 V	718.5 pC	717.5 pC	718 pC	718 pC
+150 V	715.5 pC	715.5 pC	714 pC	715 pC
-300 V	-723.5 pC	-723 pC	-722.5 pC	-723 pC

Table 6.2: Tabulation for 12 MeV

Correction for Temperature, Pressure, and Humidity

$$k_{T,P} = \left(\frac{273.15 + T}{273.15 + T_0}\right)\left(\frac{P_0}{P}\right) \tag{6.4}$$

where $T = 23^oC$, $T_0 = 20^oC$, $P_o = 101.3$ kPa and $P = 101.1$ kPa.
So, After putting in the value, $\boxed{k_{TP} = 1.0122}$.

Correction for Ion Recombination/ Saturation:

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_3\left(\frac{M_1}{M_2}\right)^2 \tag{6.5}$$

where $a_0 = 2.79977$, $a_1 = -4.50337$, $a_2 = 2.70513$ for a voltage ratio of 2, and the values for M_1 and M_2 are the averages of the meter readings for +300 volts and +150 volts, respectively. So, $M_1 = 718$ and $M_2 = 715$.
After calculating , $\boxed{k_s = 1.00538}$.

Polarity Correction:

$$K_{pol} = \frac{|M_+| + |M_-|}{2|M|} \tag{6.6}$$

Putting the values $|M_+| = |M|$ and $|M_-|$ the K_{Pol} calculation, we get $\boxed{K_{Pol} = 1.00348}$.

Corrected meter reading:

$$\begin{aligned} M_Q &= M' \times k_{pol} \times k_{sat} \times k_{TP} \\ &= 718 \times 1.00348 \times 1.00538 \times 1.0122 \\ &= \boxed{733.212 \text{ pC}} \end{aligned}$$

Absorbed does to water at $Z_{ref} = 2.7$ cm depth:

Given, $k_{Q,Q_0} = 0.919$ and $N_{D,w} = 5.734 \times 10^8$ Gy/C

$$\begin{aligned} D'_{w,Q} &= M_Q \times N_{D,w} \times k_{Q,Q_0} \\ &= 733.212 \text{ nC} \times 5.734 \times 10^8 \text{ Gy/C} \times 0.919 \\ &= \boxed{1.0061 \text{ cGy}} \end{aligned}$$

Dose at the depth of dose maxima, 100 cm SSD set up:

PDD at $Z_{ref} = 2.7$ cm for a 10 cm $\times$ 10 cm field size for a 6 MeV beam is *98.963* %.
Absorbed dose rate calibration at Z_{max}

$$\begin{aligned} D_{w,Q} &= \frac{1.0061 \times 100}{98.963} \\ &= \boxed{1.0166 \text{ cGy/MU}} \end{aligned}$$

Error calculation

- Output measured: 1.0166 cGy/MU
- Standard output: 1.0000 cGy/MU

$$\begin{aligned} \text{Error (\%)} &= \left(\frac{\text{Measured} - \text{Standard}}{\text{Standard}}\right) \times 100 \\ &= \left|\frac{1.0166 - 1.0000}{1.0000}\right| \times 100 \\ &= 1.66\% \text{ (Tolerance} = 2\%) \end{aligned}$$

7 | Conclusion

8 | References