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ANALYTICAL FORMULISM FOR THE OUTPUT FACTOR CALCULATION OF SMALL RADIATION BEAMS

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Abstract. We present new analytical formula to calculate the output factor (OF). With the established formula we present OF for collimated radiation beams. Pinpoint ion chambers (radiation detectors) was utilized to measure the radiation output factor (OF) for different collimated beams extending from (10x10 cm^2) down to (1x1 cm^2) utilizing a medical linear accelerator (Elekta) motorized with 3D-water phantom. As a result, the OFs of multileaf collimator (MLC/Jaw) beams were accomplished and the deviation between the two values were expected due to MLC leakage which becomes more significant for the small fields. The OF for MLC/Jaw-shaped beam was deviated by 2% for field size larger than 4 cm^2 and within 39% for ultra-small field size (<1.5 cm^2).

1. EXPERIMENT

1.1. INTRODUCTION

The output factor measurements were complicated by two concerns: 1) first one was the size of the ion chamber compare to the field size, 2) the lack of charge particle equilibrium (dis-CPE) (Laub and Wong 2003, Das, Ding et al. 2008, Zhu, Ahnesjö et al. 2009, Huq, Hwang et al. 2018). The distinctive ion chamber was used with various field sizes starting from 10x10 cm^2 down to 1x1 cm^2 at 10 cm depth in the water phantom for MLC/Jaw-shaped beams.

The International Atomic Energy Agency (IAEA) Technical Reports Series (TRS) no.483 provides extensive data for the small field dosimetry using a different kind of ion chambers and detectors (Palmans, Andreo et al. 2018). Several

studies had been discussed the small field dosimetry (Das, Ding et al. 2008, Zhu, Ahnesjö et al. 2009, Huq, Hwang et al. 2018), using different size detectors under charge particle dis-equilibrium conditions to provide the same conclusion; the smaller the detector the better (more accurate) the output factor readings are. But none of the previous studies were concerned to find an analytical formula to calculate the output factor for the small radiation beams.

Our recent study aims to find the analytical formula to calculate the output factor (OF) for multileaf collimator (MLC)-shaped small radiation beams under charge particle dis-equilibrium condition for Elekta (Synergy platform) medical linear accelerators.

1.2. METHODOLOGY

The Water phantom was placed in such way that the surface to source distance (SSD) was 100 cm from the radiation source (medical linear accelerator). The ion chamber is set up within the phantom such that its axis should always be parallel to the beam central axis (CAX), and the center of the ionization chamber assumed to be located at the depth of 10 cm (d=10 cm). This depth was kept constant while changing the field size of the photon beam for each measurement. Readings for the OF were taken for field sizes 10x10 cm^2 down to 1x1 cm^2 for both collimators shapes, the MLC-shaped fields with constant jaw-opening of 10x10 cm^2 and Jaw-shaped fields only. Readings were normalized to the reference field size of 10x10 cm^2.

1.3. RESULTS

The MLC device suffers from leakage radiation between the "leaves". So, it is expected that this extra leakage dose will affect the output factor readings as compared with the Jaw-shaped fields. Table 1 and Figure 1 show the OF readings as taken for 6 MV photon energy using Pinpoint ion chamber,

Table 1: Output factors with for 6MV beam, measured with Pinpoint ion chamber at depth of 10 cm of SSD 100 cm.

Pinpoint			
Field Size(cm^2)	**6MV (Jaws)**	**6MV (MLC)**	**%Diff**
1x1	0.599	0.832	38.955
2x2	0.835	0.868	3.88
4x4	0.917	0.917	0
6x6	0.947	0.947	0
8x8	0.98	0.98	0
10x10	1	1	0

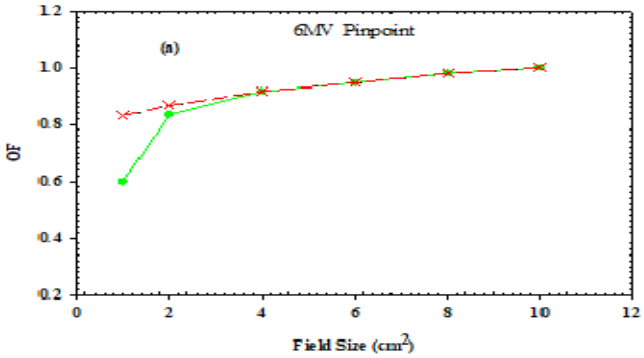

Figure 1: The Output Factor (OF) versus field size (cm^2) for MLC/Jaw beams, 6MV beam energy using Pinpoint ion chamber. MLC (Red Cross-Red dash line), Jaw (Green Circle-Green Sold line).

According to Tables 1 and Figure 1, the OFs at the large fields (>4 cm^2) for both MLC and Jaw-shaped collimator data are similar with less than 2% due to the presence of charge particle equilibrium (CPE) at the point of measurement (Hrbacek, Lang et al. 2011). The field sizes being too large that the leakage through the MLC is far away from the point of measurement and the output factor readings were not affected.

1.4. ANALYTICAL FORMULA OF OUTPUT FACTOR

For analytical formula, all OFs were calculated based on OFs that measured utilizing the distinctive ion chamber through 3D-water phantom according to equation 1.

$$\Omega_{f_{clin}Q_{msr}}^{f_{clin},f_{msr}} = \frac{D_{W,Q_{clin}}^{f_{clin}}}{D_{W,Q_{msr}}^{f_{msr}}} \qquad (1)$$

where $D_{W,Q_{clin}}^{f_{clin}}$ and $D_{W,Q_{msr}}^{f_{msr}}$ are the absorbed dose to water in the clinical field f_{clin} with beam quality Q_{clin} and absorbed dose to water in the machine specific reference field f_{msr} with beam quality Q_{msr}, respectively (Zhu, Ahnesjö et al. 2009, Huq, Hwang et al. 2018). Curves in figure 1 was fitted employing least-square fit "ideal" straight line for the large field sizes that could be represented by equation 2.

$$(OF|_{Energy} = a_0 + a_1 * Field\ size\ )_{ion\ chamber} \qquad (2)$$

where a_0 and a_1 are fitting parameters, energy-dependent and ion chamber size independent.

1.5. EXPERIMENT VALIDIAION

Analytical Formula for the output factor was validated and compared with measured data for both MLC and Jaw-shaped beams (see table 2).

Table 2: The Analytical Formula Readings vs Measured Readings for 6MV beam, measured with Pinpoint ion chamber at depth of 10 cm of SSD 100 cm.

Pinpoint					
Field size (cm^2)	**Measured OF MLC**	**Measured OF Jaws**	**Analytical**	**diff (MLC)**	**diff (Jaws)**
10	1	1	1	0	0
8	0.98	0.98	0.98	0	0
6	0.947	0.947	0.947	0	0
4	0.917	0.917	0.917	0	0
2	0.868	0.835	0.891	0.023	0.056
1	0.832	0.599	0.862	0.03	0.263

Table 2 show the "Analytical Formula Values" for the ideal straight lines based on the equation (2), the last two columns show the difference between linear value and the MLC/Jaw values. The deviation of the straight line indicates the amount of charge particle equilibrium losses. The OFs of the small filed size less than 1x1 cm^2 for the pinpoint ion chamber is deviated by 3.6% and 43.9% from analytical formula for MLC and Jaw-shaped beams respectively.

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