ELECTRON BEAM SCANNING SYSTEM

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Abstract

The equipment for accelerated electron beam shaping in irradiation technology process is very important part of irradiation facility. This equipment determines permissible transverse and longitudinal sizes of irradiated object and dose distribution in irradiation field. The fan beam scanning system is widely and successfully used for commercial irradiation. But the use of this system has some limitations. The belt beam scanning system allows to increase the electron beam use efficiency and to shape arbitrary (for example, uniform) dose distribution. This system is especially useful for the high irradiation depth. The crossing beam scanning system allows to increase the dose penetration without electron beam energy increasing. This system is especially useful for the irradiation of object, if its depth is more or equal to its transverse size.

1 INTRODUCTION

The continuous extension of field of electron linear accelerators use in technological processes results in necessity of refinement of electron beam scanning systems for providing of needed dose distribution in the irradiation field. The fan beam scanning system (FBSS) with saw-toothed magnetic induction depending on time is the most used system now [1]. This system is widely and successfully used for commercial irradiation of various objects, for example, for industrial radiating sterilization of medical items and materials, such as syringes, blood transfusion packages, various electrodes, dressing and surgical packages. FBSS is effective for irradiation of thin objects, for example, various films. However, the irradiation efficiency decreases and irradiation unevenness along object depth increases, if the longitudinal sizes of object and distance to scanning magnet are comparable.

2 BELT BEAM SCANNING SYSTEM (BBSS)

2.1 Main Imperfections of FBSS

The dose penetration $\boldsymbol{D(\tau\rho)}$ inside the irradiated object depending on object depth measured at 5 MeV electron accelerator is illustrated by Fig.1 (curve 1), where ρ is density of the irradiated object, τ is its depth, $\boldsymbol{D}(0)=\boldsymbol{D}(\tau_1\rho)$.

The whole object depth $\tau\rho$ is usually chosen as $\tau\rho=\tau_1\rho$ for guaranteeing of the uniform dose penetration (see Fig.1). The electron beam use efficiency decreases, if $\tau\rho<\tau_1\rho$. Let's introduce irradiation efficiency as

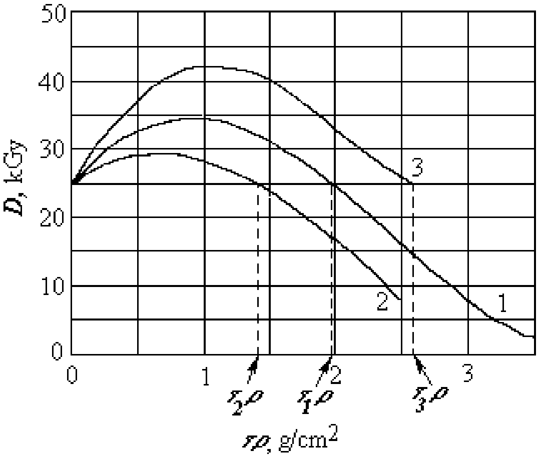

Figure: 1 The measured dose penetration inside the irradiated object.

$$\eta=\frac{\int\frac{dI}{d\varphi}\tau(\varphi)\rho d\varphi}{I\tau\rho} \tag{1}$$

where $\boldsymbol{I}$ is scanning beam current, φ is scanning parameter (scanning angle for FBSS), $\tau(\varphi)$ is the irradiated object depth in the beam direction. For example, the irradiation efficiency η=60% for the FBSS irradiation of the object with equal depth and width τ=0.3 m and the distance from scanning magnet to object surface $\boldsymbol{l}$=0.43 m. The electron beam use is ineffective at the object edges (see Fig.2).

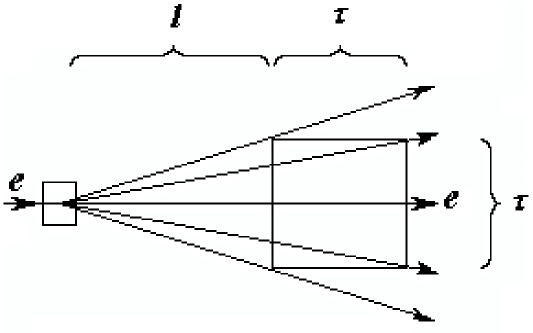

Figure: 2 Fan scanning beam irradiation scheme.

In addition the dose decreases proportionally to 1/$\boldsymbol{Z}$, where $\boldsymbol{Z}$ - distance from scanning magnet center. The FBSS dose penetration is shown in Fig.1 (curve 2) for above mentioned parameters. The value $\tau_2\rho$ ($\boldsymbol{D}(0)=\boldsymbol{D}(\tau_2\rho)$) is 30% less then $\tau_1\rho$. This is equivalent to decreasing of electron energy to $\boldsymbol{W}$=3,8 MeV.

2.2 BBSS Construction

The use of belt scanning beam (the electron trajectories are parallel to accelerator axis Z) is free of imperfections of FBSS. Really, ineffective scanning beam use at the edges of irradiated object and dose decreasing along axis Z are absent in this case. The BBSS consists of two bending magnets, as it is shown in Fig.3, where 1 is coil, 2 is core, 3 is gap, 4 is pole.

2.3 Magnet Pole Shape Calculation

Let's assume that the magnetic induction depending on time in the first and second bending magnets are $B_1(t)$ è $B_2(t)$. The flying electron meets four boundaries of magnet poles. First and fourth boundaries are rectilinear. The shape of second and third boundaries are determined by parametric functions $(X_2(t),Z_2(t))$ è $(X_3(t),Z_3(t))$ in coordinates (X,Z). Mentioned parameters are bound up with each other by following equations:

$$
\begin{aligned}
&-X_2(t)B_1(t)+X_3(t)B_2(t)=X_4(t)B_2(t)\\
&-Z_2(t)B_1(t)+Z_3(t)B_2(t)=Z_4B_2(t)\\
&\left[X_3(t)-X_2(t)\right]\left[\frac{W+W_0}{ceB_1(t)}-X_2(t)\right]=\\
&=Z_2(t)\left[Z_3(t)-Z_2(t)\right]\\
&Z_2^2(t)+\left[\frac{W+W_0}{ceB_1(t)}-X_2(t)\right]^2=\left[\frac{W+W_0}{ceB_1(t)}\right]^2
\end{aligned}
\qquad (2)
$$

where c is light velocity, e is electron charge, W and W_0 are kinetic and rest energy of electron (J).

We may get needed dependence of beam deflection $X(t)$ from axis Z on time t choosing functions $(X_2(t),Z_2(t))$, $(X_3(t),Z_3(t))$, $\hat{A}_1(t)$ and $\hat{A}_2(t)$, in accordance with (2). Beam density and therefore dose rate are inversely proportional to derivative $dX(t)/dt$. In particular case, dose rate is uniform along X axis, if $X(t)$ function is linear (saw-toothed). The magnet poles boundaries coordinates used in (2) are effective values taking into account magnetic field edge effects.

Thus this system allows to shape belt scanning electron beam with arbitrary (in particular, uniform) transverse distribution of dose.

Let's consider the BBSS example with uniform dose distribution along X axis, W=5 MeV, Z_4=0.35 m, the beam width $2X_{4max}$=0.43 m, $\hat{A}_1(t)$=-$\hat{A}_2(t)$ (increases linearly (saw-toothed) from 0 to $\hat{A}_{max}$=0,15 Ò). The calculated profiled boundaries of magnet poles are shown in Fig.4.

The rectangular magnet poles are shown by dotted line in Fig.4 [2]. These poles allow to get the belt beam with the same values $2X_{4max}$, $\hat{A}_1(t)$, $\hat{A}_2(t)$ and Z_4. The dose distributions D for profiled and D_{11} for rectangular magnet poles are represented in Fig.4. The dose distribution D for

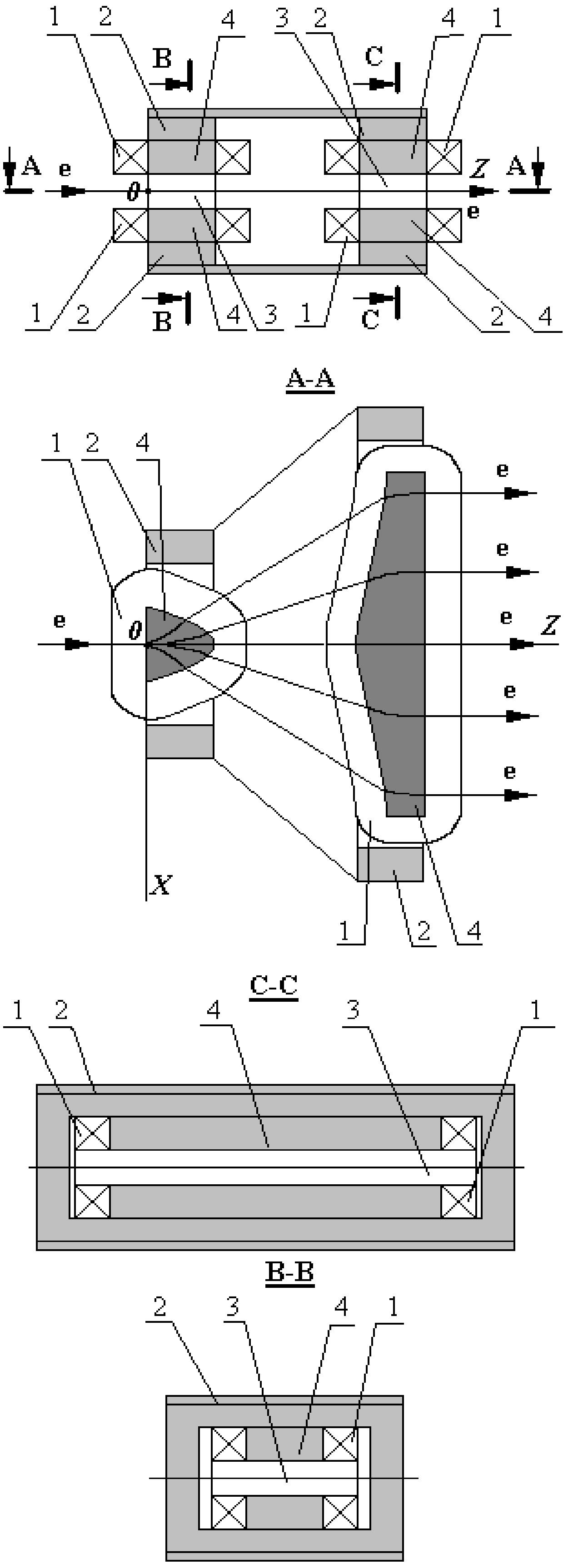

Figure: 3 Belt Beam Scanning System.

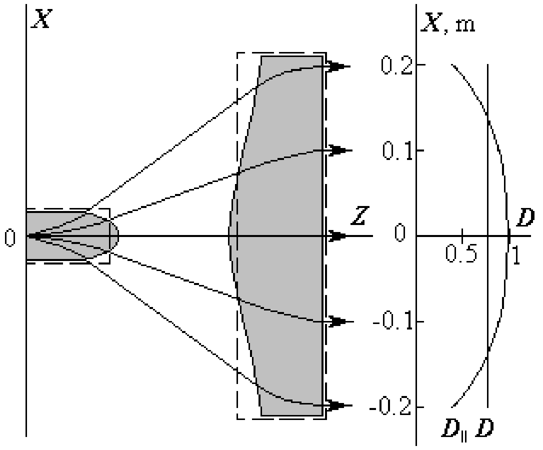

Figure: 4 The shapes of profiled and rectangular magnet poles and corresponding dose distributions $\boldsymbol{D}$ and $\boldsymbol{D}_{11}$.

profiled poles is uniform, but the dose $\boldsymbol{D}_{11}$ decreases to 35% of axis value at the rectangular magnet poles edges.The equations (2) allow also to calculate functions $\hat{A}_1(t)$ and $\hat{A}_2(t)$ for rectangular magnet poles and uniform dose distribution.

3 HIGH DOSE PENETRATION SCANNING SYSTEM

It is possible to increase dose penetration without increasing of electron energy using crossing beam scanning system (CBSS). It is enough to add the profiled part 5 to second magnet pole of described above BBSS example, as it is shown in Fig.5.

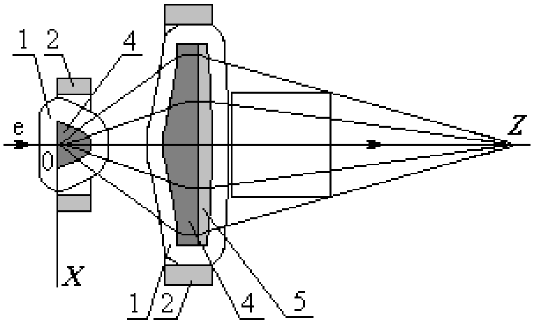

Figure: 5 Crossing beam scanning system.

The shape of additional profiled part of second magnet pole is determined by parametric functions $(X_5(t),Z_5(t))$, which may be found by equations (3), where Z_0 is the coordinate of crossover, $\alpha(t)$ is beam bending angle in the additional profiled part of pole.

The dose penetration depending on irradiation object depth $\tau\rho$ is shown in Fig.1 (curve 3) for maximum object depth 0.3 m, object width 0.3 m, Z_0=1,35 m and electron energy W=5 MeV. The dose penetration depth $\tau_3\rho$ ($D(0)=D(\tau_3\rho)$) is equivalent to dose penetration for electron energy W=7.5 MeV. The longitudinal size of additional profiled part of pole decreases from 38 mm at system axis to 31 mm at the system edges. The irradiation efficiency is η=85% in this case.

$$\begin{aligned} Z_0 &= Z_5(t) + \frac{X_5(t)}{tg\alpha(t)} \\ X_5(t) &= X_{4\,max}\frac{B(t)}{B_{max}} - \\ &- \frac{(W+W_0)(1-\cos\alpha(t))}{ceB(t)} \\ \sin\alpha(t) &= \frac{(W+W_0)(Z_5(t)-Z_4)}{ceB(t)} \end{aligned} \qquad (3)$$

4 CONCLUSION

The use of BBSS in the commercial irradiation allows to increase the electron beam use efficiency and to shape arbitrary dose distribution. The use of CBSS allows to increase the dose penetration without electron beam increasing.

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