THE DESIGN OF PERMANENT MAGNET SPREAD SYSTEM FOR 0.5 MeV IRRADIATION ACCELERATOR

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Abstract

The traditional electron beam scanning magnet has many disadvantages, for example, the regulatory of excitation current is very complex and the irradiation uniformity as well as the irradiation area is very difficult to improve and expand. Thus, the author of the paper proposes an innovative technology of a permanent magnet spread system for 0.5MeV irradiation accelerator which uses a special configuration of the magnetic field to spread electron beam bunch directly and would remarkably improve the spread uniformity, simplify the accelerator and would be helpful to protect the titanium window and expand the irradiation area. Also, the technology could as well be used on the electron beam irradiation of those irregular structured objects of large size.

INTRODUCTION

Irradiation processing has been widely applied in industries of manufacture, agriculture, bio-medicine and environmental protection because of its energy saving and environmentally friendly advantages [1, 2]. An electron irradiation accelerator, with its benefits of controllable energy, operational efficiency, no radioactive pollution source, and no energy consumption when the machine is cut off, etc, has been widely adapted in the irradiation processing industry [3, 4].

A high voltage electron accelerator mainly consists of an electron gun and an accelerator tube that is followed by a scanning magnet system, which usually uses a dipole electromagnet with a saw tooth wave energy supply [5], as shown in Fig. 1. When the electron beam passes through this system, the dipole electromagnet scans the beam in the transversal direction like the row scanning of a TV set [6].

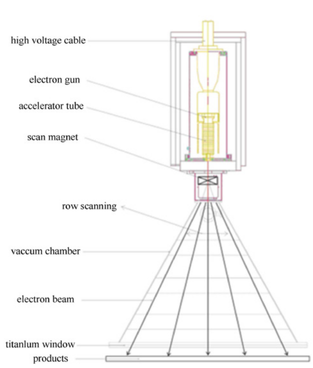

Figure 1: High voltage electron accelerator with a beam scanning device**.**

However, its shortcomings are as follows:

1. When the electron beam moves along a linear line, it tends to become overheated in some areas and burn the titanium film [7].
2. It also causes "Tail sweep" phenomenon and uneven irradiation.
3. The excessive use of electricity is liable to lead malfunction in the power system [8].
4. the speed of the conveyer belt has negative effects on the even distribution of irradiation.

The lab's invention to directly spread the electron beam with multi-pole magnetic field of specially constructed permanent magnets has perfectly addressed the inherent shortcomings of the conventional electromagnet scanning method.

THEORETICAL PRINCIPLE

Considering the relativistic effect, an electron's mass is decided by Eq. (1).

$$m = \frac{m_0}{\sqrt{1-\beta^2}} = m_0\gamma \quad (1)$$

According to the charged particle dynamics,

$$\frac{d(m\vec{V})}{dt} = e\vec{B} \times \vec{V} \quad (2)$$

Where B refers to the density of magnetic induction, e refers to the electron charge and, V refers to the electron velocity. If a Cartesian coordinate is used, Eq. (2) will be written as

$$\begin{cases} d(mv_x)/dt = qv_yB_z - qv_zB_y \\ d(mv_y)/dt = qv_zB_x - qv_xB_z \\ d(mv_z)/dt = qv_xB_y - qv_yB_x \end{cases} \quad (3)$$

In Eq. (3), the subscript refers to x, y and z components. By applying four order Ruge-Kutta's numerical integration, the equation can be solved numerically.

The deflecting distance S of electrons will be calculated by Eq. (4),

$$\begin{aligned} \vec{F} &= m\vec{a} \\ S &= \int_{t1}^{t2} a t dt \\ t &= \frac{L}{V_z} \end{aligned} \quad (4)$$

In this equation, a is the acceleration of electron, L the height of scanning box, and V the velocity along the z-axis direction. The velocity changes in a limited region, which means the distance of the electron deflection is limited in a small region. This theoretically justifies that a permanent magnet combination may satisfy the requirements of different energies. To prove the com-

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patibility of the proposed spread system, the low energy accelerators are divided into three groups (300keV/400keV, 400-600keV, 600-1000keV), which are based on 5% of different V.

NUMERICAL SIMULATION OF PERMANENT MAGNET SPREAD SYSTEM

If the energy of accelerated electron beams is to be spread is 0.5 MeV with 1 cm radius cross section, and 22.5 πmm·mrad emittance, which is the most common case for low energy electron irradiation accelerators at present. A Cartesian coordinate system is used. The Z direction refers to the mean direction of propagation of the electron beams pointing out of the paper. Both the Gaussian and uniform distributions of initial electron beam bunch are supposed in the simulation. The beam bunch is located in the center of the magnet equipment and enters the magnetic field at the very beginning. The Gaussian and uniform distributions of the electron are respectively shown in Fig.2.

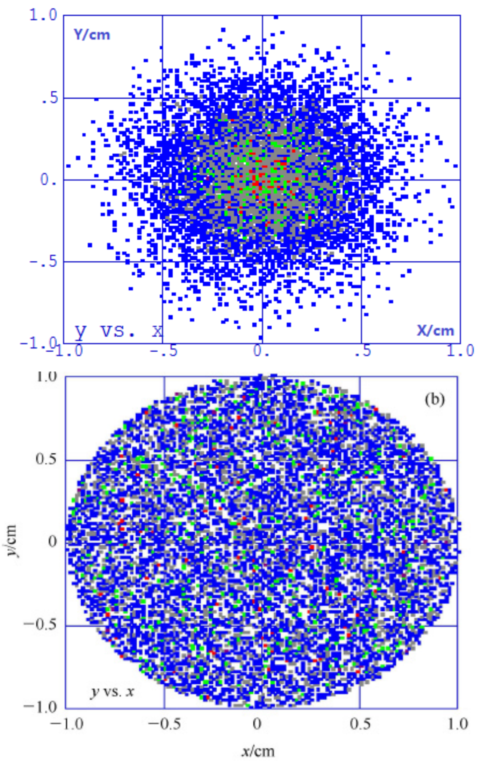
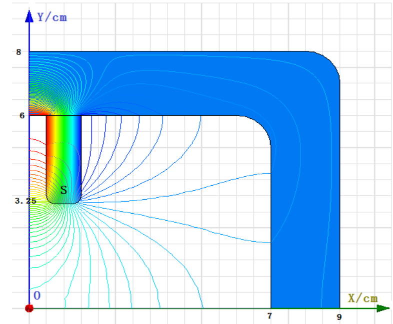


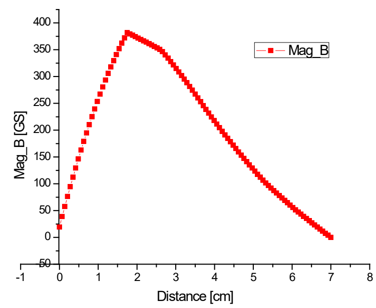
Figure 2: The electrons' Gaussian and Uniform distributions.

The Magnetic Field Analysis of Permanent Magnet Spread System

The spread system consists of 2 permanent magnets. They are 1 cm apart. The first magnet is used to spread the electron beam bunch. The second one is used to improve the distribution in four-corner areas of the bunch. The first magnet consists of 4 poles. The second magnet consists of 8 poles. DT4 pure iron is used for the magnetic yoke and rare earth permanent magnet material Nd-Fe-B for the poles, as shown in Fig.3 and Fig.4.

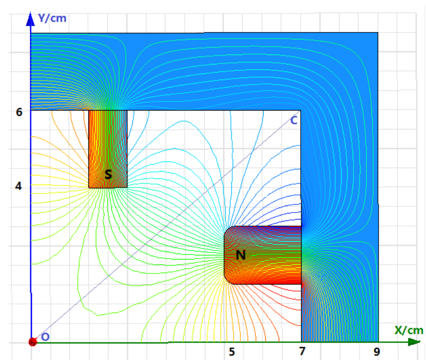


(a) The magnetic field distribution

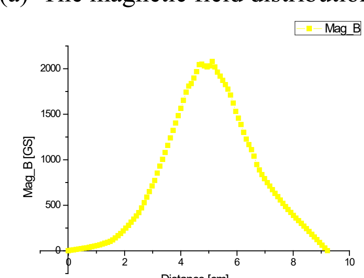


(b) The magnetic field distribution curve

Figure 3: The magnetic field of the first magnet.



(a) The magnetic field distribution



(b) The magnetic field distribution of segment EF on the second supplementary magnet.

Figure 4: The magnetic field of the second magnet.

The ideal distribution of electrons requires the poles of both the right and left side have minimized clearance. However, if the two poles were too close, the magnetic flux leakage (MFL) would increase through the magnet sides,

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thus the peak field would be reduced. According to theoretical analysis, the changes of clearance and length of the poles will cause remarkable effect on the magnetic field.

Beam Dynamics Analysis

The distribution of electrons after the electron bunch passed through two magnets is showing in Fig. 5.

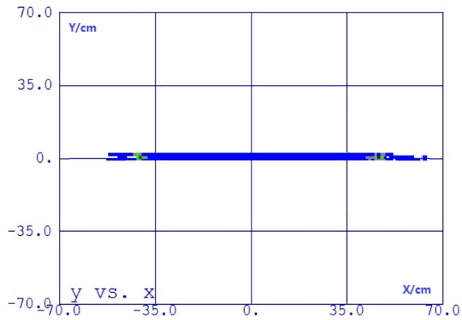

Figure 5: The beam distribution after the first and second set of magnets respectively.

The result shows that the electrons are uniformly distributed in a rectangle area with a length of 1.1m and a width of 0.2m, the lateral uniformity is ≤6.7%.

CONCLUSIONS

The proposed permanent magnet spread system remarkably improves the spread uniformity. As the spread area in the longitudinal direction could be enlarged, it might be used not only for wires, strips and panels irradiation, but also for irregular structured objects of large size.

This paper verified the excellence of the proposed system in improving the spread width and uniformity. Thus, the permanent magnet spread system is both practicable and applicable for 0.5MeV irradiation accelerators and could be used for irradiation processing.

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