ELECTRON BEAM UNIFORMITY DETECTION DEVICE FOR IRRADIATION ACCELERATOR*

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Abstract

High-voltage electron accelerator is widely used in irradiation processing industry. Beam uniformity of the accelerator has very important impact on the quality of irradiated products. Accurate measurement of beam uniformity helps to improve product quality and production efficiency. In this paper, the electron beam uniformity detection device is designed based on Faraday cup array followed by the signal shaping circuit and the digital signal processing system. Finally, the computer offers friendly interface to help users understand the operating state of the accelerator and the electron beam uniformity information. This device uses DSP technology to process the signal and optical fibre to communicate, which greatly improves noise immunity capability of the system. Through such a high precision, easy to use detection device, user can get the accelerator beam irradiation uniformity information which is very useful to direct the industry radiation process.

INTRODUCTION

Irradiation accelerator is widely used in many areas, such as irradiation processing industry [1], waste gas treatment [1], food preservation [2], and so on. To ensure the quality consistency of the products, beam uniformity of the accelerator is very important. Accurate measurement of beam uniformity helps to improve product quality and production efficiency. The measurement results can also direct the design of the irradiation accelerator.

To measure the beam uniformity is to measure the beam intensity in the scan area of the irradiation accelerator. Faraday cup is a simple and effective device to measure the beam intensity [3]. It converts the beam intensity to a current signal by collecting the charged particles of the beam. In our design, a Faraday cup array is used to measure the distribution of the electron of the beam, which reflects the beam uniformity.

A high-voltage irradiation accelerator is built in Huazhong University of Science and Technology for biological science and materials science. The structure of the accelerator is shown in Fig. 1. The scan coverage of the beam is 1 *m*. The electron beam uniformity detection device is designed to measure the beam uniformity of this accelerator. As for other irradiation accelerators, the structure of the device is similar, the only differences are the parameters of the components in the measurement circuit and the number of the Faraday cup in the Faraday cup array.

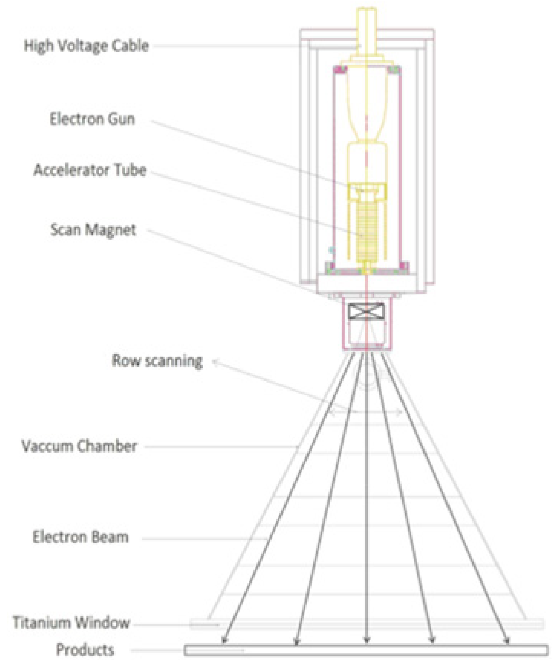

Figure 1: Structure of the high-voltage irradiation accelerator.

SYSTEM DESIGN

The structure of the system is shown in Fig. 2. It consists of four parts: Faraday cup array; measurement circuit; digital processor for optical fibre communication and digital signal processing; and the human-computer interaction interface. Firstly, the Faraday cup array collect the electrons of the beam in the scanning area. The electron current flows from the Faraday cup to the ground, which can reflect the beam density. Then the measurement circuit processes the current signal to reduce the noise and amplify the signal. In order to achieve the remote detection, while reducing EMI noise, a digital processor is used which converts a current signal into a digital signal. Digital filtering method is also used to process signals. In our design the digital filter realised using verilog HDL on the FPGA is a low pass filter. Finally, the beam signal was packaged into data frames and sent to the remote computer, and the graphical interface on a computer written by labVIEW shows the uniformity of the beam, so we can easily achieve the real-time detection of the beam uniformity.

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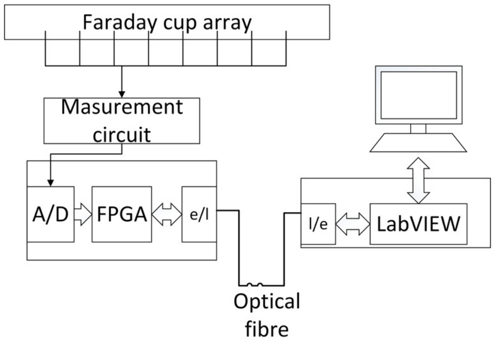

Figure 2: Structure of the system.

Faraday Cup

The Faraday cup structure is shown in Fig. 3. It consists of an inner cup for the collection of electrons and a repeller for biasing the ejected secondary electrons back into the inner cup. Since the high-energy electrons collide with the metal surface of the Faraday cup, the secondary electrons ejected from the surface. In order to reduce measurement error, repeller is used to deflect the ejected electrons. In our design, a electric repeller is used to deflect the secondary electrons. The electric fled between the repller and the inner cup make the secondary electrons reverse accelerated and collected by the inner cup again.

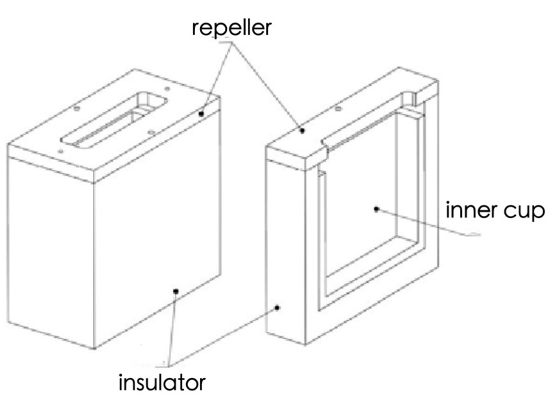

Figure 3: Structure of the Faraday cup.

Measurement Circuit

Electrons flowing from the Faraday cup to the ground will induce a current signal which can be detected. The signal measurement circuit converts the current signal into a voltage signal and amplifies the scope of the signal to the voltage stage of the A/D conversion chip. To ensure the driving capability of the signal, it's required to reduce the output impedance of the conditioning circuit. As used here, two operational amplifiers are used to complete the I/V conversion and the signal amplification. Signal measurement circuit is designed as follows. Preamp circuit converts the current signal into a voltage signal and amplifies the primary voltage. After that, a second-order Butterworth low-pass filter processes the primary amplified voltage signal. Finally, through a forward amplifying circuit, signal voltage is amplified to the dynamic range of the A/D sampling port.

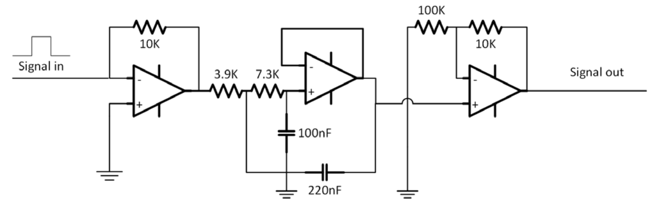

Figure 4: Measurement circuit.

Digital Filtering Algorithm

The digital filter function is implemented as a direct from II transposed structure as shown in Fig. 5. In the algorithm *n-1* is the filter order, which handles both FIR and IIR filters [4].

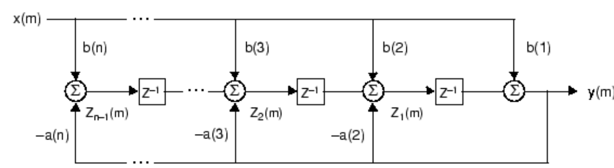

Figure 5: Block diagram of the digital filter.

The input-output description of the filtering operation in the z-transform design is a rational transfer function,

$$Y(z)=\frac{b(1)+b(2)z^{-1}+...+b(nb+1)z^{-nb}}{a(1)+a(2)z^{-1}+...+a(na+1)z^{-na}}X(z) \quad (1)$$

where *na* is the feedback filter order, and *nb* is the feedforward filter order. Due to normalization, assume a(1)=1.

The operation of the digital filter at m-th sample is given by the time domain equation which can be derived by forward difference method.

FIELD AND PARTICLE MOTION SIMULATION IN THE FARADAY CUP

To simplify the evaluation of the electric field in the Faraday cup, we establish a 2D model of the Faraday cup. According to Maxwell's equation, the electron field in the 2D model satisfies,

$$\begin{cases}\nabla\times\boldsymbol{E}=0\\ \nabla\cdot\boldsymbol{E}=0\end{cases} \quad (2)$$

The electric field E can be written as the gradient of the scalar potential φ,

$$\boldsymbol{E}=-\nabla\varphi \quad (3)$$

According to Equ.2 φ satisfies the Laplace equation

$$\nabla^2\varphi=0 \quad (4)$$

Eq. 4 can be easily solved by using FEA method. Figure 6 shows the results of the electric field.

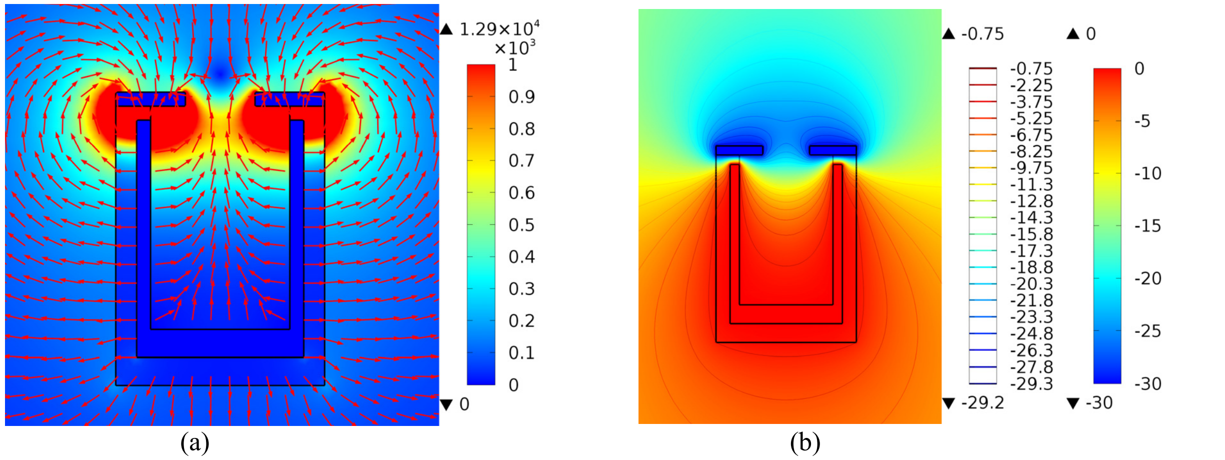

Figure 6: Electric field in the Faraday cup 2D model. (a) Pseudo-colour image and field lines of ***E***. (a) Pseudo-colour image and equipotential line of *φ*.

The trajectories of secondary electrons at the worst point are investigated. The maximum energy of the ejected secondary electrons satisfies,

$$E_{\max} = A\cos^2\theta \qquad (5)$$

Where A is the parameter related to the particle. The energy is high when the angle between the ejected electron and the normal direction of the surface is small. A random simulation of the secondary electrons is conducted as shown in Fig. 7. It shows that the ejected electrons can be captured by the inner cup.

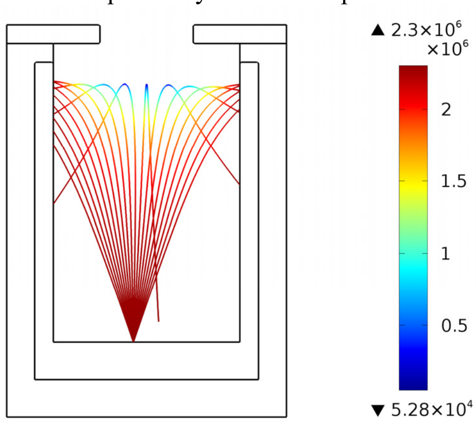

Figure 7: Simulation of the ejected electron' trajectories

RESULTS AND DISCUSSION

The non-uniformity is given as:

$$\rho 1 = \frac{N_{max} - N_{min}}{N_{max} + N_{min}} \qquad (6)$$

N_{min} is the minimum dose value, N_{max} is the maximum dose value, $N_{av} = \frac{\sum_0^n N}{n}$, the scanning length is 100cm, and the beam length is 80cm. The non-uniformity is calculated as 7.8% which is better than 10% of the GB/T25306-2010 [5].

CONCLUSION

The proposed beam uniformity detection device demonstrated an efficient, flexible and precise way to measure the uniformity of the beam uniformity, which has very important impact on the quality of irradiated products. The designed Faraday cup array can reduce the error caused by the secondary electrons when collecting the beam electrons. The mixed analog and digital circuit greatly improves noise immunity capability of the system. The graphical interface on a computer written by labVIEW offers friendly interface to help users understand the operating state of the accelerator and the electron beam uniformity information.

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