ELECTRON BEAM UNIFORMITY DETECTION DEVICE FOR IRRADIATION ACCELERATOR

LG Zhang#, Jiang Huang, Kaifeng Liu, Jun Yang, Chen Zuo

Huazhong University of Sicence and Technology, Wuhan, Hubei, China

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 waste gas treatment, food preservation, manufacturing 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.

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 figure 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.

STRUCTURE

The structure of the system is shown in figure 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.

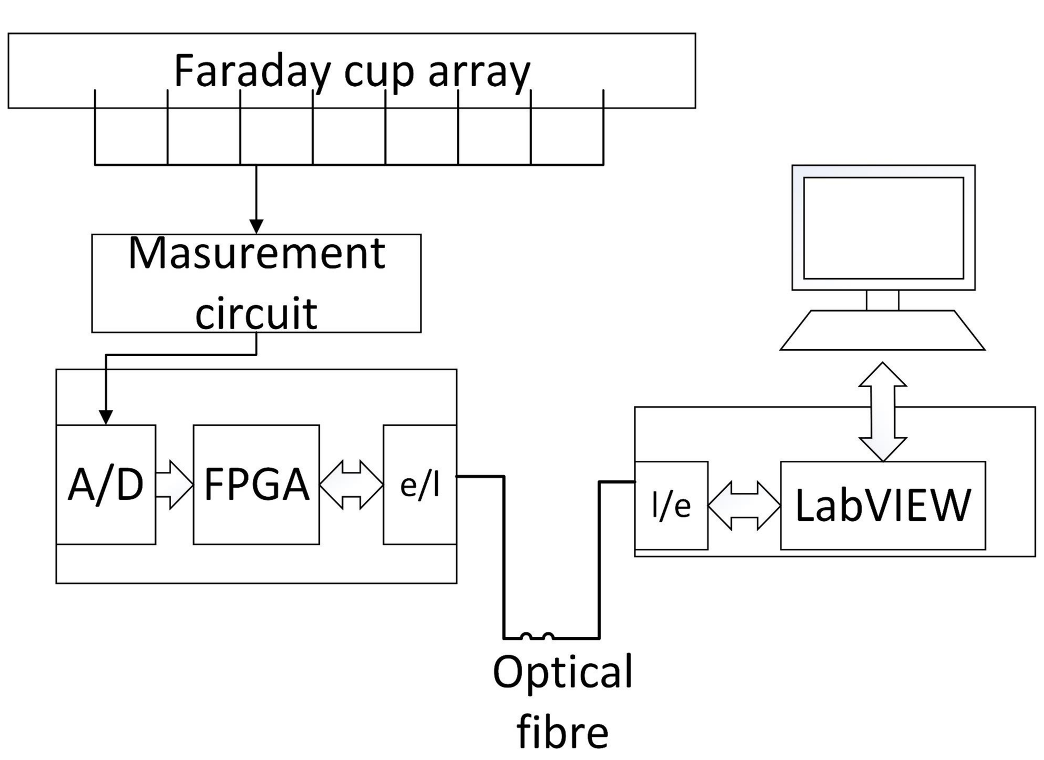


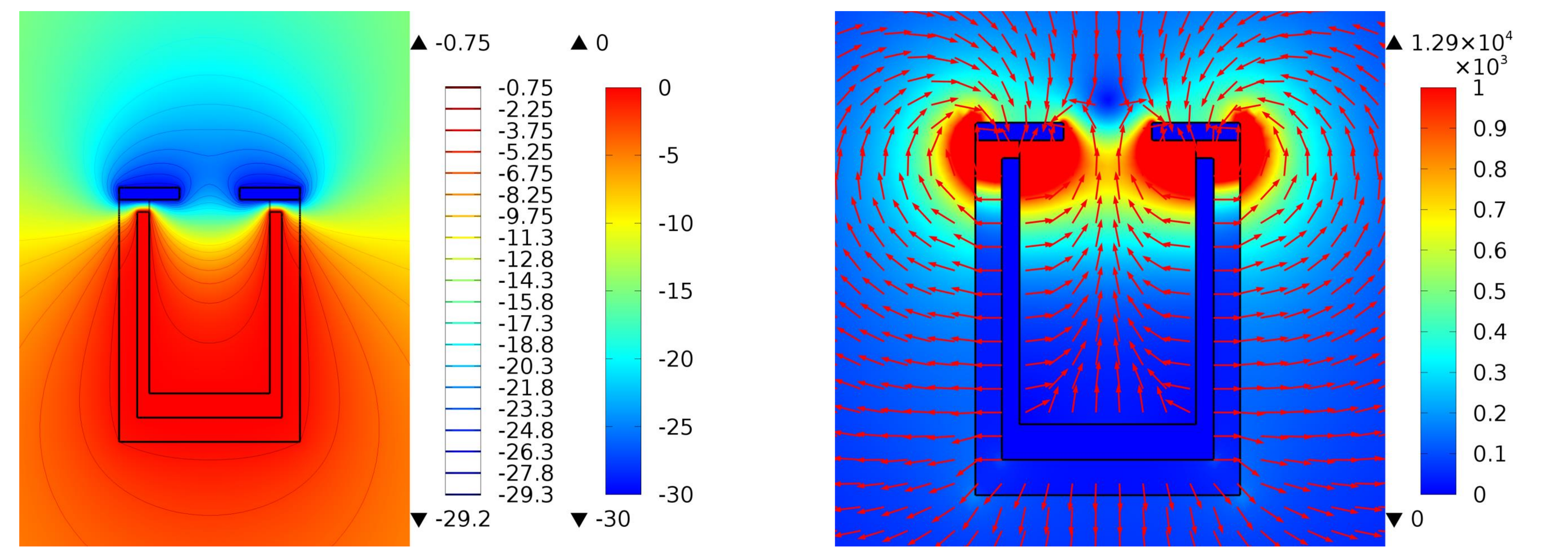
Figure 1: Structure of the system.

SIMULATION

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,

$$\begin{cases} \nabla \times \boldsymbol{E} = 0 \\ \nabla \cdot \boldsymbol{E} = 0 \end{cases} \quad (1)$$

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



(a) (b)

Figure 2: 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,

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

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 figure 7. It shows that the ejected electrons can be captured by the inner cup.

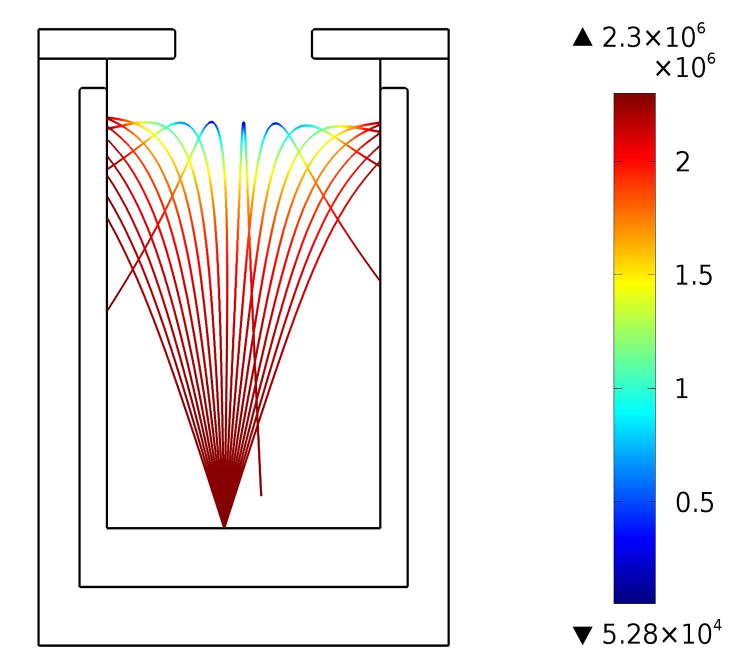


Figure 3: Simulation of the ejected electron' trajectories

RESULTS AND DISCUSSION

The non-uniformity is given as:

$$\rho 1 = \frac{N_{max} - N_{min}}{N_{max} + N_{min}} \quad (3)$$

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.

CONCLUSIONS

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.