Design and Analysis of a beam uniformity detector based on Faraday Cup Array

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Abstract

Beam uniformity of electron irradiation accelerator has a great impact results for industrial radiation process. In this paper, a beam uniformity detector, based on Faraday cup array, has been designed for a 400KV electron irradiation accelerator in Huazhong University of Science and Technology. Suitable structure has been calculated for the secondary electrons emission. Cooling system is necessary for the detector in the condition of high-intensity ion beams, and it has been designed by thermo-structural analysis. This detector now has been used for experiments successfully.

INTRODUCTION

Faraday cup is a detector designed to measure the intensity of the beam. It is a conductive metal cup hit by a beam of ions or electrons. By the electrical current in the metal, the number of charges being carried by the ions can be determined. The emission of secondary electrons should been considered. Usually a washer-type metallic lid, the repeller, is biased at a given voltage to catch the secondary electrons escaped from the metal surface. Faraday cup array is composed of multiple independent Faraday cups. Beam intensity distribution in the area can be obtained by fitting the signals of every Faraday cup. In order to detect a 400 kV accelerator beam uniformity in the longitudinal direction, a detector based on Faraday cup array has been designed in this paper.

DESIGN DESCRIPTION

As the size of the electron irradiation accelerator's titanium window is 1000mm×100mm, Faraday cup is specially designed to be square, in order to collect more electrons in the beam's longitudinal direction. The metal square cup is placed into an epoxy square cup. The repeller mounted on the epoxy cup. This beam uniformity detector is composed of a linear array of 10 Faraday cups. Every Faraday cup is mounted on a long grounded copper bar .

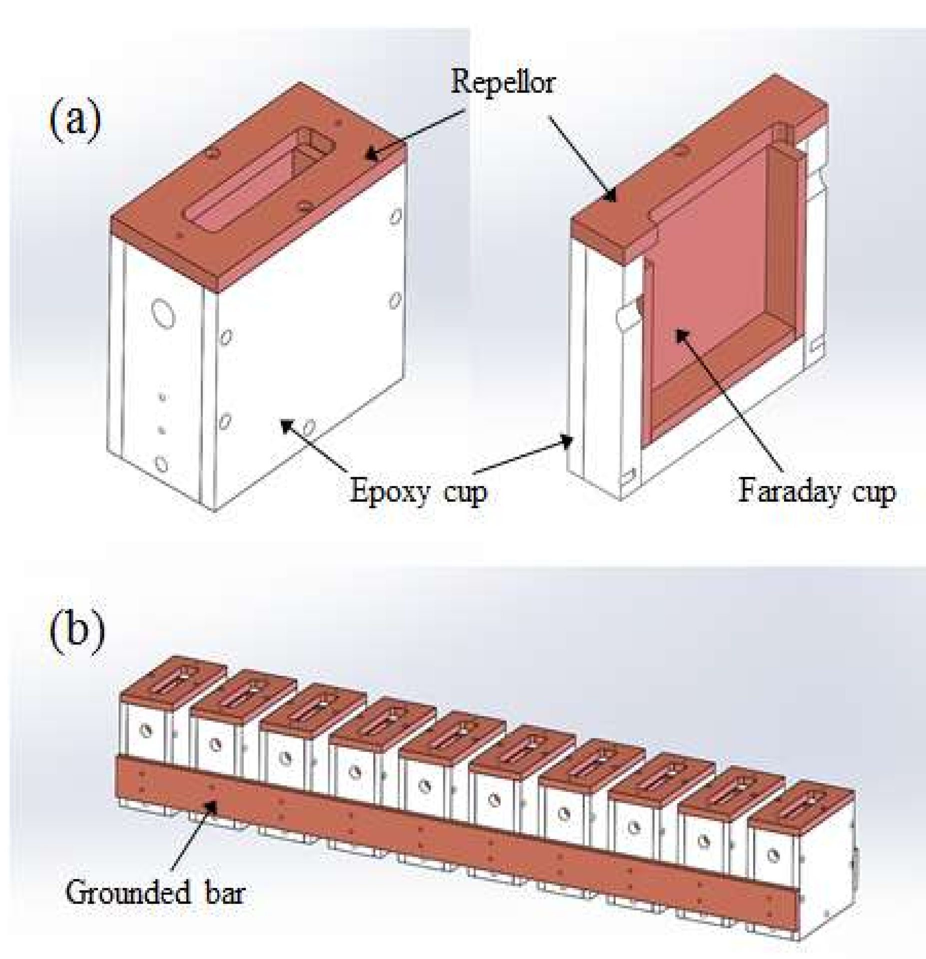

Figure 1: (a)Structure of single Faraday cup,(b) Faraday cup array

In order to stop the charged particles in the metal, the thickness of Faraday cup's bottom need to be more than the range of particles in copper. We can found out from Atomic Data that the range of electron beam is about 0.8mm, much less than the thickness of the Faraday cup's bottom.

Secondary electrons will be generated by the high power beam hitting the bottom of Faraday cup, it will result in a loss of detection value. The number of electrons emitting from the solid angle dK is in proportion to $\sin^3\theta d\theta$,where θ is the angle between secondary electrons emission line and the axis of Faraday cup. The rate of the emission electrons can be calculated by the Equation 1.

$$P = \int_0^{\frac{\pi}{2}\arctan\frac{b}{a}} 2\pi\sin^3\theta d\theta \Big/ \int_0^{\frac{\pi}{2}} 2\pi\sin^3\theta d\theta = \frac{3}{2}\int_0^{\frac{\pi}{2}\arctan\frac{b}{a}} \sin^3\theta d\theta \quad (1)$$

where a is the length of Faraday cup, and b is the radius of the bottom. When a=12.5mm, b=103mm, the rate is about 0.5%, and the influence can be ignored.

THERMO-STRUCTURAL ANALYSIS

The Faraday cup should be considered the thermal deformation. In Figure 2 the temperature distribution and the thermal deformation in the Faraday cup without cooling channels are shown. Obviously, the deformation is too high for normal operation. Water-cooling channels are necessary for both the repeller and the bottom.

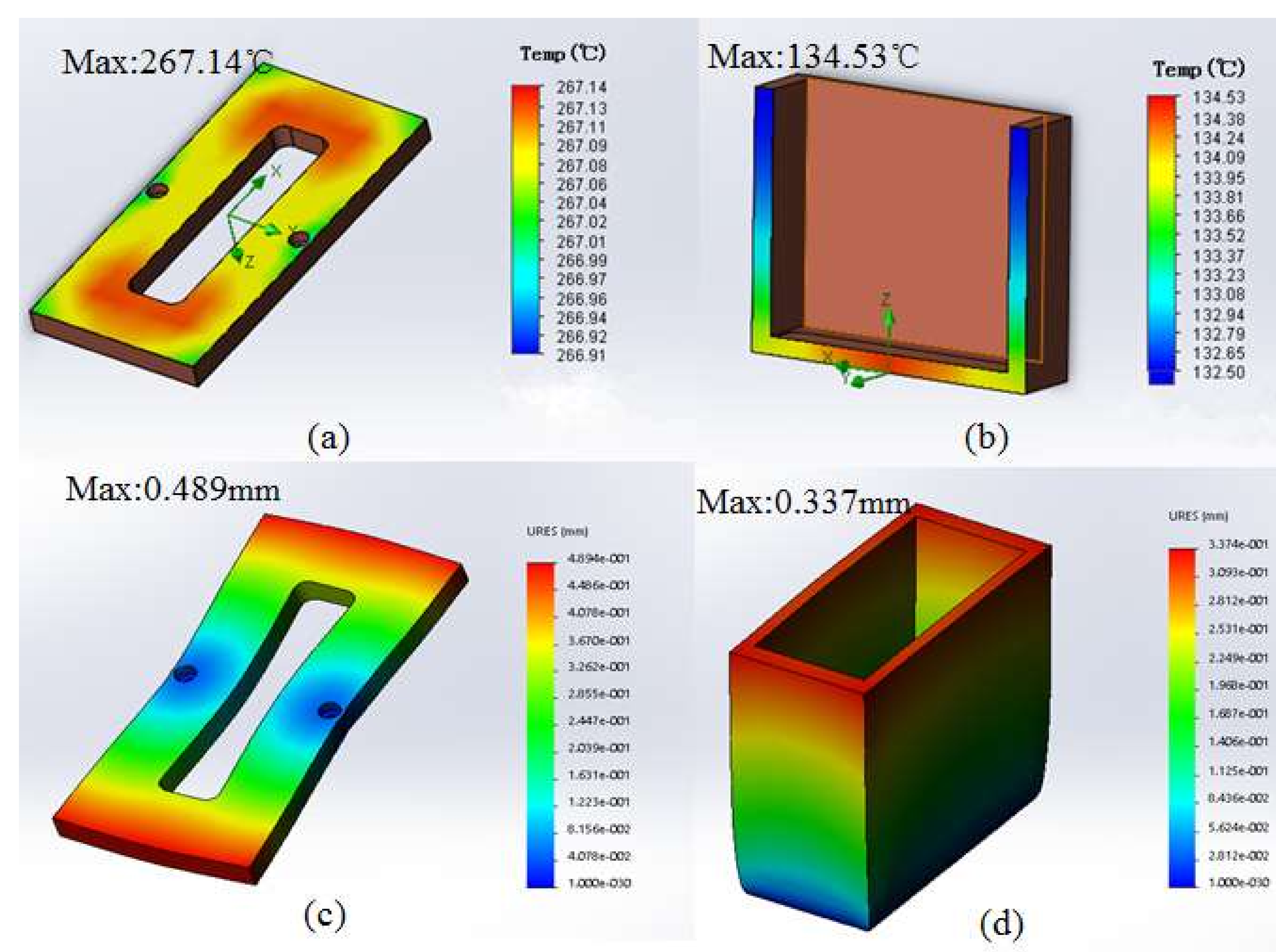

Figure 2: Temperature distribution and thermal deformation

Water-cooling circuits with ϕ3 mm inner diameter are processed separately in the repeller and the bottom. Coolant inlet temperature was always set to 20℃. Water velocity was set to 3m/s, water maximum temperature within values that do not influence electrical conductivity (<60-70℃), while stress distribution should be preliminarily kept under 107MPa.The max temperature of the repeller and the Faraday cup with water-cooling channels inside is about 22 ℃, as the influence on the thermal deformation could became negligible.

CONCLUSION

The beam uniformity detector based on Faraday cup array for electron irradiation accelerator has been designed and used successfully. The size of the Faraday cup has been confirmed, by means of numerical calculations, that was found to be the most critical component. The water-cooling channels in the repeller and the bottom were found necessary to limit the temperature and thermal deformation in the Faraday cup.