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Design and simulation of the wire scanner for the injector linac of BEPCⅡ

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Abstract BEPCⅡ, the upgrade project of Beijing Electron Positron Collider (BEPC), is an accelerator with large beam current and high luminosity, so an efficient and stable injector is required. Several beam diagnostic and monitoring instruments are used. A new diagnostic instrument — wire scanner, has been designed and will be used to measure the profile of the linac beam of BEPCⅡ. This paper describes the prototype of this system and the cause of heat generating of the wire. Some simulation results of the heat and force by using finite element method software—ANSYS®[,2] are presented and discussed.

Key words BEPCⅡ, beam profile measurement, wire scanner

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1 Introduction

The BEPCⅡ accelerator complex consists of three parts: an injector linac, beam transport lines and storage rings. The main designed parameters of the electron beam at the end of the linac of BEPCⅡ are energy 1.89 GeV, repetition rate 50 Hz and beam current 1000 mA. The BEPCⅡ is an accelerator with large beam current and high luminosity, so an efficient and stable injector is required. Beam diagnostic and monitoring instruments play an important role during the machine operation. One of those instruments is wire scanner which is employed to measure transverse beam distributions non-destructively. The linac wire scanner system is used to provide high resolution measurement of electron beam profile. In the measurement a gold plated wire with 100 micron diameter is moved across the beam transversely and gamma-ray photons, and secondary-electron, which are caused by the interaction between beam and wire, are observed by a detector[1]. This beam measuring method is based on two assumptions: i) The beam in linac is stable enough over many shots, ii) The flux of the secondary product, which currently includes scattered high energy electrons, gamma-ray photons, and secondary-electron current, is proportional to the intensity of the electron beam passing through the wire[2].

2 Mechanical designs

The design of the wire scanner prototype is shown in Fig. 1. It consists of a wire mounted on the wire card in a vacuum chamber and a body with vacuum mounting flange and bellows, a linear guide, a stepper motor and a potentiometer. The guide, stepper motor and potentiometer are placed externally from the vacuum environment.

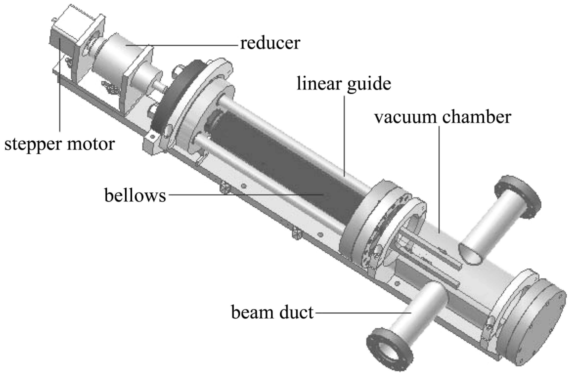

Fig. 1. Wire scanner prototype with wire chamber.

The flange, bellows, and wire card assembly are required to meet the vacuum requirements. They must resist high temperature of baking before instal-

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[2] ANSYS software is proprietary product of ANSYS, INC.

lation. The linear slide has a stroke of 125 mm. The stepper motor is selected to provide a 2.1 N·m torque, which is required to overcome the vacuum force and move the wire card into and out of the beam. A potentiometer (linearity ±0.075%) is also needed to measure the position of the wire card and installed on the body of the system.

After a long-time service, the sense wire will be usually sagging. The key to solve this problem is to mount the wire on to the inner movable wire card. A device used in LEDA wire scanner is adopted at each end of the wire, but the material we used is different from the LEDA ones, because we needn't consider the electrical isolation of the wire card. Wire clamp subassembly was designed to grasp the wire and hold it in place for making wire scan measurements. The requirements for the holding subassembly are: i) gripping and holding the wire with no slippage, and ii) to prevent the wire from sagging due to thermal expansion. A spring loaded clamp was designed to grasp the wire. Fig. 2 is an illustration of the clamp mechanism. The clamp consists of a tapered two-jawed collet, a matching tapered collar, a compression spring, and housing. The housing is made of stainless steel. The stainless steel holder is bolted to the inner movable wire card. Two mounting clamp subassemblies are used on each measuring axis to hold one wire in place. The wire is mounted into two clamps that are fastened to the inner movable wire card of the scanner assembly by first threading the wire into the collet with the spring load relaxed. The collar is slid into place on the collet in order to grip the wire. The collet-wire-collar combination is pressed lightly against the spring, and the wire is threaded into the opposite facing clamp assembly. This spring compression will determine the preload that is placed on the wire. The wire is fixed in the second clamp by repeating the same process as was used on the first clamp[3].

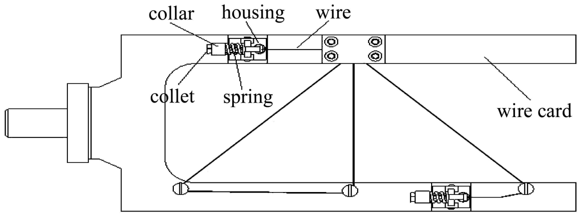

Fig. 2. Wire clamp.

3 Engineering analysis

The wire is an important part of the beam diagnostic device. The mass heat is one of the main factors that cause the wire failure, so it is necessary to check the temperature applied on the wire and confirm that the wire is available in that condition. Due to the wire moving into and out of the beam transversely, heat is generated from the interaction between wire and beam. When the electrons hit material, the energy which is deposited in material can describe by $\Delta E = E_0\ (1-\mathrm{e}^{-x/x_0})$, where E_0 is the original energy of one electron, x_0 is the radiation length and proportional to material atomic number, and x is the thickness of material[4]. For the injector linac of BEPCII, the energy of one electron is 1.89 GeV, and the wire is gold plated tungsten (x_0 is 6.76 g/cm^2 or 0.35 cm according to experience), so the energy depositing in the wire is 0.05 GeV. General assumptions for the analysis are listed: i) The scattering and bremsstrahlung energy heats the wire with a heating efficiency 100%, in fact it is less than this. We hypothesize this just to see if the wire is safe in maximum heat condition. ii) Tungsten wire diameter is 100 μm. iii) Thermal properties of tungsten are: Density (ρ) 19300 kg/m^3; Radiant emissivity (ε) 0.13; Heat capacity (c) 143 J/kg/℃; Thermal conductivity (k) 130 W/m/K.

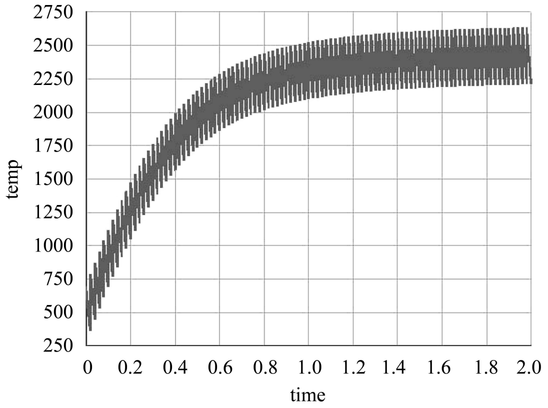

Fig. 3. The wire temperature (K) rise versus time (s).

In ANSYS we apply SOLID70 and SURF152 simulating heating process. Periodic HGEN load is applied on 2 mm length of the wire, which is the size of the gauss shaped beam. When the wire encounters the first beam pulse with 1ns pulse width, the temperature soars from 0 K to 1110 K. The wire conducts heats along the wire and radiates heat from surface before the arrival of the next beam pulse (repetition rate of 50 Hz). Because of the conduction and radiation effects, the wire temperature comes down to 370 K. So at the end of the first period, the temperature rise of the wire is about 100 K compared with that of the beginning. The simulated temperature versus time is in Fig. 3, which shows that the maximum temperature of the wire is 2700 K. Obviously, the radiation from the wire plays an essential role in temperature reduction. The radiated energy can be described using the formula below. The radiated energy Q_r scales up linearly with T^4[5].

$$Q_r \approx \varepsilon\sigma A(T_r^4 - T_o^4) = \pi\varepsilon\sigma bL(T_r^4 - T_o^4) \approx \pi\varepsilon\sigma bLT_r^4$$

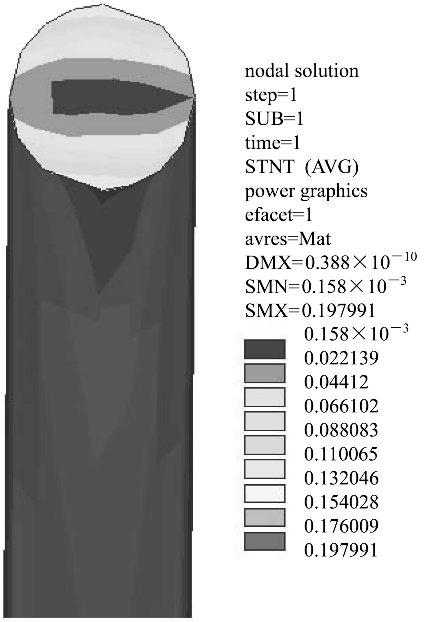

Fig. 4. The stress (N/m^2) of one section.

As the temperature of the wire becomes higher and higher, the energy lost from radiation would increase rapidly. The temperature is in balance when the energy lost by radiation just equates to that of the beam deposited in the wire. Because the peak temperature of 2700 K is less than the melting temperature of tungsten, we could choose the tungsten as the wire material.

Also a static structural force is analyzed. We know the energy will transfer from the beam to the wire due to hitting. Engineering Analysis has been done to determine the deformation and the stress of the wire. In this analysis, we apply a static force which is the momentum divided by interacting time on the wire. The results are presented in Fig. 4. The picture shows that the max stress is $0.198\ N/m^2$. Also from this simulation, the result indicates the max deformation is 0.388×10^{-10} m. The simulations of the deformation and stress indicate that the wire is safe and can meet the measuring requirements.

4 Conclusion

The simulation results show that the wire is safe for the measurement at the 1000 mA beam current with 50 Hz repetition rate. The fabrication of the wire scanner system is in progress. The system will be installed at the end of injector linac in this summer and tested with beam this fall. We thank Han Lu-Xiang for the mechanical design of the wire scanner and also thank the members of the beam instrumentation group for their useful discussion and cooperation.

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