WIRE SCANNER FOR TRANSVERSE BEAM PARAMETER MEASUREMENT IN BEPCII

Yan-feng SUI*, Jian-she CAO, Li MA

IHEP, P.O. Box 918, Beijing 100049, China.

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®, are presented and discussed.

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 1.89GeV, repetition rate 50Hz and peak beam current 500mA. The BEPCII adopts mutil-bunch and high beam current for the high luminosity, so an efficient and stable injector is required. Beam diagnostic and monitoring instruments play an important role during the machine commissioning and operation. One of those instruments is wire scanner which is employed to measure transverse beam distributions non-destructively. For the measurement, a gold plated wire with 100-micron diameter is moved across the beam transversely, the gamma-ray photons and secondary-electron, which are caused by the interaction between beam and wire, are observed by a detector[1]. This measurement method is based on two assumptions: i) The beam in linac is stable enough over many shots, ii) The flux of the secondary products, 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]. The system controller and DAQ contain a PXI chassis with a motor controller PXI-7334, a PXI chassis controller, two ADCs PXI-6250, a high voltage power source and a wire scanner actuator. Figure 1 is the schematic diagram of the wire scanner system..

MECHANICAL DESIGNS

The design of the wire scanner prototype is shown in Figure 2. 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 linear guide, stepper motor and potentiometer are placed externally from the vacuum environment.

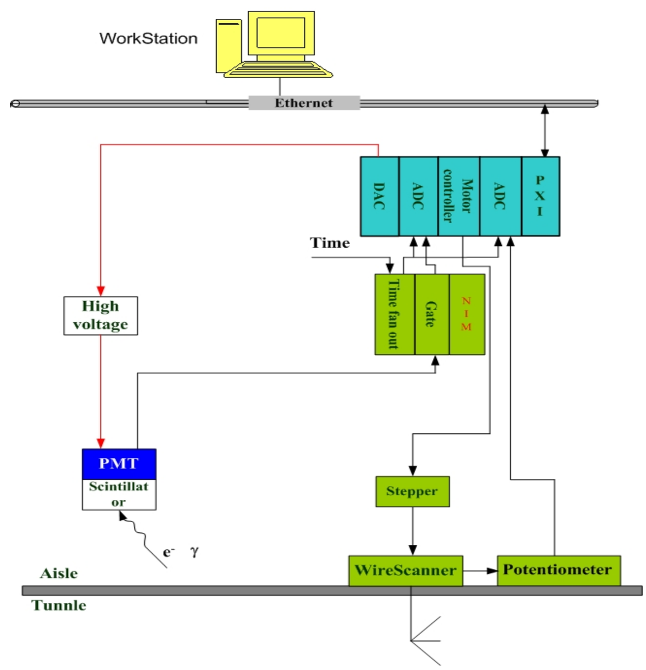

Figure 1: The schematic diagram of wire scanner system.

The flange, bellows, and wire card assembly are designed to meet the vacuum requirements.[3] They must resist high temperature of baking before installation. The linear slide has a stroke of 125mm. The stepper motor is selected to provide a 2.1N·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.

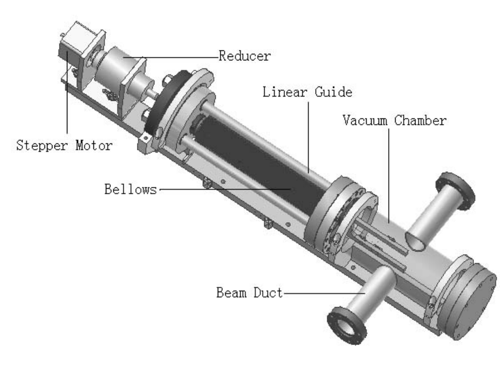

Figure 2: Wire scanner prototype with wire chamber.

syf@ihep.ac.cn

We use the potentiometer to measure the position of wire. So the accuracy of the beam size measurement is relative to the linearity of potentiometer. After the wire scanner was installed in linac, we did an experiment in order to measure the linearity of the potentiometer. Actuator was moved step-by-step in an equal-length. After each moving we measure the position of actuator and the output volt-age of the potentiometer. The plot of the measured actuator position vs. the output voltage of the potentiometer is shown in Figure 3.

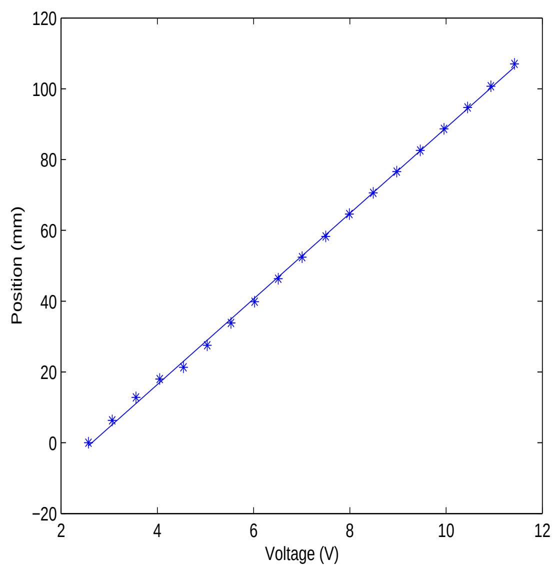

Figure 3: Position of actuator vs. voltage of potentiometer

ENGINEERING ANALYSIS

The wire is an important part of the beam diagnostic device. The mass heat is one of the main factors that causes 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 a material, the energy which is deposited into the material can be described by $\Delta E=E_0(1-e^{-x/x0})$, where E_0 is the original energy of one electron, $x_0$is the radiation length which proportional to the material atomic number, and x is the thickness of the material[4]. For the injector linac of BEPCII, the energy of one electron is 1.89GeV, and the wire is gold plated tungsten ($x_0$is 6.76g/cm^2 or 0.35cm according to experience), so the energy depositing into the wire is 0.05GeV. General assumptions for the analysis are listed here. 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 100μm. iii) Thermal properties of tungsten are: density (ρ) 19300kg/m3; radiant emissivity (ε) 0.13; heat capacity (c) 143J/kg/°C; thermal conductivity (k) 130W/m/K.

In ANSYS we apply SOLID70 and SURF152 simulating heating process. Periodic HGEN load is applied on 2mm length of the wire, which is the size of the gauss shaped beam. When the wire encounters the first beam pulse with 1ns pulse length, the temperature soars from 0k to 1110K. The wire conducts heats along the wire and radiates heat from surface before the arrival of the next beam pulse (repetition rate of 50Hz). Because of the conduction and radiation effects, the wire temperature comes down to 370K. So at the end of the first period, the temperature rise of the wire is about 100K compared with that of the beginning. The simulated temperature versus time is in Figure 4, which shows that the maximum temperature of the wire is 2700K. Obviously, the radiation from the wire plays an essential role in temperature reduction. The radiated energy Qr scales up linearly with T4 [5] and can be described using the formula below.

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

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 2700K is less than the melting temperature of tungsten, we could choose the tungsten as the wire material.

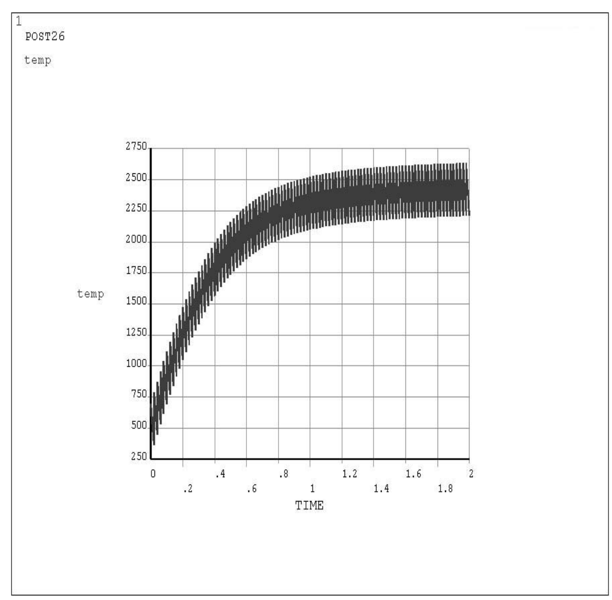

Figure 4: The wire temperature (K) rise versus time (s).

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 Figure 5 and Figure 6. The Figure 5 shows that the max stress is 0.198N/m2. Also from this simulation, the result indicates the max deformation is 0.388×10^{-10}m shown in Figure 6, which means the error from deformation of wire is so small that it can be ignored. The simulations of the deformation and stress indicate that the wire is safe and can meet the measuring requirements.

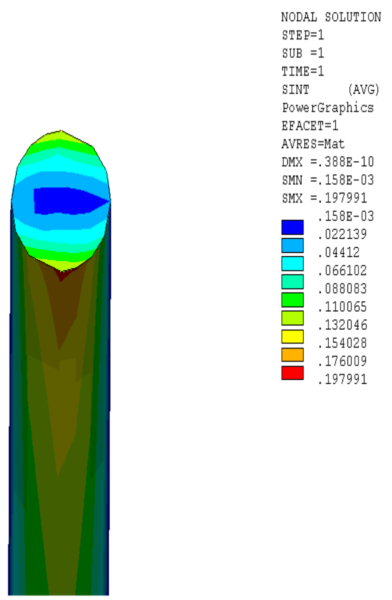

Figure 5: The stress (N/m^2) of one section.

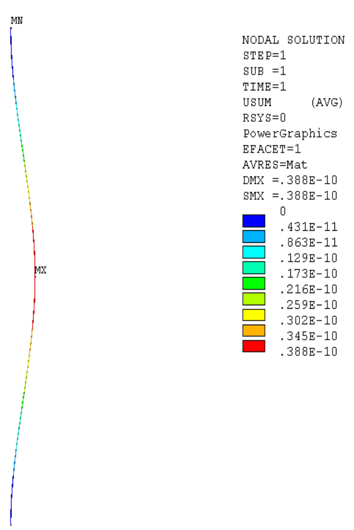

Figure 6: The deformation of wire.

CONCLUSION

The heat analysis verifies that the wire temperature rises and falls in step with the beam repetition rate, but the total temperature is rising little by little with the beam repeating. When the energy meets the balance point where the energy beam lost equates that of radiation from the wire, the temperature of this point is peak temperature. We also did static structural force simulation. The results show that the wire will deform due to the interaction with beam and also suffer stress in section, but the stress is so small that the wire is safe for the measurement at the 2-mm rms size， 500mA peak beam current with 50Hz repetition rate. Besides the error caused by wire deformation is small, so the effect to measurement can be ignored. The wire scanner system had been installed at the end of the injector linac. We have done some experiments for the past several months. Because the strong background at the end of the linac, the signal-to-noise ratio is small. The other difficulty is that nothing can be detected from the downstream of the detector when we try to use this system to measure positron beam profile. We are trying to find the reason and solve this problem. 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 fruitful discussion and cooperation.

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