DESIGN AND APPLICATION OF THE WIRE SCANNER FOR CADS PROTON BEAMS*

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Abstract

CADS Injector-I accelerator is a 10-mA 10-MeV CW proton linac, which uses a 3.2-MeV normal conducting 4-Vane RFQ and superconducting single-spoke cavities for accelerating. Seven wire scanners are designed and used to measure the beam profile of CADS Injector-I. In this paper, principal of operation, instrumentation and programming of these wire scanners are discussed. Some results of beam profile and emittance measurement with these wire scanners are also presented.

INTRODUCTION

The ADS project in China (CADS) is a strategic plan to solve the nuclear waste problem and the resource problem for nuclear power plants in China. One of the two front end injectors—injector-I of CADS has been designed and constructed by the Institute of High Energy of Physics(IHEP) [1]. 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 verify the focusing lattice, verify the functionality of the steering magnets, provide data for quad scan style emittance measurements, and helped to verify beam position diagnostics. A total of 7 wire scanners have been indigenously developed. At several critical points of the injector I linac such a set of wire scanner will be installed. In this paper principal of operation, instrumentation and programming of C-ADS wire scanners are discussed. The measured results are also presented.

WIRE SCANNER

Instrumentation

A drawing of the CADS wire scanner is shown in Fig. 1. A 100μm diameter gold plated tungsten wire is stretched simultaneously to X, Y and U directions which is 45 degree tilted from the X direction. The wires are oriented such that when the scanner insertion axis is inclined 45 degree above the beam plane, the three wires are oriented horizontally, vertically and in the 45-degree direction. In this way a single axis of motion allows the beam to be scanned in three axes. The three wires are offset from each other so that no more than one wire at a time is within the beam centre. Figure 2 shows the picture of the wire mover stage and the vacuum chamber.

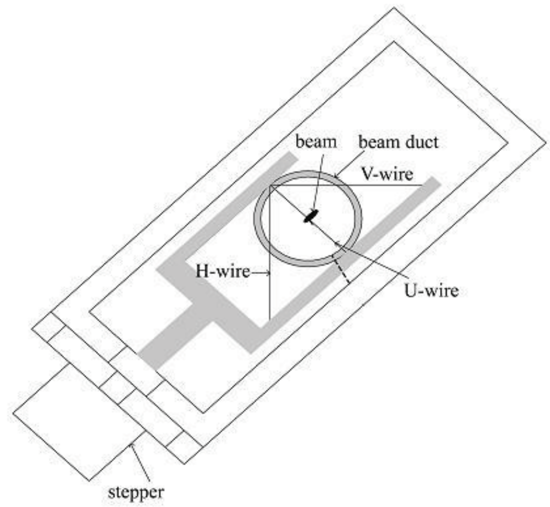

Figure 1: Schematic drawing of the wire scanner.

Figure 2: Overview system of wire scanner.

Control System

The wire scanner in CADS is controlled through PXI control system [2]. National Instrument (NI) PXI-8115 microcontroller is used for this application. The step motor is

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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 photometer is also needed to measure the position of the wire card and is installed on the body of the system. The current generated by the wire scanner is amplified by the current amplifier and led to a NI-PXI6251 A/D converter. A schematic diagram of the wire scanner is shown in Fig. 3.

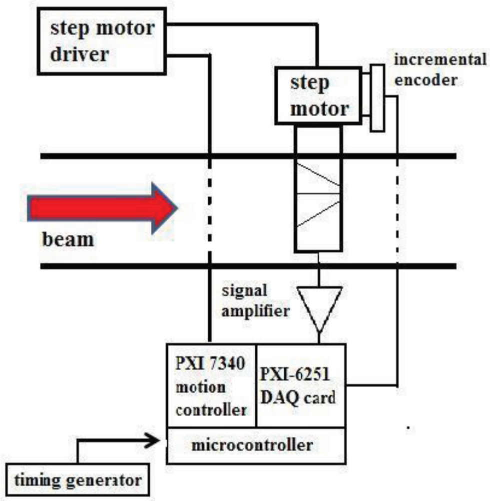

Figure 3: A schematic diagram of wire scanner.

Software Description

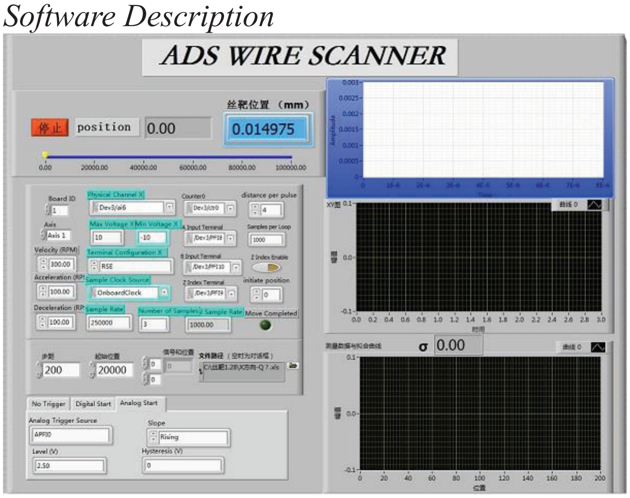

Figure 4: Graphic interface of the LabView based application for wire scanner.

To allow a complete beam scan to be done automatically, a special Labview based application was developed. Figure 4 shows a snapshot of the control screen used to set the measurement parameters and to display the data acquired by the wire scanner.

The user can specify, from the graphic screen, the initial and the final position and the displacement between subsequent measurements. The motor places the wire at the initial position and then moves it uniformly according to the chosen step. While moving, the signal and position are recorded and the acquisition is repeated until the wire comes to the final position. The scanning speed is around 30sec for one profile.

MEASURED RESULTS

MEBT-1 Layout

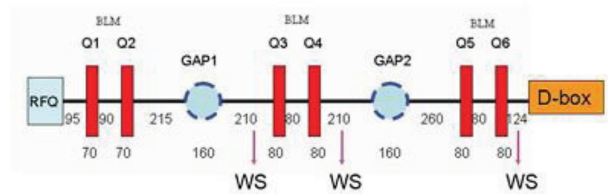

Figure 5: The layout of MEBT-1 for CADS injector-I.

We have carried out many beam profile and emittance measurements using the installed wire scanners. Here, we will show the emittance measurement of the Medium Energy Beam Transport (MEBT) Line-1.

The MEBT Line-1 of injector-I plays an important role in transporting and matching the beam from the RFQ exit to the entrance of the super-conducting Spoke-012 cavities. To quantify the beam quality and validate the design for the cryo-modules, the beam transverse emittance have been measured using a wire scanner and the quad-scan method recently [3]. The layout of MEBT-1 is shown in Fig. 5. MEBT-1 line is composed of three doublets (Q1 to Q6) and two bunchers (GAP1 and GAP2). Three wire scanners have been installed to measure the transverse beam sizes. In our measurements, we use the second wire scanner to measure the beam sizes.

Method

We consider two methods to calculate the beam sizes. First is the Gaussian with offset method. In this method, we use the function shown in Eq. 1 to fit the wire scanner data, and obtain the beam sizes.

$$I = \mathrm{B} + \mathrm{A} * \exp\frac{-(\chi-\chi_0)}{2\rho_x^2} \qquad (1)$$

In Eq. 1, I is the wire scanner intensity, B is the background offset, A is the maximum intensity of the Gaussian function, x_0 is the center of the Gaussian function, normally can be set to the position where the signal has a maximum intensity, and σ_x is the fitted beam size.

The second method is direct calculation method. We use the wire scanner data to direct calculate the root mean square beam size. The formula is shown in Eq. 2.

$$\sigma_x = \sqrt{< x^2 >} = \sqrt{\frac{\sum I_i (x_i - x_0)^2}{\sum I_i}} \qquad (2)$$

In Eq. 2, I_i is the signal intensity at position x_i.

We use typical narrow-pointed and wide-plump wire scanner signals as an example to show the difference of the two fitting methods. Figure 6 shows the different fitting results for both types of wire scanner signals. For the wide-plump signal, the two results are roughly the same. For the narrow-pointed signal, the formula calculation result is almost two times larger than Gaussian fitting results. We note that in the Gaussian fitting curves, the top of the signal is not well fitted. And because of the long tail of the signal, the formula calculated beam size is much larger.

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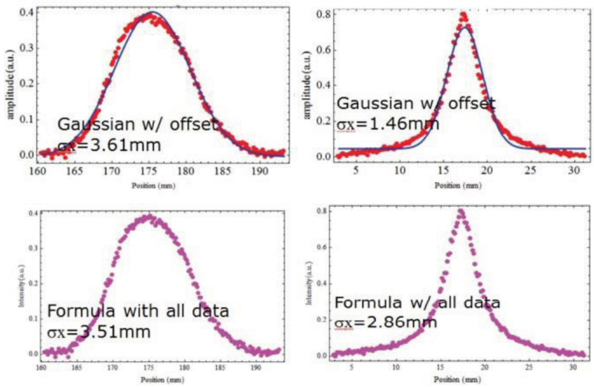

Figure 6: Fitting results for wide-plump and narrow-pointed signal with two different fitting methods.

Emittance Results

Table 1: Fitting Results of Beam Emittances at Horizontal and Vertical Planes with Two Different Fitting Methods. The unit of $\beta_{x,y}$ is m/rad, and $\varepsilon_{x,y}$ is mm mrad.

	Gaussian	Formula
α_x	-1.22	-1.07
β_x	0.113	0.10
ε_x	0.168	0.192
α_y	2.87	1.83
β_y	0.3	0.176
ε_y	0.13	0.279

The emittance difference between Gaussian fitting and formula calculation methods is ~ 20% in horizontal and ~ 115% in vertical. The difference in emittance at horizontal plane is relatively small compared to the vertical plane. This is because the wire scanner signals at vertical plane are mostly narrow-pointed distribution which have a big difference in beam sizes when using different fitting methods as described in the previous section.

From the RFQ design results, the MEBT-1 input beam parameters should be $\alpha_x = -1.31$, $\beta_x = 0.12$ m/rad, $\varepsilon_x = 0.20$ mm· mrad, $\alpha_y = 1.46$, $\beta_y = 0.13$ m/rad, $\varepsilon_y = 0.20$ mm·mrad. From Table 1, we can see that the fitting result with the formula calculation method agrees the best with the RFQ simulation results. The disagreement of the Gaussian fitting results might come from the fitting methods of beam sizes, which may not be proper when the beam phase space is severely tilted or much deviated from Gaussian distribution.

SUMMARY

Seven wire scanners have been built for high current proton beams in the C-ADS injector I. The software was developed based on LABVIEW. The beam size and emittance measurement have been carried out with these wire scanners. Two different methods for analysing the beam sizes with the wire scanner data have been discussed. We also discuss the fitted beam emittance. The results show that the emittance calculated with the beam sizes fitted by the formula is in good agreement with the RFQ simulation result.

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