DESIGN AND APPLICATION OF DOUBLE-SLIT EMITTANCE METER FOR C-ADS PROTON BEAMS*

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Abstract

To reduce the beam loss in the high current linac, beam transverse emittance is a key value which has to be characterized. At Institute of High Energy Physics (IHEP) in Beijing, the C-ADS project has started beam commissioning. A newly developed double-slit emittance meter (DEM) for pulsed proton beam from the RFQ has been installed in the beam line. In this paper principal of operation, instrumentation and programming of the DEM are discussed. The emittance measurement has been carried out with the DEM at 3.2 MeV beam energy and 10 mA beam current. Typical rms emittance for x and y direction are measured to be 0.1303 and 0.1347 π·mm·mrad, which are well below the design standard of the RFQ.

INTRODUCTION

High current proton linac is a key component of Chinese accelerator driven systems (C-ADS). To minimize the beam loss is very important for designing the linac. Transverse emittance growth during the beam transportation in a linear accelerator is the main reason leading to beam loss. Therefore, the beam transverse emittance plays a significant role on the high current linac performance. The measurement of transverse emittance is essential.

The injector-I for the C-ADS is making great progress. The ion source, low energy beam transport line (LEBT) and radio frequency quadrupole (RFQ) have been commissioned successfully. A double-slit emittance meter is indigenously developed to measure emittance of high current proton beam in continues ion beam mode. Emittance measurement can be done by several methods, such as solenoid\quadrupole scan, "pepper–pot" and "multi-slit". The solenoid\quadrupole scan method does not measure the phase space distribution, while the "pepper–pot" and "multi-slit" methods have the difficulty of data overlap between their holes or slits [1,2]. Compared with other methods, the double-slit method can achieve higher resolution, needs less electronics and has been widely used in the world. But in China there are few reports on the application of double-slit emittance meter (DEM). In this paper principal of operation, instrumentation and programming of C-ADS Double-slit emittance meter are discussed. The measured results are also presented.

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EMITTANCE METER

Double-Slit Technique

In double-slit emittance meter two slits of 0.2 mm thickness are used. The principle of the double-slit emittance meter is shown in Fig. 1. The full beam impinges upon the first slit and is cut into small beamlet. After traversing the drift length L from first slit, the profile of the small beamlet is measured by the second slit. For every position of first slit there is corresponding profile scan of second slit. The measuring procedure is as follows: after starting, the position-programming unit positions the first slit to a position S1, then it moves the second slit S2 continuously from one side to the other, at the same time the intensity behind slit S2 is measured as a function of the position S2, that means as a function of the angle. By scanning both slits throughout the whole beam area, a beam distribution in the transverse phase space can be obtained. Suppose there is M position of first slit and for every position of first slit there is N position of second slit. So one M×N matrix is generated after one emittance scan which is shown in Fig. 2.

The rms emittance of the beam is calculated from the profile of the beamlet as

$$\varepsilon_{rms} = \sqrt{\langle u^2\rangle\langle u'^2\rangle - \langle uu'\rangle^2} \qquad (1)$$

where $\langle u^2\rangle$, $\langle u'^2\rangle$, $\langle uu'\rangle^2$ are the mean square values of position, angular divergence and those product, respectively, weighted by charge density.

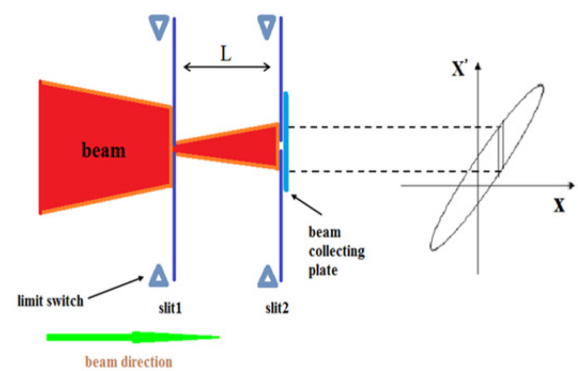

Figure 1: The principle of the double-slit emittance meter.

Slit 2 / Slit 1	1	2	.	.	N
1	n_{11}	n_{12}			n_{1N}
2	n_{21}	n_{22}			n_{2N}
.					
.					
M	n_{M1}	n_{M2}			n_{MN}

Figure 2: Data matrix of emittance scan.

Instrumentation

Double-slit emittance meter instrumentation is based on microcontroller. National Instrument (NI) PXI-8115 microcontroller is used for this application. Overview of instrumentation is shown in Fig. 3. A schematic diagram of the emittance monitor is shown in Fig. 4 and its main specification is shown in Table 1.

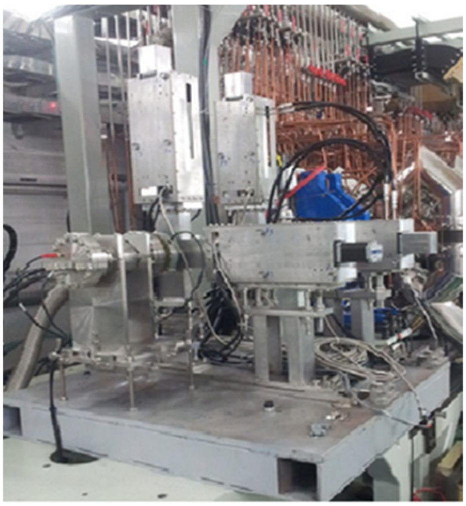

Figure 3: Overview system of double slits measurement.

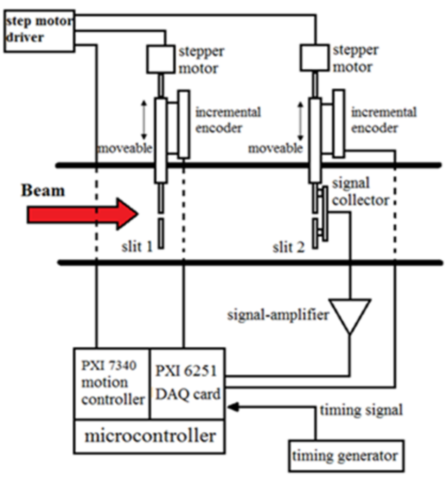

Figure 4: A schematic diagram of the emittance meter.

The emittance meter instruments are contained inside a stainless-steel vacuum chamber. This box is also the structural support of the device. The emittance meter has front and rear slit and distance between two slits is 90 mm. The two slits are 0.2 mm wide by 50 mm high and can be scanned over a total range of 100 mm. Two sets of the slits are installed in a vacuum chamber for x and y directions. The front slit has water-cooled swirl tubes and is capable of absorbing the full output high current proton beam of RFQ. It is not necessary to cool the rear slit because of the low fraction of the beam that is transmitted to it. The instrument is moved using stepper motors and transmission screws. Two high torque bipolar stepper motors of 50 kg·cm with step angle of 1.8° are used for precision motion of slits. Two microstep drivers are used to achieve further resolution in step size of slits. Normally stepper motor are used in open loop control system but here rotary motion to linear motion conversion is there. While motion conversion there are frictional losses, so to know exact location of slits two linear incremental encoder of 1 micron resolution are used. For limiting motion of slits, two limit switches of sensing distance 5 mm are used for each slit. Beam collecting plate is after the rear slit. The current collected by the beam collecting plate is amplified by the current amplifier and led to a NI-PXI6251 A/D converter.

Table 1: Main Specifications of the Emittance Monitor

Parameter	Value
Slit width	0.2 mm
Slit thickness	1 mm
Distance between front and rear slit	90 mm
Resolution of position	1 μm
Resolution of inclination angle	1 μrad
Displacement of slit	0~100 mm
Measurement time	10 mim

Software Control Description

To allow a complete beam scan and a emittance calculation to be done automatically, a special Labview based application was developed. Figure 5 shows a snapshot of the control screen used to set the measurement parameters and to display the data acquired by the emittance meter.

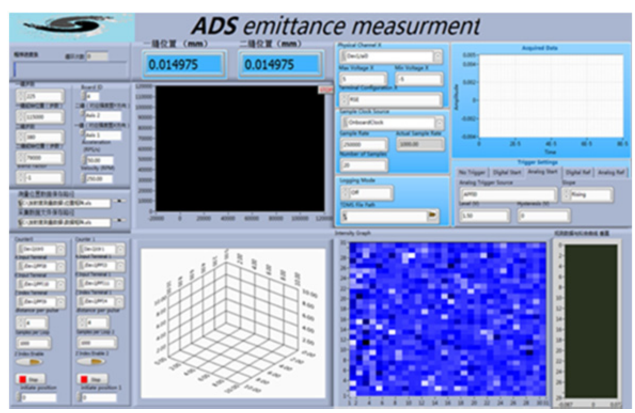

Figure 5: Graphic interface of the LabView based application for emittance measurement.

The user can specify, from the graphic screen, the initial and the final position and the displacement between subsequent measurements. The motor places the selected slit at the initial position and then moves it uniformly according to the chosen step. While moving, the detector data and position are recorded and the acquisition is repeated until the device comes to the final position.

After finishing emittance scan, the beam phase space distribution is obtained, a M x N data matrix containing all current and position values is also generated, where M

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is first slit location and N is second slit location. Two threshold levels can be set by the user in order to remove the intrinsic noise. The first one removes data under the noise level, the second one selects the data from the statistical center up to the background density level, discarding the external area. After that, a calculation routine can be invoked to obtain emittance value.

MEASURED RESULTS

At IHEP, the injector-I for the C-ADS is making great progress[3]. The ion source, LEBT and RFQ have been commissioned successfully. The designed beam parameters at C-ADS RFQ end is $\varepsilon_x=\varepsilon_y=0.15$ π·mm·mrad. In order to know the proton beam quality, the emittance measurement was carried out at the exit of the RFQ using the newly developed DEM. The beam energy is 3.2 MeV and beam intensity is 10 mA. The scanning step is 200 μm. There are 100 measurement points for both slit 1 and slit 2. The scanning distance of both slits is 20 mm. It takes about 20 minutes to measure the emittance for both x and y direction. After one emittance scan a 100×100 matrix is generated. Since the total charge of the extracted beamlet is quite small, the matrix actually include a fraction of background noise which is very sensitive to the emittance estimation. One of useful approach in this situation would be a "core emittance" estimation to deduce the actual emittance. At first the obtained phase space distribution is applied a thresholding in order to remove a given fraction of the particles after the background subtraction. An average value of the background noise is used for the background subtraction. The background noise was measured at the same time as the beam signal measurement on the standby position of the slits where slits shut out the entire beam. Then the rms emittance is calculated for the remaining core part (core emittance). Finally we find that the signal to noise ratio of the detected signal is rather good. The threshold level is set to be only 2.5% of the total charge. The results of calculated normalized rms emittances are 0.1303 and 0.1347 π·mm·mrad for x and y directions. The measured emittance values are well below the designed standard for C-ADS RFQ. The beam phase space distributions for x and y directions are shown in Fig. 6 and Fig. 7 respectively.

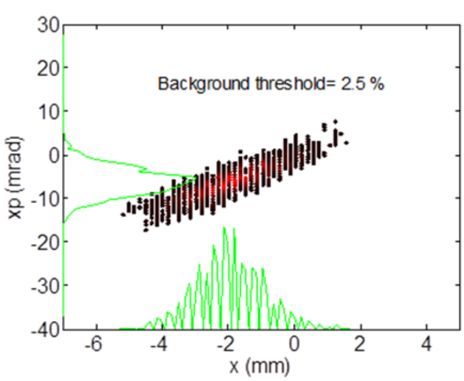

Figure 6: beam phase space distribution for x.

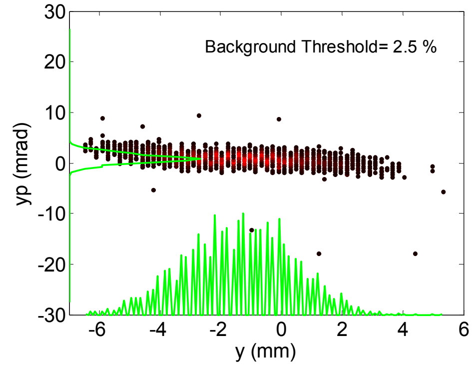

Figure 7: beam phase space distribution for y.

SUMMARY

We have developed a double-slit emittance monitor for high current proton beams from the C-ADS RFQ. The emittance measurement for both x and y directions have been carried out with the newly developed DEM at a beam energy of 3.2 MeV and a beam current of 10 mA. The whole emittance measurement process takes about 10 minutes for one direction. The calculated normalized rms emittances are 0.1303 and 0.1347 π·mm·mrad for x and y directions with a threshold level of 2.5%. The results indicate that the RFQ meets the requirements of C-ADS, and the newly developed DEM is convenient and reliable.

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