

TRANSVERSE EMITTANCE MEASUREMENTS IN CSNS LINAC

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Abstract

Commissioning of the front-end part of the Linac at CSNS has been accomplished. Double scanning slit system and wire-scanners were employed to carry out the transverse emittance measurements in both Low Energy Beam Transport (LEBT) and Medium Energy Beam Transport (MEBT). Different results of different measurement methods are presented and compared. Codes were developed for the each one of the emittance measurements methods.

INTRODUCTION

China Spallation Neutron Source (CSNS) [1] is a high intensity accelerator based scientific research facility. The accelerator complex has of an 81MeV H- linear accelerator as the injector of the 1.6GeV rapid cycling proton synchrotron (RCS). The linear accelerator mainly consists of a 50KeV H- ion source, a 3.0MeV radio frequency quadrupole (RFQ) accelerator and a drift tube linear (DTL) accelerator. The low energy beam transport line (LEBT) and medium energy beam transport line (MEBT) connect the above three parts and give the beam matching transversally and longitudinally.

Up to now, the installation and commissioning of the ion source, RFQ and the first physical tank have been accomplished. The H- beam transported through the beam line with transmission efficiency near 100% and the peak current intensity exceeded 18mA.

Parameters of the beam were measured and studied during the commissioning. Fig.1 gives the schematic layout of the MEBT where most of the measurements were carried out. A double scanning slit system and four wire-scanners are installed in this section for the emittance measurement. The following part of this paper will introduce the work of beam emittance measurements on MEBT which we have fulfilled.

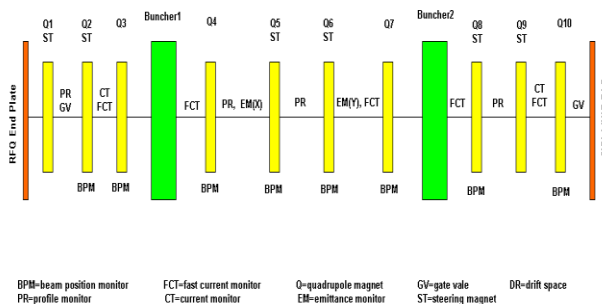


Figure 1: Schematic Drawing of CSNS MEBT.

EMITTANCE MEASUREMENTS

The emittance of a particle beam is a key characteristic for high intensity particle accelerator. Measurement and study of emittance is very important for the prediction and control of the beam particle loss. Mathematically, the emittance can be described as a distribution in a 6-dimensional space which includes all position and associated velocity coordinates along the 3 coordinate system directions. The 6-dimensional emittance is usually projected into the two-dimensional planes ($x-x'$), ($y-y'$) and ($z-z'$) and the emittance in transversal planes are the major part our study focused on. Taking the entire particle distribution into account, the root mean square (rms) emittance is defined as the quantity to describe the emittance.

Double Scanning Slit System and wire-scanners are employed for the rms emittance measurement. Different methods of measurement are introduced and the results are discussed.

Double Scanning Slit System

Double scanning slit system is one of the devices developed to get the emittance directly by measure the flux elements $f(x, x')$ [2]. Based on measured particle flux elements $f(x, x')$ passing through a relative position coordinate x with a relative velocity component x' , the rms emittance can be obtained by statistical method.

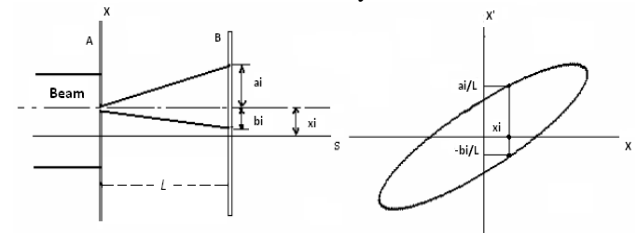


Figure 2: Schematic Diagram of Double Scanning Slit System.

Figure 2 shows the schematic diagram of a double-scanning slit system. By scanning the position of the slits (horizontal) on plate A and plate B, the current intensities of the beam elements passing through the slits can be detected and thus the beam distribution in the 2-dimensional phase space can be measured.

The rms emittance calculation largely depends on the threshold value. The statistical calculation usually ignores the data outside a certain boundary in order to cancel the background or noises. The ratio of boundary value to the peak value is defined as the threshold here. Fig. 3 shows

the rms emittance (horizontal-left, vertical-right) of beam on MEBT as a function of the threshold value selected.

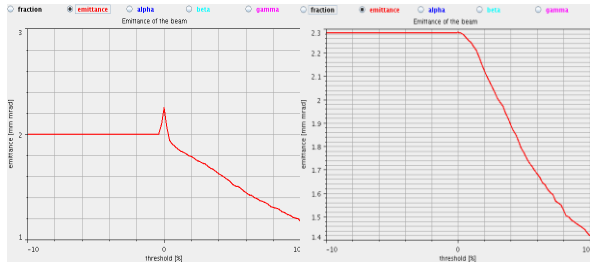


Figure 3: Threshold analysis of MEbT Emittance. (Left- horizontal, Right-vertical)

The rms emittance peaks centered on zero and decrease rapidly when the threshold is above zero. The analysis suggests that the selection threshold value of is crucial to the final result. To get the suitable value of threshold, the background of the double slit scanning system is measured and canceled.

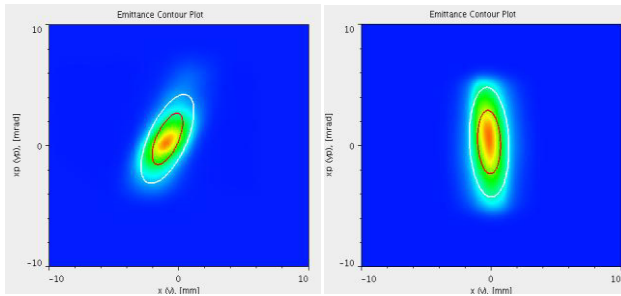


Figure 4: Particle Distributions in Transversal Phase plane: (Left- horizontal, Right-vertical).

A Java-based code was developed for the measurement data processing. The rms value and the display of particle distribution in phase space are output by the code as Fig. 4. The rms emittance in transversal plane measured by double slit scanning system:

$$\epsilon_x = 2.28 \quad \epsilon_y = 2.24$$

Multi-changing Focusing Strength Method

There are four wire-scanner devices installed on MEbT for the transversal emittance measurement as well. Two different methods for the wire-scanner measuring are employed. One is called multi-changing focusing strength method which only one wire-scanner is selected to measure while the other method is by scanning the input beam parameters which 3 or 4 wire-scanners are used. These two methods and measurement results are presented and discussed as below.

The emittance in 2-dimensional phase space can be described by 3 independent parameters: area (emittance) and shape (α and β function) which determine the transversal size of the beam.

By measuring the sizes of beam downstream a quadrupole with multi-changing focusing strength K_i ,

equations with the unknown factor ϵ, α, β are obtained as:

$$\sigma_i^2 / \epsilon = m_{11}^2(K_i)\beta_0 - 2m_{11}(K_i)m_{12}(K_i)\alpha_0 + m_{12}^2(K_i)\gamma_0 \quad (1)$$

The m_{ij} is the (i, j) element in the transport matrix from the quadrupole to the wire-scanner selected [3].

We used the 2nd and 3rd quadrupole on MEbT to perform focusing strength scanning and the 2nd wire-scanner to measure the beam size. The number of the scanning step should be more than 10 to get enough points to fit to a parabola curve. Figure 5 shows the chart of beam size changes along the quadrupole magnetic field gradient scanning.

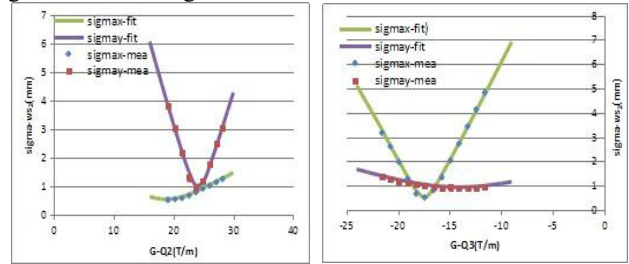


Figure 5: Beam Size VS Magnetic Field Gradients of Quadrupole Q2 & Q3rd (Left^d Q2, Right- Q3).

Solutions of ϵ, α, β are acquired by this measurement method are in Table 1:

Table 1: Alpha, Beta, Emittance Results by Multi-Changing Focusing Strength Method

	Alpha (x,y)	Beta (x,y)	Emit. (x,y)
Q ₂	(-0.12, 3.176)	(0.071, 0.334)	(2.016, 3.553)
Q ₃	(-0.02, 2.399)	(0.084, 0.266)	(2.152, 3.044)

Input Beam Parameters Searching Method

Emittance ϵ and twiss parameters α, β can be obtained by measuring three transversal beam sizes at three different locations downstream the beam line. However, the energy of MEbT is 3MeV and the peak current intensity is 15mA, nonlinear space charge force can't be neglected in this low-energy section of the high intensity linac.

Therefore, the parameters ϵ, α, β can't be precisely acquired by solving linear equations. Codes which include space charge force such as Parmila [4] or XAL[5] online model are employ to do the calculation of beam transporting and get the ϵ, α, β by Input beam parameters searching. Figure 6 shows the algorithm chart of this method.

First, we set the initial rms emittance ϵ , twiss parameters α, β and the searching step and scale. Then call the Parmila code or the XAL code to do the beam transport calculation and read the output files to get the beam profile RMS values at the wires' locations. By iteration and methods of searching, we can minimize the

discrepancy between the wire scanners' experimental data and the results given by the codes (space charge effect included). When the discrepancy reach the satisfaction standard we set, iteration and searching stop and the final twiss parameters and emittance of beam at the MEBT entrance are obtained.

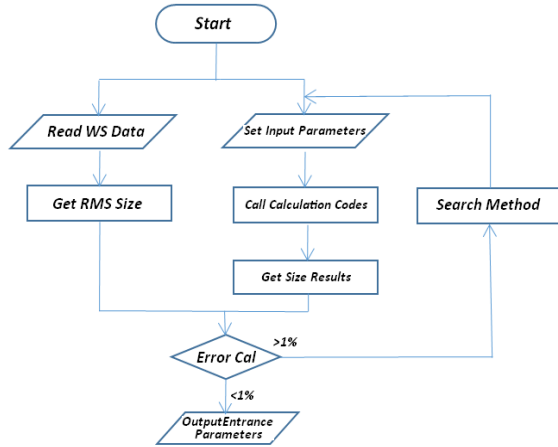


Figure 6: Algorithm Chart of Input beam parameters scanning method.

Table 2: Alpha, Beta, Emittance Results by Input Beam Parameters Searching Method

Alpha (x,y)	Beta (x,y)	Emit.(x,y)
(-0.12, 3.176)	(0.071, 0.334)	(2.016, 3.553)

The results calculated by this method are shown in the Table 2 as above. Using the results as the input beam parameters of the MEBT, we can get the rms emittance and twiss parameters at the second slit of the double-slit scanning device. Figure 7 shows the rms emittance ellipse at 2nd slit, which are very close to the result shown in Fig. 4.

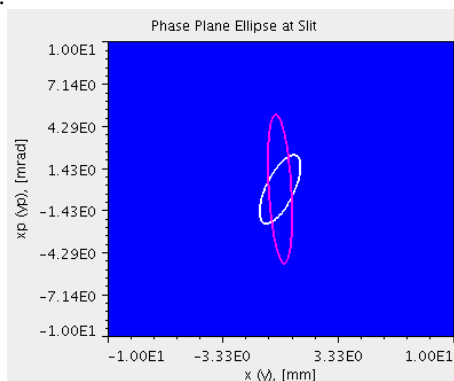


Figure 7: RMS Emittance Ellipse at 2nd Slit (White-horizontal, Red-vertical).

DISCUSSION

In this paper we present the measurements of transversal beam emittance carried out during the

commissioning of CSNS linac. Double scanning slits device and wire-scanners are employed for the emittance measurements and different methods are introduced.

Double scanning slits system is one of the devices can get the emittance directly by measure the flux elements $f(x, x')$. However, the rms emittance calculation largely depends on the threshold value. If the threshold value is not selected properly, there may be a significant deviation between the measured and real rms value of emittance. In other words, there may be errors in calculating the size of the rms emittance ellipse. But, the shape of the emittance ellipse is easy to read and could give a reference to other emittance measurements.

Multi-changing focusing strength method needs only one wire-scanner. Different results of measurements by selecting different wire-scanners could be the benchmarks to each other. However, nonlinear space charge force was neglected in this method and the emittance was assumed to be a constant along the MEBT beam line.

Input beam parameters searching method overcomes the problem of nonlinear space charge force by calling codes like Parmila. But this method needs 3 wire-scanners at least at the same time. Therefore, the overall measurement accuracy of the wire-scanners hardware has relatively large impact to the final results.

The measurement methods above which we used during the past give different but close values of transversal emittance. More study and measurements of the beam transversal emittance will be made in the following commissioning of CSNS linac.

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