Wire Scanner Beam Profile Measurement for ESRF

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Abstract

The wire scanner is used in beam transfer lines of European Synchrotron Radiation Facility (ESRF) to provide data for beam profiles, which is being used in emittance measurements. The beam energy in the first transfer line is 200 MeV and the peak current is 25 mA. This work will discuss the operation of the wire scanner, and the first results of the scanner in ESRF. We get the emittance value for the vertical plane and the horizontal plane ($1.5x10^{-6}$ m.rad, $2x10^{-7}$ mrad) receptively. When we used these values to simulate our result we find that, the simulation gives good fitting with real values.

1 INTRODUCTION

Method of beam transverse profile measurement in accelerators by wire scanner is wide spread in accelerator field [1,2,3]. The wire scanner beam profile measurement has been used extensively in the commissioning of many accelerators. It has been utilized 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. The basic principle is based on secondary electrons generated by the interaction of the beam and the wire. The wire scanner in ESRF is controlled through TACO control system [4], accelerator control system. TACO is an object oriented control system developed at the European Synchrotron Radiation Facility.

2 EXPERIMENTAL FACILITY

ESRF is located at Grenoble – France. ESRF is essentially a complex of three accelerators, the preinjector, the booster synchrotron, and the storage ring. The later being equipped with insertion devices and beam-line front ends. The pre injector is 16-m long linear accelerator, which produce the electrons and accelerates them up to 200 MeV with peak current 25 mA in long pulse mode [5]. The booster is a 10 Hz cycling synchrotron 300 m in circumference, which increases the energy of the electrons up to 6 GeV before injection into the storage ring. Storage ring circumference is 844 m, 64 beam ports are spread around the storage ring to give access to beam lines on insertion device or alternatively on bending magnets. The beam of electrons is circulating at 6 GeV which make it capable for producing X-rays at each passage inside the bending magnets or insertion devices. Wire scanner is a diagnostic tool located in the transfer lines between the three accelerators TL1 and TL2, one for each line. The purpose of the wire scanner is to provide horizontal and vertical beam profiles in transfer lines. The transverse beam emittance (ε) is deduced by the product of beam width (r) and beam divergence ($\dot{r}$) where $\varepsilon = (r\dot{r})/\pi$. The wires are made from tungsten and gold (diameter is 40 μm) and are attached to an actuator driven by a stepping motor. The principle of providing profiles is based on the amount of secondary electrons generated by the interactions of the beam and the wire and measured in incremental steps. From these measurement steps the beam profile is constructed. This paper will discuss the operation of the scanner (Hardware and Software), testing the scanner during operation, obtain the profiles and finally calculating the emittance of beam in TL1. Figure (1) show a drawing of wire scanner, The basic parts of the hardware are the stepper motor and its controller, and the two ADC cards, one for each plane. The motion of wires must be continuous to avoid the wire vibration. The user of wire scanner has the ability to set the scanning parameters for profile (start position, number of measurements, and end position) using application program interface. Scanning is done under the angle 45^o with the beam direction. Therefore, the position value obtained from the scanning is multiplied by cos 45^o. Each step equals 0.1 mm in case the frequency equals 1 Hz. An external trigger must be adjusting to read the two ADC cards synchronized with the electron beam.

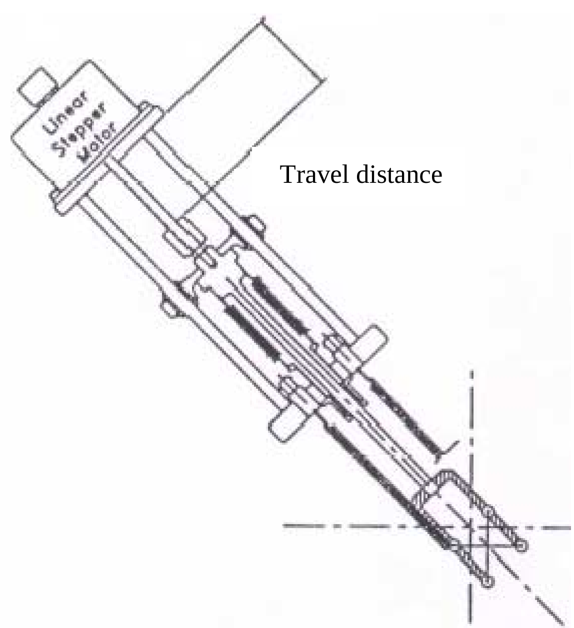

Figure (1) Schematic view of the wire scanner.

3 EXPEREMENTAL RESULTS

To get the profile of the beam, this required displacing the two wires inside the beam and measuring at each position the currents collected on the two wires. The wire scanner driver will have to drive the stepper motor (position, number of steps, speed) and drive the two ADC boards (setting the gains, reading the currents). Once the required number of measurement sequences has been completed, from the stored data of the complete cycle of measurement, we get the profile by using a special program in matlab. In order to minimize the overall measurement time, the sequence shall be synchronized on the beam pulse repetition frequency. The user of wire scanner can set it by the required frequency (1 Hz or 10 Hz). The profile data is stored in two different files. The first file contains the raw waveform data from the wire scanner for two plans (horizontal and vertical), the position data and the intensity of the beam at each point as well as the currents of the quadrupole's power supply during the cycle of measurement. Figure (2) shows the result of a typical profile measurement.

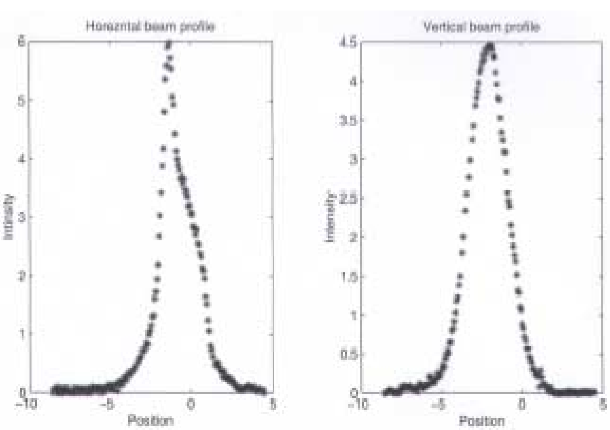

Figure (2) Typical profile measurement.

The second file contains just the processing operation to normalize the data, smoothing, calculated the width of the profiles, which will be used to calculate the emittince after that. Light beams are not straight lines in the mathematical sense [6]. They have a finite width and they are divergent, and such is also the electrons beam. The product of the initial divergence and the initial width of the electron beam is called the emittance. The smaller the emittance, the smaller the divergence and the width. The analogy between light beams and electron beam is quite strong. While the light is kept focussed by a set of glass lenses, the electron beam is being focussed by a set of magnetic lenses (quadrupoles). Quadrupole gives focusing in one plane and defocusing in the other plane. Alternating focusing and defocusing quadrupoles produce focusing in both planes. While the magnetic lenses can change the width or the divergence of the beam, they can never change the emittance according to Liouville's theorem. Therefore the emittance is a constant value along the beam line. So we can define the emittance as the area in phase space occupied by the beam. Similarly, we define the acceptance as the area in phase space where a particle can have a stable motion. The acceptance may be limited either by the non-linearities (dynamic acceptance) or by the dimensions of the vacuum chamber (physical aperture). The acceptance plays a role in the design of the injection scheme and in the lifetime of the beam. We measured the emittance in a beam line consisting of three straight sections and two quadrupoles as shown in figure (3).

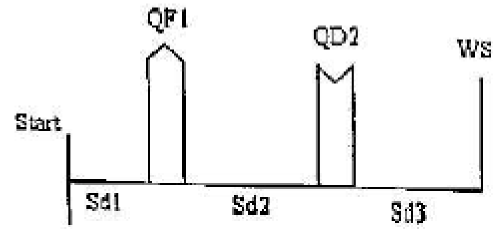

Figure (3) Beam line arrangement.

The motion of electrons in each plane can be described by the matrix expression:

$$X = T.X_o \quad (1)$$

Where X is the particle coordinate vector $X = \begin{pmatrix} x \\ x' \end{pmatrix}$

x is the position and x' is the divergence

and T transfer matrix, has the form $T = \begin{pmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{pmatrix}$

Starting from an arbitrary origin on the beam line, one can build the transfer matrix corresponding to the beam line by multiplying all the single element matrices:

$$T = T_n.T_{n-1}...T_2.T_1 \quad (2)$$

Then

$$X_n = (T_n.T_{n-1}...T_2.T_1).X_o \quad (3)$$

Due to Lioville's theorem, [7] all particles of the beam in phase space can be surrounded by an ellipse described by

$$\gamma x^2 + 2\alpha xx' + \beta x'^2 = \varepsilon \quad (4)$$

Where (α, β, γ) describe the shape and orientation of the ellipse, and ε is the emittance. The surface area of the ellipse is equal πε. From equation (1) we can solve the equation (4) according to x_o and x_o' to obtain the coefficient (α, β, γ) which can be written as:

$$\begin{bmatrix} \beta \\ \alpha \\ \gamma \end{bmatrix} = \begin{bmatrix} T_{11}^2 & -2T_{12}T_{11} & T_{12}^2 \\ -T_{11}T_{21} & (T_{22}T_{11} + T_{12}T_{21}) & -T_{12}T_{22} \\ T_{21}^2 & -2T_{21}T_{22} & T_{22}^2 \end{bmatrix} \begin{bmatrix} \beta_o \\ \alpha_o \\ \gamma_o \end{bmatrix}$$

The beam matrix is defined as

$$\sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} = \varepsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix} \quad (5)$$

Based on the transfer matrix of the beam line we can calculate the new beam matrix at position P1.

$$\sigma_{1=T\sigma_o T^T} \quad (6)$$

So, we must know the beam matrix at a given point to know the emittance. The square half beam width is given by

$$w^2 = \sigma_{11}{}^2 = \sigma_{o11}T_{11}^2 + 2\sigma_{o12}T_{11}T_{12} + \sigma_{o22}T_{12}^2 \quad (7)$$

For complete set of tunings (at least three tunes) we can solve the equation (7) to get the new coefficient of segma matrix at wire scanner position. The emittance measurement consists of measuring the width of the beam for different tunings of Quadrupole magnets. For each tune we calculated the half width of the beam at half maximum. After that we substitute in equation (9) for each tune to obtain the coefficients of segma matrix ($\sigma_{0,11}$ $\sigma_{0,12}$ $\sigma_{0,22}$). By calculating the determent of this segma matrix we obtained the emittance value. By the same manner we can apply the same processing to calculate the emittance inside the transfer line between the booster synchrotron and the storage ring (TL2). By changing the current intensity of QF1 at (QD2 = 18 A) we get the emittance value for the vertical plane is $1.5x10^{-6}$ m.rad. Also by changing the current intensity of QD2 at (QF1 = 10.46 A) we get the emittance value for the horizontal plane is $2x10^{-7}$ m.rad. When we used these values to simulate our result we find that, the simulation gives good fitting with real values as shown in figure (9). Also by the same application program we can know the convergence of the beam or divergence from the shape of ellipse.

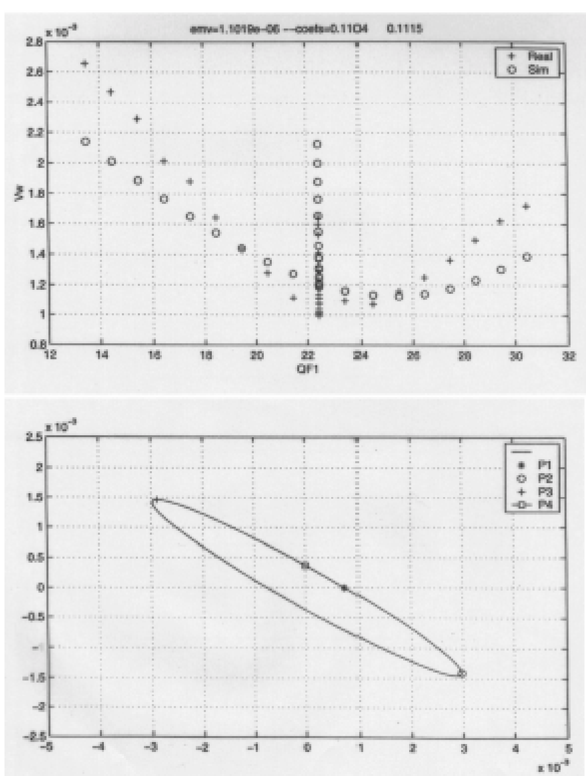

Figure (4) Width of vertical profile versus current of QF1 and simulation fitting, and the ellipps crospond to the emittince

4 CONCLUSION

The wire scanner is used in transfer lines of ESRF to provide data for beam profiles, which is used in emittance measurements. The purpose of the scanner is to provide horizontal and vertical beam profiles. It has been utilized to verify the data for quad scan style emittance measurements. The result of a typical horizontal profile measurement shows a strange shape, this will lead to change the setting of LINAC to obtain the optimum case. By changing the current intensity of QF1 at (QD2 = 18 A) we get the emittance value for the vertical plane. The value is $1.5x10^{-6}$ m.rad. Also by changing the current intensity of QD2 at (QF1 = 10.46 A) we get the emittance value for the horizontal plane. The value is $2x10^{-7}$ m.rad. And we find that, the simulation gives good fitting with real values. There still remains some works to be done for the second transport line between the booster and the storage ring.

5 AKNOWLEDGEMENT

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