TRANSVERSE BEAM MATCHING APPLICATION FOR SNS*

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Abstract

An automated transverse beam matching application has been developed for the Spallation Neutron Source (SNS) beam transport lines. The application is written within the XAL Java framework and the matching algorithm is based on the simplex optimization method. Other functionalities, such as emittance calculated from profile monitor measurements (adopted from a LANL Fortran code), profile monitor display, and XAL on-line model calculation, are also provided by the application. Test results obtained during the SNS warm linac commissioning will be reported. A comparison between the emittances obtained from this application and an independent Trace-3D routine will also be shown.

INTRODUCTION

The SNS is designed to produce 1.4 MW of neutron power by bombarding a target with a high intensity proton beam. The beam optics should be carefully controlled in the linac and the accumulator ring to avoid unnecessary radiation activation due to beam loss. A beam optics control program has been developed within the XAL framework [1, 2] to provide better transverse matching in the transition regions between various sub-systems.

OPTICS CONTROL APPLICATION

The basic features of the SNS optics control application are emittance measurement and providing quadrupole solution for transverse matching. The application can work in either online or offline mode. The offline mode is set to use saved profile monitor data files and saved machine setting snapshots from a database. Because all the XAL-based applications are initialized from the SNS global database [3], the application is automatically applicable to multiple regions such as the drift-tube linac (DTL) to the coupled-cavity linac (CCL), the high-energy beam transport (HEBT) to the ring injection and the ring-to-target beam transport (RTBT). The first test of this application was conducted in January, 2005 with the SNS DTL to CCL transition.

Emittance Measurement

The first step for transverse matching is to determine the present Twiss Parameters α and β and emittances for a given location in the transverse plane. An emittance calculation algorithm adopted from LANL [4] is applied. This algorithm is based on wire scanner (WS) profile measurement at three or more locations along the beam line. If beam profiles are measured at three different locations, an exact emittance is obtained. More than three WS profiles can provide additional statistical information for the measurement quality.

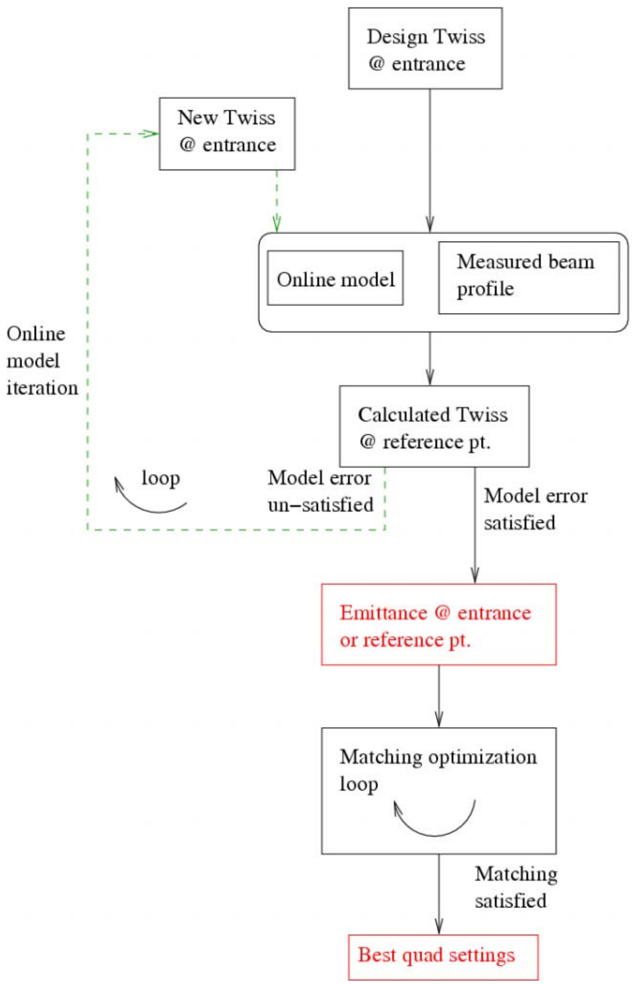

Figure 1: Schematic flow chart for the optics control application.

The algorithm for the application is shown in Fig. 1. A Gaussian curve fit to the profile data gives the root mean square (RMS) emittance. The transfer matrices used in the emittance calculation are obtained from the XAL online model including linear space charge effect [5]. For the experiment described here, the initial Twiss Parameters at the beginning of the beam line were taken from a previous measurement for the SNS medium-energy beam transport (MEBT) and then propagated, with the XAL online model and the SNS design lattice, to the beginning of the first CCL module. These initial conditions might have changed since their measurement. One quick way to obtain a set of Twiss Parameters closer to the experimental condition is to iterate the following

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procedures: taking the calculated Twiss Parameters at the reference location and tracing back to the beginning of the beam line, then replacing the initial Twiss Parameters with these new ones; continuing this process until the difference between the online model and the measured wire scanner data is below a pre-defined limit. Typically it takes between 10 and 20 iterations to reach a minimum difference between the model and the corresponding beam profile data. The minimum itself depends on various parameters and in the ideal case it is around the errors of quadrupole gradients and the wire scanner data. In reality, the situation turns out to be more complicated. We discuss the experimental picture in the next section.

For the best cases, presented in the next section, the agreement between the model and the experiment was very good (within 2% for average model size deviation from the experiment). For these data the rms normalized emittances obtained from the application were 0.32 ± 0.01π mm mrad horizontally and 0.39 ± 0.01 π mm mrad vertically at the CCL entrance. These numbers agree with a direct emittance measurement performed in the SNS MEBT at about the same time. Also, because this application is intended for the rms emittance measurement, the upstream beam should be tuned well enough in both transverse and longitudinal planes to minimize the tail effect.

A screen snapshot of the application is shown in Fig. 2. At this moment, the application does not provide control of the WSs, therefore, a set of wire scans should be taken prior to the emittance calculation.

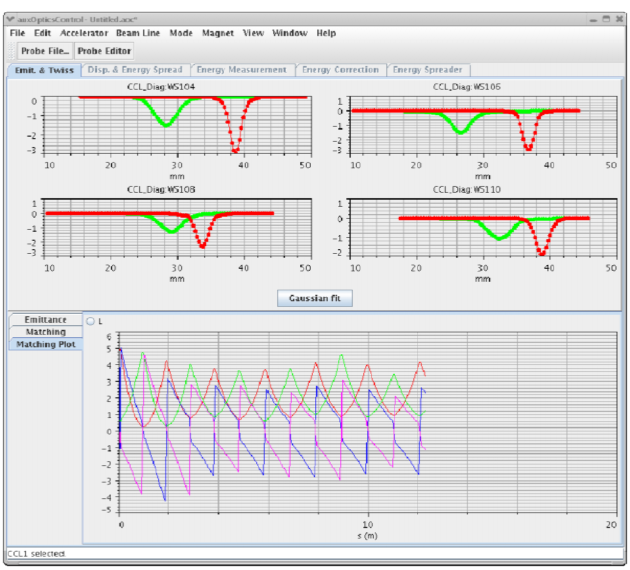

Figure 2: Screen snapshot of the optics control application applied to the SNS CCL1. The upper part of the screen shows transverse beam profiles from four wire scanners. The green curves are for horizontal and the red ones are for vertical profiles. The two curves in each plot represent both horizontal and vertical profiles. The bottom half of the screen shows Twiss Parameters α and β (in both planes) after satisfying matching condition.

Transverse Matching

Once a set of Twiss Parameters at a given upstream location is obtained from the previous step, an optimization solver will provide the best matching solution for four matching quadrupoles (two for horizontal focusing and the other two for vertical focusing). The matching goal for this application is to set the transverse Twiss Parameters at a reference location to the design values. The initial quadrupole settings are typically from the design field strengths. The optimization solver is provided by the XAL framework. Typically, the time for finding a matching solution is about 30s and about 150 iterations are required for the SNS DTL-CCL transition. A set of quadrupole settings for the time of this application test is listed in Table 1. For the case shown in Fig. 2, the maximum β oscillation before and after matching are about 15 and 5, respectively.

Table 1: Quadrupole settings before and after matching

Quad	Field (Before)	Field (After)	Change %
QH00	43.80 T	44.640 T	+1.92
QV101	25.64 T	25.833 T	+0.75
QH102	25.88 T	25.930 T	+0.19
QV103	25.05 T	24.903 T	-0.59

SPACE CHARGE EFFECT

The optics control application was tested during the SNS warm linac commissioning period. First results were not very good: the emittance and Twiss parameters numbers were chaotic, and not very repeatable. Moreover, the emittance value sometimes was in negative territory (that's the problem of the algorithm from [4]: if the transfer matrix between wire scanners is far from reality, the result for the emittance may become negative). We found that the emittance and error of the model vs. experiment depends on how well the linac is tuned up prior to taking the data. Especially, the longitudinal parameters of the beam (emittance and length) heavily influenced the measurement. Therefore, accurate information about the longitudinal bunch length for the online model calculation is vital for the emittance calculation.

The reason for this is that our four wire scanners are located such that the over determined system for alpha, beta, and emittance calculations (3 parameters and 4 equations from 4 wire scanners) were close to degenerate. Namely, the phase advance between the 1st and 4th wire scanners is close to 180 degrees. In such a case, small errors in transfer matrices between WSs lead to large errors in the calculated parameters. It turns out that the largest unknown defocusing force is the one from space charge. Also, we do not control the space charge tune shift along with our transverse measurement because of uncertainty in the longitudinal emittance, and the online model always uses some design values for the longitudinal emittance.

After some longitudinal measurements were performed we learned that the bunch length was typically longer than the design value [6]. We decided to vary longitudinal emittance to see if the difference between model and experiment depends on it.

We calculated relative model error squared, which is the average squared sum of differences between the model and the experiment at four scanner locations, divided by square of the measurement error (2% in our case), and plotted it versus the longitudinal emittance. In Fig. 3, the minimum relative model error for both horizontal and vertical emittance calculations occurs when the longitudinal emittance is about seven times the design value. This surprising result is confirmed by other independent measurements [6]. In the minimum the relative error is about 1, meaning the real error is about the 2% measurement error, which is also about the error of our quadrupole gradients. One can see that for small emittances the error sharply increases. This is because a short beam has a high defocusing space charge force, which significantly changes the linear transfer matrix between scanners.

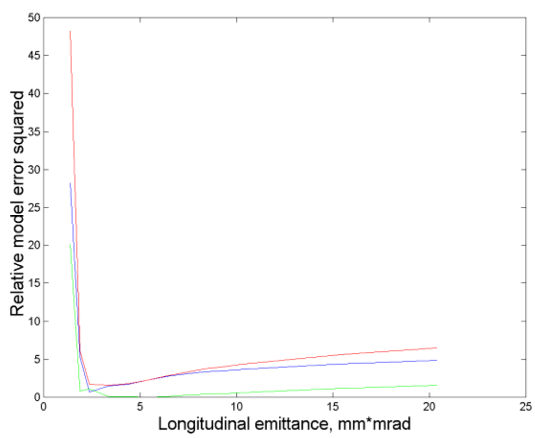

Figure3: Relative model error of the transverse size behavior vs longitudinal emittance. Green: horizontal direction, blue: vertical direction, red: sum of both directions.

Another independent emittance measurement and transverse matching program was also developed for the SNS [7]. Based on the same initial longitudinal emittance assumption, these two programs agree on the transverse emittances.

CONCLUSION

- Transverse emittance measured with the optics control application agrees with another independent method.
- The emittance calculation is sensitive to the space charge effect and the assumed initial longitudinal beam bunch length.
- Transverse matching routine improves the β function beating curves to smaller and more uniform. More studies will be conducted when further SNS downstream beam lines are commissioned.

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