The Improvement of Energy Measurement in BTS Transport Line by Using Beam Tracing Method

M. H. Wang and J. C. Lee
Synchrotron Radiation Research Center
Hsinchu Science-Based Industrial Park, Hsinchu, Taiwan, R.O.C.

Abstract

A method which measures the e^- beam energy in the booster to storage ring transport line is introduced. One of the bending magnet in the BTS transport line is chosen as the reference dipole for the energy measurement. The beam tracing method which takes into account of the fringe field effect is employed to calibrate the I-B curve of the reference dipole to enhance the accuracy of the energy measurement. The desired trajectory of the e^- beam is traced for different energy by adjusting the reference dipole current. The current correction factor with and without this calibration is -0.33 % for 1.3 GeV e^- beam for SRRC. The possible error sources of this measurement are also discussed and estimated.

I: General Description

One simple method to measure the beam energy in transport line is to use one dipole magnet as the reference dipole. By proper adjusting the strength of reference dipole the beam will go through the center of the BPM at down stream. The relationship of beam energy and the dipole strength is:

$$B\rho = C \times E \tag{1}$$

where B the magnetic field in Tesla, ρ the bending radius in meter, E the beam energy in GeV and C is a constant. For electron the constant is 3.335646. The beam goes through the center of the BPM implies that we have the designed ρ. Thus the energy is proportional to dipole field strength. The beam has to be steered such that it can launch at the designed entrance point of the reference dipole. So before the reference dipole there needs at least two correctors in the bending plane to adjust the position and the angle of the beam. It also needs two monitors to observe the result. According to the above consideration, the DM2 in transport line of SRRC was chosen as the reference dipole. The schematic layout of BTS transport line related to this measurement is shownin figure 1. The septum and horizontal corrector HC1 before DM2 is used to adjust the entrance point of the beam. BPM1 and screen monitor SCN2 are employed to help steering the beam to enter DM2 with right position and right angle. After the beam entering DM2, the strength of DM2 is adjusted to steer the beam go through the desired trajectory. The BPM2 after DM2 was used to monitor the beam to make sure the desired trajectory was achieved. Of course all the other magnets between BPM1 and BPM2 were off during the measurement.

As one can see the reference dipole is the key point in this measurement. The accuracy of the energy measurement depends on how "standard" the B field is. Thus the calibration of the DM2 has to be done to enhance the accuracy of the measurement.

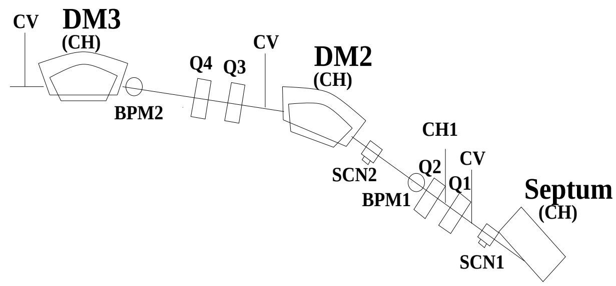

Figure. 1. The schematic layout of the BTS transport line to DM3.

II: The Calibration of reference dipole

The integrated B-I curve of the reference dipole has been provided by the Magnet Measurement Group[1] of SRRC. The assumed reference trajectory in the field measurement is an ideal trajectory. Based on this assumed reference, multipole field expansion and corresponding integrated strength is obtained. But in the real case the field and its distribution of the magnet are not ideal. It has fringe field and the trajectory of the tracing particle will deviate from the design. The beam starts to bend earlier when it encounters the fringe field. If the field is stronger than the design, bigger bending angle results. On the contrary, smaller field will give smaller bending angle. In both cases an unsymmetry tracing trajectory is obtained. Therefore the current need to be tuned to reach a symmetry trajectory as close to the design as possible.

The beam tracing program is employed to simulate the trajectory of the particle in the real magnetic field. From the discrepancy between tracing result and the design, the correction factor for the integrated B-I curve can be obtained and a symmetry trajectory will be constructed. The same method has also been applied to the ring combined function bending magnet of SRRC[2]. In the simulations of this case the coordinate is chosen to be the Cartesian coordinate with the origin at the magnet center. The tracing starts from the point of (-0.622m, -0.03909m), which is on the ideal trajectory and is the starting point of the magnetic field mapping. The tracing is ended at the the intersection point of the ideal trajectory and the line of x=0.622m. The initial tracing angle is the design angle of 5 degree and the tracing step is chosen to be 1mm in Z-axis which is the direction of beam motion. The field at the mapping edge is few ten gauss. Hence the field outside the mapping area is set to zero.

The point by point measurement of magnetic field at the current settings of 341A, 390A and 438A were measured and provided by the Magnet Measurement Group[1]. From the integrated B-I curve these three settings are interpreted as the tracing particles with the energy of 1.1651Gev, 1.3323Gev and 1.4782Gev respectively when particles trace in the same bending radius of DM2. Hence ideally particles with these three different current settings and energies will follow the same design trajectory. These three energy of beams were then traced in the corresponding measured field and the results are given in table 1. It is found that the bending angle and the integrated strength are 0.48% higher for 1.1651 Gev, 0.33% higher for 1.3323 Gev and 2.18% higher for 1.4872 Gev respectively. It is also found that the discrepancy between the tracing trajectories and the design is also larger than alignment tolerance. The integrated B-I curve approximate linear from 300A to 430A and begins to saturate above 430A. The fringe field will effect more serious on the field in saturation region. Since 1.4872 Gev beams are traced in the field powered at saturation region (438A) the field distribution will different from the linear one. This is why the current correction factor for the 438A case are about 2% higher than the unsaturated one which is only 0.3-0.5%.

In order to reduce the exceeded field and to correct the trajectory discrepancy the field is scaled down by a proper factor to make up for these two imperfections. The three energy of beams were traced again in the corresponding scaled down field and the results are also listed in table 1. Here the relationship of field and power current is assumed linear. Hence the scaled down factor for the field can be also applied to the current. From table 1 it is found that the errors of the bending angle and integrated strength are corrected to the order of 10^{-6} except that for the 1.4872Gev particles. A symmetrical trajectory is also obtained with the position discrepancy between the starting point and the end point less than the alignment tolerance. Since the BPM2 is 6 m down stream from the reference dipole, the angle error is also an important parameter to be checked. From table 1 the angle error is less than 1.7×10^{-6} rad at exit point of DM2, which will propagate about 0.01mm position offset to the down stream BPM2. That means a very good symmetrical trajectory is obtained after the corrections. Hence our attempt of trying to get a symmetrical trajectory with the position error at starting points and ending points less than the alignment tolerance is achieved. Thus particles will not deviate from the design trajectory before and after passing the reference dipole magnet. Furthermore the position discrepancy within measured field region between this obtained symmetrical trajectory and the design is also checked. It is found the maximum discrepancy in X-axis is about 0.5mm. It is much small than the good field width of $\pm$30 mm for the separated function dipole of DM2. Hence no obvious effects can be seen for this discrepancy.

The tracing result of 1.4872 Gev after field correction is bad. It is found the bending angle error is of the order of 10^{-5} and the integrated strength error is large up to 14%. This is because that the dipole current for this energy is in saturation such that the tracing trajectory deviates much from the ideal and can't be taken as a reference.

The design field of DM2 is powered at current 381A for 1.3 Gev. The measured data at 381A were not provided. But since current 381A locates in the linear region of the integrated B-I curve and is very close to 390A. Hence the measured field at 390A is scaled down to simulate the design field of 381A case. The tracing result at 381A shows the same behavior as the current at 341A and 390A, 0.3-0.5% exceeded field and an unsymmetrical trajectory. Following the same correction steps both imperfections are corrected to the acceptable levels, also shown in table 1.

III: Error Estimation

A few possible error sources are investigated for this measurement. The accuracy of the tracing program is checked first. By comparing the tracing result of the hard edge field with the design , the accuracy of the program can be obtained. The tracing step within the field distribution is 1 mm while in the neighborhood of the edge is 0.02mm to improve the tracing accuracy. By comparing with the design trajectory, it is found that the maximum position error, occurred at the exit point, is about 10^{-3} mm, the angle error is within 2×10^{-4} mrad and error of the integrated strength is 2×10^{-6}. The position error at the down stream monitor BPM2 due to the errors at the exit point of DM2 is 2 μm, which is well within the accuracy of the BPM. Hence error produced by the program is neglectable.

The second error source which will effect the accuracy of the measurement is the magnetic field error. From equation (1) we see that the errors are mainly divided into tow parts:

$$\frac{\Delta E}{E} = \frac{\Delta \rho}{\rho} + \frac{\Delta B}{B} \tag{2}$$

This classification is convenient for the theoretic analysis. In the measurement the bending radius is kept to the design value. Hence $\frac{\Delta \rho}{\rho}$ can be set to zero and all the energy measurement error can be interpreted as the field error independently. This simplification is reasonable since the only observable effect of the errors is the displacement at the BPM. The error from magnetic field is reduced by the calibration method provided in section II. The error left for the field is the dynamic field stability, which is believed to be below 10^{-3}.

Another important error source in this energy measurement is the position and angle deviation. The position errors are mainly due to the misalignment of BPM and its reading accuracy. In the beginning of commissioning the misalignment of the BPM was estimated to be 0.5 mm relative to the dipole magnet and the accuracy of the BPM reading is within 0.5 mm. As mention at section I BPM1 and SCN2 will be used to help the adjusting of position and angle of the beam into the DM2. The errors occur at BPM1 and SCN2 will cause the beam launching at the entrance point of DM2 with $\pm$1 mm position and $\pm$0.4 mrad angle errors. Accommodating with these entrance errors the beam is steered to the design trajectory within the monitor reading accuracy of BPM2 at the 6 m long down stream after DM2. Taking the field distribution of 390A after beam tracing calibration as an example, the possible tuning range for the magnetic field strength caused by these errors is simulated by the same tracing method and its result is from -0.36% to 0.37%. If we take 0.5 mm misalignment of BPM2 into consideration, the possible tuning range will be up to $\pm 0.42\%$.

The total error is obtained by taking root mean square of all the above errors, the dynamic field stability of 0.1 %, errors due to position and angle discrepancy of 0.42 % and for safety the miscellaneous error of 0.5 % for the unknown. While the 0.42

% error is enlarged to 0.5 % for the possible error of field distribution used in the simulation. Hence the possible error for this energy measurement algorithm is about 0.72%.

IV: Discussion and Conclusion

The algorithm of the energy measurement presented in this report is easy to achieve. It is based on the original design of the BTS transport line and no extra equipments are needed. The integrated B-I curve is an important information for this measurement and needs to be calibrated. By using the method of beam tracing a calibrated intergrated B-I curve is obtained.

It is found that the current needs to be scaled down by an amount of about 0.3% for the linear region near the designed energy 1.3 GeV. It is also found that the current can not be tuned to the saturation region for the SRRC.

The accuracy of the measurement is significantly effected by dynamic field(current) stability, the reading accuracy of BPM, alignment error, launching error and other unknown errors. By appropriate treatment the effect due to reading accuracy of BPM, alignment error and launching error can be factored out by the beam tracing method. By taking the root mean square of all the contribution of error sources, the possible error of this energy measurement algorithm is about 0.72 %, of which 0.5% unknown error has been assumed. There are also the unexpected errors when doing the experiment. However the accuracy is expected to be below 1% in the real experiment. From the above simulations it is also found that the alignment error and the BPM reading accuracy are important factors for the error estimation. If these two error sources are reduced the launching error will become smaller also. Hence the measurement accuracy can be better when the alignment error and the BPM accuracy are improved.

Acknowledgement

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Reference

[1] C.S.Hwang, F.Y.Lin, T.C.Fan, S.Yen, P.K. Tseng, SRRC/MM/IM/92-01

[2] J. C. Lee, Peace Chang and C. S. Hsue, ”Integral Dipole Field Calibration of the SRRC Storage Ring Combined Function Bending Magnets”, these proceedings.

Table 1. The tracing results of DM2

	Energy (GeV)	I (amp)	bending angle (degree)	$\int B_0$ds (T.m)	current correction factor	ending point x_{end} (mm)	ending point y_{end} (mm)	ending point exit angle (degree)
design	1.3	381.062	10	0.756832	———	622	-36.91	-5
ideal tracing	1.3	———	10.00001	0.756831	———	622	-36.91	-5.00001
initial tracing	1.1651	341.22	10.048	0.681564	———	622	-37.35	-5.048
	1.3	381.062	10.034	0.759384	———	622	-37.19	-5.034
	1.3323	390.51	10.033	0.778212	———	622	-37.18	-5.033
	1.4872	438.62	10.218	0.884681	———	622	-38.00	-5.218
tracing after adjustment	1.1651	339.58	9.9999	0.678297	-0.48 %	622	-36.82	-4.9999
	1.3	379.80	10.00006	0.756838	-0.33 %	622	-36.82	-5.00006
	1.3323	389.21	10.00001	0.775633	-0.33 %	622	-36.82	-5.00001
	1.4872	429.27	10.00045	0.865866	-2.13 %	622	-35.65	-5.00045