STEP-LIKE FIELD MAGNETS TO UNIFORM BEAM DISTRIBUTION AND EXPERIMENT AT CADS INJECTOR-I*

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Abstract

High power is the development tendency of proton accelerator, so obtaining uniform beam distribution on target to decrease peak power density becomes more and more important and critical. The method of using step-like field magnets to obtain a uniform beam distribution on target was presented. In the beamdump line of CADS Injector-I test facility four step-like field magnets (SFM) have been installed to uniform beam distribution to reduce the maximum current density on the beamdump. The magnetic field of step-like field magnets have been measured and discussed in this paper. The simulation results and measurement results of beam uniformization are presented.

INTRODUCTION

With the strong demand for the development of nuclear physics and accelerator application, high-power proton accelerator are rapidly developing and beam power reaches MW level, however the design difficulty of target and beam window is harder. How to obtain uniform beam distribution is more and more important. The octupole or duodecapole magnet are widely used to get uniform distribution in many laboratories and facilities and are proven to be effective. In the non-linear magnetic lenses also has been studied, for example, the so-called dipole pairs [1] or step-like field magnets (SFM) [2]. ESS have adopt beam raster system to get uniform distribution with AC dipole raster magnets [3]. For the step-like filed magnets a lot of works in CSNS [4] and IFMIF [5] have been proposed.

C-ADS Injector-I is a 10 MeV and 10 mA superconducting linac test facility shown in Fig.1 in IHEP to verify technical route of C-ADS injector, which is composed of an ion source, a LEBT, a 325MHz RFQ, a MEBT1, two cryogenic modules (CM1 & CM2) of 14 SC spoke cavities (β=0.12), 14 SC solenoids, 14 cold BPMs and a beam dump line. The commissioning of Injector-I have been finished and the measured beam energy is 10.67 MeV and beam current is 10.6 mA with repetition frequency 2 Hz and pulse length 20 μs. The measured the energy spread by energy spread analysis system is 0.32% [6]. In January 2017 the Injector-I have been operated successful in CW mode with beam current in 2.1 mA and beam energy in 10 MeV. In the Injector-I beam dump line there are four step-like filed magnets installed to uniform beam distribution.

In this paper the measurement of the magnetic field of SFM will be presented, and the magnetic measurement results are transformed to 3D filed map used in TraceWin. With the field map we have studied the beam uniformization by TraceWin in the beam dump line. At last the experiment results are discussed.

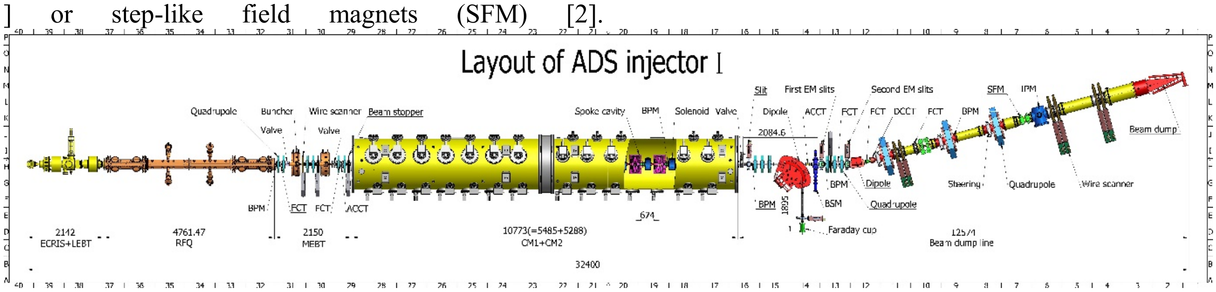

Figure 1: The layout of C-ADS Injector-I.

SFM MAGNETIC MEASUREMENT

In the beam dump line there are four SFMs and two for horizontal beam uniformization and two for vertical beam uniformization, namely SFM-X-1, SFM-X-2, SFM-Y-1 and SFM-Y-2. The two SFMs in same direction have different geometric size to get different step-field position. In a SFM there are two group coils: one is the main coils provide the dipole fields in two sides and another is the secondary coil to offset the magnetic field in the middle region of SFM. Figure 2 shows the schematic and physical drawings of SFM-X-1.

Limited by magnetic field measurement conditions (devices, alignment, and so on) and measurement time which is very tight with the very fast project promoting, meanwhile the SFM have been installed to the beam dump line when the measurement data was submitted to physics person, the measurement is not very comprehensive and the full 3D magnetic field have not obtained directly from measurement. So some assumes and data processing are need to get the 3D magnetic field for further simulation and study of beam uniformization.

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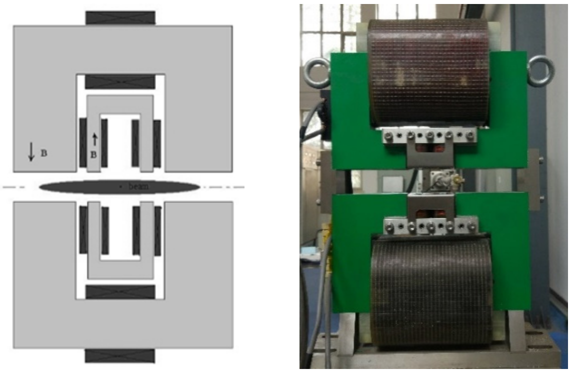

Figure 2: The schematic (left) and physical drawings (right) of SFM-X-1.

We take SFM-Y-2 as an example to introduce the measurement and data processing. The magnetic field B_x along Y direction at x=0 mm with different current independently was measured, which is shown in Fig.3. From the results one can get the magnetic field is linear proportional to coil current and there is residual magnetism in two sides which can explain the difference at large Y position.

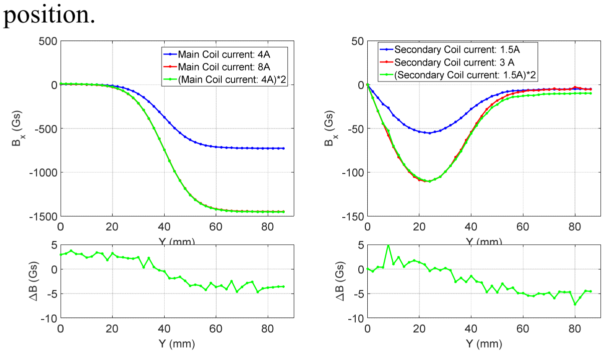

Figure 3: Magnetic field B_x along Y direction at x=0 mm with different coil current. Left is main coil and right is secondary coil.

The magnetic field B_x along Y direction at different x position was measured and shown in Fig.4. From the measurement results one can find the field is almost symmetrical and the difference with different x position is asymmetrical as theoretical expectation. We assume the difference is linear proportional to absolute value of x in the beam region and the field can be expressed as:

$$B_x(x, y, 0) = B_x(0, y, 0) + |x| \cdot \Delta B_{n,x}(y) \; . \quad (1)$$

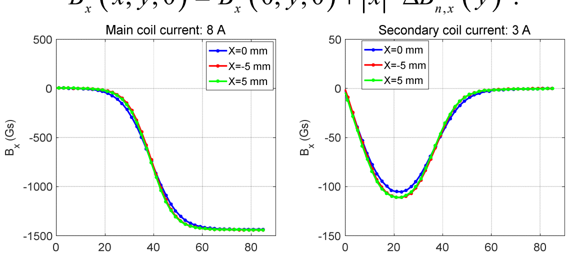

Figure 4: Magnetic field B_x along Y direction at different x position.

The magnetic field B_y along Y direction at different x position was measured and shown in Fig.5. From the measurement results one can find the field is asymmetrical as theoretical expectation. We also assume the magnetic field is linear proportional to x (not very exact) and the field can be expressed as:

$$B_y(x, y, 0) = x \cdot B_{n,y}(y) \; . \quad (2)$$

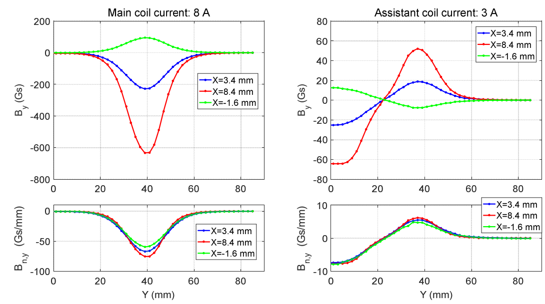

Figure 5: Magnetic field B_y along Y direction at different x position.

According to above analysis we can get the transverse magnetic field by measurement and data processing, which is shown in Fig.6. Because of SFM-X-2 is large enough there is no need big secondary coil current to offset the magnetic field in the middle region. For SFM-X-1 the geometric size is more compact, if the main coil current is 8 A, the secondary coil current is -2.7 A to offset the magnetic field.

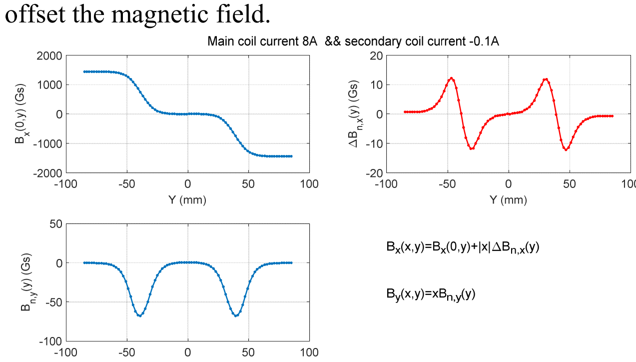

Figure 6: Magnetic field for transverse magnetic field reconstruction of SFM-Y-2.

The magnetic field at different y and z positron (beam direction) also have been measured, which is shown in Fig.7. According to the measurement results we can get 3D field map after carefully reconstruction. Magnetic field of all the four SFM have been measured and reconstructed.

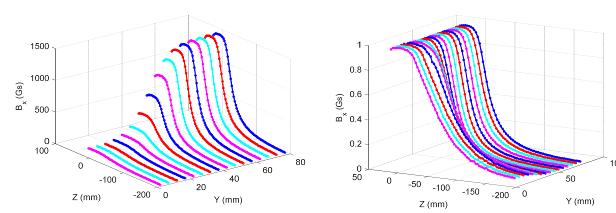

Figure 7: Magnetic field B_x at different y and z position, left figure is measured data and right figure is normalized field by $Bx(0, y, 0)$.

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UNIFORMIZATION STUDY

The method of beam uniformization by SFM is transform both sides to the middle of a large beam size thin flat beam obtained by quadrupoles to decrease beam size and uniform beam distribution. So the peak power density is decrease mainly by enlarge beam size of beam core and SFM control beam size of beam halo. Figure 8 shows the envelope of C-ADS injector-I beam dump line and the red elements are large wire scanners.

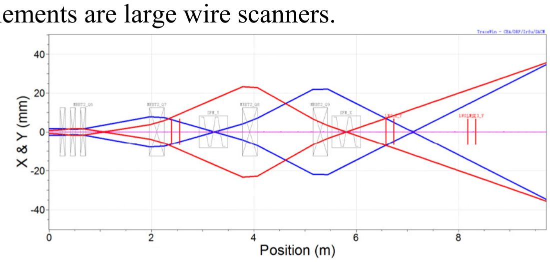

Figure 8: Envelope of beam dump line.

According to SFM magnetic field measurement one can find the field region in beam direction is much larger than SFM, so we need a 3D aperture file combined to the reconstructed field map, which means field overlap and nearby drifts will be replaced by field map. The aperture of SFM-X section is shown in Fig.9. Figure 10 shows the beam distribution on beam dump without SFM and with SFM of one case which is not the optimized results and line density in vertical plane. From the simulation results one can find uniformization by SFM is effective.

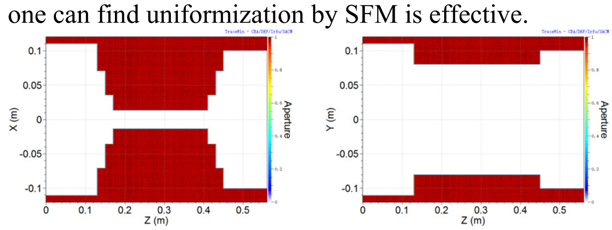

Figure 9: Aperture of SFM-X section.

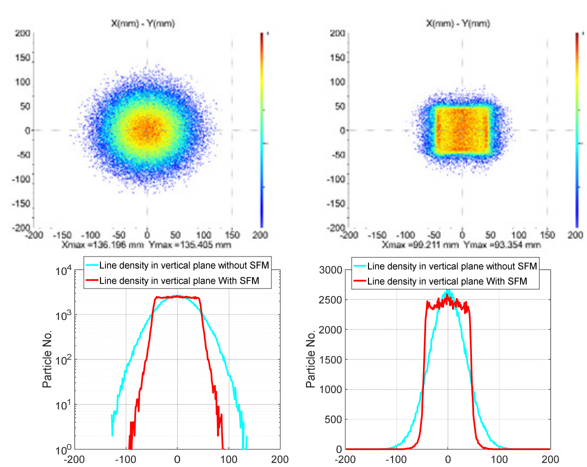

Figure 10: The beam distribution on beam dump without SFM (up left) and with SFM (up right) and line density in vertical plane (down).

EXPERIMENTAL RESULTS

The position of large wire scanner in C-ADS injector-I beam dump line is not very good for uniformization view, but we can also check the uniformization effective of SFM. Because the time for commissioning is very tight and the main aim is CW running, the experiment time is limited and beam current is low only 2 mA. The beam current is low and beam size is large, the signal-to-noise ratio of wire scanners is not very good. Figure 11 shows the measurement and simulation results of the last but one wire scanner. The results between measurement and simulation without SFM are almost agreed. The measurement results with SFM have very bad signal-to-noise ratio, which maybe is because wire scanner have not collect the peak narrow signal. Even though the single is not very good, the profile also has indication of the uniformization. We need more experiments at high beam current which can increase signal-to-noise ratio in the future to get better results.

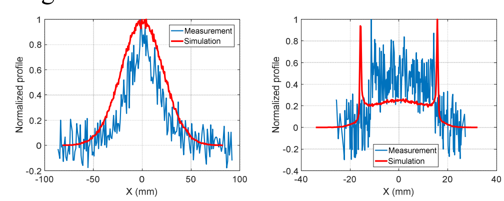

Figure 11: Normalized beam profile of measurement and simulation without SFM (left) and with (SFM).

CONCLUSION

The method of beam uniformization by SFM is discussed and detailed magnetic field measurements of SFM are presented. With the reconstructed field map we study the beam uniformization using SFM in C-ADS injector-I and the experimental results are discussed.

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