FIELD MEASUREMENTS IN THE AGS WARM SNAKE

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Abstract

A new warm snake has been produced for avoiding the transverse coupling resonance in the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory (BNL). This warm snake is the world's first normal conducting helical dipole partial snake. We measured the magnetic field of the warm snake and compared the results with 3D finite element calculations.

INTRODUCTION

Polarized proton beam has been accelerated in the AGS and RHIC at BNL for studying spin effects in QCD [1]. Higher polarization is needed for taking higher quality collision data. A warm siberian snake is designed and built to avoid the depolarizing resonances in AGS. Before installing this warm snake, a solenoidal partial snake was used for avoiding imperfection resonance which is caused by some misalignment of the main dipole magnet in the AGS. However this causes another depolarizing coupling resonance because the longitudinal magnetic field from solenoid couples the horizontal and the vertical betatron motions. So we needed to consider the imperfection resonance with also vertical betatron motion, not only the horizontal betatron motion [2]. The warm snake does not produce the coupling resonance because it is a helical dipole structure.

WARM SNAKE

3D calculation of the magnetic field is important to simulate the helical magnetic field. OPERA-3D/TOSCA [3] was used to simulate the field of the Warm Snake. The simulation model of the Warm Snake is shown in Fig. 1.

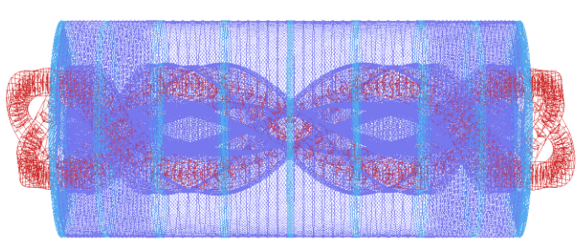

Figure 1: 3D simulation model of the Warm Snake on the OPERA-3D/TOSCA (Red: helical coil, Blue: Laminated iron yoke)

The warm snake has a 132 cm long "slow pitch" region with a pitch of 185 cm in the center, and 39 cm long "rapid pitch" regions in the ends with a pitch of 90 cm. This double pitch structure is used such that zero deflection angle or offset of the beam trajectory is achieved with a single magnet [4]. The beam trajectory is shown in Fig. 2 and Fig. 3. Fig. 4 shows a picture of the actual warm snake.

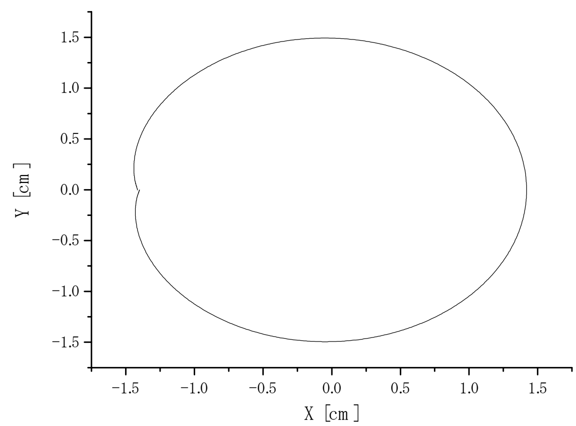

Figure 2: Transverse trajectory of the 2GeV proton beam in the calculated magnetic field of the Warm Snake

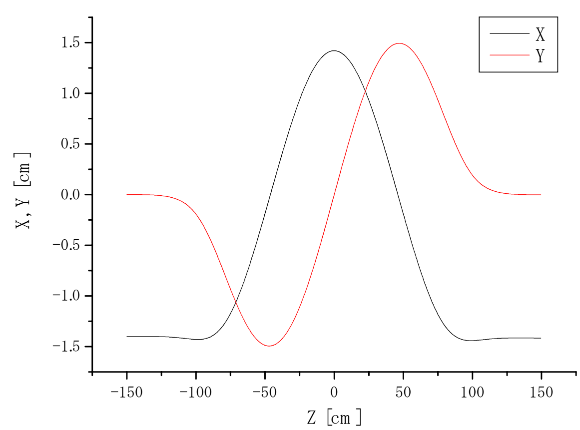

Figure 3: Longitudinal trajectory of the 2GeV proton beam in the calculated magnetic field of the Warm Snake

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Figure 4: Picture of the completed Warm Snake

MEASUREMENT

At first the temperature rise of the cooling water was measured at full current (2700 A, which is the limit of power supply). The average temperature rise is 10.5 degree C as shown in Fig. 5. It is lower than our estimate of 14.8 degree C, which is perhaps due to neglecting air cooling from the surface.

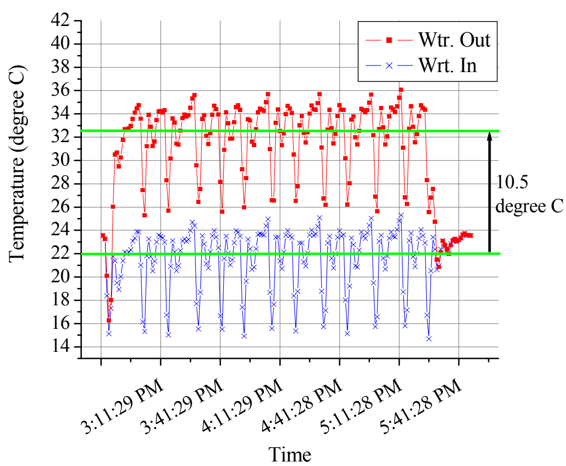

Figure 5: Temperature rise of the cooling water

The main measurement is analyzing magnetic field in the warm snake. A 51 mm long harmonic coil [5] was used to measure the field profile and a 3.58 m long harmonic coil was used to measure the integral dipole field. Fig. 6 shows the distribution of the magnitude of the dipole field.

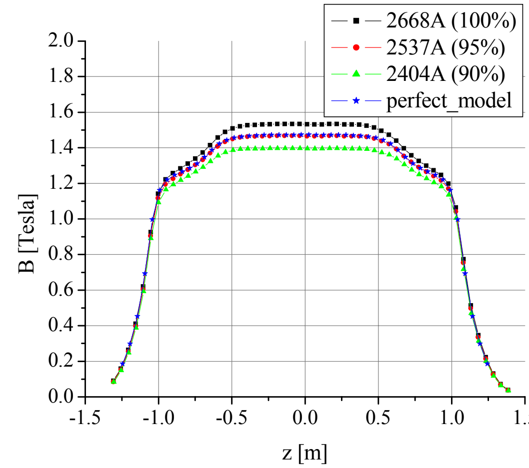

Figure 6: Dipole field distribution measured at 3 different currents and simulated data of the perfect model (no deflection or offset)

As shown in Fig. 6, the 95% operating current plot is similar to the perfect model. The distribution at 2668A (100%) is higher than the perfect model. This result suggests the warm snake has some fabrication errors. The reason for this increase of the field within the slow pitch region is a decrease in the packing factor in the rapid pitch region. This decrease is caused by the outward bending of each end plate by several mm due to Lorentz forces. Also, the volume of the slow pitch region yoke is larger than rapid pitch region. So the rapid pitch region yoke saturates faster than slow pitch region as shown in Fig. 7.

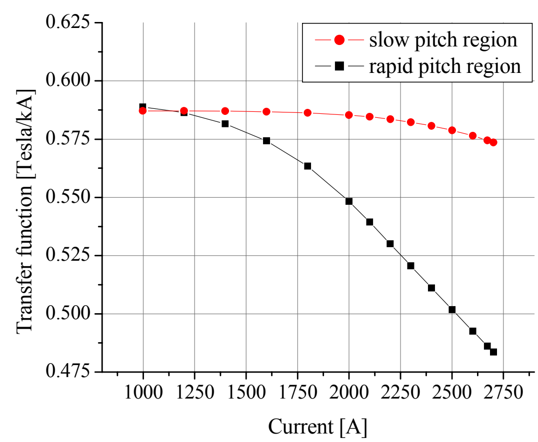

Figure 7: Measured transfer functions at the center of the rapid pitch region and at the center of the slow pitch region.

For correcting this error, a simulation model which has the same magnetic field distribution was needed. The magnetic field of this model is shown in Fig. 8 as plots of error model. This model has almost the same distribution as the perfect model. The parameters which are optimized are operating current and number of 6 mm thick iron shims added on each end plate. The results of the optimization indicate that the operating current should be 2538 A and one 6 mm thick shim should be added to the end plates [6].

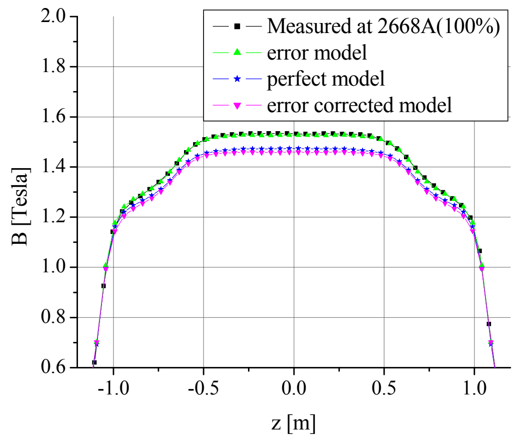

Figure 8: Field profiles before and after error correcting.

Fig. 9 shows the field angle profile measured at 2538A, as well as the calculations from the error corrected model and the perfect model. The arrows in Fig. 9 show the directions of the magnetic field vector.

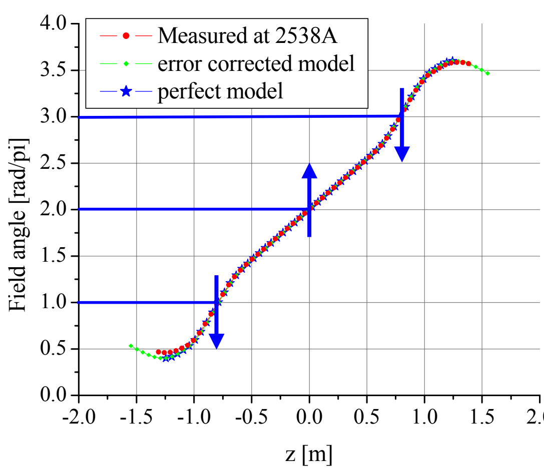

Figure 9: Field angle of the Warm Snake

The field angles agree with calculations in the yoke region, but the measurement data are asymmetric in the fringe regions. It is caused by the electrical connections of the warm snake. The agreement at the transition point between slow pitch region and rapid one shows that the construction of the yoke lamination angle was successfully completed.

Finally the integral field was measured using a long rotating coil. We believed the integral field should be equal to zero to make the beam deflection angle and offset zero. However, the integral field, as seen by the harmonic coil, was estimated from simulated data of the perfect model which gave a value of 2.25×10^{-2} T. m. This difference of integral field comes from the beam trajectory. As shown in Fig. 2, the trajectory is closed, but it is not a perfect circle. Fig. 10 shows the measured integral field as a function of current. The calculated value from the perfect model is shown as a horizontal line.

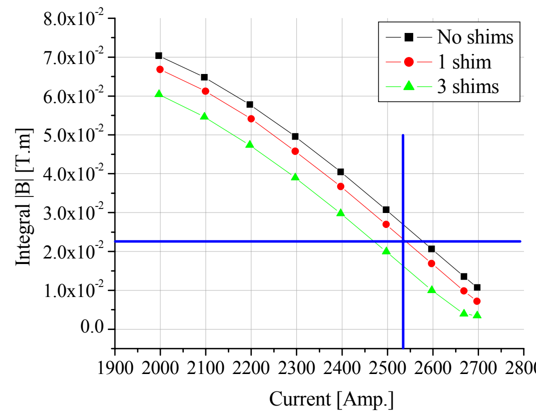

Figure 10: Integral field at the transverse center of the Warm Snake

The perfect model integral field line matches with the measured curve with 1 shim at 2541 A. This current is very similar to the estimated current of 2538 A from the error corrected model. It means that the method of error correcting is right and the warm snake should be operated with 1 shim block at 2540±3A.

CONCLUSION

The fabrication of the Warm Snake was completed but it has some fabrication errors. However the error correction had been done successfully owing to these high quality measurement data. Several Siberian Snake had been measured already and they are used in RHIC. But this measurement for the Warm Snake is very special because this magnet has world's first double pitch structure. So this measurement and error correcting method will be useful for the Siberian Snakes which have double pitch structure. The AGS has plan to be installed a Cold Snake which is superconducting helical dipole partial snake and it has been under construction in BNL. This Cold Snake has double pitch structure. So we have chance to measure a snake in case of superconducting magnet which has double pitch structure.

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