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DESIGN OF PERMANENT DIPOLE MAGNET IN TPS TRANSPORT LINE*

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Abstract

To reduce electric power consumption and advance the magnetic stability, a prototype of BTS dipole magnet in the TPS transfer line between booster and storage ring has been developed. A 1 m long, high-current dipole will be replaced by a permanent magnet made from Sm_2Co_{17}. This new permanent dipole magnet will reduce the total volume compared to the original electric one and improve the homogeneity of integral field. The assembly deviation was also discussed through simulations. This article presents the magnetic circuit design status of prototype aimed at upgrading the TPS transport line.

INTRODUCTION

The development of permanent magnet is one of mainstream trends to curb our reliance on electric power. To date, numerous accelerator facilities, including SPring-8 [1, 2], ESRF [3], SOLEIL II [4] and SLS-II [5], have upgraded their dipoles and quadrupoles with permanent magnets.

The Taiwan Photon Source, TPS, is a third-generation synchrotron accelerator. The magnets are relatively massive in volume with larger gap, requiring a broader good field region (GFR), so permanent magnets as lattice cell have rarely been used in such accelerator. However, we have collaborated with some local suppliers capable of manufacturing magnetic blocks and processed materials. The homemade permanent magnets will be attempted to replace the high-power magnets in TPS.

MAGNET CIRCUIT DESIGN

With a 24 mm gap, 1 m long dipole magnet that provided an integral field (Iy) of almost 0.9 Tm was operated at 408 A in the TPS transport line (BTS). The homogeneity of the integral field should be better than 0.1% within ±25 mm. Approximately 2.4 kW can be saved if this BTS dipole is replaced with permanent magnets.

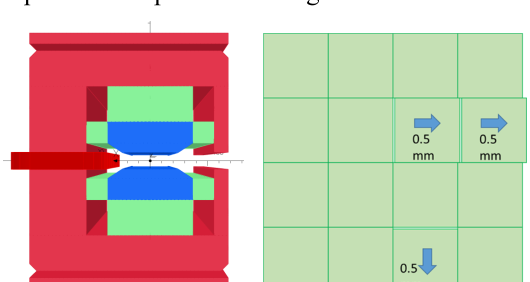

Figure 1: OPERA 3D model

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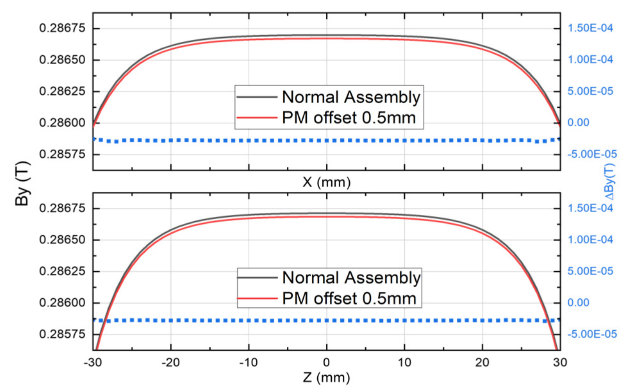

Figure 2: The assembly error of 0.5 mm offset in two directions makes filed deviation under 0.3 gauss.

Material and assembly error

The remanence (Br) of Sm_2Co_{17} is typically lower than that of NdFeB, making it more challenging to achieve a strong field. Nonetheless, Sm2Co17 is preferred because it better tolerates the effect of temperature variation.

To enhance the field strength (By), we plan to glue several magnetic blocks together and study the concept of different configurations [1-3]. In the meantime, our model was built using OPERA 3D (see Fig. 1). Furthermore, the assembly error with a 0.5 mm offset in two directions were simulated as well in Fig. 2. It can be observed that the filed deviation of less than 0.3 gauss indicates uniform flux distribution by the poles.

Design concept

First, we adjusted the dimension of permanent magnetic blocks (PM) to make top and side PMs keep a preferable ratio. The top PM contribute most significantly, while the side PM increase in size proportionally with the top PM.

Next, reducing the pole width increased the field strength, but narrowed the GFR. In this case, shimming to a depth of 1 mm improved the Iy homogeneity by six times, though it slightly decreased the magnetic field.

Coarse adjustment

We then adjusted the yoke width to approach saturation, as shown in Fig. 3, with a pair of outer plates (OP) providing coarse adjustments. Afterward, the thickness of outer plate was determined through calculations as depicted in Fig. 4 and verified by measurement.

Maintaining the nominal field in a low-slope area is advantageous for adjusting the OP in the laboratory through field measurements. Our calculations indicated that the magnetic field was not sensitive to the gap between the

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outer plate and yoke. Figure 4 shows that an OP thickness of 30 mm is similar to 15 mm at a 10 mm gap. Ultimately, a pair of OPs was decided to be 15 mm thick.

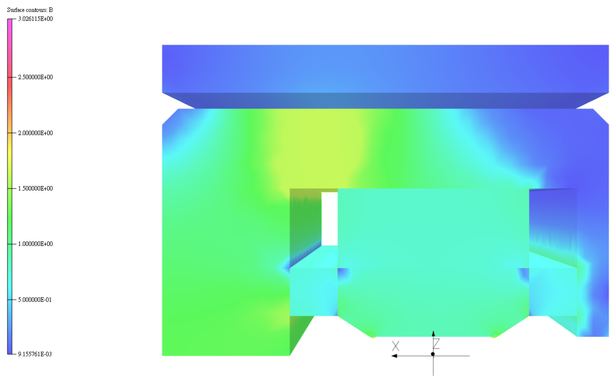

Figure 3: the magnetic field distribution in a half model of TPS BTS permanent dipole simulation

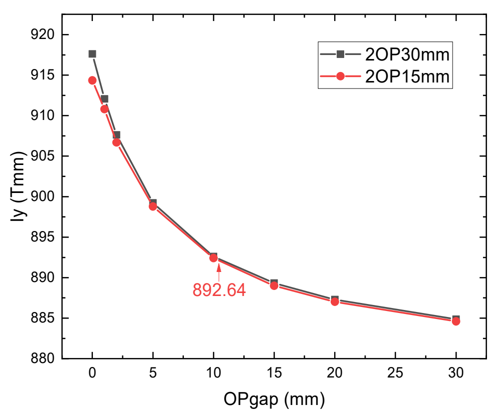

Figure 4: The magnetic field decreases with increasing outer plate gap.

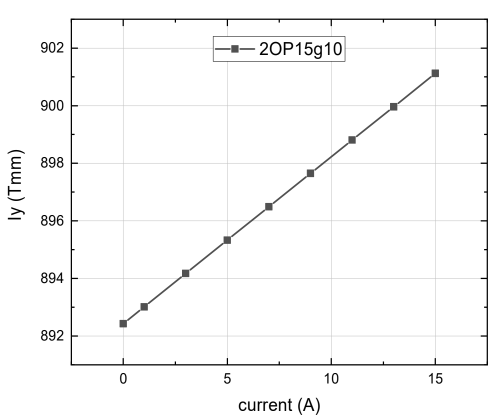

Figure 5: The magnetic field is in direct proportion to trim coil current.

Fine adjustment

Lastly, we also designed a set of trim coils with 42 turns with a cross-section size of 2x3 mm for fine adjustments from control room, if necessary. Figure 5 shows that the linear range under 15 A has a capability of 580 Gcm/A.

For various OP gaps and trim coil currents, Fig. 6-8 demonstrate that the homogeneity of the center and integral fields is less than 6E-4 and 8E-4, respectively.

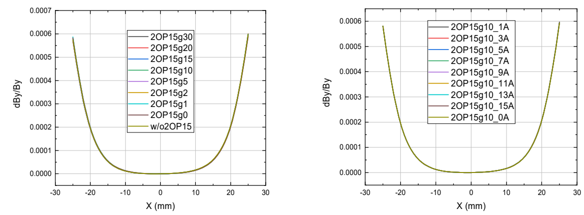

Figure 6: The homogeneity of By in different gap of OP thickness 15 mm and at various trim coil current are less than 6E-4.

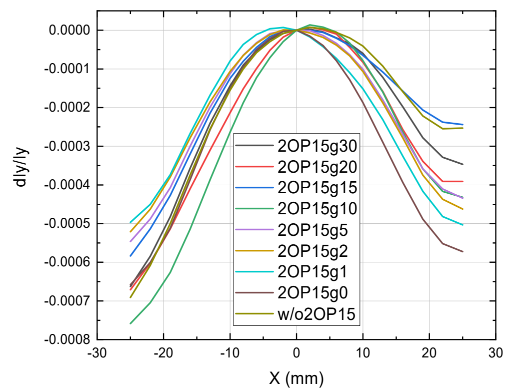

Figure 7: The homogeneity of Iy in different gap of OP thickness 15 mm is less than 8E-4.

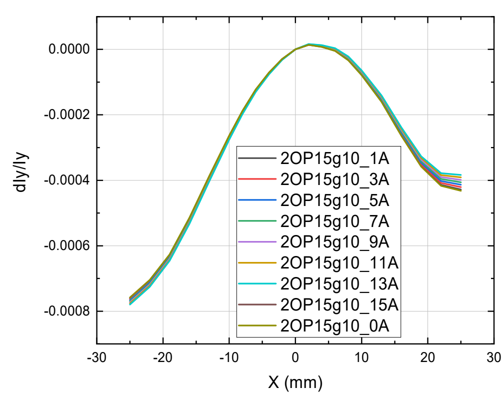

Figure 8: For OP thickness 15 mm with gap 10 mm, the homogeneity of Iy at various trim coil current is less than 8E-4.

Figure 7 illustrates that at 25 mm, the homogeneity of the integral field shows slight differences with varying gaps between the OP and yoke. Due to the nearly saturated yoke, changes in the OP gap affect the flux paths. Thus, the variation in the magnetic field with OP gap changes is related to yoke saturation.

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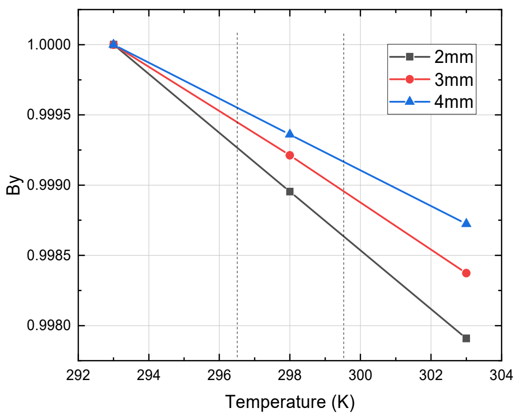

Figure 9: the variation of magnetic field with temperature for various thickness of NiFe

NiFe alloy will be used to minimize the temperature effect on the magnetic field. Considering the worst-case scenario, an environmental temperature variation of ±1.5K will impact field stability and homogeneity. To meet the field quality requirements, we calculated the magnetic field variation with temperature for various NiFe thicknesses. Fig. 9 illustrates that with 4 mm of NiFe alloy, the field variation is less than 3E-4 from 23.5 to 26.5 degrees Celsius.

Table 1: TPS BTS permanent magnetic dipole

Margin	unit	Calculation
Gap	mm	24
Iron length	m	1
Nominal field	Tm	0.893
ΔB/B in ±25mm	-	< 6 E-4
ΔI/I in ±25mm	-	< 8 E-4
PM_{top} quantity	pcs	120
PM_{top} volume	mm^3	40x50x50
PM_{side} quantity	pcs	80
PM_{side} volume	mm^3	30x30x50
Remanence, Br	T	1.04
Number of coils	turns	42
Max. current	A	15

Result

We incorporated the magnetic circuit concept, PM selection, pole width, yoke saturation, outer plates (OP) for coarse adjustment, trim coils for fine adjustment, and NiFe alloy for temperature effects into our BTS permanent magnetic dipole design (see Fig. 10). The simulation data is compiled in Table 1, which lists the calculation results and information.

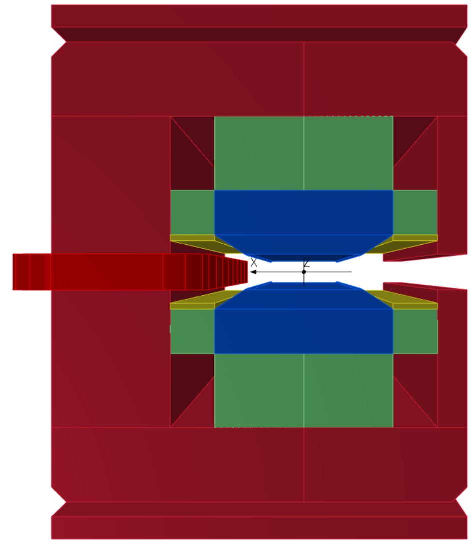

Figure 10: TPS BTS permanent dipole model contains PM, pole, yoke, OP, trim coil and NiFe.

CONCLUSION

The volume of the new BTS dipole magnet, measuring 280x330x1000 mm^3 and based on permanent magnets, will be smaller than the original one. The field strength and homogeneity in the same gap were also achieved.

Despite the sacrifice in field strength, the use of Sm_2Co_{17} and NiFe alloy materials ensured magnetic field stability with temperature variations. The design of outer plates and trim coils for coarse and fine adjustments, respectively, is rare in third-generation synchrotron accelerators. We have integrated these features to construct the new PM dipole to replace the original one. Furthermore, the prototype is domestically manufactured. Field measurements in the laboratory and operation in the TPS tunnel will be completed in the future.

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