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# Sensitivity of Field Harmonics in Nb3Sn Dipole Magnet to the Correction Strip Position

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*Abstract* – The method of correction of the coil magnetization effect in Nb3Sn dipole magnet using thin iron strips has been proposed in TD099-048. This note presents the results of calculation of field harmonics sensitivity to the correction strip geometry and position variations in magnet bore. A possibility of reduction of strip alignment errors on the field quality is also discussed.

## I. INTRODUCTION

Coil magnetization effect in superconducting accelerator magnets makes worse the magnetic field quality in the bore at low fields and thus reduces the accelerator dynamic aperture, decreases the operation field range for SC magnets and complicates the machine correction system. Analysis shows that this effect becomes even more important in high field magnets based on the Nb3Sn strands. These magnets are being developed for post-LHC Very Large Hadron Collider [1]. The methods of correction of the coil magnetization effect in Nb3Sn dipole magnets using thin iron strips or thin pipe have been proposed and studied in [2-4]. The correction scheme based on thin iron strips placed in magnet bore looks quite simple and very attractive for the use in Nb3Sn accelerator magnets. This note presents the results of calculation of forces applied to the strips as well as the results of sensitivity analysis of field harmonics to strip geometry variations and possible strip misalignment. The possibility of reduction of strip alignment errors on the field quality is also discussed.

## II. RESULTS AND DISCUSSION

Thin iron correction strips are installed on the beam pipe (glued to the beam pipe for mechanical stability) under the ground insulation layers. The ground insulation provides an additional mechanical support to the strips affected by the magnetic forces.

The values of forces acting on the magnetized strips placed in the external magnetic field were evaluated by the Maxwell stress integrals for 0.23 mm thick strips in 11 T field. Table 1 summarizes the force and stress components for two strips and Figure 1 shows the force directions. As it can be seen, the forces are directed outwards the beam pipe outer surface. However, the values of tear stress and shear stress are quite small for the epoxy glued materials less than 20 kPa. It should not cause any problem with the strip mechanical support.

Table 1: Forces and stresses at bore field of 11 T.

| Strip | Width, mm | Fx, N/m | Fy, N/m | Fr, N/m | Fϕ, N/m | Pr, kPa | Pϕ, kPa |
|---|---|---|---|---|---|---|---|
| Lower | 3.81 | 73.9 | 15.1 | 66.9 | -34.7 | 17.5 | -9.1 |
| Upper | 5.20 | -35.0 | 122.7 | 96.4 | 83.6 | 18.5 | 16.1 |

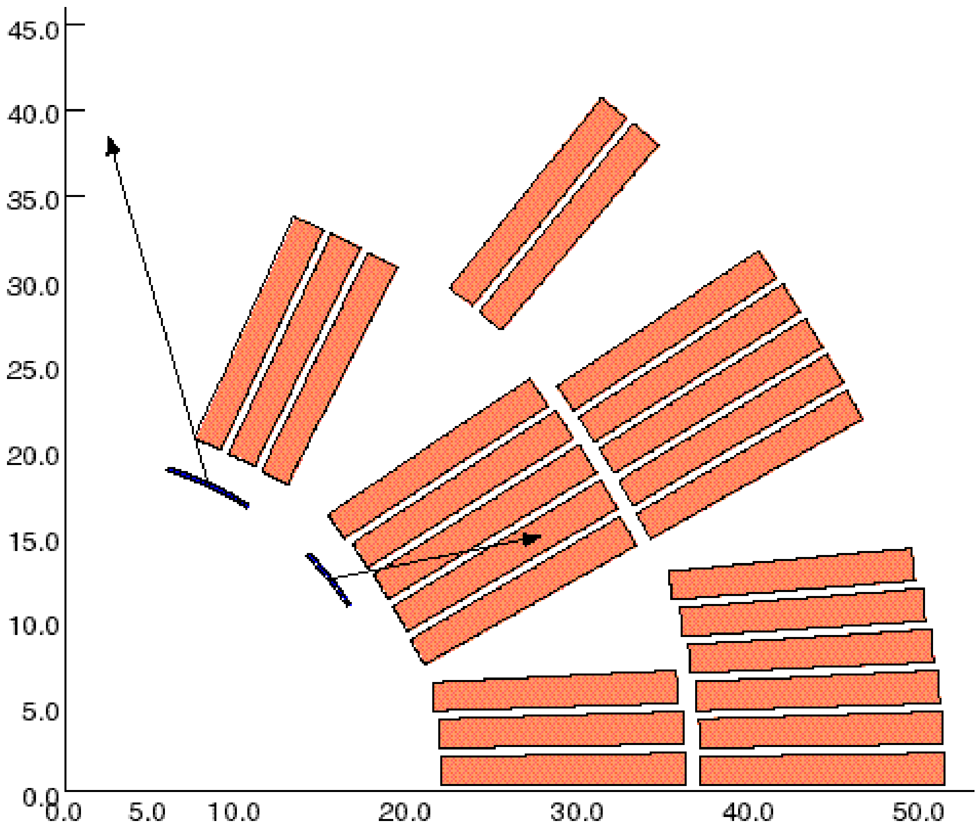


Figure 1. Force direction.

The calculation of sensitivity of field harmonics to strip geometry and position variations has been also performed. The calculations were done using OPERA 2D code for magnet central field of 1 T. The results of sensitivity analysis of field harmonics to strip size variations and symmetrical radial and azimuthal displacements are reported in Table 2. As it can be seen, the most critical parameter is the strip thickness. Its variations should be less than 10 microns which is ~5% of the strip thickness.

Table 2. Sextupole and decapole variation due to strip size variation and displacement.

| Variable | Variation range, mm | Δb3, unit | Δb5, unit |
|---|---|---|---|
| Azimuthal position | +/- 0.5 | -/+ 1.7 | -/+ 0.1 |
| Radial position | +/- 0.1 | -/+ 0.25 | +/- 0.44 |
| Strip width | +/- 0.5 | +/- 3.58 | -/+ 1.21 |
| Strip thickness | +/- 0.05 | +/- 8.95 | -/+ 3.71 |

Several possible cases of strip asymmetrical displacement from the design position were also analyzed. They were:

- beam pipe misalignment in horizontal and vertical planes
- beam pipe azimuthal rotation
- one strip azimuthal misalignment

The results are summarized in Table 3. As it can be seen, the biggest error of 3.7 units in quadrupole corresponds to the pipe displacement in horizontal or vertical directions. An azimuthal rotation of whole pipe gives 3.1 units in skew sextupole and azimuthal displacement of one strip gives 0.52 units in skew quadrupole.

Table 3. Field errors due to strip asymmetrical displacement.

| Strip displacement | Value, mm | Normal multipoles, units | | | | Skew multipoles, units | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Δb2 | Δb3 | Δb4 | Δb5 | Δa1 | Δa2 | Δa3 | Δa4 | Δa5 |
| Pipe horizontal | 0.5 | 3.7 | 0.12 | 0.66 | 0.12 | 0 | 0 | 0 | 0 | 0 |
| Pipe vertical | 0.5 | 0 | 0 | 0 | 0 | 0 | 3.7 | 0 | 0.54 | 0 |
| Pipe azimuthal | 0.5* | 0 | 0.16 | 0 | 0.05 | 0.45 | 0 | 3.12 | 0 | 0.39 |
| One strip azimuthal | 0.5* | 0.25 | 0.36 | 0.50 | 0.10 | 0.04 | 0.52 | 0.48 | 0.09 | 0.37 |

* - 1.45 degree

As it follows from Table 2 and 3, the main requirements to strip size and their position variations in the magnet are quite reasonable and practically achievable.

To maintain the required strip alignment they could be glued to the inner surface of coil during the coil fabrication. In this case the strip misplacement relatively to the coil could be considerably smaller (at a level of cables misplacement). A drawback of this idea is an inability to replace strips after coil fabrication, as they will be glued to the coil during an epoxy impregnation.

## REFERENCES


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