Eliminating field distortions caused by the HTS beam screen coating in FCC dipole magnets

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1) Abstract:
In order to decrease the beam impedance the beam screen of the FCC ring is planned to receive a high-temperature superconductor coating. However, the persistent currents induced in the coating would distort the ring's magnetic field.

Rather than trying to suppress this effect we examine the possibility to use a tailored thickness profile of the coating such that these currents produce a field with the same symmetry as the external field, giving an offset to the dipole field rather than distorting it.

2) Problem:
A resistive (copper) beam screen would limit the intensity of the FCC beam. Planned solution: reduce the beam impedance by a thin HTS coating on the beam screen [1]. However, such a superconducting layer would distort the field, introducing higher order components via the persistent Eddy currents [2]. The distortion is more significant at low field, therefore we optimized the coating's thickness at 1 T (injection).

3) Proposed solution:
Instead of trying to eliminate the persistent currents (difficult), we can try to master them. Goal: find a specific thickness profile of the coating such that the field generated by the Eddy currents have the same symmetry as the external field. This does not distort the field, only adds an offset to it, which can be compensated by adjusting the power supply.

Note: if J(B)=const and the beam screen is cylindrical, d(θ)=cos(θ) would give a dipole contribution.

4) Assumptions:
• Calculate the fields in 2D and assume the set-up is infinitely long in the third dimension.
• The cross-section of the beam screen is constructed of straight segments. HTS thickness is constant within a segment.
• Segments are grouped according to symmetry (see Fig. 1). All segments within a group have the same thickness $d_{i,m}$.
• The field generated by the Eddy currents is much smaller than the external field – evaluate $J(B)$ at the external field. Different parts of the HTS coating do not interact, so they can be treated independently.
• Substitute the HTS layers by infinitely thin surface currents: $d_j J(B)$.

5) Calculations:
I) Determine the current density within the segments. In dipole external field this is simply $\pm J_1(B,\beta)$ in the two halves of the segment where $\beta$ is the angle of the segment w.r.t. the external field. For a quadrupole field this step is more complicated.

II) Numerically integrate the contribution of one segment group $i$ to the vector potential at any point $(x,y)$, assuming unit thickness of the HTS layer.

III) Sample the vector potential around a circle (at $2/3$ “aperture”) and Fourier-transform it to get the multipole components: $F_{i,m}$ is the $m$th multipole component due to the segment group $i$.

IV) Due to the negligible interaction between segments, the problem is linear. The total multipole component with layer thickness $d_i$ is obtained as (sum over all segment groups):

$$F_m = \sum_i d_i F_{i,m}$$

V) A given multipole component $m$ can be exactly cancelled with physical thicknesses (all $d_i>0$) if not all $F_{i,m}$ have the same sign.

6) Results:
Thanks to the setup’s symmetry the even multipole components are zero.

1st configuration: zero sextupole component is achievable if the ratio is $d_1:d_2=0.772$.

2nd configuration: to eliminate the sextupole component the thickness ratio has to be $d_1:d_2=4.607$.

3rd configuration: It is possible to simultaneously eliminate the $m=3,5,7$ components with the following ratio: $3.630 : 3.032 : 2.015 : 1$.

In the 1st and 2nd case the first nonzero component (decapole) is 5% and 3% w.r.t. the dipole component of the coating (both are around 0.4% of the external dipole field).

In the 3rd case the 11th component was the biggest one, still being only 0.15% of the dipole component, and 0.01% of the external field.

The induced field can be seen in Fig. 2.

7) Conclusion and outlook:
A tailored thickness profile could drastically reduce the distortion of an external dipole field.

To do: use the same method (with a more complicated algorithm to determine the Eddy currents) to minimize the distortions in a quadrupole external field.

References
http://indico.cern.ch/event/619380/contributions/2527417/

Figure 1: Three possible configurations. Colors indicate segment groups with the same thickness of the HTS layer. The circle in the middle is at the 2/3 of the beam screen inner diameter where the generated field was sampled.

Figure 2: The B field induced by the beam screen in case of 1 μm tapes (left), and with a tailored thickness profile (right), both in case of 1T dipole external field.

Figure 3: Multipole components as a function of B for configuration 3 (thickness profile optimized at B=1 T)