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Longitudinal Periodicity in Superconducting Dipole Magnets

M. Kuchnir
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

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Recent magnetic measurements sensitive to the persistent currents in superconducting HERA dipole magnets uncovered a longitudinal periodic pattern with a period equal to the pitch of the strands in the cable[1]. Not all the observed facets of this phenomenon have been explained yet. Although the existence of this pattern does not affect the performance of the accelerator, it is of interest to understand its exact source.

In this note it is suggested how this pattern could result from differences in the strands making up the cable. More specifically, from differences in their $\langle Jc*D \rangle$, the average of the product Jc*D, of the filaments of a strand, where Jc is the critical current density and D is the diameter of the filament. These strand-to-strand differences in a cable are to be expected from the selection process that probably occurred in the cable manufacture: strands of high and low critical current were mixed in order to maximize cable production yield.

At Fermilab this pattern was recently observed in the remanent dipole field of DSA321, a short 50 mm SSC dipole prototype[2]. The sinusoidal pattern observed after an excursion to 7500 A had an amplitude of 1.3 gauss over an average remanent dipole of 10.5 gauss. Hints of a sinusoidal pattern were observed[3] back in August of 1986 in the NMR scan of the first full length SSC dipole, DD0001. The scan done with the magnet carrying 2000 A, shows the amplitude of the pattern to be of the order of 50 ppm or 1 gauss. Although the occurrence of this pattern has not yet been confirmed experimentally in Tevatron superconducting dipole magnets, it is expected there too.

Of the three equivalent descriptions: superconductor magnetization, persistent current distribution or trapped flux pattern the latter is more appropriate to this explanation. It is the contribution from the trapped flux to the dipole field and its harmonic distortions (sextupole, decapole etc.) that concern us here. M.A. Green[4] elaborates on how the $\langle Jc*D \rangle$ of the strand is the parameter reflecting the magnetic properties related to the trapped flux or remanent field. As was mentioned above, $\langle Jc*D \rangle$ varies from strand to strand in the same cable. Therefore the contribution from the trapped flux will have a pattern reflecting the zigzag of the strands in a Rutherford type cable provided it is not averaged out. We proceed to describe how complete averaging is prevented.

The amount of trapped flux in samples of cables as quantified in magnetization measurements, depends on the superconducting filaments, their temperature and the magnetic field history through which they were submitted. Time is also a parameter of relevance here since time dependent eddie currents contribute to the magnetizing field and the trapped flux changes with time via the flux creep mechanism. Figure 1 presents a typical magnetization curve for a Tevatron cable[5] that was cycled slowly at least twice (the first cycle is different from the subsequent ones since it holds a very different history). Note that the absolute value of the magnetization (magnetic moment per unit volume) has two maxima one at fields of the order 0.1 T for increasing fields and another at the lowest field for decreasing fields. Let us further note that for cycles involving lower maximum fields the transition (dashed lines) from the ascending field part of the curve to the descending field part of the curve happens at this maximum field with no change of the low field portion

of the hysteresis curve. For cycles with even lower maximum magnetic fields, the hysteresis curves get severely distorted and for some particular maximum field, the hysteresis leads to a "special contribution" to the remanent magnetization.

Figure 2 presents the magnetic field lines of an old SSC prototype superposed to the region occupied by the cables. The positions of a single "distinctive" strand are indicated representing the strand-to-strand differences. The magnetic field lines were calculated as due only to the transport current through the coil[6]. The contribution from persistent currents (i.e. superconductor magnetization) is not included and can be treated as a correction[7]. One now calls attention to the low magnetic field regions over the cables around the horizontal midplane of the magnet. These quasi-circular field lines expand or contract as a function of the cycling of the transport current in the magnet. The intersection of the narrow quasi-circular distribution of lines corresponding to the "special contribution" magnetizing field and the position of strands with "distinctive" $\langle Jc*D \rangle$ gives a contribution to the magnetic field that is hard to be averaged out and has the observed cable pitch periodicity.

The mechanism described above coupled with flux creep phenomena[8] aside from explaining what was observed in HERA magnets predicts, for the SSC magnets , a predominant influence of the outer coil cable pitch on the pattern.
It remains to show that typical variations in $\langle Jc*D \rangle$ can yield the observed pattern quantitatively.

References:

[1] H. Bruck, D. Gall, J. Krzywinski, R. Meinke, H. Preissner, A. Freter, M. Halemeyer, P. Schmuser, R. Stiening, D. ter Avest, L.J.M. van de Klundert -"Observation of a Periodic Pattern in the Persistent-Current Fields of the Superconducting HERA Dipole Magnets" - DESY HERA 91-01 (January 1991)

[2] M. Wake & Lab 2 - private communication

[3] M. Kuchnir, Edward E. Schmidt, R.W. Hanft and J.B. Strait -"NMR Measurements in SSC Dipole D00001" - Fermilab TM-1420 September 12, 1986.

[4] M.A. Green -"Residual Fields in Superconducting Magnets" - Proc. of the Magnet Technology Conf. MT-4, p 339 (1972) Brokhaven National Laboratory.

[5] M. Kuchnir and A.K. Ghosh -"Magnetization Measurements of some Superconducting Cables" - Fermilab TM-1286 (Dec. 14, 1984)

[6] R.W. Hanft - private communication

[7] H.E. Fisk, R.A. Hanft, M. Kuchnir and A.D. McInturff "Passive Correction of Persistent Current Multipoles in Superconducting Accelerator Dipoles" - Proceedings of ICFA Worshop on Superconducting Magnets and Cryogenics Brookhaven National Laboratory Publication BNL 52006, p.222, May 12-16, (1986), also Fermilab TM-1411, also SSC-N-236

[8] M. Kuchnir and A.V. Tollestrup -"Flux Creep in a Tevatron Cable" - IEEE Transactions on Magnetics, vol 25, 1839 (1989), also Fermilab TM-1544.

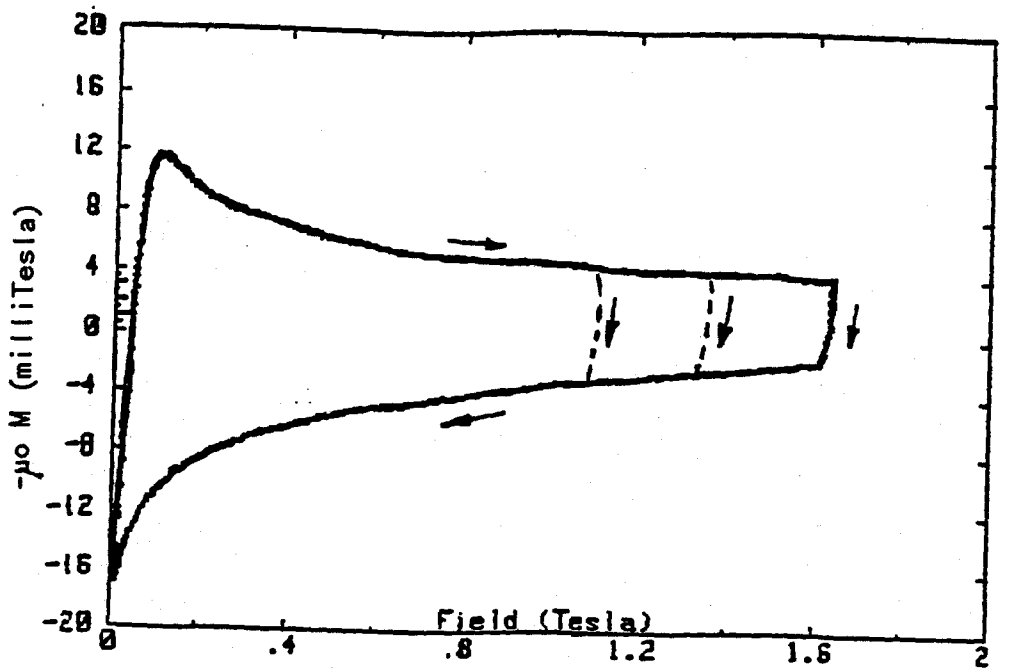

Figure 1. Typical Tevatron cable magnetization data

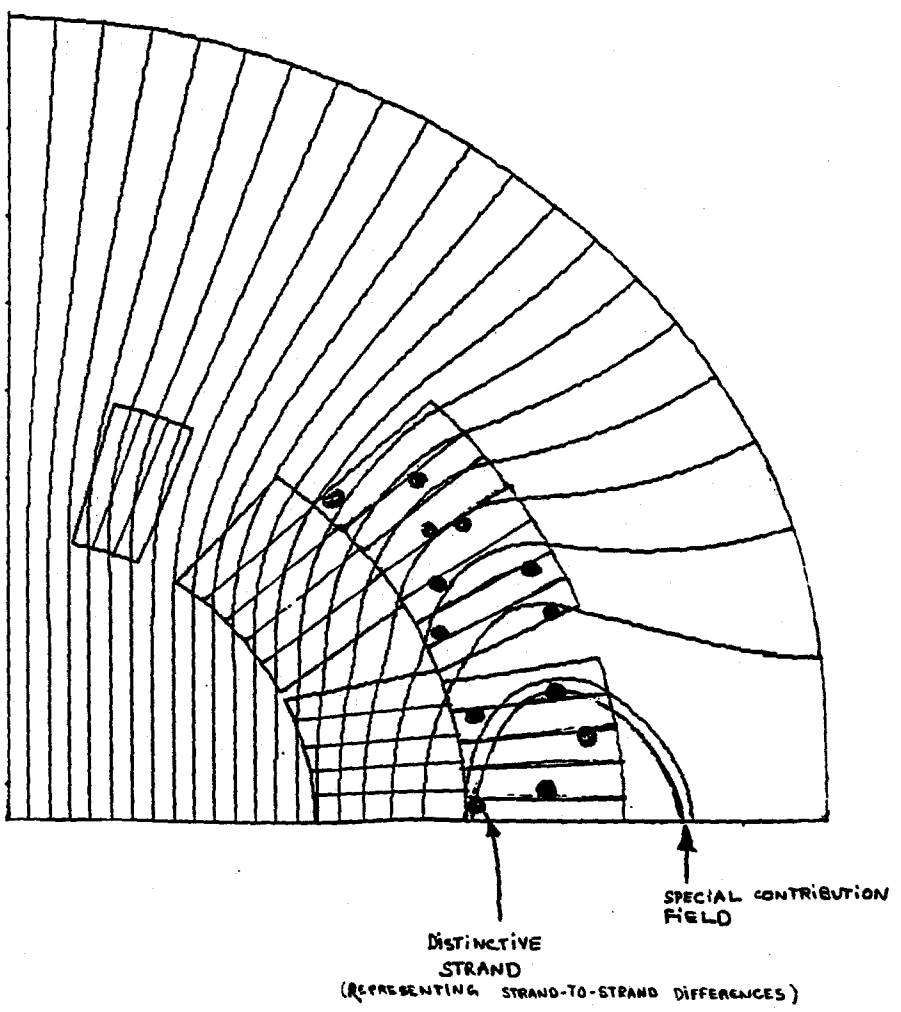

Figure 2. First quadrant of old SSC prototype dipole showing magnetic field lines