Fermilab

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Masayoshi Wake

Coil Deformation and Transfer Function Change

Funny distortions in transfer function of DSA324 and DSA326 are difficult to understand. If it is due to the warm bore magnetization, it should be saturated at low current. If it comes from the yoke material anomaly, saturation field is one of the most difficult characteristics to change. Packing error of iron yoke should result as the early or late saturation. The transfer function plots in the attached figures show some nonlinear change of transfer function when the current is increased. It seems like having a different behavior between regions in the return end half and lead end half. Especially, in the return end half, there is an increase of transfer function with current. First of all, all these changes are too large compared to the calculation made by Gupta.

An estimation of the effect of coil deformation on the transfer function might be interesting to understand the phenomena. Detailed numerical calculation must be made but here I will present a simple analytic model.

Assuming an arc shell of inner radius $r_1[cm]$, outer radius $r_2[cm]$ and pole angle θ, the dipole field $B[kG]$ is given [1] as:

$$B = \frac{4}{5} j(r_2 - r_1)(1 + \frac{r_1^2 + r_1 r_2 + r_2^2}{3R^2}) \sin\theta \tag{1}$$

where, $j[kA/cm^2]$ is the current density and $R[cm]$ is the inner radius of the iron yoke. Total current in the cross section $I[kA]$ is

$$I = (r_2 + r_1)(r_2 - r_1) j\theta \tag{2}$$

Therefore the transfer functionT_f is:

$$T_f = \frac{B}{I} = \frac{4}{5}(1 + \frac{r_1^2 + r_1 r_2 + r_2^2}{3R^2})\frac{\sin\theta}{\theta} \tag{3}$$

Taking derivative of equation,

$$\frac{\partial T_f}{\partial \theta} = \frac{4}{5}(1 + \frac{r_1^2 + r_1 r_2 + r_2^2}{3R^2})\frac{\theta\cos\theta - \sin\theta}{\theta^2} \tag{4}$$

*Distribution: R.Bossert, J.Carson, S.Delchamps, S.Gourlay, T.Jaffery, W.Koska, M.Kuchnir, M.Lamm, G.Pewitt, R.Sims, J.Strait

[1] Derivation of basic formula is given by K.Halback, Nucl.inst.meth. 78 185 (1970)

$$\frac{\frac{\partial T_f}{\partial \theta}}{T_f} = \cot\theta - \frac{1}{\theta} \tag{5}$$

taking $\theta = 60°$ as the average of inner and outer coil,

$$\Delta T_f = -0.378\Delta\theta$$
$$\Delta T_f[\%] \sim -0.042\Delta l[mil] \tag{6}$$

Note that the coefficient is negative. The azimuthal compression of the coil increases the transfer function. Now, the compression of the coil in the radial direction is estimated by :

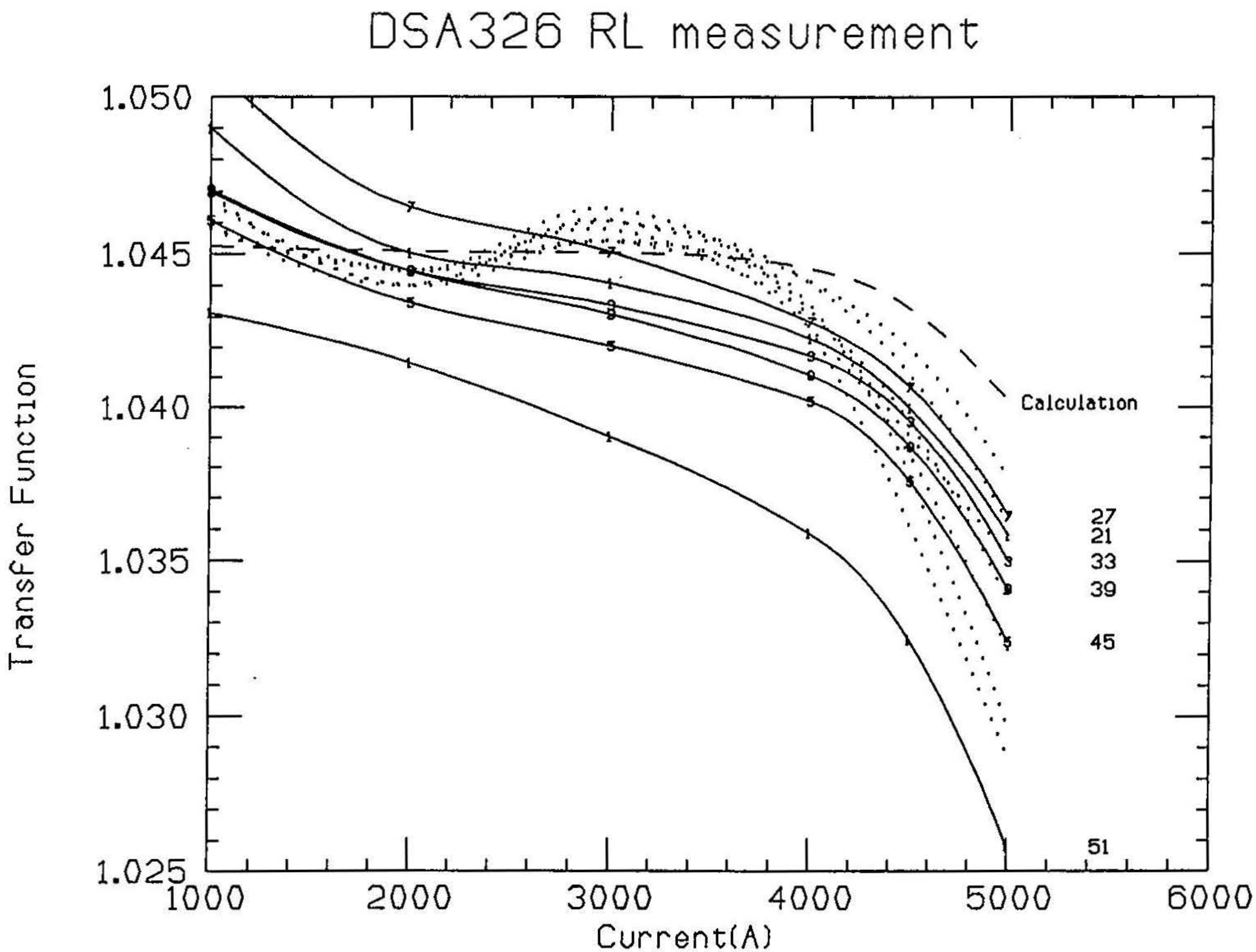
$$\frac{\frac{\partial T_f}{\partial r_1}}{T_f} = \frac{2r_1 + r_2}{3R^2 + r_1^2 + r_1 r_2 + r_2^2} - \frac{1}{r_2 - r_1} \tag{7}$$

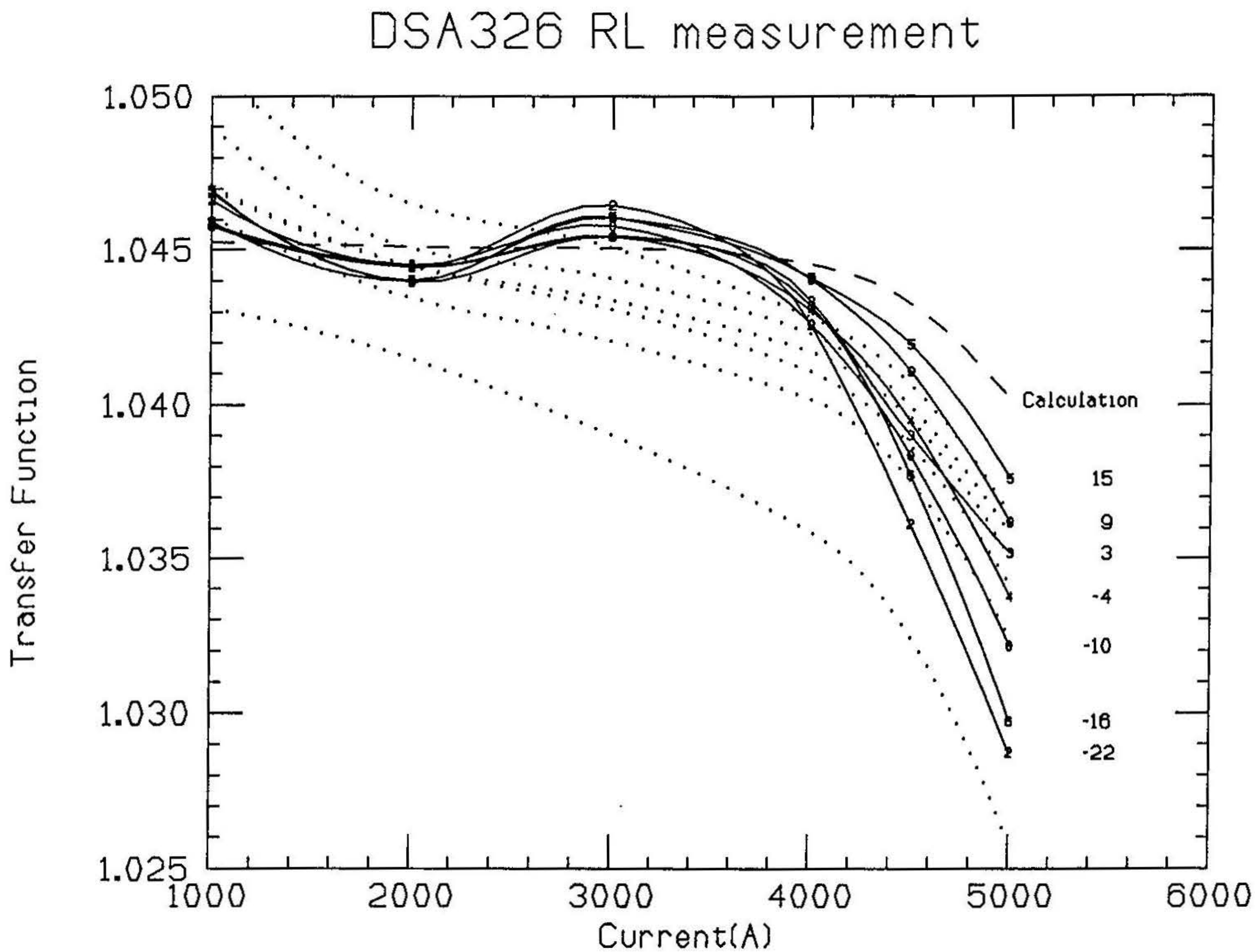
Giving some rough number such as $r1 = 2.5cm, r2 = 4.9cm$ and $R = 6.8cm$,

$$\Delta T_f[\%] = -0.08\Delta r_1[mil] \tag{8}$$

The compression due to the hoop stress decreases the transfer function. The real deformation of the coil is of course much more complicated. Ovalization of the cross section may happen but should be very small. The collar and yoke was designed for that. The change of the center of current occurs even if there is no coil motion at mid-plane and pole angle as I talked in the R&D meeting the other day[2]. But this should happen in every magnet. Some combination of these motion could explain change of transfer function. If the azimuthal motion happens due to some errors in the collaring pressure in the return end side half of the magnet and the whole magnet receives radial compression by the hoop stress, the transfer function behavior can be accounted for. Although, the amount of motion which correspond to the measured data have to be about 10 mil. This number seems too large to be real. If this is true, the effect to the multipole should be even larger but we do not observe it. Could there be any effect which has larger effect on transfer function than that on sextupole? The mystery continues.

[2]to be written in some TS-SSC note.


DSA326 RL measurement
Transfer Function
1.050
1.045
1.040
1.035
1.030
1.025
1000
2000
3000
4000
5000
6000
Current(A)
Calculation
27
21
33
39
45
51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9
3
-4
-10
-16
-22