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Finite Element Analysis of NC-9 Dipole

Note #6

Lorentz Force Loading of Coils in a Rigid Cavity

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Introduction

This note reports the results of finite element calculations of the NC-9 dipole coils confined to an infinitely rigid cavity and loaded with Lorentz forces corresponding to magnet energization of 6408 amps. By studying the coils isolated from the collars and the inner coil separated from the outer coil it is possible to determine whether various phenomena noticed in the complete dipole cross-section [1] are caused by the flexibility and interaction of the collars, the interaction between the two coils, the distribution of the Lorentz forces or some other cause. The studies of each coil separately also allow for verification of the model with respect to the simple, one dimensional, force balance spring model.

To facilitate these calculations, three models were used, based on the full dipole model [2]:

I) Inner coil only.

II) Outer coil only.

III) Both coils and the interfacing solid.

In all three models each conductor is composed of three elements and each wedge is composed of six elements. The elastic modulus of the conductors is 1.5×10^6 psi. The coils were constrained azimuthally at both the poles and the midplanes. In the models involving only a single coil, the outer radius of the coil was constrained radially. For the model with both coils, the interfacing solid was used between the two coils and between the outer radius of each coil and the rigid cavity. In this model, the interfacing solid at the outermost radius is constrained radially.

The models were loaded with Lorentz forces corresponding to 6408 amps [3]. These forces, which are given for the centroid of each element, were distributed to the four nodes in each element.

Results

One way of modelling the motion and stresses of the coils as they undergo the Lorentz loading is to use a series of springs, one spring per conductor, with forces applied at each junction of two springs [4]. The total force applied to this series of springs is the sum of the azimuthal forces on the coil, where the force on each individual conductor is taken to be proportional to the conductor number. For this model, the stress loss at the pole is given by:

$$F_{pole}=\frac{\alpha}{6}(N)(2N+1)$$

where

α = Total azimuthal Lorentz force/N.

N = Number of conductors

The average azimuthal stresses for the three models are presented in Table 1. For comparison, results from the full dipole model and the one dimensional spring model are also presented. The full dipole model uses a conductor modulus of $1.5\text{x}10^6$ psi and a rigid horizontal constraint to simulate an infinitely rigid yoke.

Table 1: **Average azimuthal stress loss (psi), 6408 amps.**

	Inner coil pole	Outer coil pole
1 D model	3200	2700
Inner coil in a rigid cavity	3225	-
Outer coil in a rigid cavity	-	2775
Both coils in a rigid cavity	4025	2550
Full dipole model	2900	1125
Typical Measurements (LBL magnets)	5000+	1000

Discussion

The models of the single coils compare well with the one dimensional spring model. This provides some verification for the finite element model being used.

Measured values for the stress loss of the outer coil have always been substantially less than those predicted by the one dimensional spring model. It is generally hypothesized that this is due to a Poisson's effect of the radial pressure of the inner coil. However, comparing the stress loss between the model of only the outer coil in a rigid cavity and the model of both coils in a rigid cavity shows little effect due to the addition of the inner coil radial pressure. When the elasticity of the collar is added to the calculation, however,the outer coil stress loss is halved, and closely matches measured results.

Conclusions

Results of studying the coils confined to a rigid cavity show that the interaction between the aluminum collars and the coils, as well as the interaction between the coils themselves, have an effect on the stresses in the coils. The collars are primarily responsible for the stress loss seen at the pole of the outer coil, while the interactions between the two coils do contribute somewhat to this effect.

The agreement of the single coils with the one dimensional spring model verifies that the coils are being modelled correctly in the full model.

References

1. Results for the Lorentz force loading of the complete dipole model will be reported in a separate note. The model of the complete dipole has a coil modulus of 1.5×10^6 psi and a rigid horizontal constraint to simulate an infinitely rigid yoke.

2. **Finite Element Analysis of NC-9 Dipole, Note #1, Model Description**, SSC-N-530, by B. Wands and M. Chapman.

3. **Lorentz Forces for LBL NC-9 Dipole Cross Section**, SSC-N-364, S. Caspi and M. Helm.

4. **AIP Conference Proceedings: Physics of High Energy Particle Accelerators (Fermilab Summer School, 1981) - Superconducting Magnets**, A. V. Tollestrup