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Forces on AGS Corrector Solenoid

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Superconducting Magnet Division

Magnet Note

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Title: Forces on AGS Corrector Solenoid

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Forces on AGS Corrector Solenoid

Ramesh Gupta, 12/23/03

The following are the parameters of the current solenoid design for AGS Snake:

Inner coil diameter: 0.092 m
Number of layers: 2
Cable: Same as in AGS snake, ~1 mm dia, 6-around-1
Length: 0.82 m (-0.41 m to +0.41 m, i.e., it is located at the middle of the snake)
Number of turns: 1360 (680 per layer)
Turn-to-turn spacing (axially): ~1.2 mm

The above design roughly cancels the axial field caused by the AGS snake on the nominal trajectory of the injected beam. The design assumes that the solenoid is powered in the series of snake (same current in both). There is possibility of varying the field generated by the solenoid. In that case, it may be prudent to increase the length of the solenoid to increase its quench field as in the present design both the snake and the solenoid have about the same quench field.

The maximum local Lorentz force density on the solenoid at the design field of AGS snake (3 T) is:

$\sim 10^9$ N/m^3 *(~1 N/mm^3 or ~3.72 kilo-pound force/inch^3).*

The case of particular interest is the axial component of the Lorentz force on solenoid in the presence of a rotating dipole field. The total build up of this force at any angle depends on the number of wires, the magnitude of current and the variation of the field on the solenoid beside the angular position. The maximum local axial pressure on an individual cable by itself (un-accumulated) is ~1 MPa (~145 psi). Since a helical pitch of 205.3 degree/m in the middle section of the AGS snake (0.786 meter) extends to most of the solenoid (0.82 meter), for simplicity we assume that it is the same along the length of the entire solenoid. In this case, the axial component of the Lorentz force density on the solenoid at any angle θ can be approximated by:

$$L_z(\theta,z) \sim 10^9 \sin(\theta + z*\pi/180*205.3) \qquad \textit{(Units: N/m}^3\textit{)}$$

The cumulative axial force at any angle is obtained by integrating along the z-axis on the surface of solenoid (r=0.092 m to r=0.094 m and z = -0.41 m to z = +0.41 m). The cumulative force at an angle θ_o, on an angle dθ, for small values of dθ, is given by:

$$F_z(\theta_o) = 10^9 * 0.092 * .002 * 360/\pi/205.3 * \sin(.41*\pi/180*205.3) * \sin(\theta_o) * d\theta$$

(Units: Newton, 1 Newton = 0.22 Pound-force)

Or

$$F_z(\theta_o) \sim 10^5 * \sin(\theta_o) * d\theta \qquad \textit{(Units: Force in Newton, } d\theta \textit{ in radian)}$$

The calculations performed by complex OPER3d models have been found to be in good agreement with the above expressions.

The local Lorentz force density as a function of axial position is shown in Fig. 1 for various angles.

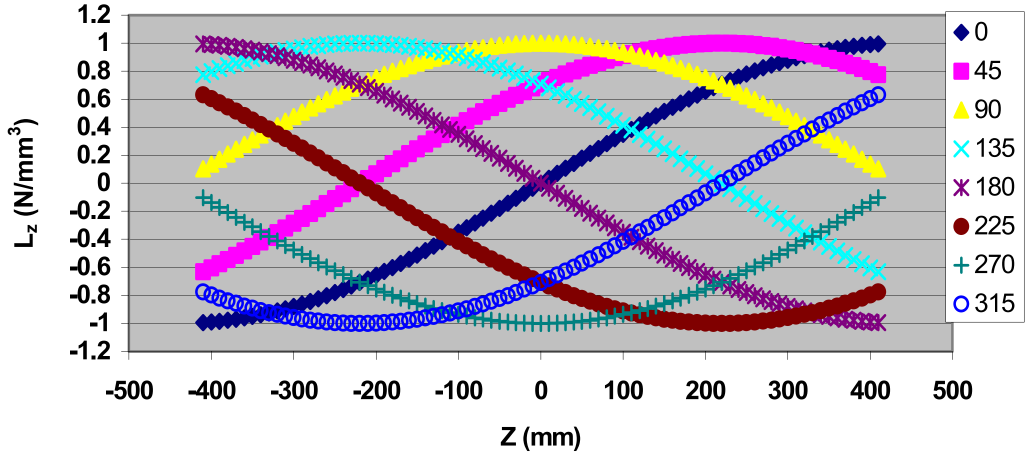

Fig. 1: The local Lorentz force density on solenoid.

The integrated axial force on the solenoid is shown in Fig 2. It is integrated over the entire length (820 mm) of the 2-layer solenoid (2 mm) for an angle of 1.25 degree (2 mm arc length).

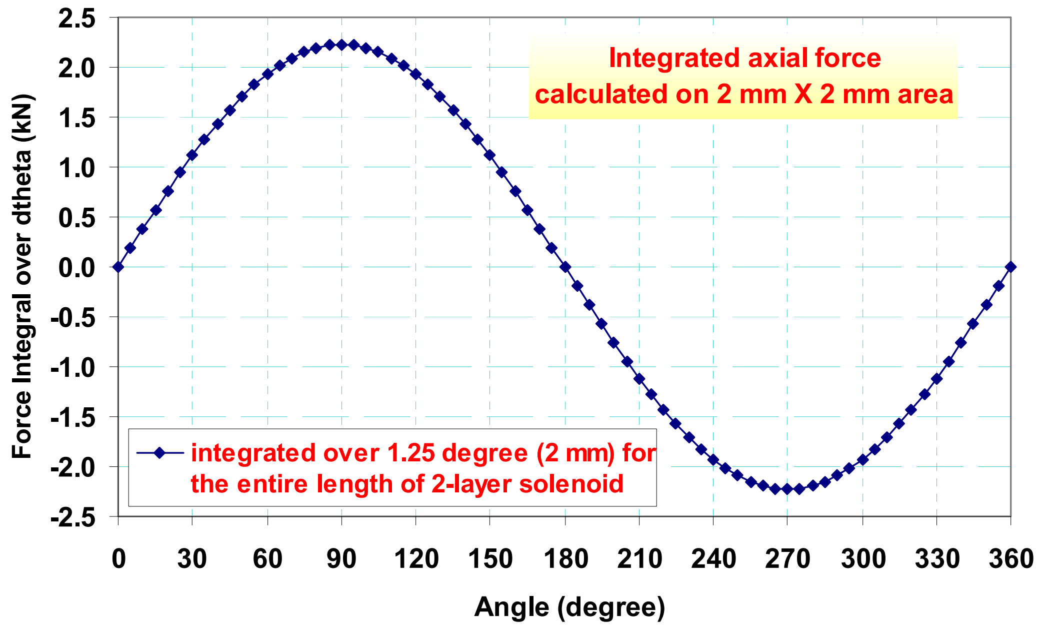

Fig. 2: The integrated Lorentz force on the 2-layer solenoid for 1.25 degree.

The computed accumulated axial pressure is shown in Fig. 3. For computational purpose, we chose a small area of about 2 mm by 2 mm (the pressure, of course, is independent of the area; but it should be small enough to avoid significant cancellations).

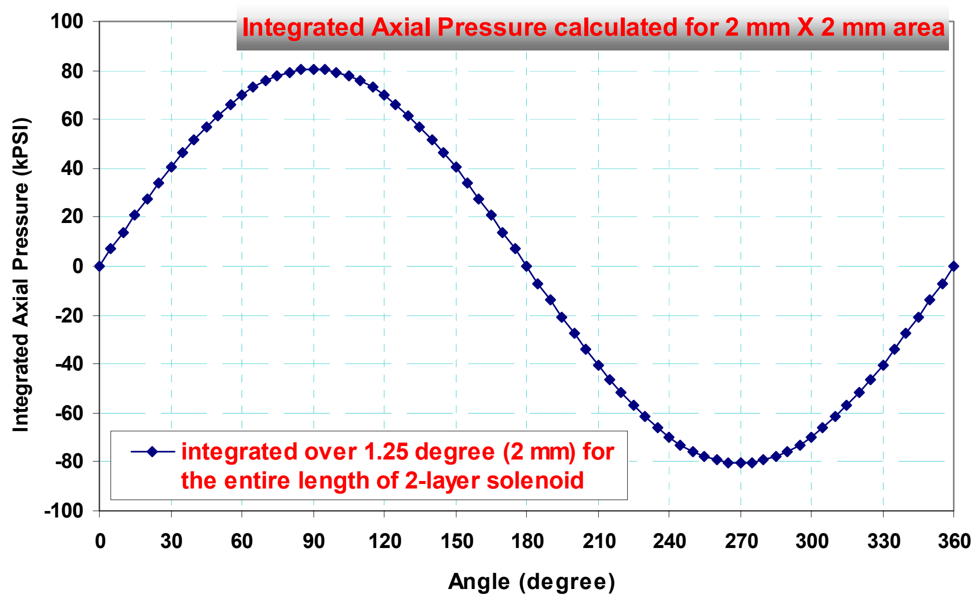

Fig. 3: The cumulative axial pressure at the end of solenoid.

For reference, magnitude of the computed Lorentz Force density at the center of the magnet with the code OPERA3d on both solenoid and helical coils is shown in Fig. 4. The discontinuity is artificial and is due to limited binning in the histogram plot.

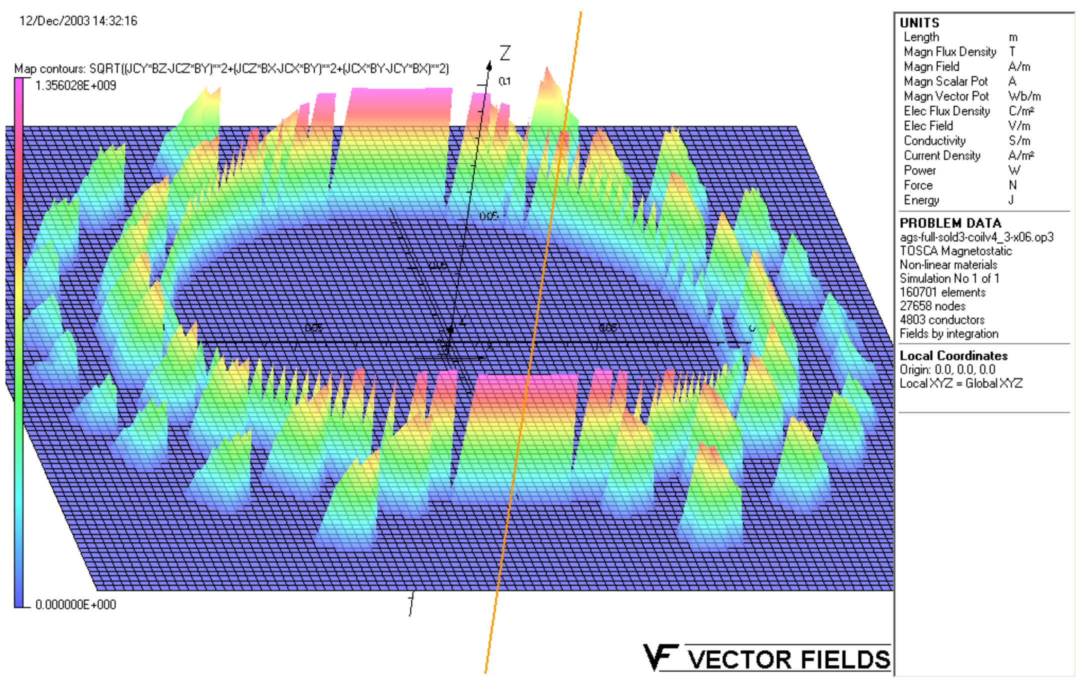

Fig. 4: Lorentz force density on solenoid and helical coil at the center of the magnet.