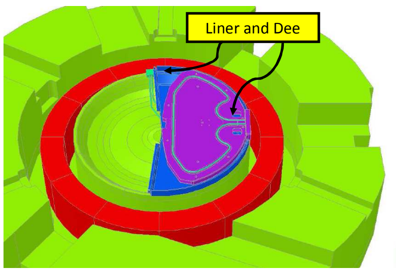
IBA S2C2 Quench Study: Induced forces on Dees and Liner

Wiel Kleeven

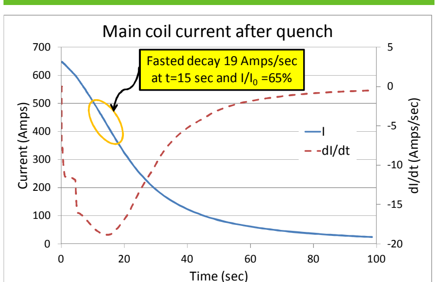
The S2C2 is the first synchrocyclotron as well as the first superconducting cyclotron ever produced at IBA. In this communication, a study is presented of the forces that are acting on the accelerating structure (dees and liner) due to the eddy currents that would be induced in these copper structures by the decaying magnetic field after a quench of the main coils. For this purpose a simplified semi-analytical approach is developed. It is found that these forces are not so small (about 400 N) but can be handled by the mechanical design of the structure.

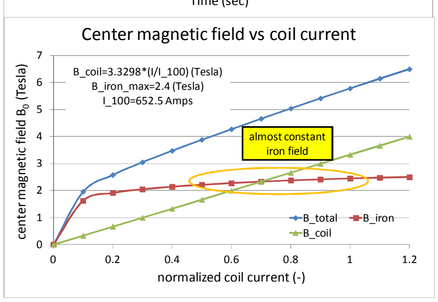


A SIMPLIFIED MODEL

- ❑Eddy currents in the dees and liner are generated by a decrease of magnetic flux after a main coil quench
- ❑The total magnetic field is the sum of external fields and the eddy currents induced fields
- ❑The induced fields are small and can be ignored
- ❑The forces on the RF structure result from the interaction of the eddy currents with the external field
- ❑The external field is the sum of the coil and iron field
- ❑The iron is fully saturated => eddy currents are only produced by the decaying coil field
- ❑In the gap the magnetic field is rotational symmetric
- ❑Induced currents flow parallel to the median plane.

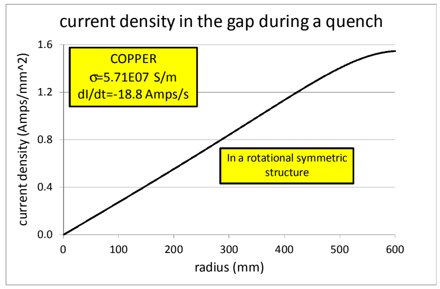
MAIN COIL CURRENT DECAY AFTER A QUENCH





- ❑Obtained from ASG quench model=> After a quench detection a safety circuit to a dump resistor is activated
- ❑Maximum decay:19 A/sec occurs after 15 sec when main coil is still at 65% => iron almost fully saturated

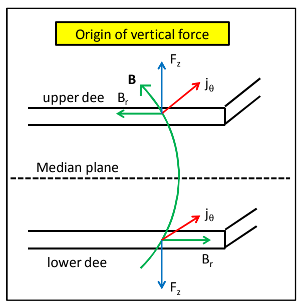
INDUCED CURRENTS

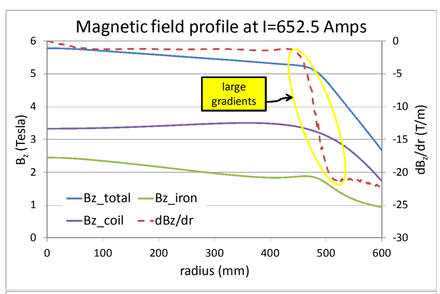


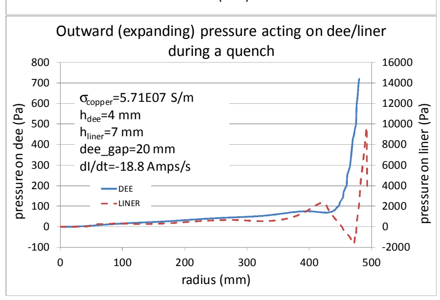
- ❑ Induced magnetic field can be estimated by assuming all currents to be concentrated in a thin sheet. => they are very small (about 40 Gauss)

VERTICAL FORCES

- ❑ Interaction of eddy current with radial field B_r
- ❑ Large if field gradients are large (fringe field)
- ❑Similar to vertical focusing force acting on beam
- ❑But opposite sign (expanding) because eddy currents flow in opposite direction of beam current

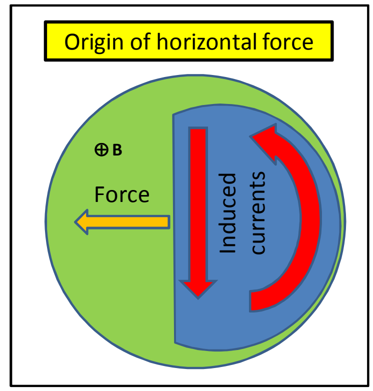


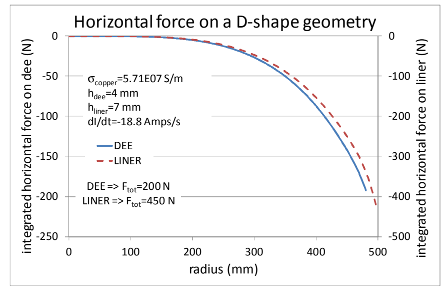




HORIZONTAL FORCES

- ❑ Consider dee or liner as a demi-circle in a radially decreasing magnetic field => Induced currents follow same geometrical pattern
- ❑Total force due to unbalance between circular part and straight returning part





MAGNETIC FIELD

$$B_{tot} = B_{ext} + B_{ind}$$

$$B_{ind} \approx 0$$

$$B_{ext} = B_{iron}(\mathbf{r}, I) + B_{coil}(\mathbf{r}, I)$$

Saturated iron + rotational symmetry

$$B_{ext} = B_{iron}(r,z) + \frac{I(t)}{I_{100\%}} B_{coil}(r,z)$$

INDUCED CURRENTS

$$V = -\frac{d\Phi}{dt}$$

$$E_\theta = -\frac{1}{r I_{100\%}} \frac{dI}{dt} \int_0^r r B_{coil}(r) dr$$

$$j = \sigma E_\theta$$

VERTICAL FORCES AND PRESSURE

$$dF = -2\pi r \times B_r(r,z) \times j_\theta \times h dr$$

$$P = -B_r(r,z) \times j_\theta \times h$$

HORIZONTAL FORCES (circular part)

$$dF_x = B_z(r) \times dI \times \int_{-\pi/2}^{\pi/2} r\cos\theta d\theta$$

HORIZONTAL FORCES (closing straight)

$$dF_x - = 2 \times dI \times \int_0^r B_z(r) dr$$

CONCLUSION

- ❑ Maximum vertical expanding force
  - ❑On dees 35 N
  - ❑On liner 400 N
- ❑Maximum horizontal force
  - ❑On dees 400 N
  - ❑On liner 900 N
- ❑These are upper limits due to pessimistic assumptions in the simplified model
- ❑These forces can be handled by the mechanical design of the RF structure