IBA S2C2: coil forces and median plane errors due to coil displacements

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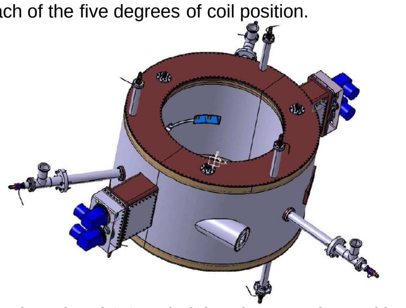
INTRODUCTION

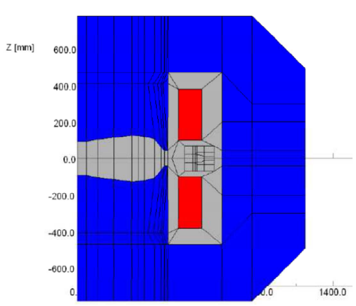
During the commissioning of the S2C2 it is intended to move the main coil assembly in the cryostat into an optimum position such that the overall effect of the median plane error during acceleration and extraction has the smallest impact on the extracted beam. The main coils are held in position by horizontal and vertical tie-rods. This allows placing these coils with five degrees of freedom (3 displacements and 2 rotations). During this operation care has to be taken, because the forces and torques acting on the coils can be large. Furthermore the system is unstable: the forces acting on a displaced coil are directed such that they intend to increase the displacement. Forces and torques acting on the main coils and median plane errors that due to coil displacement and rotations are calculated using different OPERA finite elements models in 2D as well as 3D. Forces and torques are therefore given as differential quantities. A large part of the median plane error in the S2C2 is created by the vertical asymmetry present in the design of the iron parts that are placed at the exterior of the cyclotron. These errors have been given in another communication. Median plane errors are compensated by main coils shifts. Median plane fields are computed for each of the five degrees of coil position.

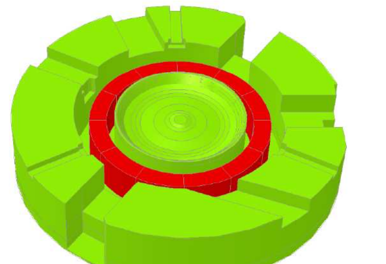


3 horizontal tand 2x3 vertical tie-rods are used to position the coil-assembly in the cryostat and to hold the forces

DIFFERENT OPERA MODELS

1. OPERA2D => rotational symmetry => used as benchmark for 3D models and for calculation of radial field error due to vertical coil-shift
2. OPERA3D-preprocessor => includes full up-down cyclotron geometry with all yoke penetrations but without exterior elements => model is more difficult to make but uses hexahedral mesh which generally gives more precise magnetic field results
3. OPERA3D-modeller => same geometrical features as previous case => easier modeling => tetrahedal meshing => more noise fields => details can more easily be modeled
4. OPERA3D-modeller=>full up-down geometry, all yoke penetrations and all external systems such as yoke-lifting system, cyclotron feet, cryo-cooler and rotco shields and external beam line



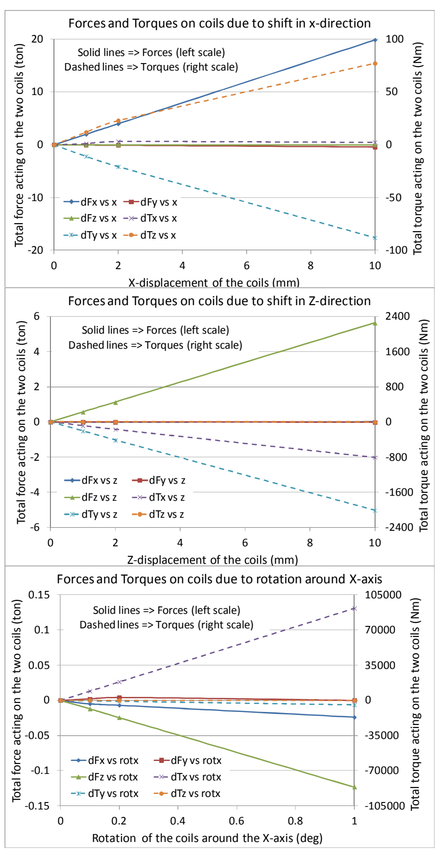


COIL ALIGNMENT ERRORS

- ❑ Five different alignment errors were introduced
- ❑ Displacements along X,Y and Z-direction
- ❑ Rotations around X and Y-axis
- ❑ The two coil are considered as one assembly
- ❑ Three effects are calculated: i) Forces acting on the coils, ii) Torques acting on the coils, iii) Median plane magnetic field error

FORCES AND TORQUES

- ❑ Forces and torques vary linearly with displacements up to at least 10 mm and rotations up to at least 1 degree
- ❑ Maximum force: about 2 tons per mm displacement
- ❑ All displacements and rotations are unstable, i.e. forces and torques are directed such that they tend to increase their initial displacement or rotation
- ❑ Tie-rods have to be designed in order to keep and position the coils in stable position



Total forces (left scale - solid line) and torques (right scale – dashed line) acting on the assembly of two main coils for a given displacement of this assembly in the X-direction or Z-direction and for a rotation of this assembly around the X-axis respectively (calculated with the pre-processor model)

FORCES AND TORQUES ACTING ON THE MAIN COIL SYSTEM DUE TO COIL DISPLACEMENTS AND ROTATIONS							
		FORCES			TORQUES		
		dFx ton/mm	dFy ton/mm	dFz ton/mm	dTx Nm/mm	dTy Nm/mm	dTz Nm/mm
coil shift	x-direction	1.99	-0.05	0.00	0	-9	8
	y-direction	-0.05	2.00	0.00	10	2	41
	z-direction	0.00	0.00	0.56	-80	-201	0
coil rotation		dFx ton/deg	dFy ton/deg	dFz ton/deg	dTx Nm/deg	dTy Nm/deg	dTz Nm/deg
	around x-axis	-0.02	0.00	-0.12	91559	-4609	-80
	around y-axis	-0.05	-0.01	-0.30	-4484	91305	79

Forces and Torques for well-centered coils (Full geometry)		
F_x	ton	-1.301
F_y	ton	0.025
F_z	ton	-0.781
T_x	Nm	-647.0
T_y	Nm	-1648
T_z	Nm	4.750

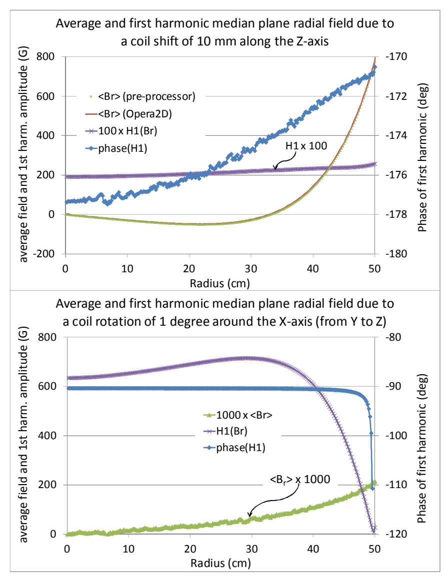
When the coils are well centered geometrically, there are still substantial forces acting on it due to the asymmetry created by the yoke penetrations and the external systems such as cryo-shielding, rotco-shielding, cyclotron feet, yoke-lifting system and external beam line

MODEL COMPARISON

- ❑ There is good agreement between models created by the modeller and models created with the pre-processor
- ❑ There is some difference Opera2d and both 3D models for z-shifted coils. This is partly due to the absence of yoke penetrations in the 2D model. The vertical force in the absence of yoke-penetrations reduces from 0.56 to 0.49 Ton/mm (pre-processor-case)

Comparisson between modeller, pre-processor and Opera2D					
			pre-processor	modeller	Opera2D
x-shift	dF/dx	ton/mm	1.99	1.6231	NA
z-shift	dF/dz	ton/mm	0.56	0.6046	0.3773
x-axis rotation	dTx/dα	Nm/deg	91559	91276.1	NA
	dTy/dα	Nm/deg	-4609	-4150.2	NA

MEDIAN PLANE ERRORS



Average value and first harmonic amplitude and phase of the radial magnetic field in the median plane due to a 10 mm vertical shift of the coils and due to a rotation of the coils with 1 degree along the X-axis. For the upper case a perfect match is obtained between the 2D and 3D model. A vertical shift of about 0.2 mm will be needed in order to compensate the median plane errors due to intrinsic asymmetry in the magnetic circuit