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Design of the inductor of a superconducting machine with magnetized bulk HTS

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Abstract

The development of cryo-magnets based on REBaCuO type superconductors that can generate up to 17 T requires the implementation of a magnetization system and therefore, it involves one or more coils around the superconducting materials. Currently, the most convenient way to magnetize a bulk High Temperature Superconductor (HTS) is to use a Pulsed Field Magnetization (PFM). It can generate strong magnetic fields while using a relatively compact and simple coil. Thus, bulk HTS can be directly magnetized, *in situ*, into the final application. In a previous work, we have studied and designed different coils in order to magnetize, using PFM, an inductor of a radial flux superconducting machine with one pair of poles. Each pole contains four HTS bulks that can be placed in a square or rectangular pattern. For a given primary source of energy, here a capacitor bank of 5 mF, the PFM process strongly depends on the inductance value of the coil used to magnetize because it defines the waveform of the current: the peak value and the time constant. The maximal magnetic field applied to the sample is in the range of 6 to 10 T, which is more than enough to consider magnetizing HTS bulks above 2 T. In this paper, the induced currents and trapped fields in HTS bulks are calculated by means of 3D numerical simulations, with taking into account saturated iron and the non-linear resistivity of HTS. Results are the maximal trapped magnetic flux density of each bulk HTS, and the estimated flux of the poles of the inductor.

Radial flux superconducting machine with HTS bulks

Cross-sectional drawing and 3D isometric view

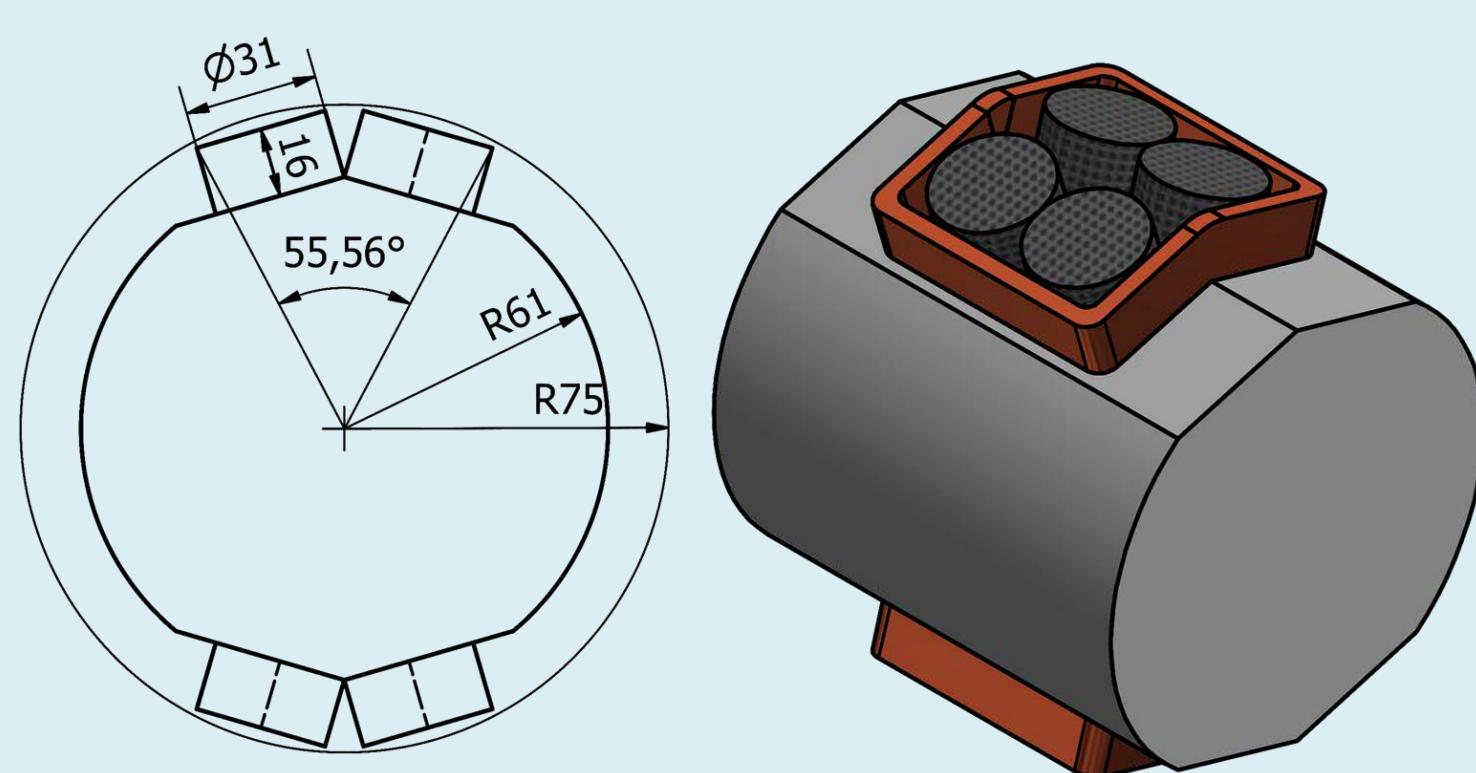
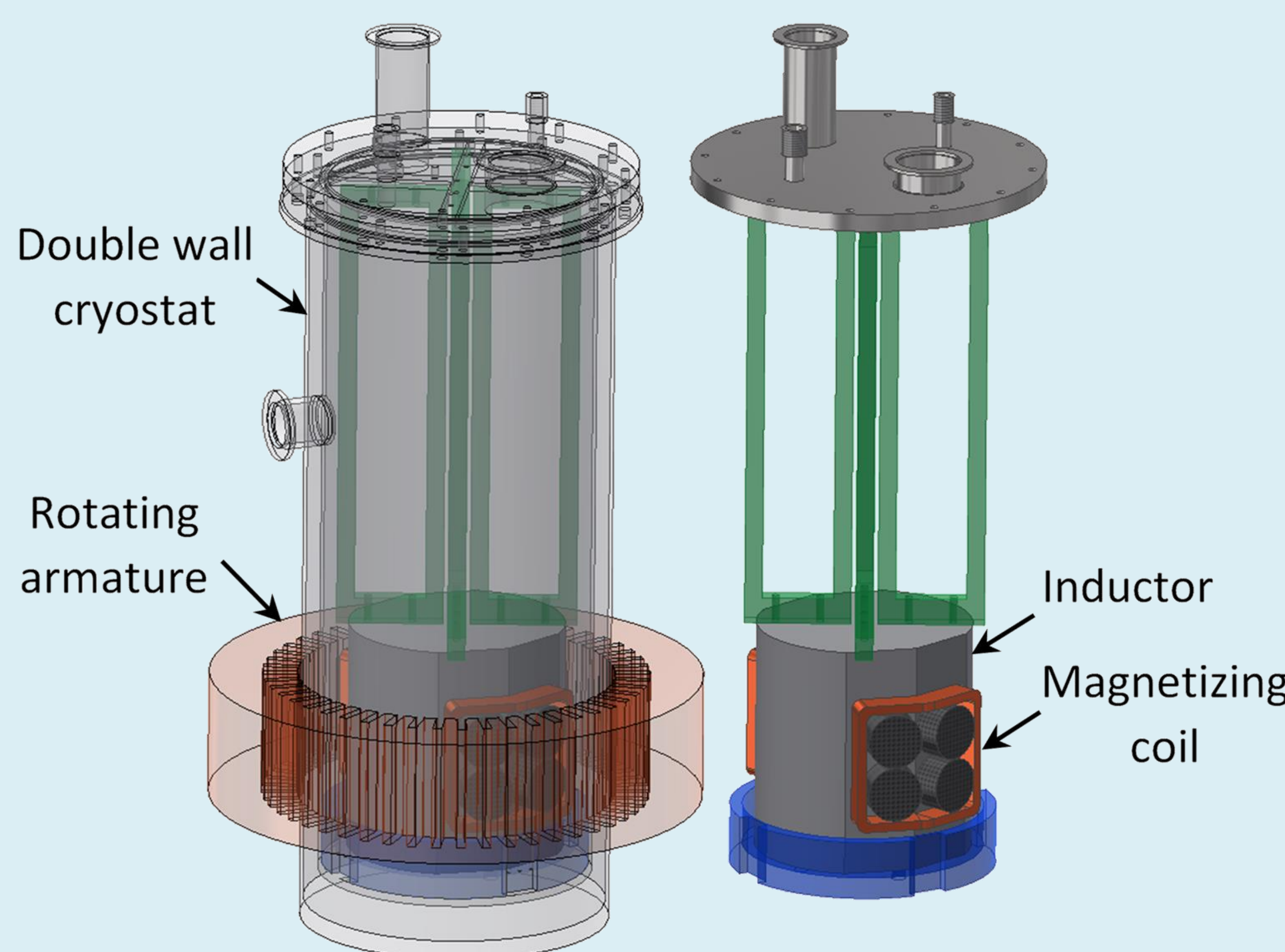


TABLE I
SOME GEOMETRICAL PARAMETERS OF THE MOTOR

Symbol	Quantity	Value
R_{cyl}	radius of the ferromagnetic cylinder of the inductor	61 mm
R_{ind}	overall radius of the inductor including the HTS bulks	74 mm
e_1	mechanical air gap between the inductor and the cryostat	1 mm
R_{rm}	inner radius of the cryostat	75 mm
e_2	overall thickness of the cryostat	12 mm
R_{out}	outer radius of the cryostat	87 mm
e_3	mechanical air gap between the armature and the cryostat	2 mm
R_{arm}	inner radius of the armature	89 mm
e_4	total air gap between the inductor and the armature	15 mm
L_{arm}	active length of the armature	70 mm

Preliminary design of the whole structure

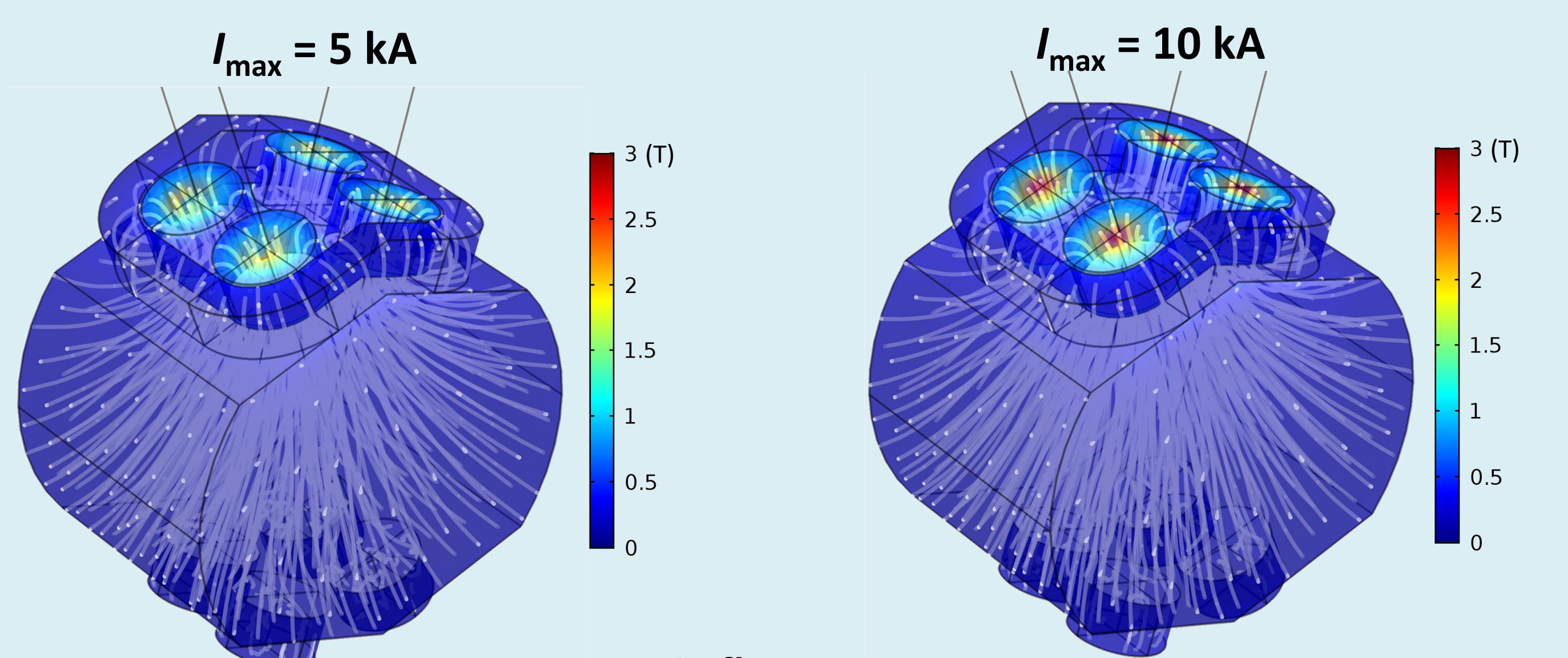


Description

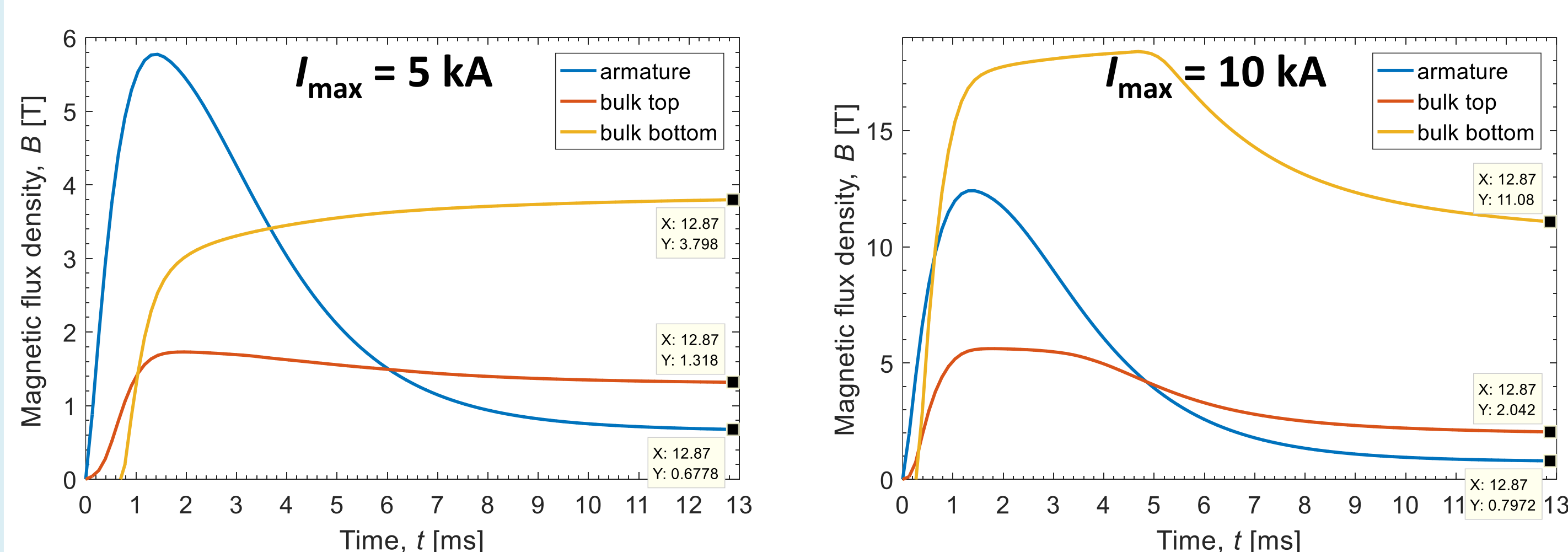
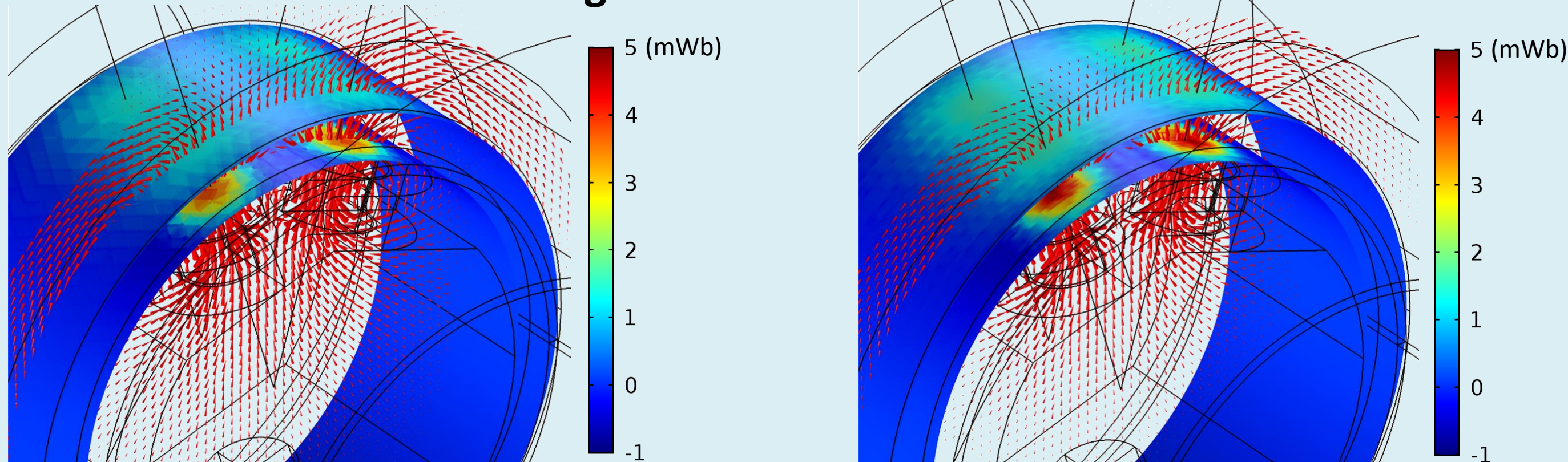
- ✓ The rotating machine, shown on the left side, has the particularity to have an inductor part mounted inside a stationary cryostat and a rotating armature outside the cryostat.
- ✓ The inductor will consist of one-pole pair, each pole contains four HTS bulks to be magnetized, mounted on a square pattern. We planned to use melt textured (RE)BCO bulks of 31 mm of diameter. The typical trapped magnetic flux density of one bulk with a PFM process is 700 mT @ 77 K.
- ✓ Several cooling systems are being considered:
 - Liquid Nitrogen,
 - A cryocooler placed on the lower part of the cryostat,
 - Frozen Nitrogen,
 - Liquid Helium,
 - In transient stage with Helium gaz.

3D numerical modeling

Magnetic flux density distribution at $t = 10\tau$



Magnetic flux at $t = 10\tau$



Modelling Framework

The conductor used for the coil is a copper foil of 0.2 mm thickness and 12 mm high, insulated using Kapton tape 25 μ m. The coil consists of 28 turns. The coil current is assumed to be known and imposed as :

$$i(t) = I_{\max} \frac{t}{\tau} \exp\left(1 - \frac{t}{\tau}\right) \text{ with } I_{\max} = \{5; 10\} \text{ kA and } \tau = 1.3 \text{ ms}$$

The iron parts being saturated, $\mu_r = 10$ has been considered

H-formulation with non-linear resistivity

$$\nabla \times \mathbf{E} = -\frac{\partial(\mu_0 \mu_r \mathbf{H})}{\partial t} \text{ and } \nabla \times \mathbf{H} = \mathbf{J} + \mathbf{J}_s, \text{ with } \mathbf{J}_s \text{ the current density applied in the coil}$$

$$\text{In the HTS bulk: } \mathbf{E} = \rho(\mathbf{J})\mathbf{J} \text{ with } \rho(\mathbf{J}) = \left(\frac{E_c}{J_c} \left(\frac{\|\mathbf{J}\|}{J_c}\right)^{n-1} + \rho_0\right) \text{ and } \rho_0 = 10^{-14} \Omega \cdot \text{m}$$

$$J_c = 200 \text{ A/mm}^2 \text{ and } n = 21$$

Conclusion & perspectives

- ✓ A 3D non linear problem of a HTS machine has been simulated using H-formulation in COMSOL,
- ✓ A trapped magnetic flux density of 2 T are achieved on the top surface of the HTS bulks,
- ✓ The maximal magnetic flux at the stator radius is around 1.5 mWb,
- ✓ This leads to 21 mWb/m (per active length of the machine), which is comparable to others machines,
- ✓ Thermal and magnetic dependencies of HTS bulks have to be taken into account,
- ✓ Other configurations have to be studied in order to increase the magnetic flux.