SCOPE - B2

THE APPLICATION OF FEM PACKAGES FOR DETERMINATION OF MAGNETIC FIELD DISTRIBUTION IN SUPERCONDUCTING DEVICES

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ABSTRACT

At current stage of advanced research on the application of superconductivity, the crucial thing is to use novel methods for the numerical investigation of different phenomena in superconducting devices such as Superconducting Fault Current Limiter (SFCL), transformers, electromagnets, and others.

At the designing and constructing of superconducting devices experimental verification of brief foredesign is then essential. Due to specific operation of superconducting devices that require expensive cooling it is necessary to limit the number of experiments and the application of numerical simulations.

The application of FEM packages for advanced numerical models of superconducting devices allows for detailed analysis of their operation without constructing expensive physical models and their examination.

One of the most important problems, connected with designing and using superconducting devices is recognition of the influence of electromagnetic field distribution on superconducting devices operation.

This paper describes selected examples of numerical analysis of the distribution of electromagnetic field of the superconducting devices. The results were determined using the QuickField 4.2 and OPERA 3D FEM software.

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INTRODUCTION

One of the most important problems, connected with designing and using superconducting devices is recognition of the influence of electromagnetic field distribution on superconducting devices operation.
This paper describes selected examples of numerical analysis of the distribution of electromagnetic field of the superconducting devices.

INDUCTIVE TYPE OF SFCL

The operation of inductive Superconducting Fault Current Limiter is based on the fast quench, i.e. transition from the superconducting to the resistive state. This type of SFCL has been designed as the transformer with a shorted secondary winding. The secondary winding is usually a HTS cylinder whose function under normal conditions (in superconducting state – SC state) is to shield the flux generated by the primary winding from entering the iron core of the limiter. The primary winding made usually by copper is connected directly to an electric circuit. If the secondary winding is driven beyond the critical current of the superconductor it reverts to a resistive state, thereby destroying the ampere-turns balanced of the transformer and flux from the primary winding enters the iron core. The inductance and impedance of the primary winding rapidly increase limiting the fault current of the circuit.
The small model of inductive SFCL with 625 A HTS tube was made in Cryoelectromagnets Lab. The parameters of the model, which been described in Kozak and Janowski (1), are shown in table 1.

TABLE 1 – Parameters of inductive SFCL.

Primary Cu winding	
Number of turns	236
Height of winding	49 mm
Inner diameter of winding	73 mm
Secondary winding – Bi-2223 HTS tube	
Critical temperature	108 K
Inner diameter	59 mm
Height	50 mm
I_c in tangential direction (77 K)	625 A
Cross-section of magnetic core	20 mm x 20 mm
Height of magnetic core limb	103 mm
Width of core window	36 mm
Operating parameters	
Limiting current	2.65 A

In order to compute the distribution of magnetic flux density and determine the operating states of the limiter the numerical model of SFCL was made, using the QuickField 4.2 FEM software. The numerical model of the limiter is shown in figure 1.

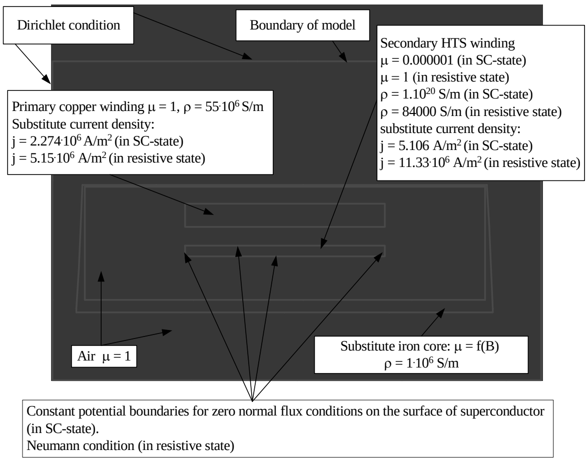

Figure 1: Numerical model of inductive SFCL

The distributions of the magnetic flux density were determined for limiter being in superconducting state and then, after quench, for limiter being in resistive state. The two-dimensional distributions of total magnetic flux density along the cross-section of the limiter are shown in figure 2.

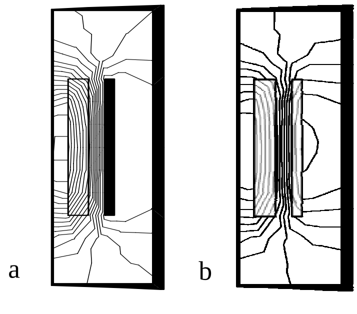

Figure 2: Two-dimensional distribution of total magnetic flux density: a- limiter in SC state; b- limiter in resistive state

The charts presented above show two states of operation of inductive SFCL. The figure 2a, shows the shielding properties of the superconducting tube. Under superconducting state of the limiter, the flux is shield from entering the iron core. Figure 2b shows that flux from the primary winding enters the iron core, after revert the superconducting tube to a resistive state.

SUPERCONDUCTING OGMS SEPARATOR

The Open Gradient Magnetic Separator (OGMS) was another device which was subject to numerical calculation in FEM package. The operating principle of the deflection type separator represented by OGMS depends on the selective deflection of the particles, according to their magnetic susceptibility, during their passage through a high nonhomogeneous magnetic field generated by an electromagnet with an appropriate configuration of coils or wires. The experimental model of the OGMS separator consists of two solenoids, which generate opposing magnetic fields. In this type system the separation process depends on magnetic field density distribution in separation chamber. The resultant force acting on separated particles depends on magnetic flux density B and its gradient. To secure effective separation of the particles, high values of magnetic flux density B and its gradient are required and this may be achieved only using superconducting magnets. In designing of OGMS separator the most important problem is obtaining the maximum efficiency of the system and simultaneously the minimum of operating and building costs. It has been described in Janowski and Kozak (2). For the optimum design of OGMS system the magnetic flux density distribution changes can be reached by local flux diverters which been described in Kondratowicz-Kucewicz (3). The physical properties of object were defined according to technical parameters of OGMS separator model. These parameters are shown in table 2.

TABLE 2 – Parameters of NbTi electromagnet.

Parameters	Values
Inner diameter	0.104 m
Outer diameter	0.126 m
Length	0.111 m
Number of turns	6916
Operating current	110.7 A
Current density in coil	$314.4 * 10^{6}$ A/m^2
Maximal magnetic induction	5,68 T
Induction inside coil	3,77 T

The numerical model in OPERA-3D package of OGMS separator with sample flux diverter is shown on figure 3.

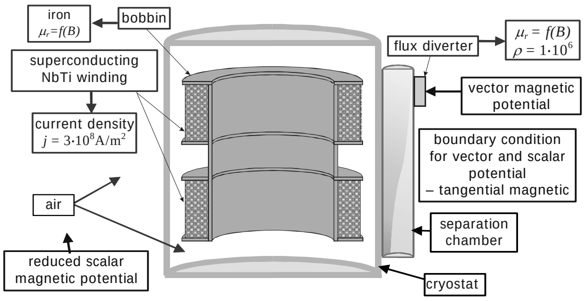

Figure 3: The numerical model of OGMS separator

The magnetic field distribution (examples on figure 4 and figure 5) in a working separator is the most important feature of proper designing and the operating of the separator. we can reach the effective OGMS separator construction by modification of electromagnet parameters, current magnitude, materials and also by using flux diverters around the cryomagnet.

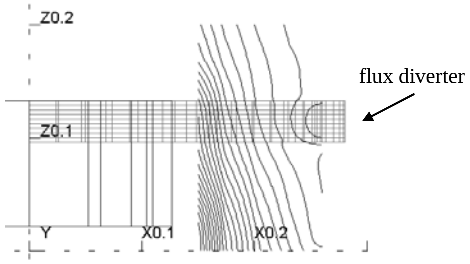

Figure 4: The flux density B distribution in separator

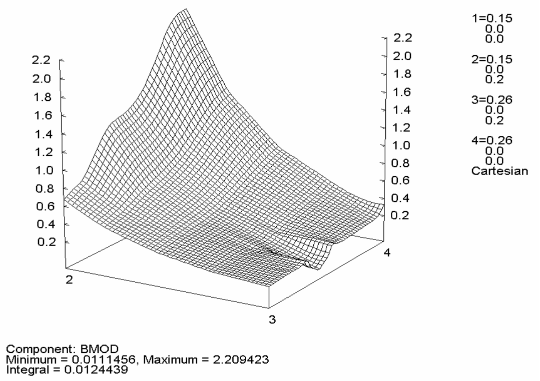

Figure 5: The magnetic flux density distribution in separator work chamber

Numerical simulations of magnetic flux distribution in OGMS separator enable to determine the optimal location of flux diverters for separator's efficiency.

CONCLUSION

Numerical models opposed to physical ones enable to change construction parameters and carry out the analysis in different operation conditions. SFCL magnetic field distribution, for two operating states, and the influence of flux diverters on magnetic field generated by OGMS electromagnet allow for the verification of brief foredesign and defining construction recommendations of physical models.

REFERENCES

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