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# Study of a superconducting motor with high specific torque

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 Vandoeuvre les nancy

**Abstract** We present a new kind of superconducting inductor for the synchronous machine. This inductor is composed of a two superconducting coils having the same axis and fed by a currents with the same direction. A superconducting bulk is used in order to achieve a variation of the flux density in the air-gap. Due to the superconducting coil the value of the magnetic field in the airgap could be upper than 4T. With the proposed superconducting inductor, we obtain a two-poles electrical machine with an important specific torque and specific power. Therefore these kind of superconducting motor could be sized for aircraft application..

## Introduction

Improving the performance of electrical machines is a big challenge for decades [1-5]. One of the most important parameters to improve machine performance is the generation of a high magnetic field by an inductor. Superconductors are very attractive materials because of their absence of resistive losses when they are fed by DC current, and due to the very high current densities. For these reasons, they have the advantage of allowing to build lighter electrical machines with better performance than conventional motors. We propose a new superconducting inductor structure. The topology uses an inductor formed by two superconducting field coils and a bulk superconductor which is a magnetic screen leading the flux density in the air gap [6-1].

A three-dimensional analysis of the magnetic field, is made, using a 3D finite element software, to study the performance of the proposed inductor.

## Principle of the superconducting inductor

Figure.2 shows the structure of the proposed inductor. It is composed of two coaxial superconducting coils. The coils are supplied with electric currents having the same direction to generate a magnetic field ( $B_1, B_2$ ).

A bulk superconductor is placed between the two coils. The superconductor is inclined along the length of the inductor. This superconductor is used as a magnetic barrier, and is located between the two solenoids, thereby creating a variable magnetic field. In order to improve the radial distribution of induction, we also used a ferromagnetic material between the two coils. The superconductor is inserted between the ferromagnetic parts as shown in Figure 1, Iron guide the magnetic field toward the centre of the inductor and therefore reduce the leakage field near the coil.

The geometric parameters of the proposed structure are given in Table 1 These parameters were chosen after a sizing of a superconducting motor to obtain a high magnetic field and correspond to a realistic size machine. For the simulations, a current density of

650A / mm<sup>2</sup> will be chosen by using the behaviour law for low critical superconducting temperature wire.

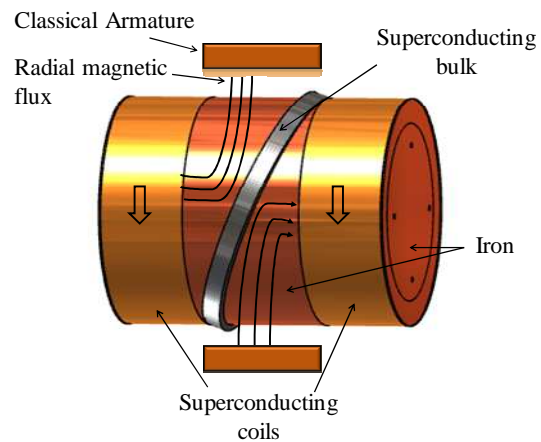


Fig. 1: Principle of the superconducting inductor

Further study on the choice of  $J$  would require the consideration of the behaviour law  $J_c(B)$  of has a high critical temperature superconducting wire. These wires are constantly improving.

Outer radius	Rex (mm)	68
Inner radius	Ri (mm)	53
Distance between solenoids	C (mm)	45
Solenoid length	L (mm)	45
Thickness of the screen	E (mm)	10
Density de courant	J (A/mm <sup>2</sup> )	650

Table 1: Geometrical parameters of the inductor

## Study of the whole superconducting motor

The principle of the whole superconducting motor is described on figure 2. We have a classical cooper armature or a superconducting armature with a back iron. In the first case, we have one cryostat for the superconducting inductor, in the second case, we need to design a cryostat for the inductor and the armature.

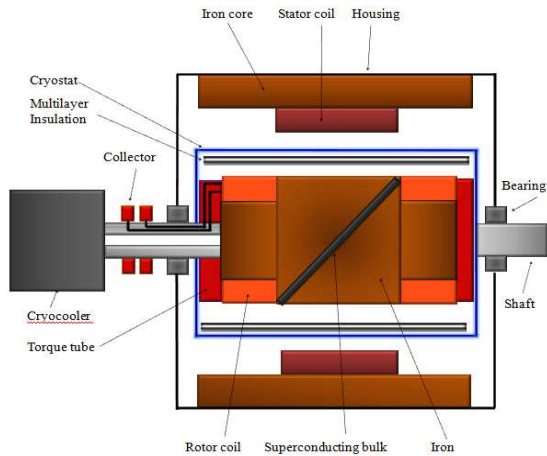


Fig. 2: Principle of the superconducting motor

In this paper we present results with a classical copper armature and a superconducting inductor with an airgap of one centimetres. This airgap is very high due to the cryostat which are located inside.

So, after simulation using FEM software, we obtain the distribution of magnetic flux presented on figure 3. The magnetic field varies between -4T and 4T. If we compare to a classical motor it is four time greater. Therefore, we can increase by a factor 4 the specific power and torque of the motor. This magnetic field is calculated on the outer radius of the inductor

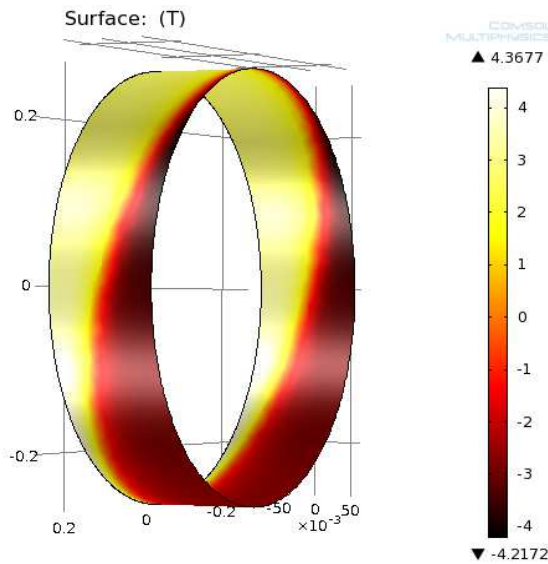


Fig. 3: Magnetic flux in the airgap of the superconducting motor

### Experimental results

We decided to build a machine based on this principle. The superconducting coils will be made in NbTi. The NbTi superconducting wire is a low critical temperature material cooled by liquid helium at 4.2 K. The superconducting screen is an YBCO plate. Initially, before realizing the entire machine, we tested

the inductor alone. To this end, all of the inductor, coil and YBCO bulk, are immersed in nitrogen tank. The YBCO bulk is superconducting at the temperature of liquid nitrogen. The coils made of NbTi, will not superconducting at this temperature. They will therefore be fed with a very low current to avoid destructive heating of the wire but still enough to have a measuring magnetic field.

The purpose of this experiment is to check the form of magnetic induction created by our induction to verify our computational tools.

The inductor is realized with geometric parameters given in the table 1, but with a current density of 10.6 A/mm<sup>2</sup>.

The experimental bench consists of our inductor, and a Hall probe that we can move along the height of the inductor and along its bore diameter. We also have the supply of the superconducting coils, of the Hall-probe and the acquisition system. This is shown in Figure 4.

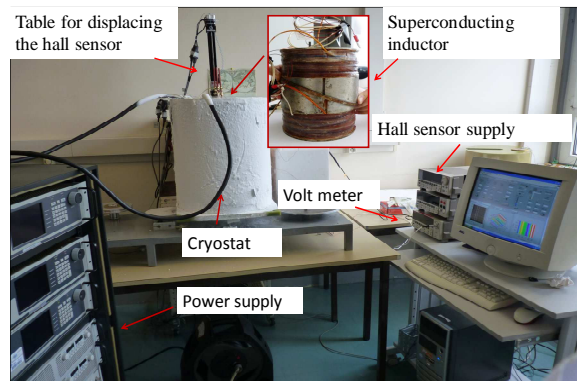


Fig. 4: Experimental bench

The results are shown in the figures 5 to 7 and show the correlation value of shape of the magnetic field between the theoretical and experimental results. The measurements are made at a distance of 1.5 cm from the inductor.

In Figure 6, we have shown the variation of the induction along the bore diameter. In Figure 7, we have shown the variation of the induction along the useful length of the inductor. The observed induction values are low because we are far from the current rating of the inductor, 4 A instead of 200 A, when the superconducting coils will be in liquid helium.

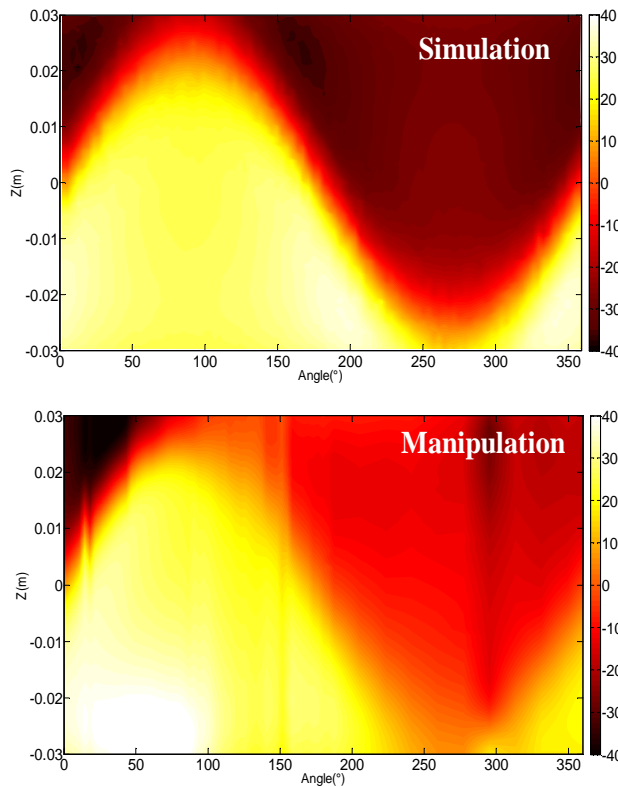


Fig. 5: Shape of the magnetic field

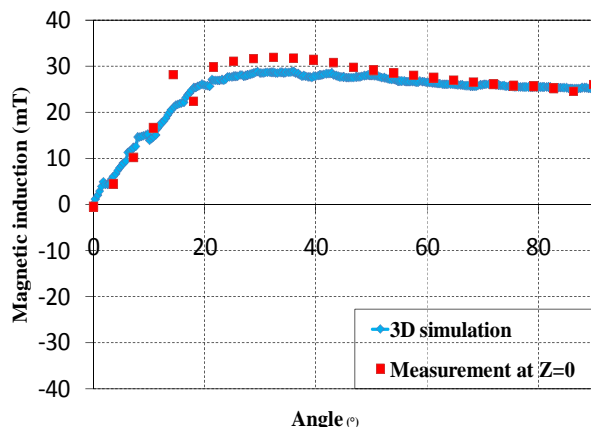


Fig. 6: Shape of the magnetic field versus angle

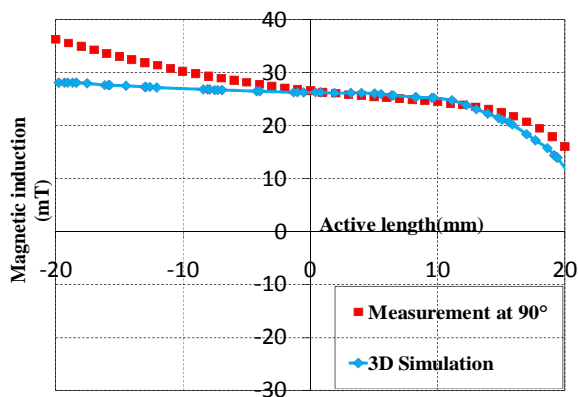


Fig. 7: Shape of the magnetic field versus axial length

## Conclusions

A new type of superconducting machines was studied. It helps to have a variation of radial magnetic field of 4.12 T, this value was calculated by 3D simulations for two low Temperature superconducting coils fed by current density of  $650 \text{ A / mm}^2$ . This interesting structure must provide a very compact machine. The first experimental tests of the inductor alone proved the validity of the calculations.

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