NOTES ON MAGNETIC FIELD DESIGN ON PROCURE

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31/01/2021

CONTENTS

1 $\vec{B}$ field configuration study 2
2 Heat dissipated on the coils 3

LIST OF FIGURES

Figure 1 The Helmholtz coils setup is representes on the left and on the right the line fields of the magnetic field on the XZ plane. 2
Figure 2 Magnitude of the magnetic field produced on the z-axis when varying the distance between the coils. 3
Figure 3 Tilted coil of 10 degrees. 4
Figure 4 Tilted coil of 10 degrees. 4

LIST OF TABLES

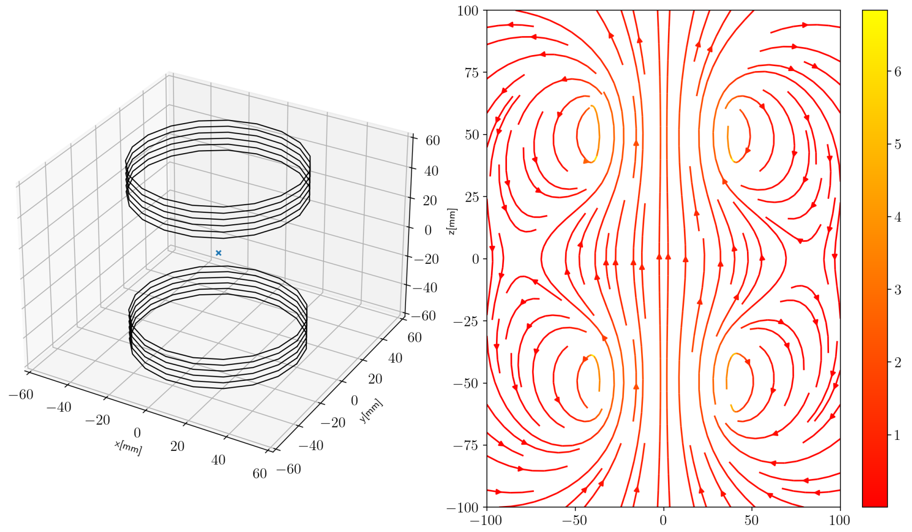

Figure 1: The Helmholtz coils setup is representes on the left and on the right the line fields of the magnetic field on the XZ plane.

1 $\vec{B}$ FIELD CONFIGURATION STUDY

Here is an initial investigation on the magnetic field produced by the under-vacuum coils designed for the PROCURE machine. The setup is a pair of solenoids with about 5 turns. I consider here as an example, solenoids with radius of 40 mm and a distance between the two solenoids (in a Helmholtz configuration) of about 80 mm or the diameter of the coils. The current chosen to plot the graphs is 20 A. On figure 1. This setup generates a highly homogeneous magnetic field at the trapping site, which has a cubic volume with a length of $l = 30 \times 5$ μm ≈ 0.15 mm.

For those parameters the magnetic field produced at the trap is on the order of 1 mT. Varying the distance between the coils by 2 mm leads to a change on the magnitude of the field on the order of 10^{-2} mT but the homegeneity is kept nearly the same, which is on the order of μT. Results are shown on figure 2.

Next I tilt the one of the coils by about 10 degrees. On figure 3 is shown the geometric deformation and on figure 4 is the magnitude of the magnetic field on the z-axis. There is a shift on the minimum of the magnetic field and variations on the magnetic field on the level of 10^{-3} mT.

We can conclude that we don't need to worry too much about the exact geometry of the solenoid for homogenous magnetic field at the level of μT (or better than 0.1 Gauss), in this approximation and in the trapping region of about 0.15 mm.

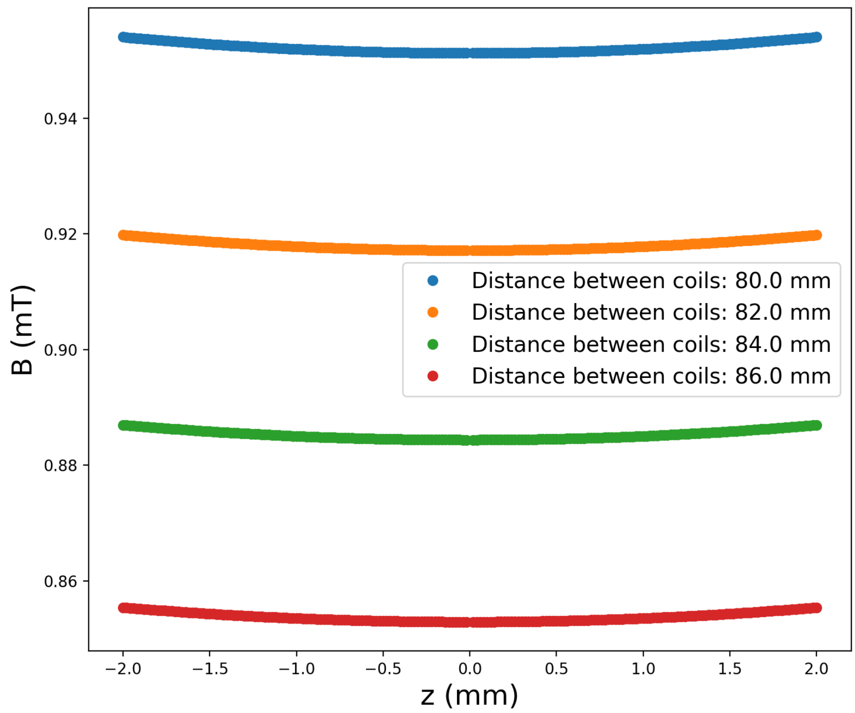

Figure 2: Magnitude of the magnetic field produced on the z-axis when varying the distance between the coils.

2 HEAT DISSIPATED ON THE COILS

Considering ideal coils with N turns copper wire with a given diameter, the resistance of the solenoid is given by:

$$R_{solenoid} = \frac{L\rho}{\pi r_{wire}^2}, \tag{1}$$

where ρ is the resistance of the copper, L is the length of the wire making the solenoid and r_{wire} is the radius of the wire. The length of the wire can be approximated as $L = 2\pi\rho_{solenoid}N$, being $rho_{solenoid}$ the radius of each turn.

The total resistance of the solenoid is:

$$R_{solenoid} = \frac{2\rho_{solenoid}N\rho_{copper}I^2}{r_{wire}^2} \tag{2}$$

The power dissipated is just RI^2 and as a scaling law:

$$P \approx N(I/r_{wire})^2 \tag{3}$$

If we want to dissipate as minimum heat as we can, thicker wire and maximize the number of turns in the solenoid is desired. If the number of turn in the solenoid is increased by a factor of f then the dissipated power is reduced by a fact of f. Considering a 1.5 mm radius wire and $\rho_{copper} = 0.0171\ \Omega\ \mathrm{mm}^2/\mathrm{m}$, and a solenoid with 4 turns, that gives a total lentgh of about 1 m, a total resistance of about 2 mΩ and $I = 20$ A, then 1 W will be dissipated as heat on each solenoid.

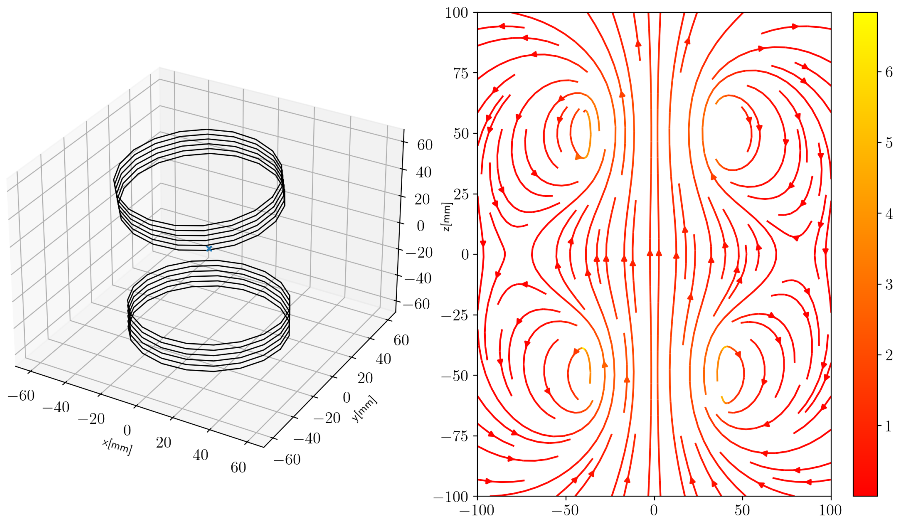

Figure 3: Tilted coil of 10 degrees.

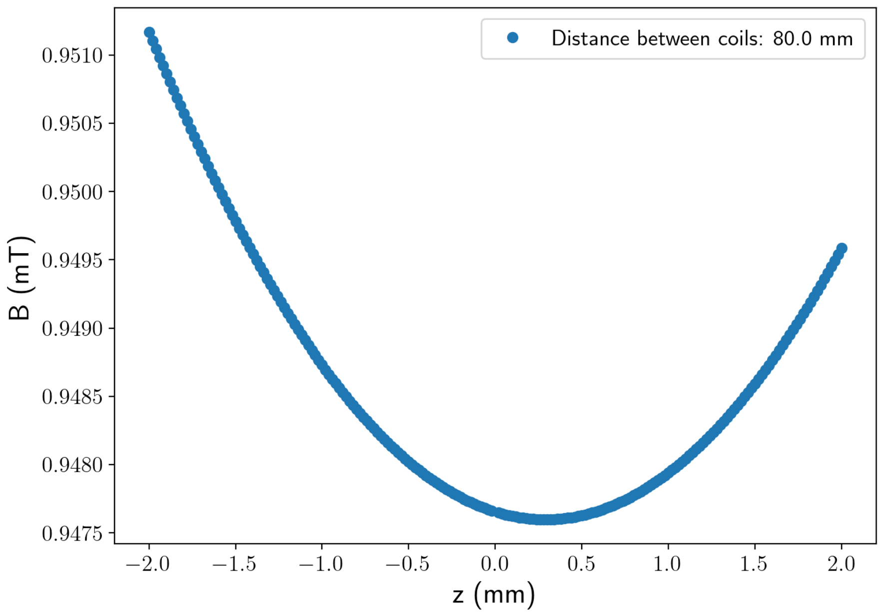

Figure 4: Tilted coil of 10 degrees.