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Modelling and characterization of a ReBCO HTS degaussing demonstrator

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Abstract

- The magnetic modelling and experimental validation of a superconducting degaussing system for maritime vessels is discussed. Degaussing coils compensate for the distortion in the earths' magnetic field by the magnetized steel hull of a ship, thus rendering it 'invisible' for magnetic field sensors. Whereas typical power requirements with copper coils are of the order of 100 kW, an HTS degaussing system in principle allows to reduce this by an order of magnitude. In order to validate such efficiency estimates and to demonstrate the required hardware, a table-top test set-up was realized with magnetic ship steel. The vessel-imitating cylindrical demonstrator is equipped with six degaussing coils, grouped in three sets that act in two different directions, with each set consisting of one copper and one ReBCO coil, the latter one equipped with a sub-cooled forced-flow liquid nitrogen system. Static and dynamic magnetic field measurements are reported and compared to both analytical and numeric finite element models. The results illustrate how even relatively simple analytical models can be used as a powerful tool to extrapolate design parameters and thus to predict the power requirements of large-scale degaussing systems.

Introduction

- Degaussing systems are used to compensate the distortion of earths' magnetic field caused by the magnetized steel hull of a ship. Conventional copper degaussing systems have power requirements of up to several 100 kW [1]. The power requirements of the system can be reduced by using ReBCO instead of copper cables [2]. To estimate the possible power reduction, analytical and finite-element models have been created. These models can be used to estimate the current and power requirement for full-scale degaussing systems.
- A ReBCO degaussing demonstrator was build to compare a conventional copper and ReBCO degaussing system, in order to validate the models.

Analytical model

- The magnetic field around a spherical ferromagnetic shell can be described using a series of equations as described by Baker and Brown [3]. The magnetic field around a spherical shell with current bands outside or inside the shell can be described by solving the Laplace equation for the vector potential A. The general form of the solution is

$$A_\psi = \sum_{p=1}^{\infty} \left[A_p r^p + \frac{B_p}{r^{p+1}} \right] P_p^1(cos(\theta)) \tag{1}$$

details of the analytical solution can be found in the accompanying paper.

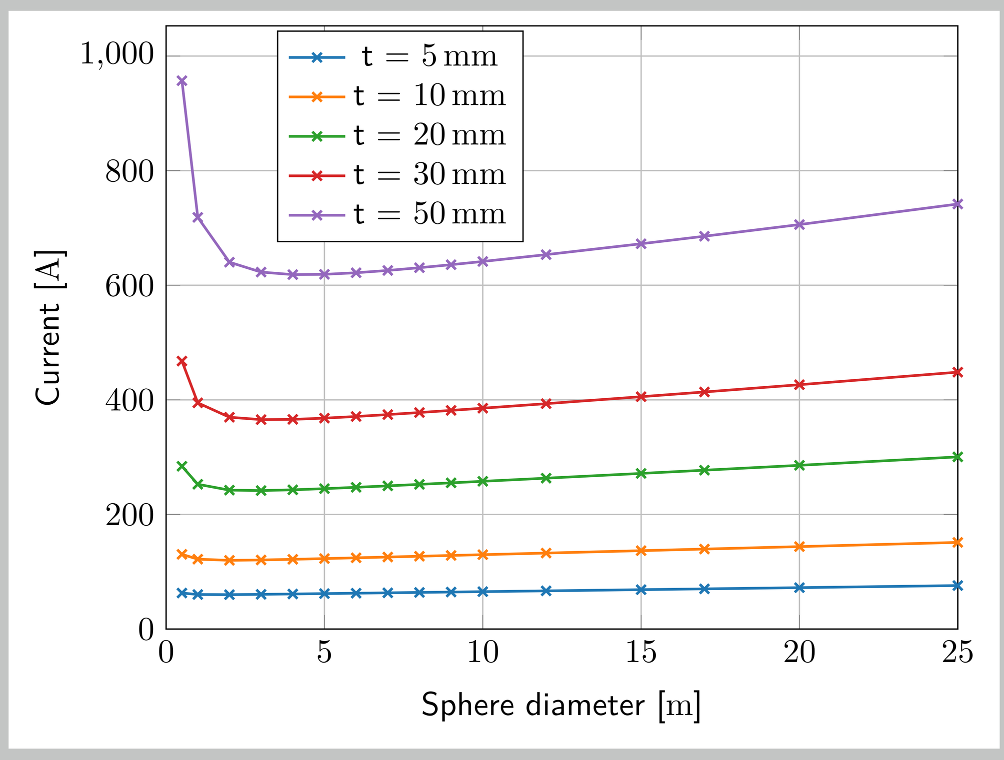

Figure 1:The analytical solution is used to plot the optimum degaussing current as a function of the size of the object with a relative permeability of $\mu_R = 100$, for several different wall thicknesses.

- Figure 1 shows the optimum degaussing current as a function of the diameter of a spherical shell, this is done for a current band on the outside of the sphere. This way the optimal degaussing current and with that the power requirements for a full-size ship can be determined. For each sphere size, the optimal degaussing current is determined at a distance of 1.5 times the sphere diameter.
- The model can be used to determine the optimum degaussing current as a function of a number of variables including the number of degaussing coils, location of degaussing coils, wall thickness, relative permeability and size.

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Magnetic signature measurement setup

- Magnetic field measurements were performed around the demonstrator pipe shown in Figure 2. A rail was placed on the ground below the pipe on which a fluxgate magnetometer was placed to measure the magnetic field as a function of the distance. The magnetic field is measured at several different heights, ranging from 40 cm to 60 cm beneath the demonstrator pipe.
- A first set of measurements was performed without the demonstrator pipe to determine the background field at the measurement location. A second set of measurements consists of measurements with the demonstrator pipe present. Thirdly, the magnetic field was measurements with several different currents in the different degaussing coils. By subtracting these measurements from each other the magnetic signature of the object and effect of the degaussing coil can be measured.

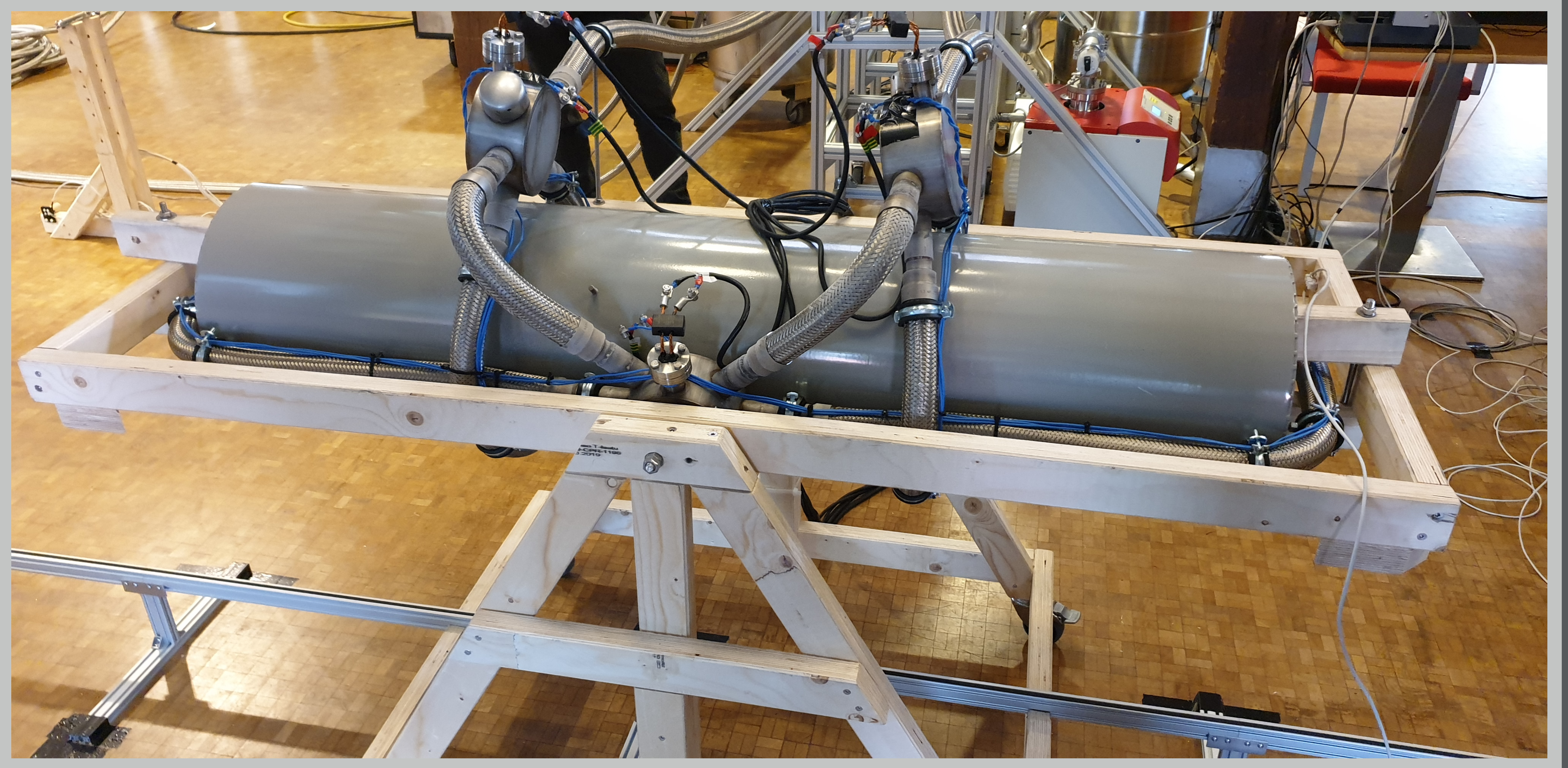

Figure 2:The demonstrator pipe around which the magnetic field measurements were performed. The pipe has a length of 1.5 m, a diameter of 0.3 m and a wall thickness of 5 mm.

Measurement results

- The relative magnetic permeability of the demonstrator pipe was measured and found to be 270. The magnitude of the magnetic field measured around the demonstrator pipe is plotted in Figure 3, together with the finite-element model results. The result of using the three degaussing coils is shown in Figure 4.

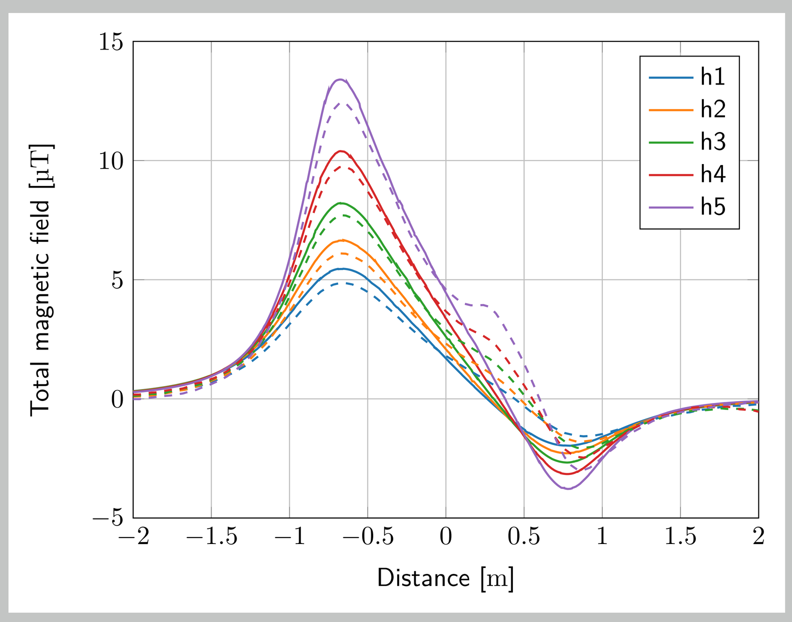

Figure 3:The magnetic signature is plotted as a function of the distance. The dashed lines show the measured data, the solid lines show the finite-element model predictions. The measurements were carried out from 60 cm (h1) to 40 cm (h5) beneath the center of the pipe.

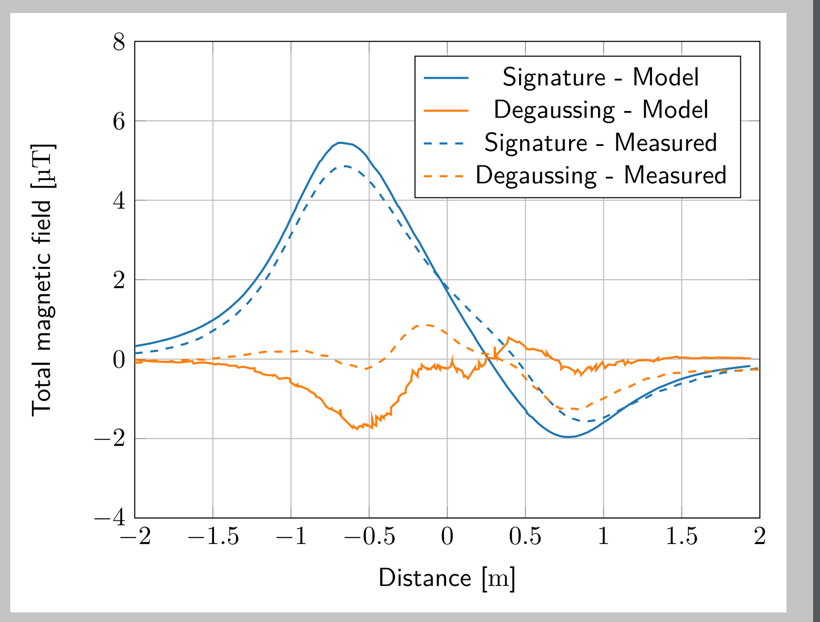

Figure 4:The magnetic field is plotted with and without the degaussing coils turned on. The result is not optimal since only three degaussing coils were used. The measurements and model predictions are shown.

Conclusion and outlook

- A combination of an analytical model, a finite-element model and magnetic field measurements are used to optimized an HTS degaussing system.
- The analytical model is shown to be especially useful in estimating the optimum degaussing current and power requirements of large-scale degaussing systems.
- The finite-element model agrees well with the magnetic field measurements. The model was used to validate the analytical model and can be used to estimate the power requirements of larger systems.

References

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