SUPERCONDUCTOR JOULE LOSSES IN THE ZERO-FIELD-COOLED (ZFC) MAGLEV VEHICLE

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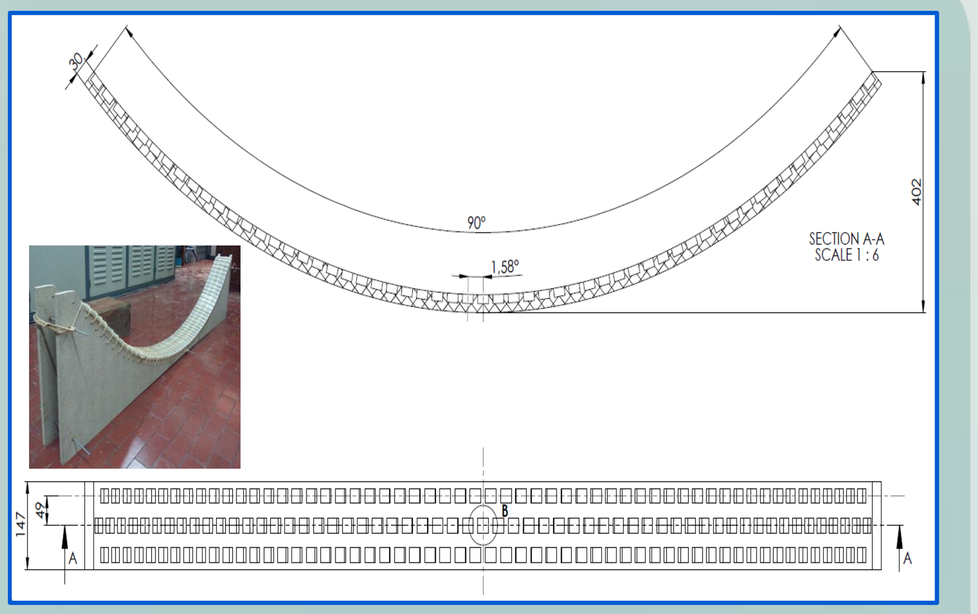
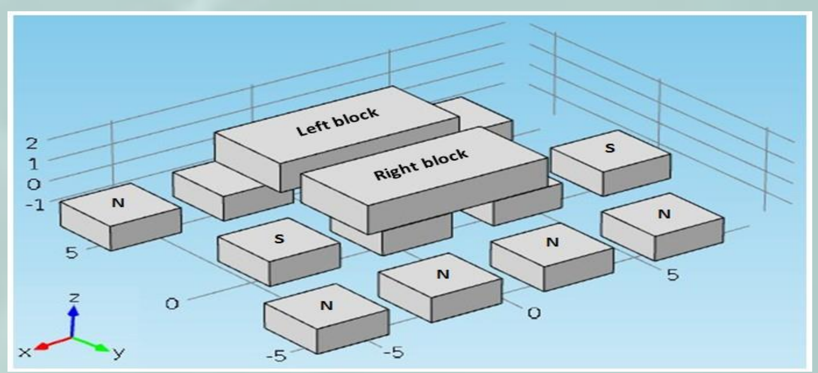
Introduction

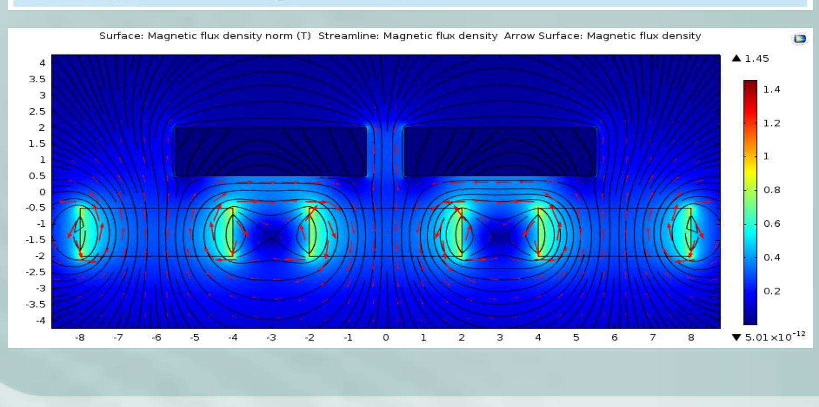
This paper estimates for the first time the Joule losses in the YBCO superconductors in the Zero-Field-Cooled (ZFC) Maglev vehicle. Imposing a pendulum like movement to the vehicle, and since the aerodynamic losses were taken into account in the experiments, obtained results show the Joule losses occurred in the superconductors during the vehicle's movement. Four movement tests were completed, which allow measuring the average losses in superconductors that were responsible by vehicle's damping abstract. A FEM model of the vehicle allowed us to show how and why YBCO Joule losses are function of the vehicle speed. It quantifies the losses and indicates that in the ZFC-Maglev these are clearly reduced since the significant losses are located only in a very small layer at the superconductors' surface.

Modelling, evaluation and estimation of Joule losses in the superconductors of the ZFC-Maglev

Superconductors Joule losses in the ZFC Maglev are experimentally quantified using a pendulum like rail as shown in figure. The aerodynamic losses during the vehicle's movement were taken into account. Hence, several movement tests were completed, which allowed measuring the average losses in superconductors that were responsible by ZFC vehicle's damping.



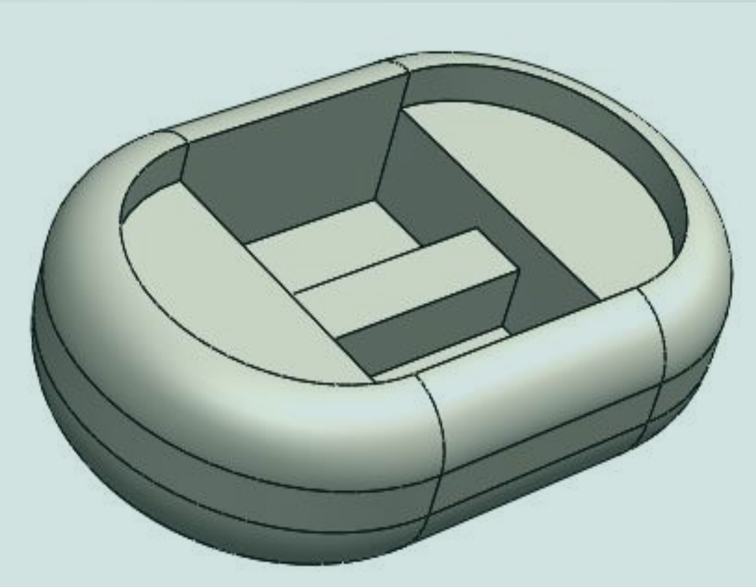




For a better understanding of these results, it required to develop a finite element model for the HTS YBCO material that includes its hysteresis characteristic. With this model and after its experimental validation, the power losses density in the superconductors was estimated as function of the Maglev speed. This allowed us to characterize the energetic consumption and the operational costs associated between the ZFC Maglev, notoriously connected with the Joule losses in the set of superconductors.

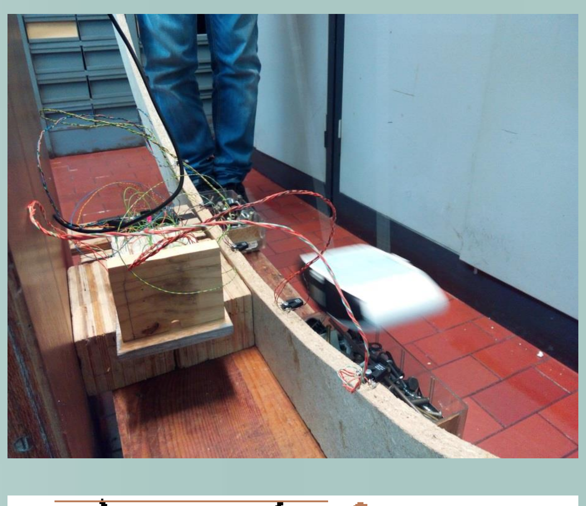
ZFC-MAGLEV vehicle configuration

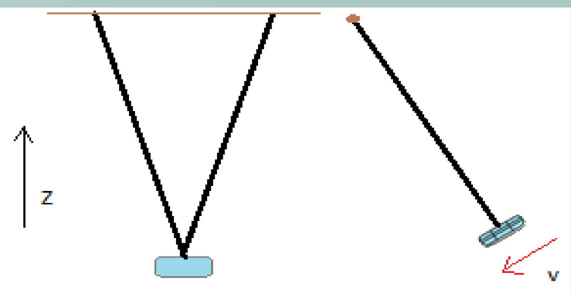
Figures show the vehicle designed to store the superconductors in a way they would maintain the correct distance between themselves (1 cm). The vehicle also has an extra space to store a small amount of liquid nitrogen. This was required because the superconductors need to be maintained under its critical temperature during the tests. The vehicle was built with polyurethane (blue material) since this material is easy to use, it is impermeable and also has a very good thermal insulation. Two sets of two superconductors were placed inside the vehicle.

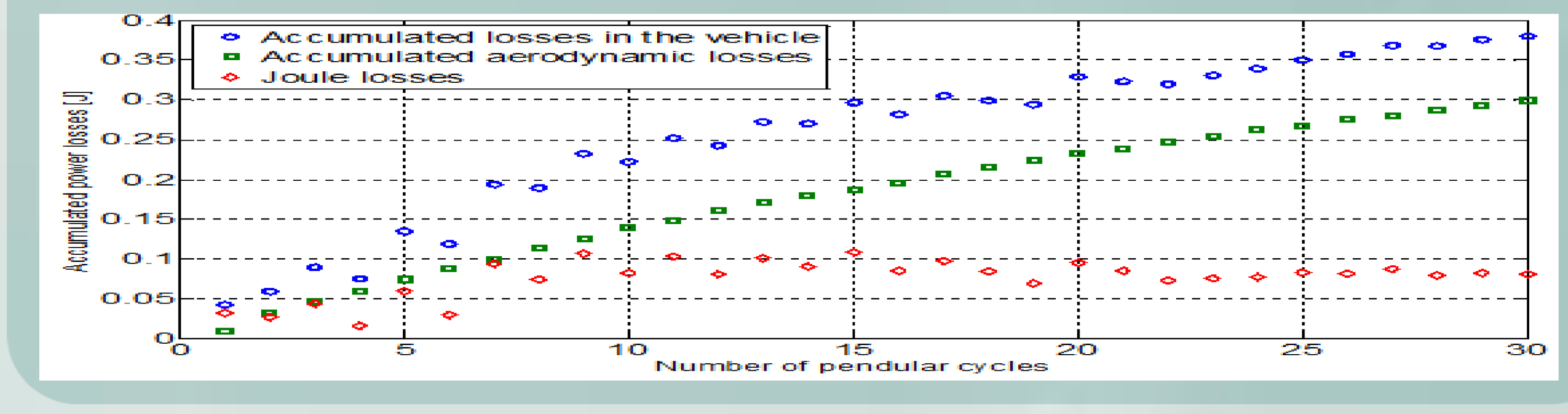


Quantification of YBCOS' joule losses

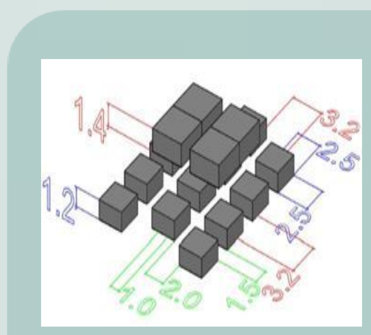
Since the velocity is easily obtained with the optical sensors described in the last section, it is possible to obtain the aerodynamic losses. One way to do it would be by computing the vehicle drag coefficient, assuming the flow is turbulent. However, this method implies solving difficult non-linear equations. The other method is experimental and consists in obtaining the velocity variation of the vehicle without interacting with the permanent magnets. The vehicle was then suspended in a circular bar, as illustrated in Fig. 8, being the distance to the axis equal to the structure curvature radius, having a pendulum-like movement. With this approach and taking into account the setup of the sensor, data related with the velocity of the vehicle per cycle was acquired. After that, equation (4) was used to compute the accumulated losses for each cycle. The friction of the cables was considered negligible.

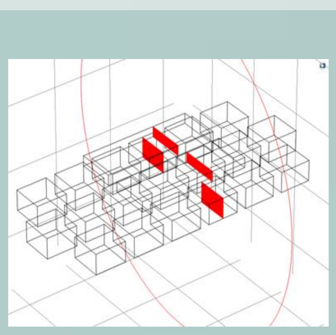


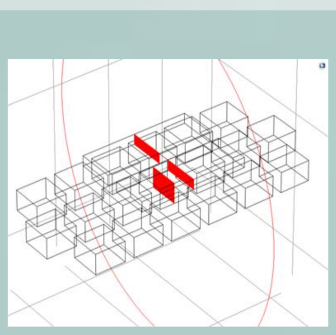


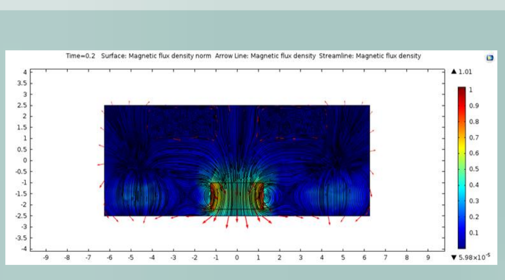


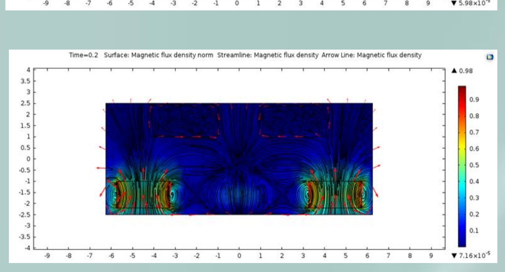
FEM HTS model and its validation



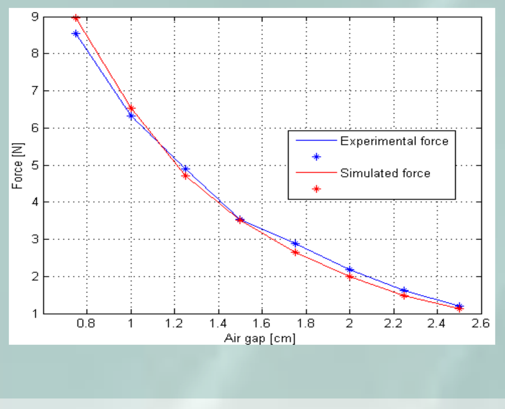






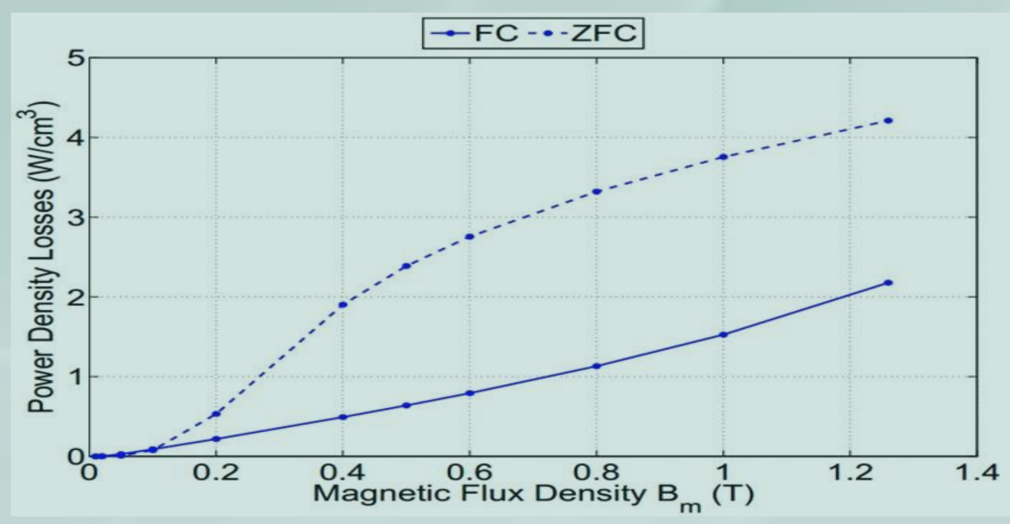


The levitation forces previewed by the model and those ones measured in the lab. There is a consistent small error between those experimental and simulated values on average of 11%. This comes from the numerical precision associated with the mesh used. This could be removed using a finer mesh in FEM model. However, the computational effort was too much for our current hardware. Since, the order of the error values is almost the same, independent of the air gap, the FEM model can be considered validated.



Joule losses at ZFC-MAGLEV vs Maglev-Cobra and associated operational costs

The results achieved have to be analyzed and compared with those obtained from direct measurement of the Maglev-Cobra, allowing a characterization of the energetic consumption and the operational costs associated between the type-ZFC superconductor vehicle and the Maglev-Cobra superconductor vehicle.



ZFC-Maglev and Maglev-Cobra power losses density in function of the magnitude of the applied magnetic field over the superconductor for 5Hz.

CONSUMPTION OF LIQUID NITROGEN BY THE ZFC-MAGLEV IN A 12 HOUR

Volume of liquid nitrogen (l)	Power losses: 24 superconductors (W)	Power losses density (W/cm^3)
3.68	0.14	5.5×10^{-5}

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