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SPS EXTRACTION KICKER MAGNET - THERMAL ANALYSIS

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Abstract

As the SPS accelerator will be used for the CNGS project and as LHC injector, the proton beams passing through its extraction kickers will have a much higher intensity than in the past. The image currents generated by this beam may provoke a temperature increase in the magnet's ferrite core to temperatures above the Curie temperature, unless the heat produced is effectively removed. A further complication arises from the fact that a high voltage is applied to the ferrites. The solution adopted consists in transferring the heat via Aluminium Nitride insulators to a water cooling circuit. The heat transfer analysis and the calculated thermal distribution of the magnet are presented.

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1 INTRODUCTION

The existing SPS fast-pulsed ferrite kickers, which will be used to extract the beam towards the LHC and the CNGS target, are divided into seven cells, each one made of three ferrite blocks. They are insulated from the earth potential frame via aluminium oxide spacers. The magnet has a total length of approximately 1.7 m and is placed inside a vacuum vessel as shown in Fig. 1. Due to the large image currents generated by the beam, the ferrite blocks will heat up [1]. In the original design, radiation, the main means of power evacuation, is insufficient to maintain the ferrites below their Curie temperature (125 ^{o}C). The ideal solution would be to implement a metalized ceramic chamber for the circulating beam. This would prevent the cores from being heated by the image currents. Such an important modification to the existing magnet design would alter, unacceptably, the rise time of the magnets and their physical aperture. Therefore the most time and cost efficient solution relies on improving the heat transfer from the outer surfaces of the ferrite blocks, via highly thermal conducting plates, to a water cooling circuit [2].

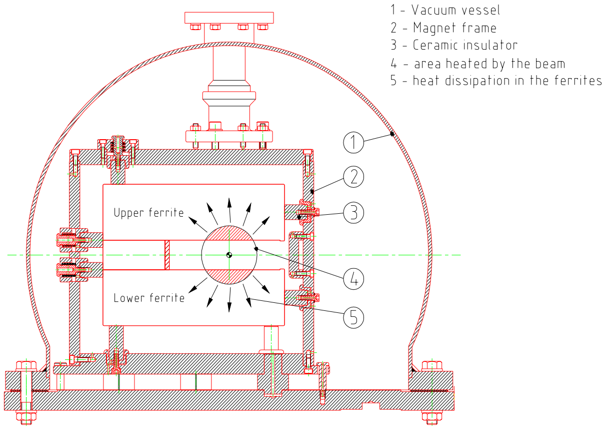

Figure 1: MKE magnet cross section

2 COOLING DESIGN CONCEPT

A series of seven coupled plates of high thermal conductivity rest above and below each ferrite yoke, joined by a copper water cooling circuit running along their extremities as shown in Fig. 2. As the ferrites are in a vacuum tank at high voltage, the material used for the plates must be a very good thermal conductor, an excellent electrical insulator and have a very low out-gassing rate. AlN (Aluminium Nitride) combines these properties.

For good thermal exchange between the ferrite blocks and the AlN plates, smooth surfaces and tight flatness tolerances are required. A spring-loaded pad applies a constant pressure of approximately 0.1 bars on the AlN plates, as shown in Fig. 2.

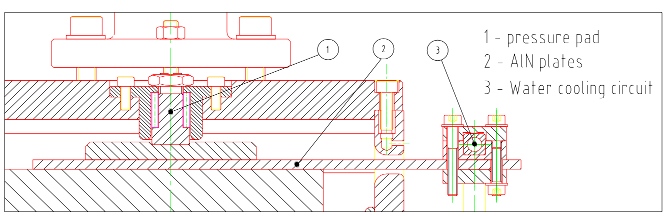

Figure 2: Heat conducting AlN plates

3 THERMAL ANALYSIS

The thermal analysis consists of two parts: Finite Element Analysis (FEA) calculations, and measurements on a specially built cooling "test bench". Results obtained by these means were compared to each other and to the temperature measurements carried out during operation on the magnets equipped with the cooling system.

3.1 FEA calculations

The simulations were carried out using Design Space® [3] and Ansys® [3]. Both FEA calculations used conduction as the only means of heat transport, and contact surfaces were supposed perfect. Two areas in the model are of interest: the supposed hottest area, likely to approach the Curie temperature of the ferrite and the area in which a temperature monitoring device is installed in the magnet as shown in Fig. 3. Results obtained with both programs, for a power input value of 0.3 kW/m, agree within 10 % as shown in Figs. 4 & 5. Design Space® results show temperatures of 80 ^{o}C for the supposed hottest area and 55 ^{o}C for the probe area. As for Ansys®, results show 77 ^{o}C and 52 ^{o}C respectively. Results obtained with Design Space®, for power values of 0.2 kW/m and 0.85 kW/m and assuming a linear relationship between power and temperature, show that the Curie temperature would be reached for a beam power of 0.55 kW/m as shown in Fig 6. The cooling design is therefore considered to be efficient enough to fulfill the requirements for nominal beam powers, which are estimated to be lower than this [4]. These results are compared to the experimental results and machine measurements in paragraph 3.3.

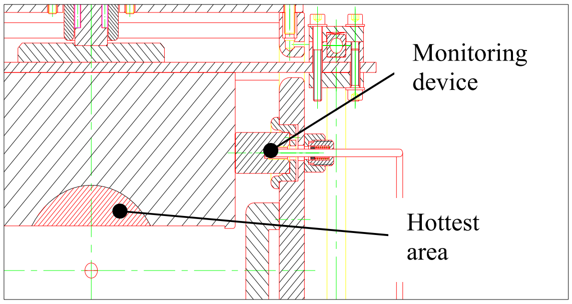

Figure 3: Temperature probe

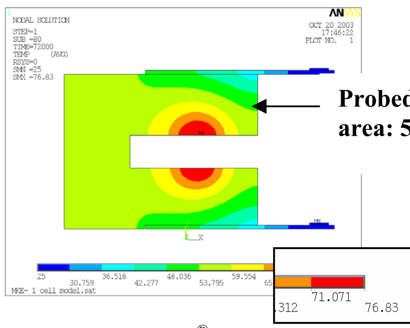

Figure 4: Ansys® simulation result for a given power of 0.3 kW/m

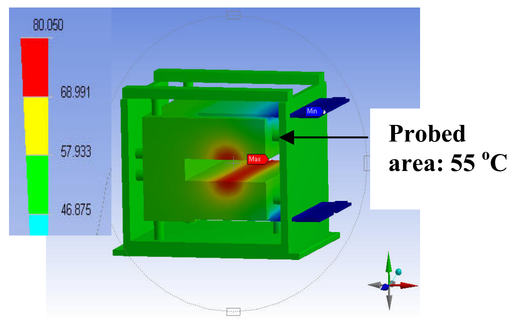

Figure 5: Design Space® simulation result for a given power of 0.3 kW/m

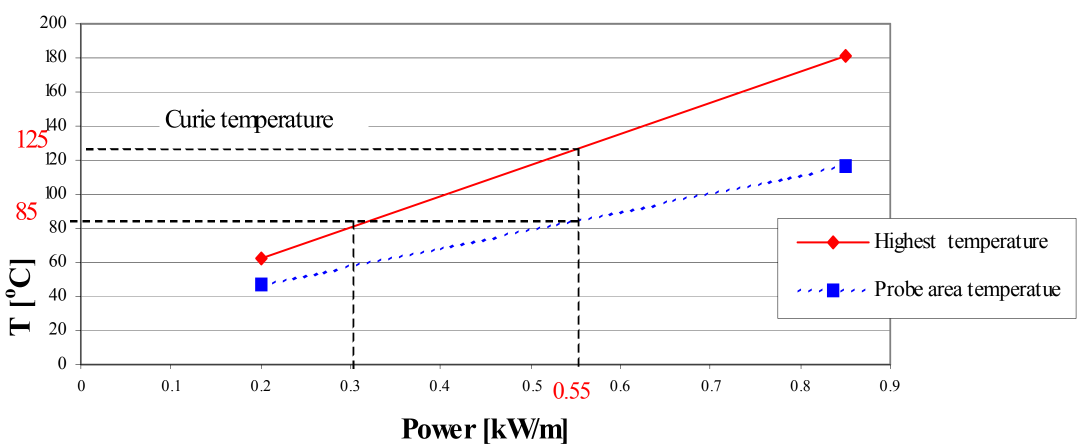

Figure 6: Design Space® graph results for given powers of 0.2 kW/m and 0.85 kW/m

3.2 Laboratory measurements

In order to verify the results obtained with the FEA calculations, an MKE magnet cell "test bench" was built, using 3 ferrite blocks equipped with the cooling system surrounded by an aluminium frame as shown in Fig 8. This unit was placed in a vacuum tank. To heat the ferrite area, which is normally heated by the beam, two titanium bars connected to a power generator are pressed against the upper and lower ferrites inside the gap. Four temperature probes are installed around the ferrite blocks and the aluminium nitride plates. The first probe measures the supposed hottest area, the second measures the magnet-probed area, the third measures the top of the ferrite and the fourth measures the AlN plate. For comparison, only the side and front probe temperatures are given. Temperatures measured for a beam power of 0.55 kW/m are 120 °C on the side probe and 110 °C on the front probe as shown in Fig 8. This confirms within 5 % the results obtained with the FEA calculations in the hottest area. Nevertheless the temperature (110 °C) measured around the probed area is considerably higher than in the model (85 °C). This difference remains unexplained and is most likely due to certain assumptions in the calculations concerning the material properties and the thermal contact resistivity between the AlN plates and the ferrites, which was considered perfect. Further FEA calculations and laboratory measurement would be required for a better understanding.

4 MACHINE MEASUREMENTS

1 Side probe
2 Front probe
3 Heating bars

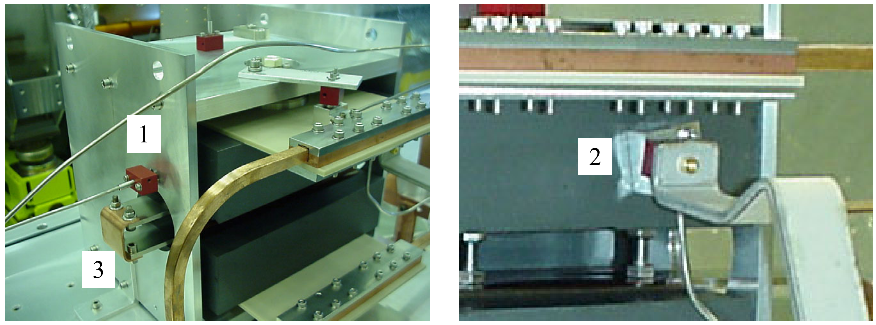

Figure 7: Test bench

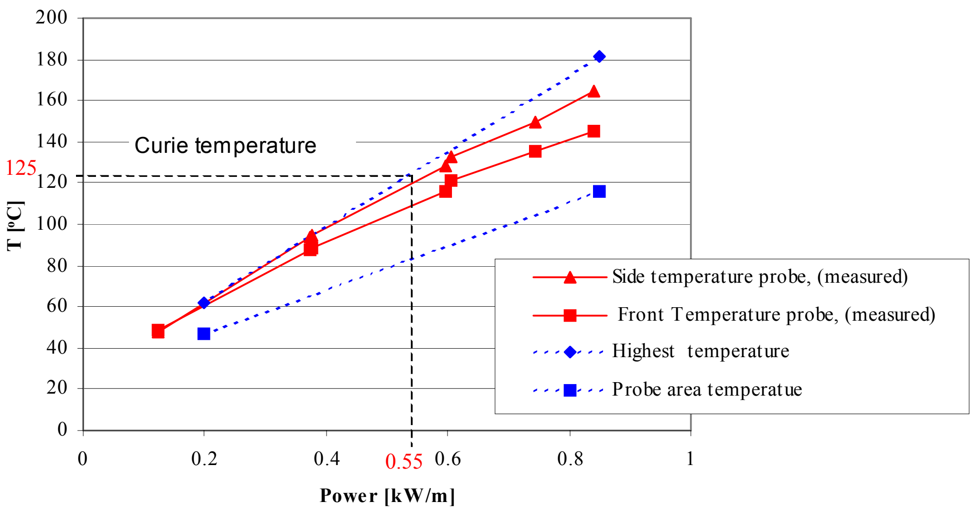

Figure 8: Test bench measurements compared to FEA simulations

In order to verify the calculated values, the kick strength of an MKE magnet has been evaluated by analysing the kicker-induced beam displacement with the SPS "1000 turn" measurement system [5]. The results are shown in Fig. 9. It can be observed that the kick strength starts diminishing from 80 °C onwards (measured with the temperature sensors). According to the simulations with Design Space®, (see Fig. 6), this corresponds to a ferrite temperature of 125 °C i.e. to the Curie temperature of the ferrite and confirms the correctness of the model.

Similar measurements have been performed on the MKQH magnet, which has a similar design but has been equipped neither with water-cooling nor temperature sensors. The corresponding temperatures have been measured on the MKE magnet. The decline of the kick strength starts from about 50 °C onwards. It can be concluded that the cooling system allows the magnet to be operational with approximately double the beam-deposited heating power.

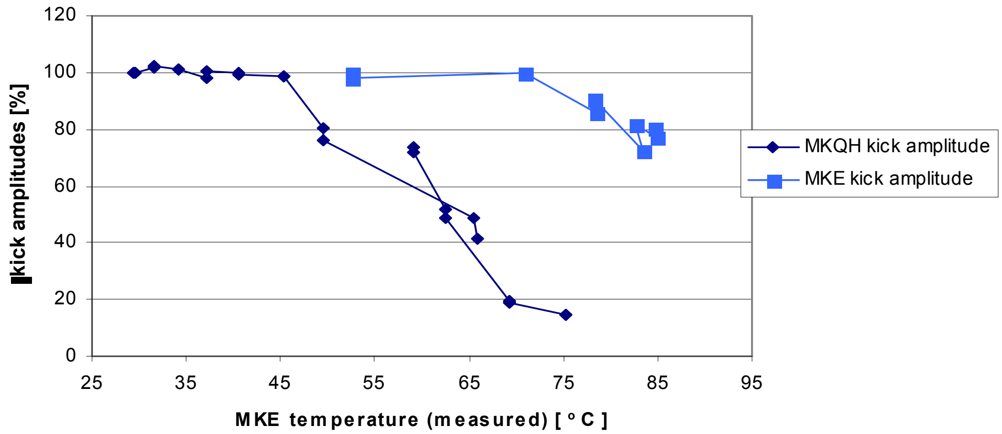

Figure 9: Kick strength measurements for the MKE and the MKQH as a function of the measured MKE temperature.

5 CONCLUSIONS AND DISCUSSIONS

The modified MKE kicker magnets have been equipped with a water-cooling system in order to limit the temperature rise due to beam-induced heating. The aim is to keep the ferrite temperatures below the Curie temperature. Finite element simulations with Design Space® predict temperatures of the ferrites, close to the circulating beam, which agree to within 5 % with the measurements performed at the test bench. These results are also confirmed by measured temperatures and kick strengths on the operational modules in the SPS. However, significant temperature differences have been found between the calculated and the measured temperatures at other positions on the ferrites. This is most probably due to certain assumptions in the calculations concerning the material properties and the thermal contact resistivity. Further investigations with more refined models and more precise values for the material properties could improve these simulations significantly. This was not possible within the given time frame.

Although the modelling of the MKE cooling system leaves some questions open, the most important parameter, the highest temperature in the ferrite and its relation to the probe temperature for the machine model, seems to be accurate. The conceptual design of the cooling system was approved and the series production was launched. The magnets were installed and perform according to the specifications of the cooling system.

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REFERENCES

[1] F.Caspers et. al.; Impedance Evaluation of the SPS MKE Kicker with Transition Pieces between Tank and Kicker Module http://doc.cern.ch/archive/electronic/cern/preprints/sl/sl-2000-071.pdf

[2] M.Timmins et. al.; SPS extraction kicker cooling design; AB-Note-2004-005 BT

[3] Ansys® and Design-Space®, Ansys inc. group http://www.ansys.com

[4] J. Uythoven; Estimates on operational performance made in the APC meeting http://ab-div.web.cern.ch/ab-div/Meetings/APC/2003/apc031003/apc031003.html

[5] G. Morpugo; The BOM 1000 Turn Display; a Tool to Visualize the Transverse Phase-Space Topology at LEP. EPAC '98, Stockholm, Sweden http://cdsweb.cern.ch/search.py?recid=359911&ln=en