THE AGOR SUPERCONDUCTING EXTRACTION CHANNEL EMC2

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ABSTRACT

Only recently, one of the two elements of EMC2 was completed and was tested with liquid Helium to measure its performance in a varying transversal magnetic background field of maximum 3T. It was found that all superconducting coils are capable of handling at least 150A at 3T, although the main coil set shows training above 100A at 3T. Compared with the 150A at 5T for the single superconducting wire, this result is quite good.
Further it was found that with a local heat input of 15W continuously, the quench current is still 100A at 3T. Since the coils are operated at a maximum of 80A at 4T, the thermal stability of the Aluminum mandrel and its cooling seems to be good enough to keep the coils superconducting under all operational conditions of the cyclotron.
Up to this date the production of both elements of EMC2 is almost completed.

1. INTRODUCTION

In 1989 the lay-out of a superconducting electromagnetic extraction channel for the AGOR cyclotron was presented[1,2]. EMC2, being one of the two electromagnetic channels of the cyclotron, is devided into two almost identical elements named EMC2-1 and EMC2-2. Both elements contain a main dipole coil set, a gradient coil set and a correction coil set. All corresponding coil sets are electrically connected in series and are powered by a separate power supply.
The position of the two elements in the median plane of the cyclotron is adjustable for good alignment with the beam that is to be accelerated. The total (almost radial) adjustment possibility is in the order of +-9mm.
By now EMC2 is almost completely manufactured* and a preliminary version of EMC2-2 has been build for testing. The test results are presented in this paper.

* The superconducting coils and elements are build by the University of Twente, The Netherlands, The cryostat and moving mechanism is build by Leybold Woerden, The Netherlands.

2. MAGNETIC STRUCTURE

The mandrel of both EMC2 elements are machined out of a single piece of Aluminum. The superconducting coils are wound and impregnated on separate mandrels and later pressed into the Aluminum structure. The coils are cooled by conduction only. For that purpose two liquid Helium channels are made, one located below the coils one located above the coils. Small holes drilled through the structure connect both Helium channels and form a feedthrough for the conductors of the lower coil set. Liquid Helium enters the element in the lower channel and leaves the element through the upper channel. All electrical connections are placed in the upper liquid Helium channel and glued there in place.
The completed EMC2 elements are then closed by means of electron beam welding. Figure 1 shows a section of the EMC2-2 structure.

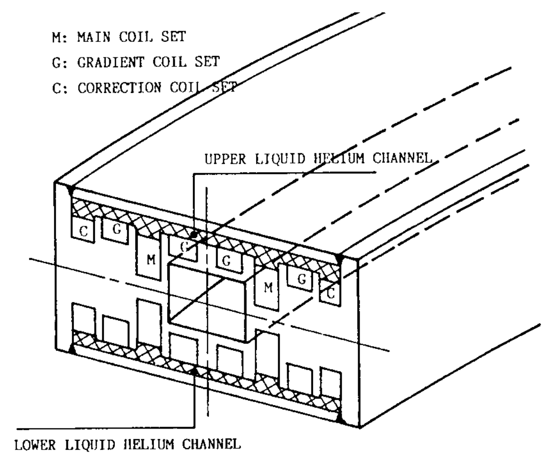

Figure 1: The geometry of the EMC2 coil system

3. MECHANICAL STABILITY

Extensive mechanical calculations using the three dimensional CAE program PATRAN showed that under normal operating conditions the Von Mises stress level is not more than 16N/mm^2 where as the maximum deflection is less than 0.2mm (operational point B of the cyclotron, B=4.05T). Since the forces acting on EMC2 differ both in direction and magnitude (especially under fault conditions) the mechanical stability of the structure is a point of great concern in the design. Figure 2 shows the maximum forces on the elements of EMC2 and the corresponding deformation of the structure.

POINT	FORCE (N) EMC2-1	FORCE (N) EMC2-2	THETA deg EMC2-1	THETA deg EMC2-2	STRESS (N/mm^2)	DEFLECTION (mm)
B	676	890	110	142	16.0	0.20
B corr. coils only	3092	2835	118	143	53.9	0.62
E	274	38	-93	-84	13.7	0.14
E corr. coils only	2800	1949	-63	-37	43.4	0.50

Note: The 330^0 degree line of the cyclotron is roughly the line through the center of the cyclotron and the center of EMC2-2

Figure 2: Maximum forces with corresponding stress level and deflections of EMC2

The positioning of EMC2 relative to the beam makes a guide/slide mechanism to connect EMC2 to the world necessary. Three motor driven guide/slide constructions make a +-9mm positioning parallel to the 330^0 line of the cyclotron possible (see figure 2). The position of EMC2-1 relative to EMC2-2 is achieved by linking both elements using a hinge construction. Figure 3 gives the construction of these guide/slide mechanisms.

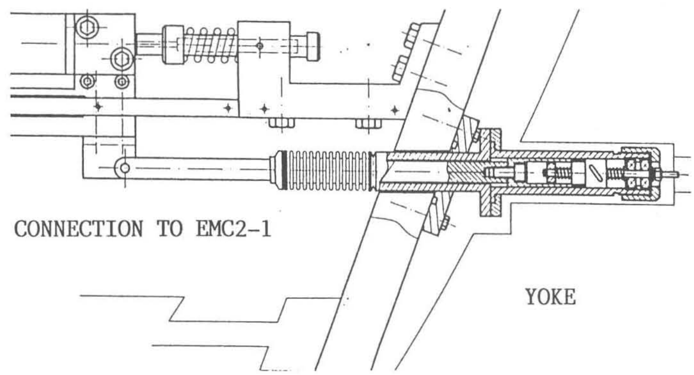

Figure 3: The mechanical construction of a guide/slide mechanism

Figure 4 shows the hinge construction connected to the 80K radiation shield. Via a glass-epoxy thermal bridge EMC2-1 and EMC2-2 are firmly connected to one side of the 80K radiation shield. The guide-slide mechanism is connected to the other side of the 80K shield.
FEM thermal calculations showed that without additional cooling the equilibrium temperature of the 80K shield would be 175K. Therefore, the 80K shield is connected to the 13bar, 80K cooling circuit of the system main Helium liquefier thus keeping the outer radiation shield of EMC2 at a temperature of approximately 70K.

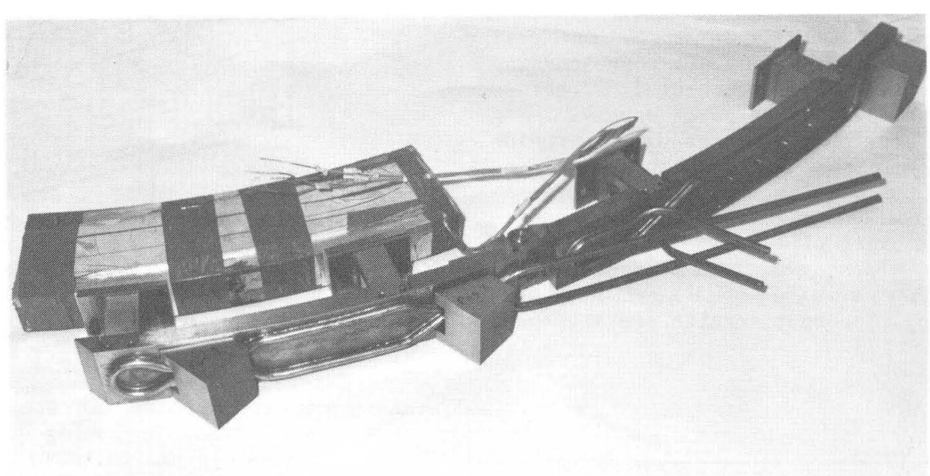

Figure 4: EMC2-1 connected to the 80K shield. The hinge construction between EMC2-1 and EMC2-2 is visible

4. QUENCH BEHAVIOUR AND THERMAL PERFORMANCE

To gain production experience and for doing quench test measurements, EMC2-2 is build on a full scale. The results of the quench tests for the different coil sets are given in figure 5.

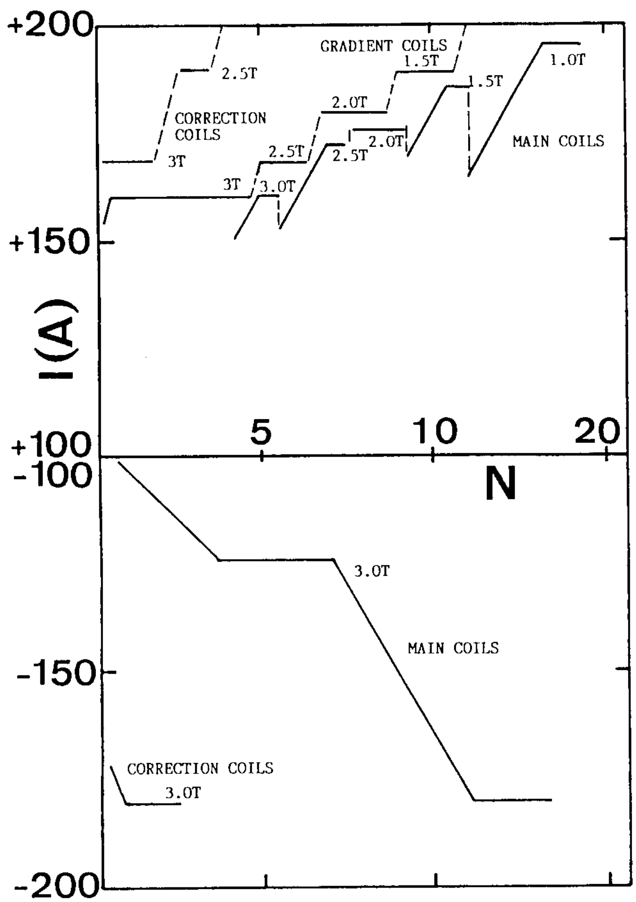

Figure 5: Results of the quench test done on EMC2-2

From figure 5 it is clear that all coils are able (after training) to carry at least 150A at 3T transversal magnetic background field. The main coil set is the least stable since the cross-section of this coil is not constant. However also for this coil training only occurs above 100A at 3T. Since for the superconducting wire 150A at 5T is given by the manufacturer, and keeping in mind that the maximum coil current is 80A at 4T, the results are fully acceptable.

From the viewpoint of thermal heat loads on the elements, there are in the first place radiative and conductive heat loads. Conductive heat loads are reduced by introducing glass-epoxy elements between 4.2K and 300K, radiative heat losses are reduced by introducing an outer 80K radiation shield all around the EMC2 elements and an inner radiation shield in the beam bore of the elements. This inner shield not only reduces the radiative heat load from 300K, but also reduces the radiative heat load of the beam by a factor of 10^2. Since the beam has an energy between $100W/mm^2$ and $200W/mm^2$, and a certain percentage of this energy is lost in EMC2, this inner shielding is a must.

Figure 6 gives the results of the quench test performed while heating the bore of EMC2-2 using small heaters (dimensions 20mmx20mm, the background field is 3T).

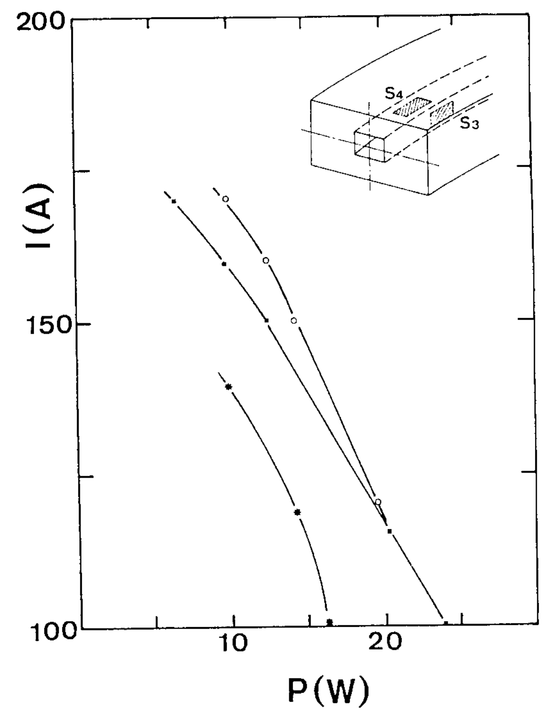

Figure 6: Quench current of EMC2-2 in relation to a simulated beam load on the bore of the element

The thermal stability of the Aluminum structure assures a quench current in the order of 100A at 15W heater power in 3T background field. This thermal stability seems enough to garantee the operation of EMC2 under all normal operating conditions of the cyclotron.

5. PRESENT STATUS

The construction of both EMC2-1 and EMC2-2 as well as the outer cryogenic system is almost completed. Planning is that the assembly of the total structure is done in August 1992, followed by a total system test at the IPN in Orsay in september 1992.

REFERENCES

1) S. Gustafsson, "A superconducting electromagnetic channel for AGOR", Proc. 12th Int. Conf. on Cyclotrons and their applications, Berlin 1989, pp354-357.
2) K. Pieterman et al., "A design study for a superconducting extraction element for AGOR", Proc. 12th Int. Conf. on Cyclotrons and their applications, Berlin 1989, pp358-360.