LOW TEMPERATURE TESTS OF THE AGOR SUPERCONDUCTING COIL SYSTEM

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ABSTRACT

In the period from November 1991 till June 1992 low temperature tests have been performed on the AGOR coils and cryostat first in Genoa where early December the factory tests were succesfully done by reaching the contractual point X where in air the maximum specified attracting force between the coils are obtained (4.5 MN). After warm up and transport the coils and cryostat were installed inside the yoke in Orsay where final acceptance tests are underway. The performance of the cryogenic system will be described in this paper.

1. GENERAL INTRODUCTION

AGOR, the joint project of the Dutch organisation FOM and the French organisation IN2P3 has now reached the phase of final testing of the different subsystems. The general overview of those systems is given in another paper[1]. Here we will focus on the superconducting coil system and its cryogenic support system that are presently under final acceptance test in Orsay. A general description of this system has been presented earlier[2,3]. Final assembly of the coils and cryostat has been realised at the premises of Ansaldo Componenti Srl in Genoa Italy, the company that has been responsible for this contract.

During final assembly of the four different coils special attention was paid to the relative positioning of the coils to obtain the close tolerances that were specified in the contract. After shrinking on the 40 mm thick hoop stress cylinders the magnetic axis and the medium plane of the coils were measured magnetically by running a small current through the coils. Based on those measurements mechanical references were machined in the outer diameter of the hoop stress cylinder both for axis and plane. Those refences have been used for the final machining and mounting of the upper and lower halves of the coil system. Before connecting the upper and lower coil sets additional magnetic measurements were done to obtain the optimum relative positioning of the two parts. Final positioning of the coils was realised within the specified 0.2 mm tolerance field.

Final assembly of the coils, radiation shields and cryostat was done in August and September 1991. During assembly some minor modifications have been made especially on connecting cryogenic tubing, to assure enough space between the different temperature levels as in general mounting space was very limited. Figure 1 shows the system during assembly. After completion of the system the external cryogenic connections were made and the pumping of the cryostat vacuum started on November 1, 1991.

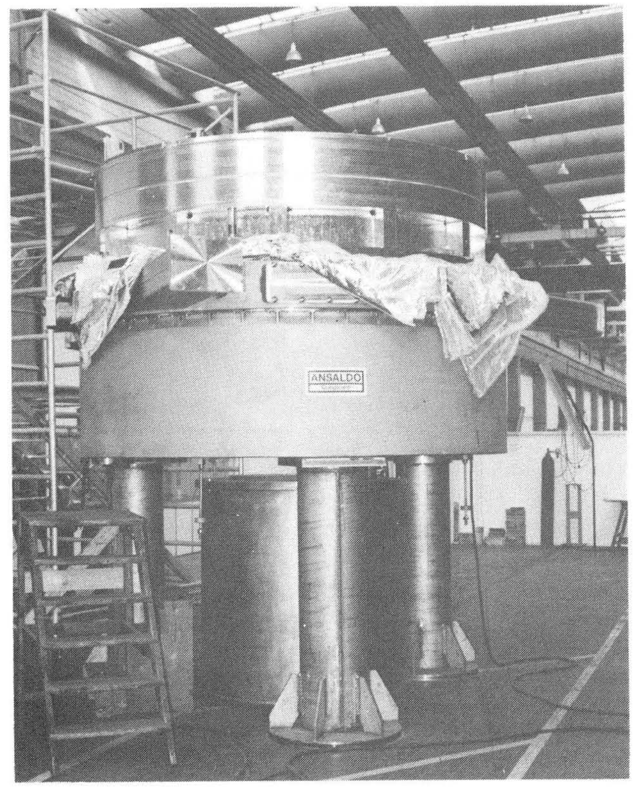

Figure 1. The AGOR cryostat during assembly.

2. FACTORY ACCEPTANCE TESTS

2.1. Cooldown

After a final check of all subsystems including a 1 kV test on the isolation of the coil system to ground cooldown started on November 4, 1991. The cold gas flow was regulated to keep the temperature gradient over the coils below 40 K to avoid high thermally induced stresses on the coil system. A maximum of 5 K for the temperature gradient over the coils and 20 K between adjacent coils were also set but we found that the maximum gradient of 40 K over the complete coil system was sufficent to regulate the cooldown. The coils superconducting state was reached on November 29, 1991. The cooldown time was in agreement with the calculated time of 3 weeks taking into account a few regulation problems with the liquefier. With the shields filled with liquid Nitrogen we observed a small cold spot in the oval medium plane support at 35°. The cryostat vacuum was $2x10^{-6}$ mbar and a check with the helium leak detector showed that there were no helium cold leaks.

2.2. 4K Operation.

Stabilizing the helium level inside the cryostat turned out to be difficult and could only be obtained by keeping a constant warm gas return flow of about 4 Nm^3 per hour in addition to the warm gas return of the current leads. A measurement of the losses of the cryostat was done by closing the liquid helium filling line as well as the cold gas return and adjusting the warm gas return valves in such a way that a constant pressure inside the cryostat was maintained. Table 1 gives the specified and measured values.

Table 1: losses of the cryostat.

Temp. level	Specified	Measured
80 K	190 W	71 W
4 K cold return	10,1 W	18,4 W
4 K warm return	6,5 l/h	6,1 l/h

After a final 1 kV to ground test energising of the coil system could start.

2.3 Coil Performance.

The coil tests were performed using the AGOR dual power supply (900 A,10 V and 1800 A,15 V) delivered by Foeldi, Switserland. Due to transport damage the slow dump cabinet could not be used during these tests. As primary security the quench detector that was part of the delivery of Ansaldo was used. At currents up to 100 A the behaviour of the power supply and quench detector were tested. To gain experience with the operation of the power supplies we used a software program that allowed full manual control. Strong disturbances were observed on the quench detector from the voltage regulation during charging of the coils. By carefully regulating the voltage steps of the power supply and small modifications to the quench detector the coils could be charged to higher currents.

The voltage taps on the coils are measured in such a way that the four coils form a measuring bridge. An amplifier mounted close to the cryostat amplifies the bridge signal by a factor of 25. The quench detector gives a warning signal if a voltage peak of 1 V (40 mV on the coils) is detected. A quench is regarded as occurred if the integral of the signal over 1 second is greater than 1 V or a voltage level of 3 V is surpassed disregarding the peak width. A signal of 40 mV from the coils roughly corresponds with a normal zone length of one winding. Taking into account the propagation velocity of the normal zone this was regarded as sufficient[4].

The coils were charged towards the contractual point X (I1 = 450 A, I2 = 900 A, see Fig. 2) the attracting force between the coils reach the same value

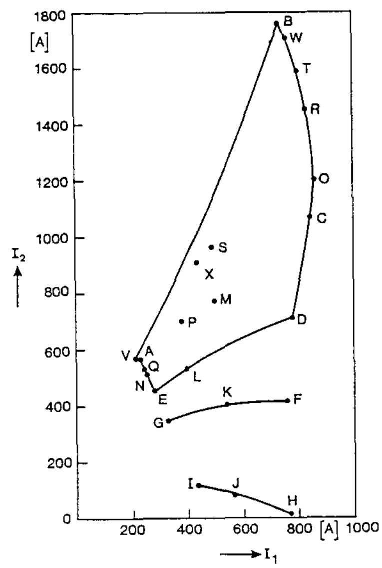

Figure 2. Operating diagram of the AGOR coil system.

(4.5 MN) as at point B (the maximum field operating point with iron). At the point where the power supply started to regulate in order to stabilize the current at this level (I1 = 445 A, I2 = 850 A) an opening of the breakers was observed. Analysis showed that no quench has occured neither at the opening of the breakers nor afterwards during the fast dump. By adjusting manually the voltage regulation we obtained a stable current level at I1 = 445 A and I2 = 895 A on December 6, 1991. At this point field maps were made to check both the radial off centering of the coils and the magnetic medium plane. The results obtained are given in table 2.

Table 2: Magnetic coil behaviour at point X.

offcentering	coils 1 (mm)	coils 2 (mm)
radial absolute	0.76 @ 296°	0.82 @ 298°
relative	0.06	
medium plane absolute	-0.41	-0.37
relative	0.04	
magnetic	**specified (mT)**	**measured(mT)**
C1 (Bz)	0.17	0.007
C2 (Bz)	0.55	0.007
C1 (Br)	0.17	0.196
mean Br	0.17	-0.097

Only the first harmonic C1 (Br) of the radial field is higher than the specified value due to a local anomaly at 240°. Figure 3 shows the measured Bz at point X.

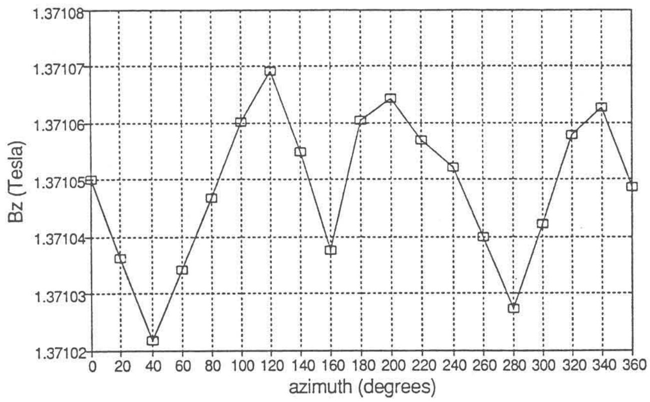

Figure 3. Bz modulation at maximum attracting force

The modulation can be explained by a coil deformation under the maximum attracting force of 0.06 mm. This deformation is about a factor two lower than foreseen in the original design calculation.

To test the breaker system we externally activated the quench detection system at point X. At this point an induced partial quench was detected at the lower coil B2, where a maximum temperature of 8.5 K was observed. The total stored energy in the system at point X (deducted from the measured inductances L1 = 16.3 H, L2 = 12.4 H and M = 6.8 H) was 11.9 MJ. 98.5% of this energy was dumped inside the fast dump resitors and 1.5% inside the coil system.

2.4. Factory Tests Conclusions.

Apart from the small anomaly in the radial field measurements the magnetic coil performance was excellent. The high accuracy in coil winding and assembly realised by Ansaldo made it possible to meet the tight tolerances specified by AGOR.

To optimize the stabilisation of the level inside the cryostat it was decided to modify slightly the internal cold gas return circuit of the cryostat to better equalize the pressures between the Helium volume at the liquid inlet and the current leads.

After analysing the cryogenic performance we found two main reasons as for why the 4 K losses were higher than expected. First the anchoring temperature of the upper spport (185 K) was too high with respect to the design value and secondly we found that three small 80 K covers at the oval medium plane support were mistakenly not mounted. The combined effect of this could well explain the difference with the specified losses at 4 K. The 80 K losses were considerably less than expected, partly because of the higher anchoring temperature and indicating a good efficiency of the applied superinsulation.

Some anomalies were observed in the read out of the upper tie rod strain gauges that was believed to be a torsion effect. It was decided to mount four instead of two of these sensors to form a compensated bridge.

Essential experimental data were obtained with the regulation of the power supplies to develop the final software for this system.

3. FINAL ACCEPTANCE TESTS IN ORSAY.

The AGOR coils and cryostat were delivered to their temporary site in Orsay on February 14, 1992, with the modifications that resulted from the factory tests implemented. Figure 4 shows the cryostat before mounting inside the yoke. Seven weeks after arrival

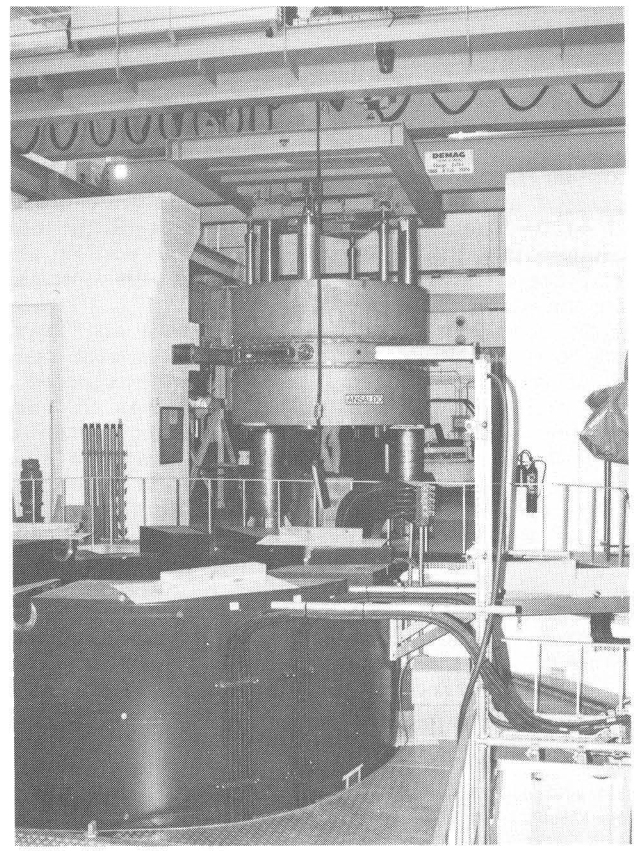

Figure 4. The AGOR cryostat at the Orsay test site

the system was mounted inside the yoke, the external cryogenic system connected and all electrical connections made and tested. The second system cooldown using the AGOR refrigeration system delivered by Sulzer, Switserland was started on April 6, 1992. As it was the first full scale use of the complete cryogenic system it took somewhat longer than expected to reach the 4 K level. Expecially during the final cooldown from 80 K to 4 K a number of minor modifications were made to the control software before we were able to operate the system in full automatic mode. Despite of a careful repositioning of the shields during the mounting procedure in Orsay we still observed a small coldspot at the same position as during the factory tests. By attaching a 25 W heater to the spot we could avoid condensation and ice formation.

Normal operation of the system at 4 K level was obtained on May 12, 1992. The modifications of the internal cold gas circuit made by Ansaldo proved to be succesfull as liquid Helium level stabilisation was obtained without any problem. Also the 80 K recondensor that has not been used before, operated as expected. A first measurement of the 4 K losses of the cryostat was done by isolating the cryostat from the liquefier and keeping a constant level and pressure in the cryostat by transferring Helium from the 1000 liter dewar and returning all gas at room temperature to the suction side of the compressor. The total loss at 4 K level was 29 W, including transferline and valve box losses. The latter were not measured seperately but taking their expected losses we may conclude that also in this respect the modifications to the system realised after the factory tests were succesful. A check on the cryostat vacuum with the leak detector revealed a Helium level of 10^{-6} mbarl/s that seems to be decreasing. Further checks are necessary on this point.

At low field level (2.5 T) a number of tests were carried out with the newly implemented control program for the power supplies that proved to be very succesfull as no inacceptable disturbances were observed on the quench detector. Adjustement of the coil position both with respect to medium plane position and radial centering was done with the results obtained from the AGOR fieldmapping system.

On June 24, after having proved that all subsystems operated satisfactory, high field tests were started. Around the maximum field strength we observed a sharp rizing of the tension in the radial tie rods indicating a strong increase in offcentering force. At 3.8 T the secondary safety system activated a slow dump as the force on the tie rods surpassed rapidly the 45 kN level that was used in the protection system (25% of the maximum allowed force). The maximum force observed was 110 kN indicating the strong destabilizing effect of the offcentering force. Nonetheless the coils remained perfectly stable and no quench was induced by the activation of the slow dump circuit at this field.

We obtained stable operation of the system at a field strength of slightly over 4 T on July,1 by adjusting the radial tie rods as good as the mechanical system allowed. Up to this point, almost at maximum specified field and stored energy no irregularities in the superconducting system were observed.

4. CONCLUSIONS

The coils show perfect stability towards the maximum obtained field strength at present (4 T). The signal of the quench detector is very stable and no disturbances were observed. Even at the activation of the slow dump circuit at high field the system remained stable.

After having solved some minor regulation problems in the refrigeration system it performs very well in automatic mode. The overall losses both at 4 K and 80 K are comfortably within the capacity of the refrigeration system, giving us more reserve capacity than foreseen for the cooling of the superconducting extraction elements.

The only remaining points of concern are the fact that we still have a cold spot at the medium plane inside the beam vacuum that at the moment is heated away and the fact that Helium was detected inside the cryostat vacuum. Those points will be addressed when the system is to be dismantled for final transportation to the KVI in Groningen. We are also considering to mount stronger radial tie rods to reduce their stress level caused by the offcentering force. With the experience obtained sofar however we feel secured that the system performance is more than sufficient to allow for the beam tests foreseen in Orsay.

5. REFERENCES

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