PROGRESS IN THE DESIGN, MANUFACTURE AND TESTING OF THE KLOE SOLENOID FOR THE DAΦNE RING AT FRASCATI

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Abstract

Oxford Instruments took over the manufacture of the 5.8 m outer diameter 4.4 m long 0.6 T Solenoid for the KLOE detector on the DAΦNE ring when the Austrian company ELIN closed its magnet manufacturing plant. The paper begins by briefly discussing the magnet design before describing the approach Oxford Instruments has taken to the completion of the magnet. The results of system testing at Oxford Instruments will be described along with the proposed installation schedule.

1 INTRODUCTION

In January 1994, ELIN (an Austrian electrical company) was awarded the contract for the design and manufacture of the KLOE solenoid for the DAΦNE ring at Frascati. Until December of that year the company had worked on the design and procurement of elements of the system before the holding company decided to close its superconducting magnet manufacturing plant in Weiz, Austria. Oxford Instruments took over completion of the system at this time as sub-contractors to ELIN with INFN's agreement.

The superconducting magnet is designed, in conjunction with its iron yoke, to produce 0.6 T over a 4.3 m long 4.8 m diameter volume to act as a detector in the search for the solution to the "matter - anti matter" imbalance. The magnet specifications are below.

Table 1 - magnet specifications

Central magnetic field	0.6 T
Vacuum case length	4.4 m
Vacuum case inner diameter	4.86 m
Vacuum case outer diameter	5.76 m
Coil shell inner diameter	5.19 m
Cold mass	10 tonnes
Vacuum case mass	26 tonnes
Iron return yoke mass	475 tonnes

2 DESIGN

The design constructed by Oxford Instruments is shown in the schematic below.

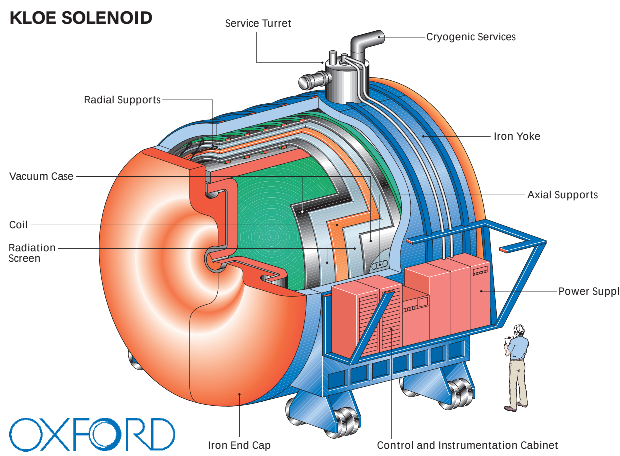

Figure 1 - KLOE schematic

2.1 Coil Shell and Conductor

Oxford Instruments took over responsibility for the shell after the coil shell made by Elin was rejected by INFN; Oxford Instruments changed the design to one fabricated from a number of 12 mm thick aluminium sheets and cooling channels. The new design relied on achieving the diametrical tolerances (eased by INFN to ± 8 mm) by fabricating it on an adjustable spider that allowed the ribs to be moved around until the tolerances were met. The inner skin was fully welded to the ribs whilst the outer was partially welded. No machining took place on the shell although the inner welds were all hand dressed. This approach was very successfully carried out by Vosper Thorneycroft (Southampton, UK).

This new design of coil shell was designed, manufactured and delivered in 6 months thus minimising the delay to the system manufacturing schedule.

The conductor is a 10 mm by 5 mm composite consisting of a Rutherford cable co-extruded with high purity aluminium. The conductor, provided by LMI, was cleaned and then wrapped with two half lapped layers of 0.125 mm glass tape.

The two layer coil was wound inside the coil shell by rotating the shell on motorised rollers in a controlled manner whilst the conductor was fed in and directed on to the shell face from a spool mounted off the winding machine. The conductor was wound on flat and between the two layers 1 mm thick high purity aluminium sheets were placed in order to improve propagation velocities and reduce the peak quench temperatures.

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After winding, the coil was lined with aluminium, to act as an impregnation vessel, before being turned axis vertical and placed inside a 7 m cubic impregnation oven. The aluminium liner was supported against collapse by a fabricated support structure before the coil space was evacuated, filled with epoxy and then cured at 100° C for 48 hours. The major coil parameters are listed in Table 2.

Table 2 - coil parameters

Layers	2
Turns/layer	368
Ampere-turns	2.14 MA-T
Operating current	2902 A
Stored energy	14.3 MJ
Inductance at full field	3.4 H
Discharge voltage	250 V
Peak quench temperature	80 K

2.2 Radiation Screen

The radiation screen will be cooled by helium gas from the DAΦNE refrigerator.

The inner and outer radiation screen cylinders are simple end cooled screens each constructed from eight pre-fabricated panels - each panel consists of three components - two 1 mm thick flat aluminium sheets and one 1 mm thick corrugated aluminium sheet. The three components are all bonded and riveted together on a former of the correct diameter in a sandwich construction consisting of flat sheet - corrugated sheet - flat sheet. The cooling pipe is welded to the panels over a length equivalent to 30 % of their circumferential extent. This minimal approach to the cooling of the radiation screens is possible only as a result of the extremely low radiant and conducted heat loads. The guaranteed heat load is given in Table 3. The screen is supported from the vacuum case by stainless steel cables.

Table 3 - guaranteed heat load

Source	**Heat load**
Current leads	0.6 g/s
4 K Radiation and conduction	55 W
70 K Radiation and conduction	530 W

2.3 Service Turret

Little design work had taken place before contract hand over and the refrigerator contractor was not selected until early in 1996: as a result many design issues were not finalised until then.

The space available for the service turret is very restricted due to the need to minimise the cut out in the iron and the very restricted height. The service turret provides the following functions:

- supply and control of liquid helium
- 150 litre helium storage volume
- supply and control of 70 K helium for radiation screens
- gas cooled 3,000 A current leads from 300 K
- instrumentation connections to the coil and radiation screens

The delay in the settlement of some of the design issues meant that connections to the refrigerator were finalised after the service turret was in manufacture. This, coupled with a lack of space forced by the need to minimise the iron cut-out, has led to a need for a separate valve box. This will be mounted on top of the iron and contains a number of valves to facilitate safe and easy connection to the refrigerator.

The system is now complete and the cryogenic guaranteed parameters are summarised in Table 3.

2.4 Power Supply and Control Instrumentation

The power supply was originally to be a thyristor controlled switch mode system. However, because of concern about electromagnetic interference with the experimental detectors a series regulated supply designed for low EMI has been provided.

The control and instrumentation can be subdivided as shown in Table 4.

Table 4 - controls & instrumentation

Functions	**System Component**
Overall control + monitoring	Labview running on Pentium PC
Temperature measurement	Oxford Instruments ITC-600
Helium valve control	Weka valve controlled by Labview driver
Current leads control	Northvale Korting Bossmatic valve controlled by separate PID controller

The system has distributed control with centralised monitoring via Labview.

3 WORKS TEST

The system was assembled in January 1997 ready for the works test which began in February. The system components tested consisted of the following:

- Magnet and Cryostat
- Service Turret
- Power Supply
- Control and Instrumentation
- Valve Control Panel

The additional valve box was not subject to a cryogenic works test and the iron yoke was not involved.

The coil cooling system and radiation screen were externally connected in series so that they could be cooled by a single controlled flow of nitrogen. The system took nineteen days to cool from 300 K to 77 K and used 36 tonnes of liquid nitrogen. After pumping and flushing with helium, the coil and service turret were cooled to 4 K in a further two days using 3,000 litres of helium. Magnet energisation and heat load tests took a further day before the system was actively warmed, using the power supply and by airing up the vacuum space with nitrogen gas, back to room temperature in a further 6 days.

The 4 K heat load was found by monitoring the boil off gas flow rate. The test was performed with the coil at 4.3 K, with liquid in the service turret, the transfer siphon (used to fill the service turret from transport dewars) removed from the service dewar and the coil energised at a steady 1,000 A. The radscreen was at a steady temperature of 83 K throughout the test. The steady boil off measurement, after removing the current lead contribution, was 1.38 g/s and produces a 4 K heat load of 27.6 W - compared with a guaranteed value of 55 W. The current lead boil off for both leads was 0.12 g/s at 1,000 A which compares well with the scaled guaranteed value of 0.2 g/s.

The system was energised to 1,000 A at a charge rate of 1.4 A/s (specified rate is 0.5 A/s) without problem and the magnet operated at this current during other system tests. The quench detector, power supply, contact breaker, free wheel diodes and dump resistors were all checked along with all the safety interlocks.

The magnet proved to be difficult to quench. Even after drying out the helium in the service turret and coil cooling channels and warming the coil the conductor had still not quenched two hours after all helium had been removed. The current lead protection system took over when the lead temperature exceeded its threshold and the magnet ran down on the power supply resistor.

The 77 K heat load was measured after removing all cryogens from the radscreen by monitoring the mid screen temperatures over a 48 hour period. The temperature rose from 85 K to 104 K which, given a mass of 1,250 kg and enthalpy change of 8,650 J/kg, gave an equivalent heat load of 62.6 W at 77 K. This compares favourably with the guaranteed value of 530 W.

4 COMPLETION SCHEDULE

Subsequent to the status report and schedule reported in [1] the completion schedule has advanced significantly and it is now expected that commissioning and acceptance will be over by July 1997 rather than October 1997.

5 CONCLUSION

Many detailed and some major design and manufacturing changes have been made to the original ELIN design. The system has been assembled and successfully tested at reduced current at Oxford Instruments' facility in Eynsham UK. Testing at Oxford Instruments took place in early 1997 and delivery to Frascati took place in March 1997. Full tests will take place at Frascati in the iron return yoke ready for handover by mid 1997, assuming the INFN test facilities are available as scheduled.

6 ACKNOWLEDGEMENTS

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REFERENCES

[1] K.D. Smith, A.J. Broadbent, M. Greenslade, S.M. Harrison, D.M. Jenkins, J.S.H. Ross, A.J. Street, M.C. Townsend and J.M. Wiatrzyk "Progress in the Design and Manufacture of the KLOE Solenoid for the DAΦNE ring at Frascati", *ASC*, August 1996.