DEVELOPMENT IN THE DESIGN OF THE SUPERCONDUCTING TOROIDAL MAGNET FOR THE CONTINUOUS ELECTRON BEAM ACCELERATOR FACILTY (CEBAF) LARGE ACCEPTANCE SPECTROMETER

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Abstract--The initial design of the toroidal magnet system was carried out at CEBAF and was reported at ASC in 1988. Subsequently in February 1991 a design and construct contract was awarded to Oxford Instruments who are now nearing completion of the detailed design phase. The magnet system comprises six, flat 'kidney' shaped coils arranged radially to produce a toroidal field with a peak value of 3.5T. Features of the design which will be presented and discussed include a modular coil design enabling single coil works testing, indirectly cooled/aluminium stabilised conductor, support of coils via in-plane warm tension links to each vacuum case, out-of-plane load sensing for alignment and fault sensing, passive internal quench protection and an integrated instrumentation and control system.

I. INTRODUCTION

Since the contract was placed in February 1991, Oxford Instruments has completed the electromagnetic and mechanical design of the magnet system and are progressing well with the manufacture and assembly. The design is a development of that previously submitted by CEBAF [1] who defined the geometrical limits, coil profile and ampere turns.

A modular coil system has been developed which facilitates site assembly and allows for works testing of single coils. The coil design features an aluminium stabilised conductor which is indirectly cooled by force-flow, supercritical helium.

A sophisticated control and instrumentation system is being developed based on TACL control software from CEBAF. The system utilises the out-of-plane supports for load sensing to enable coil alignment whilst cold and to detect fault conditions. Figure 1 shows a general view of the proposed Torus system.

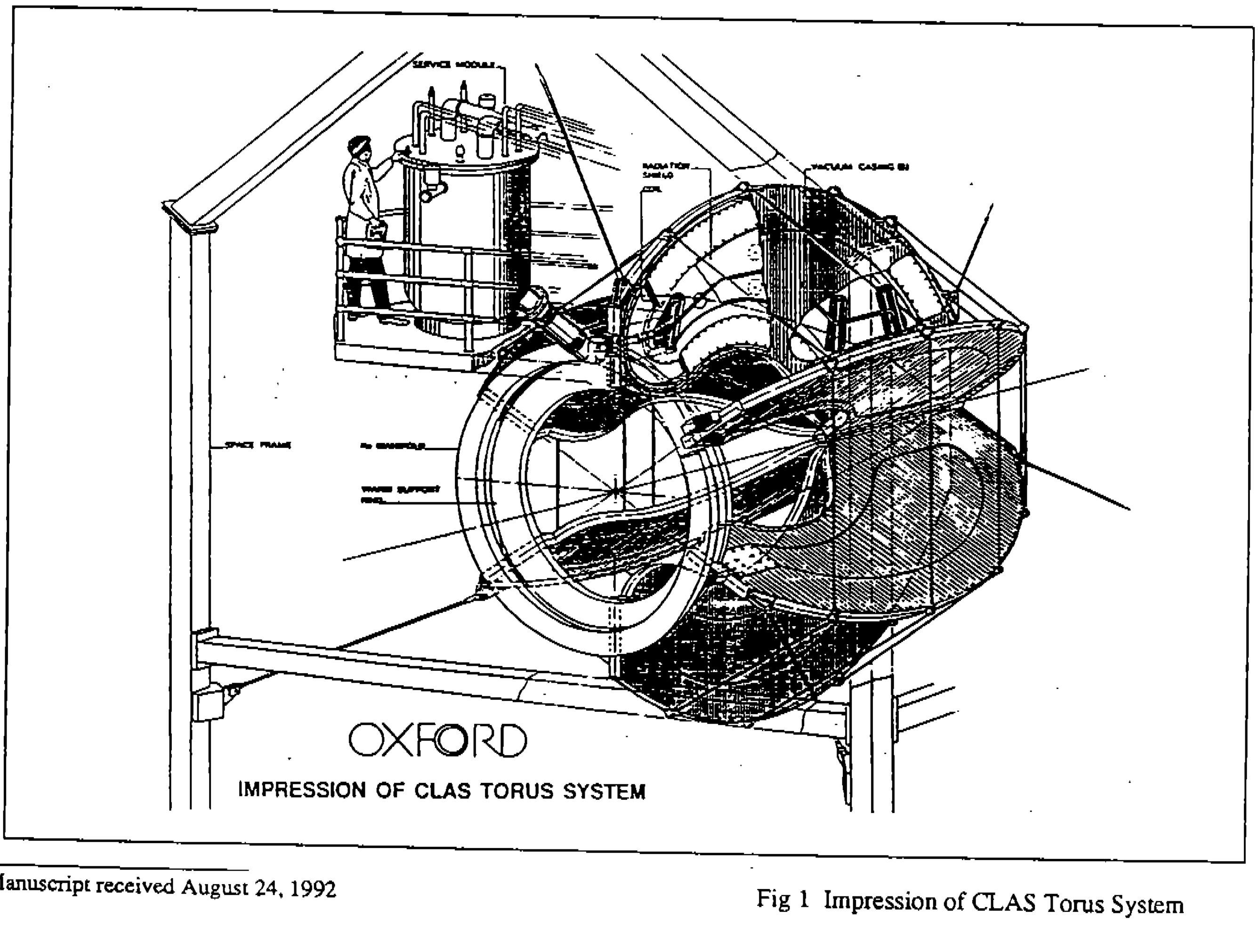

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Fig 1 Impression of CLAS Torus System

II. CONDUCTOR

The design is based on an aluminium stabilised conductor comprising a NbTi/copper cabled insert which is co-extruded with the aluminium.

The aluminium stabiliser enhances the stability of the coil through its high thermal conductivity and low resistivity. Also its thermal contraction closely matches that of the aluminium alloy coil case.

The superconducting insert is a fully transposed roebel bar (Rutherford cable) of nine wires of 0.95mm diameter with 90 micron filaments.

The operating current of around 4kA represents a compromise between the requirements for low internal voltage during a quench, winding convenience, high stability and conductor cost (favouring high current) and those of low heat loads, low EMI and high power supply stability (favouring low current). The 4mm thick conductor in the preferred four layer winding configuration gives an operating current of 3790A.

Tab. 1 Conductor Parameters

Current	3790A
Bare dimensions	3.875 x 10.95mm
Insulated dimensions	4.245 x 11.32mm
Aluminium RRR at 0T	1000
Critical current at 3.5T & 4.2K	7700A
Length per coil	2500m (2 x 1250m)

The principal parameters of the conductor are given in Table 1 above.

The stability of the conductor has been estimated from the analysis given by Wilson [2]. This gives a generation temperature (θg) of 5.9K and a minimum propagating energy (E) of 1.0 Joules.

The conductor was manufactured by Vacuumschmelze in Germany and was supplied uninsulated. Cleaning and insulation was carried out by Oxford Instruments; insulation consists of a double wrap of 0.1mm thick glass tape which is subsequently vacuum impregnated with epoxy resin (Bisphenol A).

III. COIL AND COIL CASE

A modular coil design has been developed whereby the magnetic forces on each coil are transmitted to the vacuum case at room temperature. This approach simplifies site assembly and allows works testing of each coil.

The coils are formed by winding the insulated conductor into a CNC machined recess in the coil case. Each coil is made up of four layers of fifty-five turns. The coil case is manufactured from a single piece of forged 6061-T6 aluminium plate. This construction ensures that the accuracy of the coil is well defined and minimises coil-to-coil variations. Once the coil has been wound, a cover plate is fitted to the case and the whole coil is vacuum impregnated with resin.

The coils are indirectly cooled and maintained at 4.5K by a hollow cooling channel located on the inside edge of the windings. The channel carries a 5g/s pressure fed flow of supercritical helium at 2.8ata. There is one helium flow path per coil and all coils are connected in series. A final heat sink of two-phase helium at 4.4K and 1.2ata ensures a constant base temperature.

Conduction throughout the coil windings is enhanced by means of ultra high purity aluminium liners on the top and bottom face of the coil. These liners are welded to the cooling channel. Intermediate liners are also provided between the layers of the coil but these are not connected to the channel.

A cross-section of the coil windings is shown schematically in Figure 2

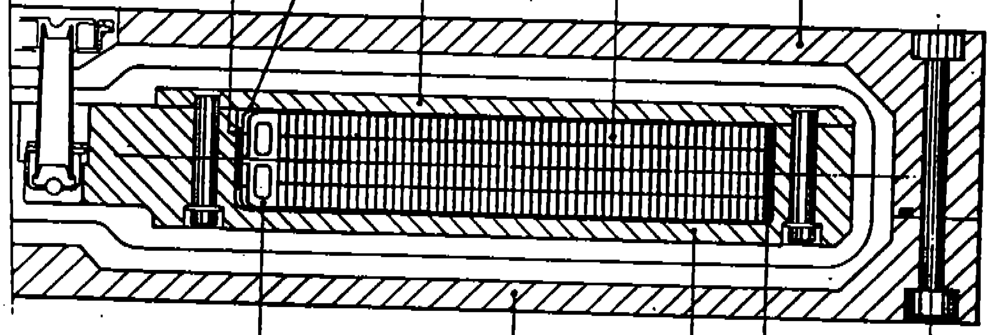

Fig. 2 Cross-section of the Coil Windings.

Tab. 2 Torus and Coil Parameters

Number of coils	6
Turns per coil	220
Total inductance	2.5H
Total amp-turns	5×10^6
Total stored energy	18MJ
Peak field	3.5T
Operating current	3790A

The in-plane forces of 140 Tonnes on each coil are reacted back to the vacuum case by three tension supports. These supports are manufactured from 316LN-ESR cold-worked stainless steel. This material was chosen for its favourable mechanical and fracture properties over the complete temperature range 300K to 4K [3]. Out-of-plane forces are taken by six pairs of short epoxy-glass compression struts between the coil case and its vacuum case.

Extensive finite element analysis has been carried out on the coil, coil case and vacuum case. COSMOS was mainly used for this analysis which covered the full range of service and fault conditions.

Quenching of the coil system has been analysed using a proprietary program, 4-QUENCH, developed by Oxford Instruments. All of the stored energy can be safely dissipated within the coils and a maximum temperature of 100K is reached at the point of quench initiation. A peak voltage of 140V occurs within the coil system although no voltage is developed across the complete coil during a quench.

A quench-back system ensures that a spontaneous quench in a single coil is transmitted to the remaining coils within one to two seconds. The ensuing current decay occurs within twelve seconds, and the stored energy is dissipated throughout all six coils.

IV. RADIATION SHIELD

A nitrogen-cooled radiation shield is provided between the coil case and the vacuum case. The shield is force cooled from a pipe using two-phase nitrogen at 80K. These planar shields are 7mm thick and are manufactured from an aluminium honeycomb bonded to epoxy-glass facing sheets. The two shields within each coil are connected by means of thin copper sheet wrapped over the outer edges of each coil case.

The radiation shield is separated from the coil case by 20 layers of superinsulation. The heat load on each radiation screen from both structural loads and via the superinsulation is 70W (≈400W for Torus); the superinsulation comprises 40 layers of Jehier IR 305-10 and a flux of around $1 W/m^2$ is allowed for at 80K. This system allows the heat load on each coil to be reduced to 7W, the majority of which is conducted heat load from the in-plane and out-of-plane coil supports.

V. VACUUM CASE

Each vacuum case is in two parts with a bolted O-ring joint close to the mid-plane; each half is machined from AISI 304L stainless steel plates initially 112mm or 80mm thick. The finished thickness is 15mm over most of the area of the vacuum case. In machining the cases, 85% of the initial material is removed as swarf (105 Tonnes). This method of construction was needed to meet the strict limits on dimensional accuracy agreed with CEBAF.

Each of the vacuum cases, with its coil, must be carefully aligned so as to restrict the out-of-plane magnetic loads to manageable levels. This is provided by six sets of carbon fibre ties which connect adjacent vacuum cases; each tie rod is capable of an ultimate load of 12 Tonnes. Carbon fibre was chosen because of its transparency to collision product particles.

In addition to the magnetic loads and self-weight loads, the vacuum cases also have to carry the wire chambers for the detector system. These chambers are fitted within the toroid, between adjacent vacuum cases and also outside the vacuum cases. The total weight of all chambers amounts to 7.5 Tonnes and they cover a volume of $40 m^3$.

Most of the out-of-plane and in-plane loads on the vacuum cases are reacted at a common location close to the beam line where all the vacuum cases meet. There is also an annular supporting ring at the upstream end of the toroid which assists in the coil-to-coil support.

VI. CONTROL AND INSTRUMENTATION

An extensive control and instrumentation system is being developed to monitor coil and coolant temperatures, pressures, voltages, out-of-plane loads, the cryogenic system, power supply and vacuum system.

The system will be based on CEBAF TACL control software run on a HP workstation and will integrate with the CEBAF control system.

The out-of-plane supports will be used as load monitors to initiate a run down of the magnet if out-of-plane forces occur. Such forces could be generated by positioning errors in the coils or by current imbalance.

VII. CONCLUSIONS

The design has been completed of the first commercially produced, superconducting Torus magnet of this scale. The design milestones were completed on target. The design is the result of an extremely successful collaboration between Oxford Instruments and CEBAF.

The conductor has been delivered and insulated. The first coil has completed winding with no significant problems. Testing of the first coil is due to take place in February 1993.

Individual coils will be works tested at Oxford. When all the coils are complete they will be shipped to CEBAF and the whole system assembled and commissioned by Oxford Instruments staff. Completion is due to take place at the end of 1994.

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