FINAL DESIGN AND CONSTRUCTION PROGRESS FOR CEBAF'S COLD IRON QUADRUPOLES

S.R. Lassiter, P.D. Brindza, M.J. Fowler, R.T. Wines
The Continuous Electron Beam Accelerator Facility
12000 Jefferson Avenue, Newport News, VA 23606

S.R. Milward, A.G. Day, M. Brown, G.H. Harding, J.C. Schouten
OXFORD INSTRUMENTS LTD.
Oxford, England

Abstract--CEBAF's High Momentum Spectrometer's [1,2,3] cryostable superconducting quadrupoles [4,5] have progressed from the conceptual design stage to manufacturing. These cold iron, cryostable, superconducting, large aperture magnets will operate over a decade of pole field excitation, from 0.2 tesla up to 2.1 tesla. This paper will present a description of the modifications and changes that have occurred to these magnets. The use of a three-dimensional magnetotstatic program, as a means of quality control for these changes, and a description of the structural modifications to the cryostat will be included. The current status of the project will also be presented.

I. INTRODUCTION

CEBAF, a 4 GeV/c superconducting electron accelerator nearing completion in Newport News, VA., has awarded the contract to build the high momentum spectrometer's (HMS) superconducting quadrupoles to Oxford Instruments Ltd. The HMS, a QQQD design, is a superconducting focusing spectrometer. Oxford Instruments chose to develop the reference conceptual design (RCD), with CEBAF being responsible for the magnetic performance. Modifications to the RCD have occurred as results of more comprehensive studies and the availability of materials. By using TOSCA [6] as a means of a quality control check, we have been able to quantify the effects of these changes and to advise on the acceptability of the modifications. Fast turn around time has allowed us to keep the impact of these changes to the schedule at a minimum.

II. QUALITY CONTROL USING TOSCA

All major design modifications were first assessed for their effect upon the magnetic performance. This was done by modeling the proposed change with TOSCA at three current excitations of the magnet. These excitations were: at low current, where effects due to iron saturation were not prevailing, at the nominal field corresponding to a beam momentum of 6.0 GeV/c and finally at the maximum cryostable current for the conductor. Most changes were accepted on the first iteration. Examples of the parameters modeled included conductor size and placement, holes within the yoke, the removal or adding of yoke material, pole chamfering of endplates, lamination stacking factors and characteristic BH curves. A brief description of the more important changes follows.

A. Conductor

The most important modification made was in the choice of the conductor. The original conductor was an 11-strand, multi-filament, NbTi-copper, Rutherford cable which was extruded into a high purity aluminum stabilizer [5]. A lower current, NbTi-wire in copper channel was proposed. Table 1.0 lists the conductor specifications for this wire. The lower current conductor equates to a smaller heat load from the current leads to the helium cooling system but, requires more turns to achieve the necessary Amp-Turns. This increase in the number of turns resulted in a new coil profile to achieve the required magnetic performance (See Figure 3).

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Table 1
HMS Quadrupole Conductor Specifications

Type:	Wire in Copper Channel
Dimension:	Width (mm) 4.26 ± 0.04 Height (mm) 2.12 ± 0.01
CompositeWire:	CU:NbTi:1.0/1.0
Diameter of Composite:	1.20 ± 0.01 (mm)
NbTi CriticalCurrent (3T):	2204 (Amps)
Max. Cryostable Current:	1086.6 (Amps)
Copper RRR:	>120
Copper Resistivity:	<2.3 x 10^{-10} ohm at 4.2K and 2.6 Tesla
Copper Surface Coating:	Nominal 7μm insulating varnish
Stability:	Cryogenic stability utilizing boiling heat transfer enhancing surface coating.
Recovery:	Cold End Recovery
Maximum Stable Cooling	5600 W/m^2
Number of Turns:	Q1 = 169 Q2/Q3 = 321

B. Yoke

The increase in the number of conductor stacks required the removal of some of the iron yoke behind the conductor (the requirement being that the increase of the coil block is not to decrease the warm aperture of the magnets). This was a most critical condition for the narrow leg of Q1 (See Figure 3). An increase in the depth of the iron yoke for this narrow leg was made possible by reconfiguring the helium pressure vessel. This was done without increasing the outer cryostat dimensions, thus ensuring that the forward angle requirement of the HMS will be maintained. Cooling holes have been incorporated into both the Q1 and Q2/Q3 yokes to aid in holding the laminations together and to facilitate a more uniform cool down of the iron pole/yoke assembly. Stainless steel tie bars will be used within the cooling holes to clamp the laminations to the required pressure ensuring that the proper stacking factor is met. The size and location of these holes were included in the TOSCA models to determine their impact on the field harmonics. Pole chamfering, limited to the endplates only, was incorporated into the final design to reduce the peak fields in the end plates, to reduce the end-field harmonics and to lessen the variation of the effective field length with respect to field excitation.

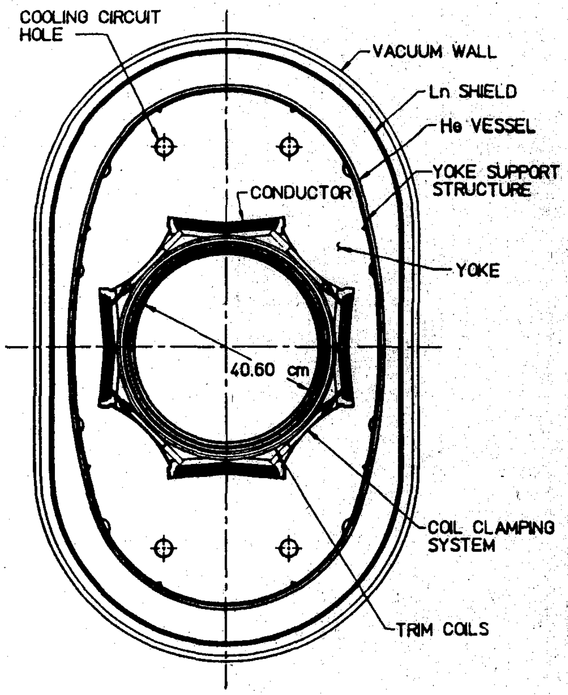


Figure 1.0
Cross Section View of the Q1 Cold Iron Quadrupole

III. CRYOSTAT MODIFICATIONS

The outer helium containment vessel of the RCD has been replaced with two separate structures [7]. A yoke support vessel will be used to hold the yoke together and to provide the necessary preload to the yoke and coils. This shell will also have to bear the stresses due to the thermal contraction differences between itself and the iron yoke. The sum of these stresses will be 236MPa for the quadrupoles Q2/Q3. These high stresses can be safely taken by the utilization of the mechanical properties of 304LN stainless steel which has a yield strength of 900MPa at 4.2 Kelvin. By using the yoke support vessel to take in the thermal and preload stresses, the helium containment vessel has only to bear the internal helium pressure and thus can be designed to the ASME Pressure Vessel Codes [8]. For the narrow width quadrupole, Q1, the elimination of the reinforcing ribs for the outer helium vessel was made possible by resorting to a more oval shape yoke and vessel. This shape will allow for the internal pressures to be taken as pure hoop tension and it will provide more uniform pre-load to the yoke and coils.

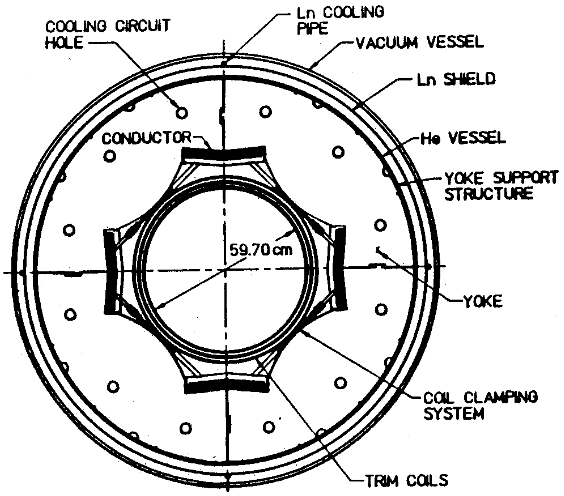


Figure 2.0
Cross Sectional View of the Q2/Q3 Cold Iron Quadropole

IV. NITROGEN COOLED SHIELD

The stringent radial space requirements of the cryostat has resulted in a new design for the nitrogen intercept shield. The inflated stainless steel panel of the RCD has been abandoned in favor of a thin copper foil sheet that is cooled by conduction from liquid nitrogen carried in pipes located along the outside shield [7]. To reduce excessive forces in the event of a quench, the copper foil is cut into a longitudinal series of strips along the inner bore tube. Nitrogen circulation will be by means of natural thermo-syphon effect. Table 2 details the expected heat loads for the cryostats of Q2/Q3.

Table 2
Cryostat Heat Load for Q2/Q3

Source	Heat Load (Watts)	
	LN2	LHe
Support System	15	3.1
Service Turret	5	2.0
Main Current Lead	-	2.9
Trim Current Lead	-	0.15
Cryostat (radiation)	30	8.0
Total	50	16.15

V. COIL WINDING FIXTURE

Oxford Instruments has successfully tested a coil winding fixture that they plan to use for both Q1 and Q2/Q3 coils [7]. The unique feature of this device is that the end clamping fixture and the bobbin are in integral assembly and supports the coil when it is transported from the winding table to the yoke quadrants. The coils can be pre-compressed on the winding fixture prior to installation within the yoke quadrants. Using the coil winding fixture and a similar conductor, the required amount of pre-load needed to fully compress the coil pack to eliminate voids and coil sponginess has been determined.

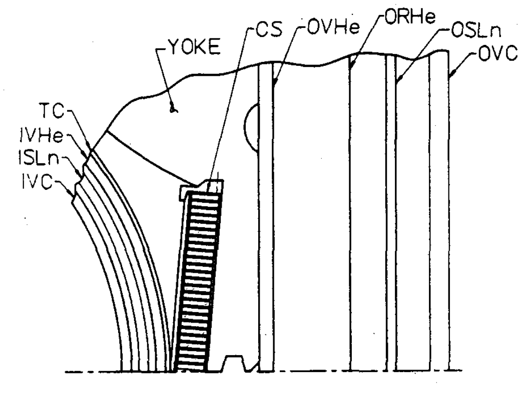
VI. CURRENT PROGRESS

The order for the manufacturing of the pole/yoke laminations and the thicker endplates was placed to the subcontractor Tesla of Sussex, UK. The pole and yoke laminations, punched from Magnetil BC Steel, have been supplied by Cockerill-Sambre. The endplates will be manufactured from Armco soft iron supplied by Saarstahl (UK) Ltd. of London, UK. The order for the conductor was placed to Furukawa Electric Ltd. of Japan. The first batch of conductor for the trim coils has been ordered from Oxford Superconducting Technology of Carteret, NJ. This wire is a Multi-filamentary composite of round insulated NbTi/Copper. Table 3 lists the characteristics of this wire.

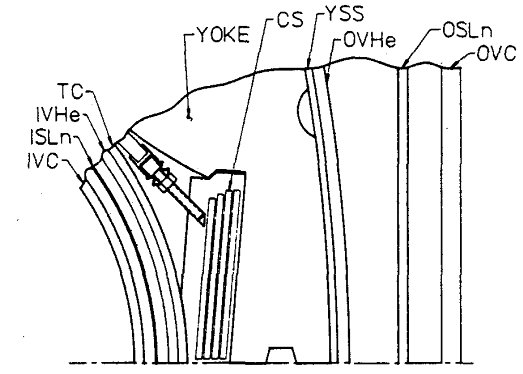
Table 3
Trim Coils Conductor Specifications

Wire diameter:	0.36 mm width with insulation
IOP	38 amps for Q1, 26 amps for Q2
Cu:NbTi ratio:	1.4:1.0
No. Filaments:	54
Wire Twist Pitch:	42 mm
Critical current (4.2K):	117 amps at 3.0 Tesla

Work is progressing on the support structure, the inner helium bore cylinder, which has to take the trim coil Lorentz forces, the service turret and the helium reservoir.



OLD CONFIGURATION



NEW CONFIGURATION

ABBREVIATION LIST

IVC = INNER VACUUM CAN
ISLn = INNER Ln_2 SHIELD
IVHe = INNER He VESSEL
TC = TRIM COIL
CS = CONDUCTOR STACK
OVC = OUTER VACUUM CAN
OSLn = OUTER Ln_2 SHIELD
OVHe = OUTER He VESSEL
ORHe = OUTER He VESSEL RIB
YSS = YOKE SUPPORT STRUCTURE

Figure 3.0 Comparison of Q1 Coil & Yoke Modifications

VII. SUMMARY

The final expected magnetic performance as modeled with TOSCA are listed in Table 4 for the HMS quadrupoles. As modifications and manufacturing details have manifested, workable solutions have been implemented that preserves both the magnetic and mechanical specifications as well as keeping to the delivery schedule. At the present time, orders for most of the major components have been placed, a quality assurance plan has been approved and a preliminary engineering design meeting between Oxford Instruments & CEBAF was held. Delivery of the first Q2/Q3scheduled to arrive at CEBAF in mid August 1993.

Table 4
Final Magnetic Performance of the HMS Quadrupoles as modeled with TOSCA

	Q1	Q2
Pole Radius (m)	.25	.35
Max Kilo Amp Turns	736.6	1399.0
Max Gradient (T/m)	7.294	6.320
Effective Field Length (m)	1.88-1.89	2.11-2.22
Max Integrated Quadrupole (T.m)	3.423	4.528
Max Integrated Octapole % of B(2)	-0.278	0.000
Max Integrated Dodecapole % of B(2)	1.923	3.00
Max Integrated Icosapole % of B(2)	-0.219	1.00

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[6.] Tosca (r), Trademark of Vector Field Limited, Oxford England.

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[8.] 1989 ASME Boiler and Pressure Vessel Code Division 1 Section VIII.