CLM - P 181

United Kingdom Atomic Energy Authority

RESEARCH GROUP

Preprint

SUPERCONDUCTING QUADRUPOLE FOCUSSING LENS

D. N. CORNISH

Culham Laboratory
Abingdon Berkshire

1968

UNCLASSIFIED
(Approved for Publication)

CLM - P 181

SUPERCONDUCTING QUADRUPOLE FOCUSSING LENS

by

D.N. CORNISH

ABSTRACT

A quadrupole focussing lens is being developed as a joint venture involving C.E.R.N., The Oxford Instrument Company and Culham Laboratory. This paper is an interim report discussing winding details and results obtained on a preliminary test coil. It is intended to be read in conjunction with Dr A. Asner's contribution which discussed the analytical design.

U.K.A.E.A. Research Group,
Culham Laboratory,
Nr Abingdon,
Berks.

August, 1968

CONTENTS

1. INTRODUCTION

A quadrupole focussing lens is being developed using Nb.Ti/copper composite superconductor. C.E.R.N., Culham Laboratory and The Oxford Instrument Company are co-operating to carry out the work, which is also being partially financed by the Ministry of Technology. This paper discusses the problems associated with the superconductor, the general construction of the quadrupole and preliminary tests on a test solenoid. The analytical design of the lens is described in the paper by Dr. A. Asner.

2. WINDING DETAILS

2.1 SELECTION OF SUPERCONDUCTOR

Since a high overall current density is required in the winding if a worthwhile performance of the quadrupole is to be obtained, a fully copper stabilised winding is unsuitable for this application. The coil has been designed, therefore, to operate in the partially stabilised mode such that transient normalities, associated with short lengths of the conductor, will not result in a quench of the coil. To obtain this the heat transfer at the surface of the conductor has been limited to 0.4 watts/cm^2 and cooling channels 0.01" wide have been provided between all layers.

From current density considerations, the optimum size of conductor would be a copper-clad 0.01" diameter Nb.Ti wire, but the problems of winding a coil of this shape with such a small wire and preventing subsequent wire movement are very severe. A larger, rectangular conductor incorporating a number of superconducting filaments has therefore been used.

Details of the conductor, manufactured by I.M.I., are as follows:-

Overall dimensions - 0.06" x 0.16"
Nb.Ti superconductor - 16 strands 0.01" dia.
Operating current - 820 amps (at approx. 46 kG)
Copper resistance ratio - $\geqslant$ 200/1 (H = 0)
Critical current - 900 amps at 50 kG
Conductor insulation - 0.00075" thick Formvar

2.2 INTER-LAYER INSULATION

A specially manufactured nylon net is inserted between all layers to ensure that the two wide surfaces of the conductor are in contact with liquid helium. The net consists of 0.012" dia. nylon mono-filaments, spaced 16 to the inch, in a direction perpendicular to the direction of the winding, held in position by interwoven 0.0001" dia. filaments. The woven net is calendered to an overall thickness of 0.01" to increase the surface area in contact with the conductor. The overall current density in the winding is 1.1×10^4 amps/cm^2 with a conductor current of 820 amps.

2.3 GENERAL WINDING DETAILS

Figure 1 is an illustration prepared from preliminary drawings to show the general arrangement of the quadrupole. The windings are wound on hollow formers fabricated from non-magnetic stainless steel. Winding surfaces are insulated with resin-bonded glass fibre sheets with machined channels for liquid helium access. Part way through the winding the length of the layers is gradually decreased. These layers are supported by progressively inserting a thin steel plate, backed with stepped and channelled insulation, along the straight faces of the pole as the winding proceeds.

When the winding is completed a metal helmet is placed around the curved ends, with a small thickness of Epoxy cast between it and the outside of the winding. To reduce the maximum field strength at the ends of the poles, the current density is reduced by inserting half-moon shaped pieces of insulation between the layers at a number of points in the winding (not shown on illustration). Steel bands surround the four poles to restrain the windings against the outward radial electro-magnetic forces.

3. TEST COIL

Before commencing manufacture of the first pole, a small test solenoid was wound to check the operation of the conductor in a thermal environment similar to that in the quadrupole. The coil parameters were as follows:-

Inside diameter = 1.0 "
Outside diameter = 4.37"
Length = 3.94"

The anticipated load line of the quadrupole and that of the test solenoid are shown on Fig.2. The solid (H-I) curve was obtained by multiplying the manufacturer's typical curve for a 0.01" dia. wire by 16. The dotted curve has been drawn parallel to this through a single spot check point measured on a sample of the conductor used in the coil.

3.1 TESTS ON SOLENOID

For the first series of tests the coil was mounted with its axis vertical. In all instances the coil was cooled to $77^{\circ}K$ by heat transfer through helium gas to nitrogen outside the helium cryostat. The pressure in the vacuum chamber of this cryostat was raised to allow heat transfer to take place and it was re-pumped when cooling below $77^{\circ}K$ was commenced.

When fully immersed in liquid helium the coil was energised and the current increased until it quenched. This procedure was repeated a number of times - the quenching value being 930 amps on all occasions except the first which was 850 amps. The coil was then re-mounted with its axis horizontal and the test repeated; the results of this series are shown on Fig.3.

Since the minimum angle between the plane of the layer and the horizontal plane will be 26° on the quadrupole, the coil was then tested with its axis tilted at this angle. The coil was quenched many times, reaching the critical current on each occasion. The current through the coil was also reversed without affecting the quench value.

The final run in this series of tests was carried out with the coil horizontally-mounted exactly as on the previous occasion. The critical current was now reached every time.

3.2 FLUX JUMPING

A copper search coil had been wound on the outside of the test solenoid and its output signal was continuously recorded on a multi-channel recorder during all the above tests. It is interesting to note the current at which signals were observed on this trace immediately prior to a quench during the second series of tests when the coil behaved erratically with the axis horizontal. The positions of the last few 'flux jumps' have been shown for this series on Fig.3. This trace also indicated that all quenches at 930 amps, with the exception of run number 12, started with a smooth run-away whereas all the other quenches were initiated by a 'flux jump'.

3.3 TESTS WITH ADDED AXIAL PRESSURE

The forces caused by the axial component of the magnetic field tend to expand the central turns of a layer more than the end turns where this component is weaker. The radial component of field produces axial compressive forces along the layers. It was thought possible that the signals observed on the pick-up coil might have been triggered by inter-turn movement resulting from the radial pressure being released in jumps as the frictional force between turns was overcome. The coil was re-wound after the weld holding one of the end checks to the former had been machined off and was now held to the former by 3 axial tie bolts. With the coil mounted vertically, its performance was checked by running it up to 915 amps a number of times without a quench occurring. The tie bolts were then tightened such that the coil length was reduced by 0.025". There was no change in the signals on the pick-up coil and the coil performance was unaltered. After tightening 2 bolts to their full extent, compressing the coil by a further 0.012", the brazing on the third bolt broke. The coil performance was again unaltered.

After repairing the tie bolt, further tests were carried out and, whilst the flux jump signals were unaltered, the coil behaviour was erratic and quenched at currents between 500 and 810 amps. Potential taps had been added to a number of the layers when the coil had been re-wound and signals from these indicated that the quenches were being triggered by flux jumps and that the quench was propagating from varying points in the vicinity of the central layers. When the coil quenched at full current, it started in the inner, high field, region.

Subsequent examination of the coil showed that the P.T.F.E. packing at the ends of the layers had been axially compressed by the force of the tie bolts and this had resulted in a corresponding expansion in the radial direction between the inter-layer nylon strands, thus partially blocking many of the cooling passages.

3.4 CONCLUSIONS FROM SOLENOID TESTS

The following conclusions are drawn from the results so far obtained on the test coil:-

(a) The coil produces transient signals which appear to be caused by flux jumps and not by mechanical movement of the wiring or heating due to frictional forces.

(b) If the cooling passages are not blocked, the performance is unaffected by these disturbances and the critical current of the conductor is reached before the coil quenches.

(c) If the cooling passages are partially blocked, the energy associated with the flux jumps is sufficient to cause the coil to quench prematurely. In these cases normality is initiated in a low field region.

The behaviour of the coil when tested horizontally suggests that the cooling ducts were partially blocked the first time but that the blockage was cleared for subsequent tests.

(d) The current interval between flux jumps appears to be related to the probability of quenching at a flux jump. Above about 700 amps, in most cases, if the current interval between jumps is not greater than 60 amps then the coil will not quench until the critical current is reached. If, however, the current is increased by more than this amount without a flux jump occurring, it is probable that the next flux jump will initiate a quench.

4. PRESENT POSITION OF QUADRUPOLE

The first pole has now been wound and it will be tested in the near future.

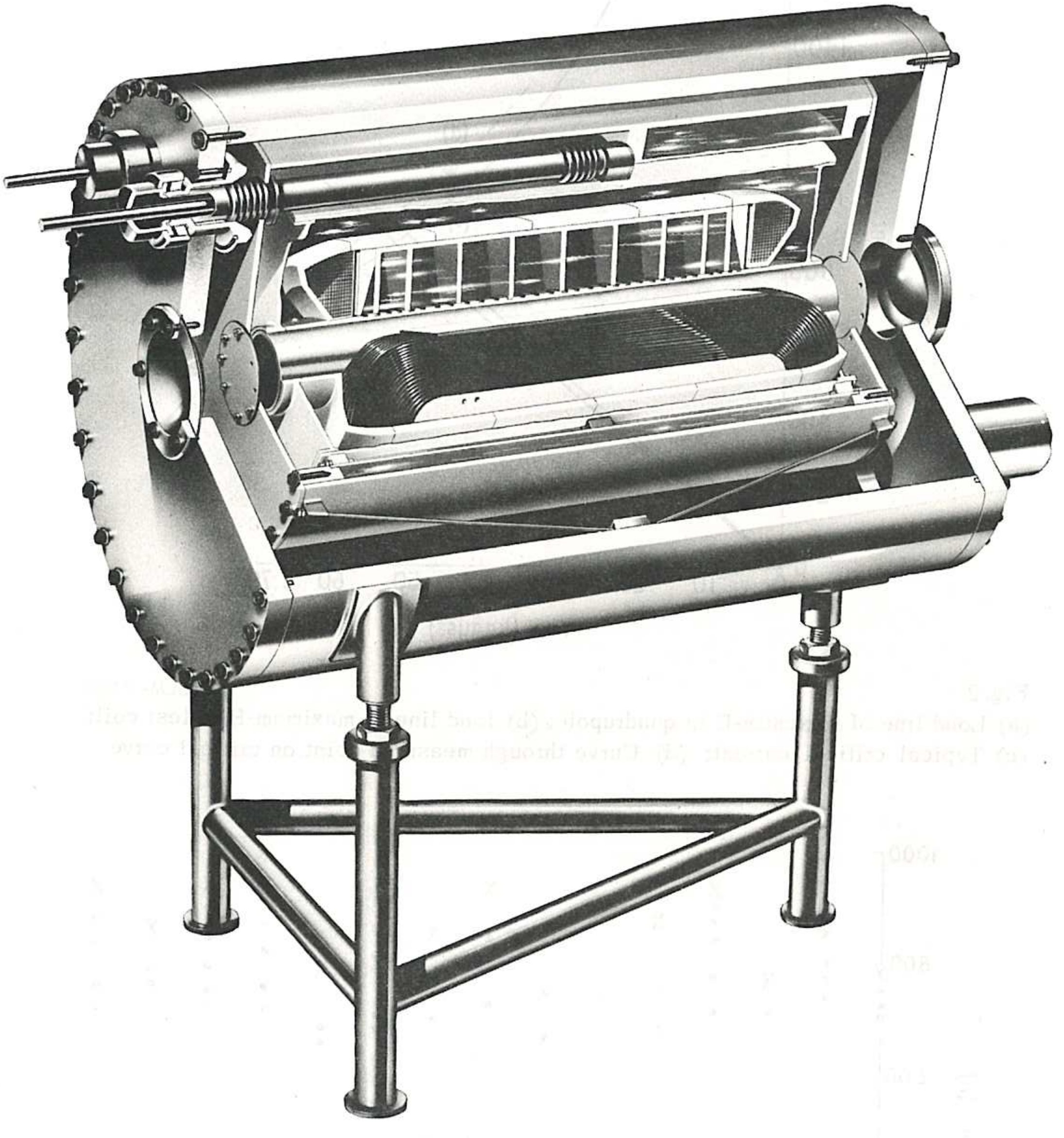

Fig. 1 Superconducting quadrupole focussing lens (CLM-P181)

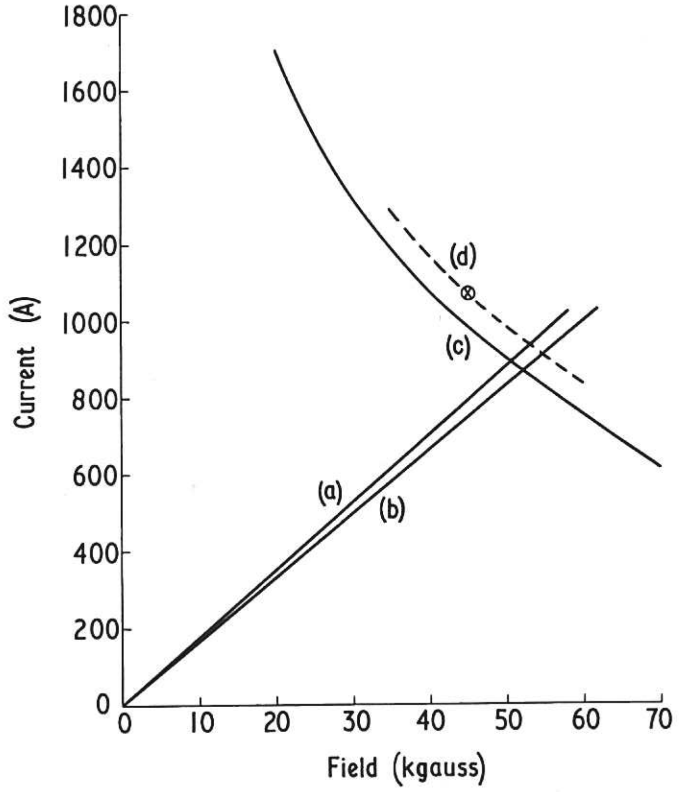

Fig. 2 (CLM-P181)
(a) Load line of maximum-B in quadrupole; (b) load line of maximum-B in test coil; (c) Typical critical current; (d) Curve through measured point on critical curve

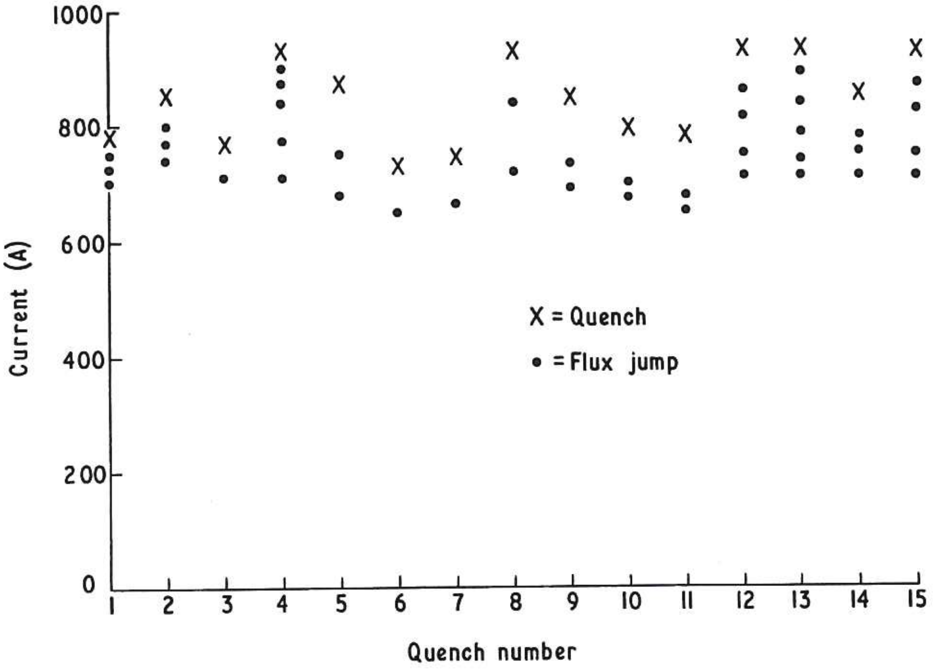

Fig. 3 (CLM-P181)
Quench and flux jump currents with test coil mounted horizontally