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A SUPERCONDUCTING LEVITRON

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Corrigendum to
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Main Parameters

2nd paragraph , 2nd line, the corrected sentence reads:-

The inner coils are each rated at 900 kA turns and the outers at 550kA turns.

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Introduction

Various magnetic configurations are used to study the stability and confinement of plasmas in fusion research. In a Levitron the plasma is contained in the field surrounding a current-carrying ring which is supported by a magnetic field.

A superconducting ring with a persistent current has a number of advantages over a resistive ring. In the latter type the plasma is deposited in any leads or supports. Also, if the current is induced in a resistive ring, the field decays into the ring carrying the plasma with it. A superconducting ring suffers from neither of these deficiencis and the field is truly D.C.

This paper discusses very briefly the cryogenic and superconducting aspects of a superconducting machine of this type which is being built at Culham Laboratory.

Main Parameters

The levitated ring is 600 mm major diameter and carries a total current of up to 500 kA. Its minor diameter must not exceed 90 mm at any point and it is to be suitable for use in a vacuum of 10^{-10} torr.

The vertical field is also to be generated by superconducting coils which can be seen in the illustration in Fig.1. The inner coils are each rated at ~~550~~ 900 kA turns and the outers at ~~900~~ 550 kA turns.

A toroidal field is also required and is generated by water-cooled copper coils carrying a total of 1 MA through the vertical axis of the machine.

The ring is in unstable equilibrium and must be stabilised against tilt and sideways motion. Stabilising copper windings coupled through amplifiers to an optical position sensing system will hold the ring in the correct position.

Levitated Ring

There are a number of stringent requirements for the ring. Lack of space prohibits the use of thermal insulation on the ring. The difficulties of re-fuelling with cryogenic fluid without impairing the vacuum or gaseous cleanliness of the ring surface lead to the ring winding being sealed in a stainless steel container. The space between the winding and the container will be filled at room temperature with helium gas to a pressure of 150 atomospheres. The winding must therefore be capable of operating satisfactorily in one to two atmospheres of helium gas at its operating temperature.

A high current density and winding profile closely approximating to a circle are required. The ring will be wound with intrinscially stable Nb-Ti conductor which will be vacuum impregnated in epoxy resin to prevent inter-turn movement and to give the required mechanical strength. The conductor to be used will be 0·75 mm dia., 2 : 1 copper to superconductor ratio, 121 twisted filaments. The ring is wound in two halves in a special jig - a test winding using copper wire is shown in Fig.2. The maximum deviation of the profile from circular is ± 1 mm. The conductor is treated with a thermoplastic coating over the normal insulation so that after heating it in an oven the coil can be removed from the winding jig without turns being displaced. The two halves are subsequently taped together and impregnated as a whole.

Development Coils

The mechanical and thermal shock properties of impregnated windings have been investigated on copper coils. Small coils, 47 mm inside diameter, 100 mm outside diameter, 43 mm long were used to check the impregnation process. They were then thermally cycled to $77^{O}K$ several times, and cut into two halves which were subjected to repeated axial compression tests at room temperature.

The stress/strain curve for a well impregnated coil was linear up 10^4 lbs in^{-2} (12 kg mm^{-2}).

In addition to the steady magnetic loading on the ring, the winding must be capable of withstanding shock loads if the stabilizing system should fail to operate correctly. In this case the ring will be accelerated into a catching cage with a velocity equivalent to dropping the ring from a height of 6 feet. Preliminary tests have been carried out on a short straight section simulating the ring and a complete copper winding in its case will be subjected to drop tests at 77^oK.

A number of 200 mm and 425 mm mean diameter coils have been built and tested to check the superconducting properties of this type of coil. The load line and short sample curve for the wire for one of the 200 mm coils are shown in Fig.3(a). The coil was mounted in a thick copper case and suspended in a cryostat above the helium level. It was then possible to vary the coil temperature by careful use of heaters in the liquid and on the coil case. The quenching current was obtained and is shown plotted against temperature in Fig.3(b). Also shown in this figure are the estimated critical currents of the wire using the critical current versus temperature relationship given in Ref.1.

Fig.4 shows a pair of the larger coils being prepared for test. The conductor is similar to that to be used for the ring with the exception of the copper to superconductor ratio which, in these coils, is 3 : 1.

These coils operate either singly or as a pair at the critical current. The two coils together produce a maximum field of 37 kG with a winding density of $2{\cdot}3 \times 10^4$ A cm^{-2}. The total ampere turns in these two coils is 5×10^5 which is the value required in the levitated ring.

Vertical Field Coils

A similar method of construction will be used for the vertical field coils. The conductor is 1·42 mm dia. and the copper to superconductor ratio is 2 : 1 for the smaller and 4 : 1 for the larger coils. Fig.5 is a photograph of a section of a copper model of a 600 mm diameter coil in which the winding cross-section is 50 × 75 mm. Each field coil will consist of two such sections contained in a stainless steel case.

Cooling

Cooling will be by means of a closed cycle refrigerator. The ring will be cooled by conduction from indium tipped removable clamps through which helium at 2·5 atmospheres and $3^{o}K$ is circulated. Radiation from nitrogen cooled surfaces and energy from the plasma will cause the ring temperature to rise. The time interval before recooling is necessary will depend on the surface emissivity of the ring, the operating current and surface vacuum conditions. It is expected to be between several minutes and several hours.

The field coils will operate in gaseous helium at $4{\cdot}5^{o}K$. The use of gas instead of helium simplifies very considerably the construction of the apparatus and its controls.

Acknowledgements

The author wishes to thank Mr J.W. Partridge and other members of the Superconducting Group and Mr S. Skellett and colleagues in the Levitron Group for their contribution to the work described. Also acknowledged is the preliminary design study work by Mr H.R. Whittle.

Reference

1. HAMPSHIRE, R. et al. Effect of temperature on the critical current density of Nb 44 Ti alloy. Conf. on Low Temperatures and Electric Power, London, 1969.

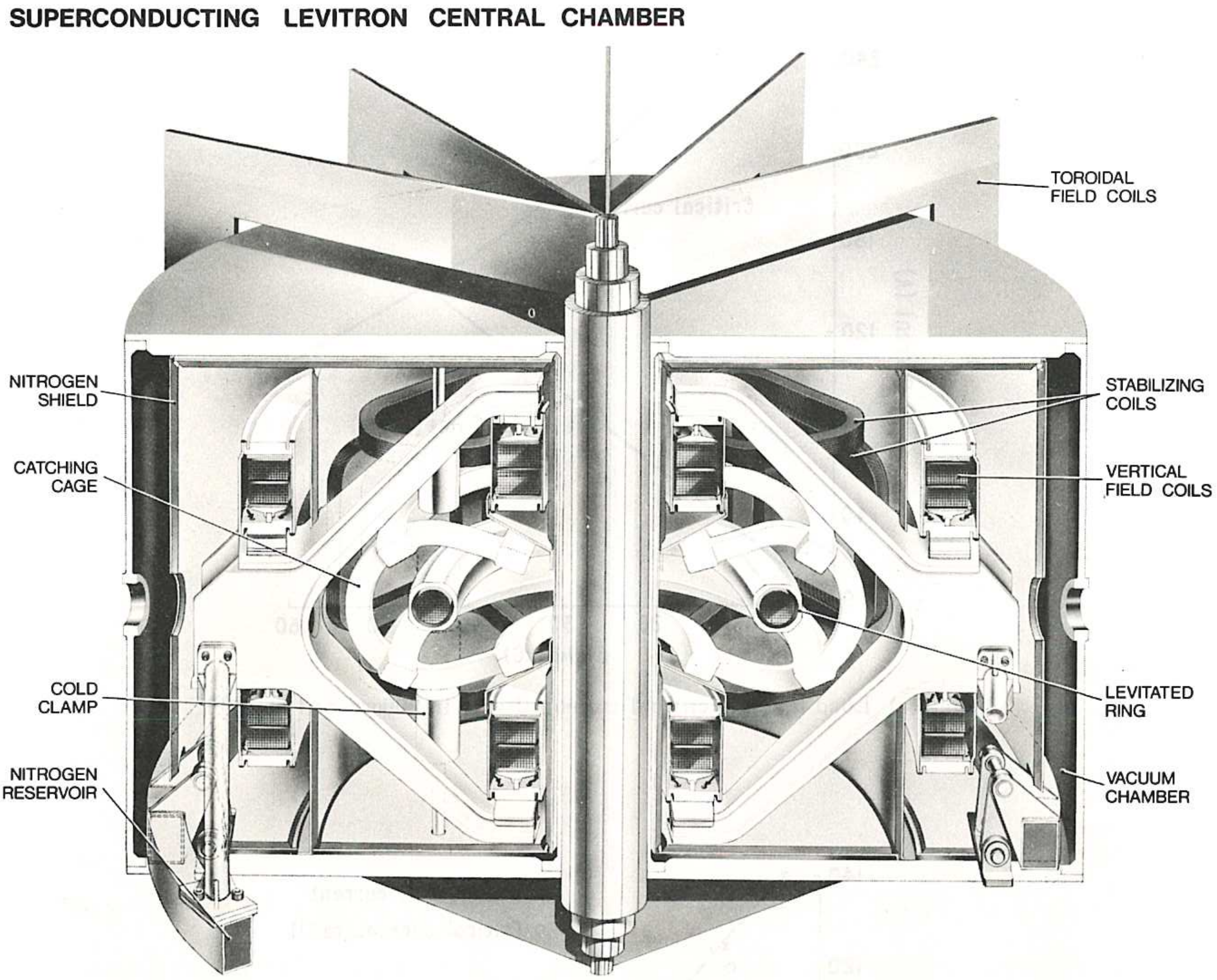
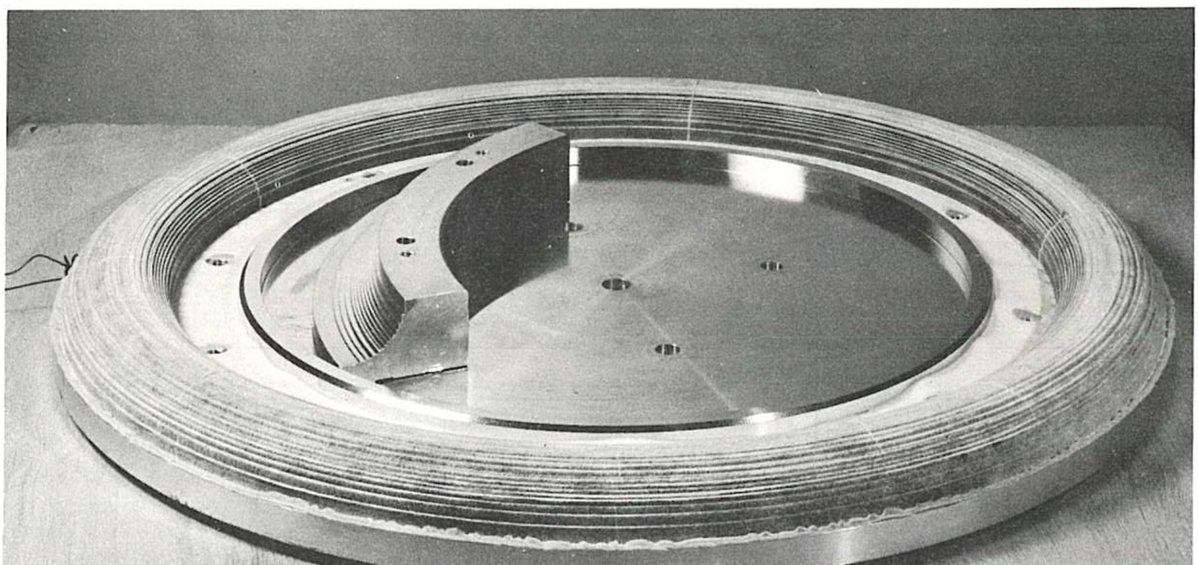


Fig.1 Illustration of Superconducting Levitron.



Fi g.2 Half section of Levitron ring wound with copper wire. CLM-P238

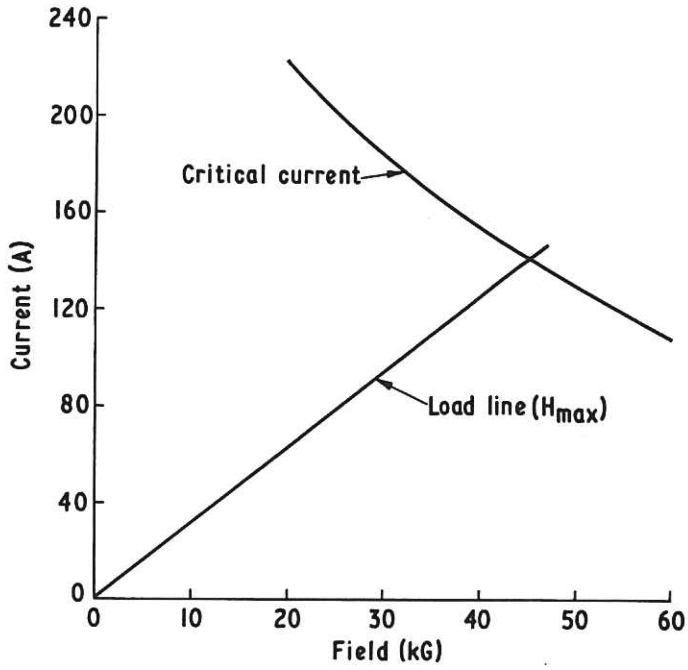


Fig.3(a) Load line and critical current of wire in 200mm coil at 4·2°K.

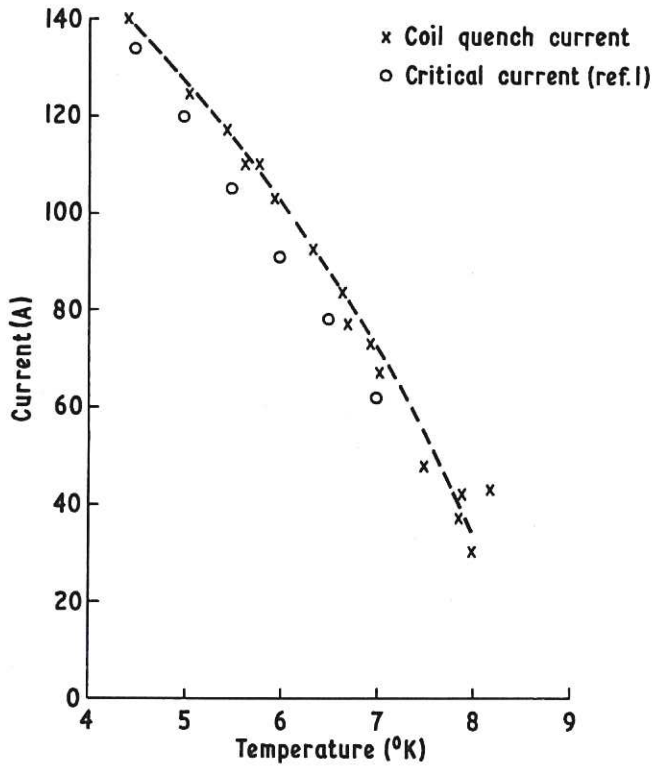


Fig.3(b) Quench current versus temperature for 200mm coil. CLM-P238

Fig.4 Pair of 425mm coils being assembled for test. CLM-P238

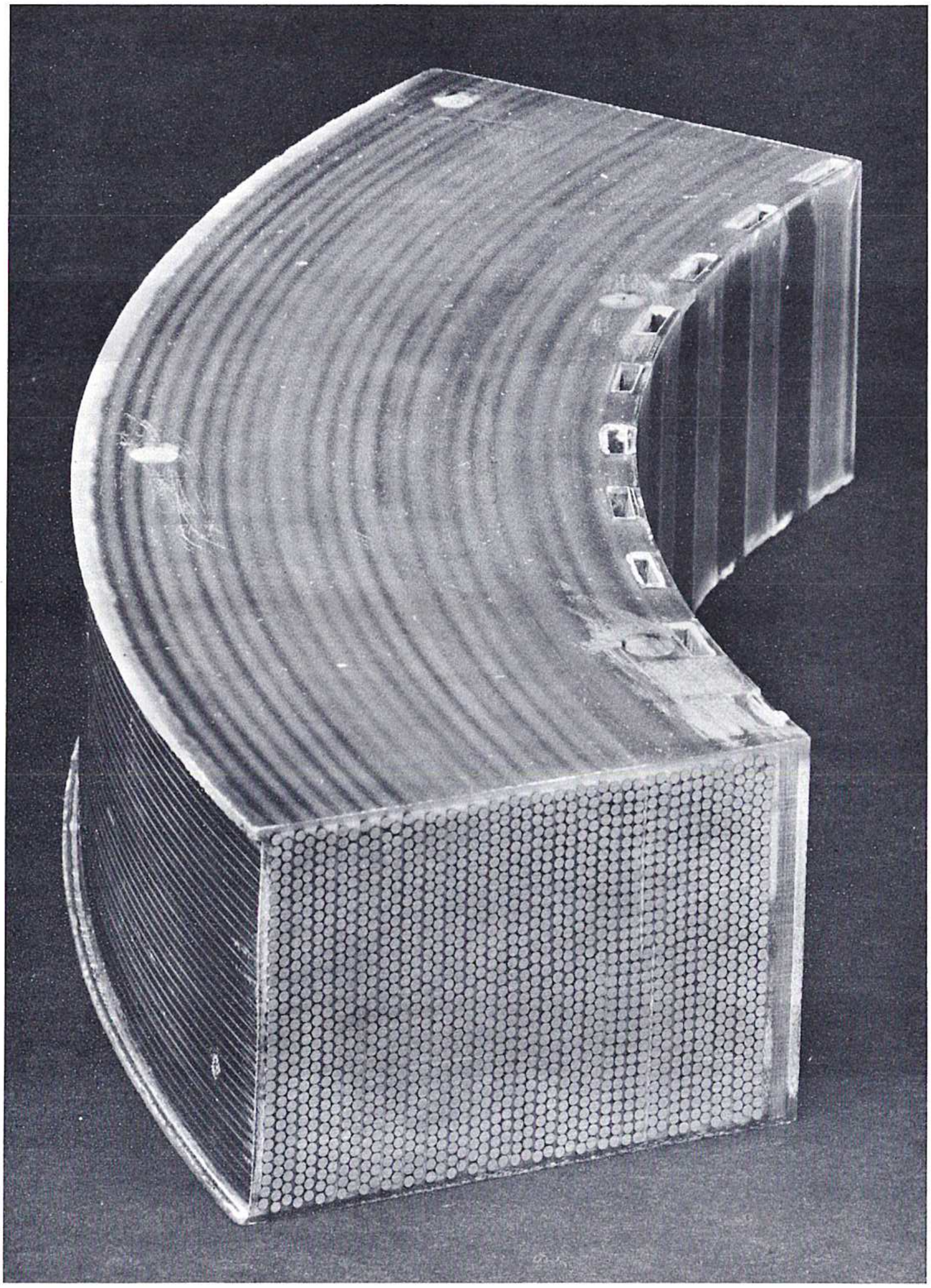


Fig.5 Piece of 600mm copper coil having a cross-section of 50 ×75mm. CLM-P238