Prototype Tests and Description of a 60 Tesla Quasi-Continuous Magnet

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ABSTRACT - **The National High Magnetic Field Laboratory has designed and will build a large bore, 60 tesla, 100 ms (quasi continuous) flat-top magnet for installation and use at Los Alamos. The magnet consists of eight concentric, resistive, solenoid coils fabricated from high strength, high conductivity copper supported by external stainless steel shells. Before each pulse the magnet is cooled to 77 K with liquid nitrogen. The energy for the magnet is provided through converter power supplies from a 1430 MVA, 24 kV alternating current energy storage generator. Plans for prototype tests of full scale portions of the magnet are discussed. A detailed description of the magnet is presented along with available information on fabrication methods to be employed in its manufacture.**

I. INTRODUCTION

The National High Magnetic Field Laboratory has made the commitment to make available to the high magnetic field research community a 33 mm bore pulsed solenoidal magnet that will produce a 60 tesla field for a 100 ms duration. Construction of such a magnet using presently available materials presents a challanging task. The large bore creates stress management problems and the long duration causes heat management problems. Containment of the stress requires high strength conductors and a complex design of several nested coils with external reinforcement shells around each of the interior coils. Management of the thermal loading requires the conductors to have high electrical conductivity enhanced by liquid nitrogen cooling. The magnet design is a result of extensive materials research [1], analytical computations and optimization, and finally finite element analysis of the coil structures with realistic loading.

A set of prototype coils are designed and are to be manufactured and tested to verify manufacturing techniques and the structural analysis, to determine operating envelope and the electrical integrity of the design.

II. Magnet Description

The 60 tesla-100 ms pulsed magnet is constructed from eight mechanically independent, concentric, nested, resistive, solenoid coils (see Fig. 1). The inner seven coils have external stainless steel reinforcing shells. The eight coils with their leads and busbar are supported with their longitudinal axes vertical, in a fiberglass epoxy laminate and stainless steel frame. The frame is mounted within a stainless steel dewar vessel. To meet schedule and reliability requirements magnet materials were selected from characterized, commercial materials available from dependable sources of supply.

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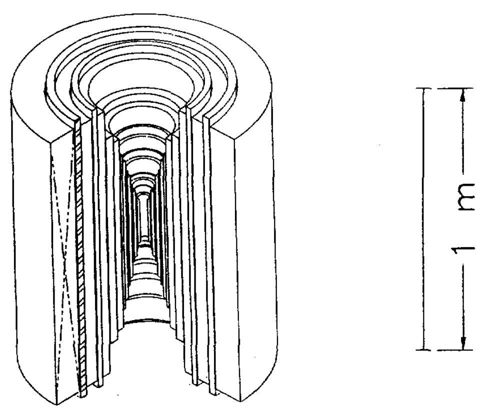

Fig. 1. Isometric drawing of the 60 tesla magnet showing the coils and the shells

Individual coils are constructed from drawn aluminum oxide dispersion strengthened copper conductors insulated with E-glass fabric tape and cloth combined with polyimide film tape (Fig. 2). The coils are formed by winding the tape insulated conductor about a mandrel, inserting the wound coil

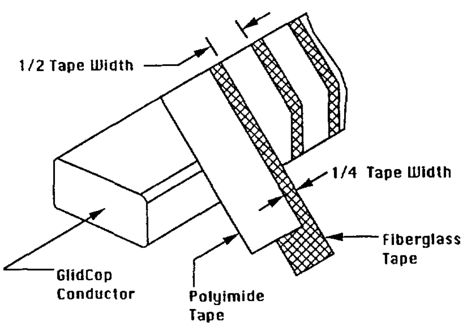

Fig. 2. Insulation wrapping about conductor. Insulation is applied as the magnet is wound.

into the external supporting shell and then vacuum impregnating the coil with cryogenic rated, anhydride cured, epoxy resin.

The external supporting shells are constructed from nitrogen-alloyed manganese stainless steel (Fe-21Cr-6Ni-9Mn). The shells, by their stiffness and strength, reinforce the coils by carrying a significant portion of the radial and axial loads produced by magnetic forces [2]. The large elongation and high ultimate tensile strength of the shells provide containment in the event of a coil failure.

Coil leads are arranged at one end of the coil, in an interlocking manner, as shown in Fig. 3, to allow the hoop loads from the end turns and the repulsive loads from the leads to react against each other. This constrains the leads from splitting apart and channels the loads directly into the high strength conductor and external supporting shell without depending upon the shear strength of the electrical insulation system on the end turns. Leads from each coil are paired together and project axially from the coil. The leads are heavily insulated, bound together with high strength S-2* glass roving and impregnated at the same time as the coil. Coil conductors and leads are rigidly supported by epoxy fiberglass laminate filler pieces or other conductors throughout the coil. Cross-overs between layers at coil ends are fully supported by filler pieces and when required incorporate space for brazed conductor splices.

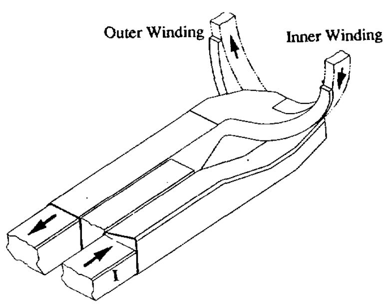

Fig. 3 . End on view of coil 1 showing the coil leads projecting out of the figure.

The coil support frame consists of thick epoxy fiberglass laminate hubs and endplates (Fig. 4). These hubs and plates are axially joined using stainless steel tie rods. The coil support frame positions the individual coils and busbar system, supports gravity loads, absorbs magnetic loads from the busbar and coil magnetic misalignment and provides a means of channeling liquid nitrogen for cooling between the coils. Mounting and fastening in the frame accommodate thermal expansion and magnetic misalignment. The frame provides a means of lifting a coil or coils from the dewar. Containment in the event of coil failure is also provided by the frame.

The coil dewar is fabricated from non-magnetic stainless steel. It supports the gravity loads of the magnet frame, reduces the external thermal load on the magnet and experimental apparatus and contains the liquid nitrogen and nitrogen gas used to cool the magnet. The dewar contains an optical window at its base. The head or top of the dewar

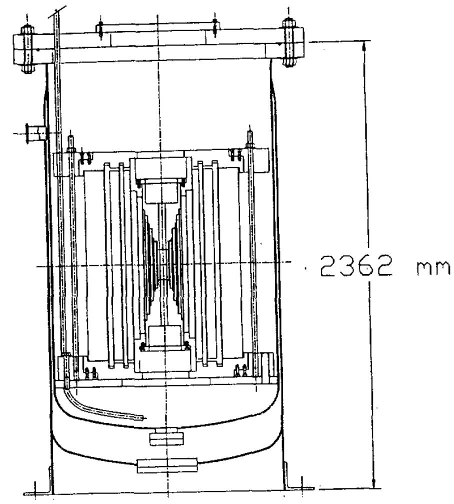

Fig. 4. Cross sectional drawing of magnet showing coil frame and dewar.

incorporates fittings and provisions for the mounting of experiments, the attachment of electrical power and liquid nitrogen feedthroughs and venting of nitrogen gas.

III. Prototype Tests

The power supply

A simulation of the exact stresses in the prototype coils can not practically be devised because of the lack of a full coil set. We selected the 2 inner coils for the prototype test because they are the least expensive coils to manufacture and have most of the design features of the rest of the coils. To stress the coils near the actual operating conditions requires higher current densities than the full coil system because of the lack of external fields produced by the remaining coils. Such a current overdrive changes the stress distribution in the prototype coils but will still permit us to compare our finite element model predictions against actual performance.

We will use a 22 mf, 10 kV capacitor bank as a current drive for the prototype tests. The two coils will be nested and connected in series. The circuit response has been calculated, see Fig. 5. With a capacitor charge voltage of 4 kV, the discharge cycle will produce a peak current of 54 kA with a half-period of 4 ms. This current level is estimated to produce the correct radial loading on the shells of the coils. A finite element calculation, which models the structural response of the coil and support shell, will be necessary to predict the actual current necessary to produce the desired coil and shell loading.

* S-2 glass is a trademark of Owens Corning Fiberglass Corp.

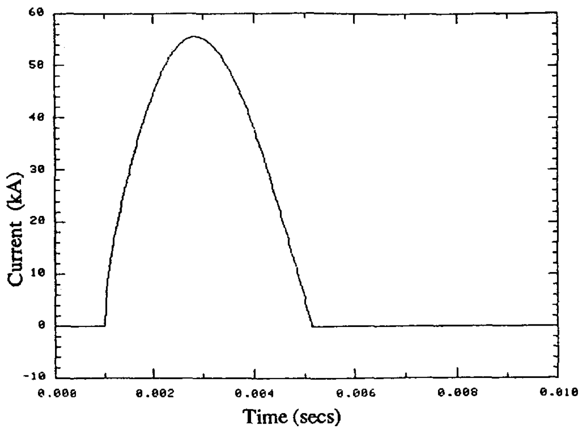

Fig. 5. Current waveform produced by the capacitor bank discharge into the coil 1 and coil 2 prototypes

The Diagnostics

Strain measurements are the most desirable data from the tests. The external surface of the coil shells will be instrumented with an array of strain gauges and strains will be measured before and after coil excitations. We also will try to instrument some strain gauges so that we can acquire the dynamic response of the coil and the support shell. This may be difficult because of the changing magnet flux present at the strain gauge locations. We have had success in making four terminal measurements in the presence of large dB/dt by using the AC phase sensitive detection technique. Such a technique, however, will only permit us to make relative strain measurements because AC excitation of the strain gauges will have an associated skin effect.

REFERENCES

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[2] L. M. Lontai and P. G. Marston, "A 100 kilogauss quasi-continuous cryogenic solenoid - Part I," *Proc. Intern. Symp. Magnet Technology*, 723, Standford, 1965.