IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

THE ISABELLE MAGNET SUPPORT AND ADJUSTMENT SYSTEM*

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Summary

The ISABELLE superconducting magnet is supported at the quarter points within a carbon steel vacuum vessel by four fiberglass straps. These are positioned at a small angle to the vertical so that contraction of both the magnet core and the suspension straps do not change the position of the magnet centerline. Two smaller fiberglass straps at each support provide horizontal position location. The fiberglass straps are fabricated of uniaxial epoxy fiberglass tape. Creep tests at room temperature and 1.3 times design load show no extension after one year and there was a factor of safety of 5 in breaking strength. An Engineering Test Model was constructed and cycled to 5° K. Heat leak for the eight straps was less than 0.5 W and position stability was within ± 0.005". The vacuum vessel is vertically positioned by means of three jack screws with sliding pads and spherical washers between the top of the jacks and the support boxes. Longitudinal and lateral positioning is done by three horizontal screws at each support box. Three shim plates on the top of the support boxes are used to set the magnetic plane and sockets in two of these are used to set the lateral plane.

Introduction

The magnetic fields in alternating gradient circular accelerators have to be aligned to a predetermined lattice figure within limits of about 0.25 mm rms and must hold this position over long periods of time. In most conventional accelerators using room temperature electromagnets, the magnetic field position is determined by the pole tip geometry and thus fiducial marks related to the pole tip can relatively easily be placed at appropriate places on the magnet exterior. These marks can then be relied upon with high accuracy to determine the magnetic field position.

In superconducting magnets such as those used in ISABELLE, there is no direct geometrical factor which is either easily accessible or can directly be used to relate the outside of the magnet core to the magnetic field. Also, the magnet core is suspended in a vacuum vessel when warm and may move when it is cooled down. In ISABELLE the steel laminations are held inside a stainless steel core tube, which acts as both a structural member and the low temperature helium container. The magnet core and coil, are suspended by means of a stable suspension system inside a carbon steel vacuum vessel. The suspension system must have the same long term stability as a room temperature system. Cryogenic superinsulation and a liquid nitrogen cooled heat shield are placed between the vacuum vessel and the magnet core. In addition, the heat leak through the suspension system must be minimized because the magnet core is maintained at 4° K.

Suspension System

A schematic drawing of a dipole magnet is shown in Fig. 1. The suspension system can be divided into two sections. One is the vertical suspension system, and the other the lateral and longitudinal stabilizing system. The magnet core has four attachment points located on the horizontal centerline at one quarter the magnet length from each end. Attached to these points are four fiberglass suspension straps. At one end of the magnet these straps go directly to rectangular boxes in the vacuum vessel through screw adjustments, and at the other end the straps are attached to ends of a yoke. The center of the yoke is in turn attached to the vacuum vessel by an adjustable clevis. By this means the four point attachment at the magnet core is converted to a three point suspension in the vacuum vessel.

The vertical suspension is temperature compensated to maintain the magnet core in the same horizontal plane as it is cooled from room temperature to liquid helium temperature. This is done by having the centerline of the suspension straps at a small angle to the vertical toward the vertical centerline of the magnet core. In Fig. 2 the relationships which determine this angle are shown. For the dipole magnet Δs is 0.015 in., s is 18.0 in., ΔL is 0.165 in. and L is 55 in. The angle for compensation is 5.2°.

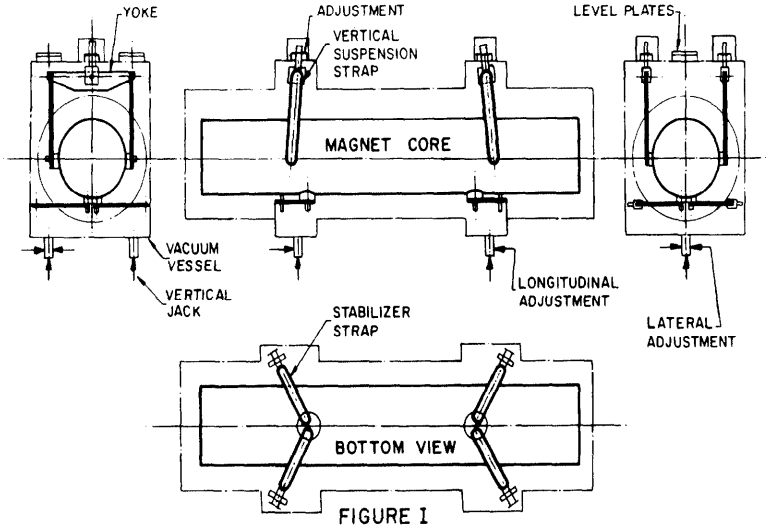

FIGURE I
SCHEMATIC LAYOUT OF ISABELLE MAGNET SYSTEM

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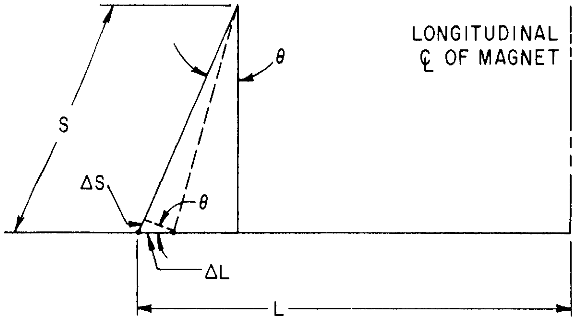


$$\sin\theta \approx \frac{\Delta S}{\Delta L}$$

FIGURE 2
VERTICAL SUSPENSION TEMPERATURE
COMPENSATING SYSTEM

Horizontal Stabilizer System

The horizontal stabilizer system must minimize magnet movement due to any forces up to five hundred pounds that may be applied laterally and longitudinally. The stabilizer straps are designed for a load of fifteen hundred pounds, which includes a pretension of five hundred pounds to establish the position of the magnet core. Underneath the magnet core on the vertical centerline and in the same cross section plane as the vertical attachments are the two stabilizer attachment points. Two stabilizer straps are attached to each point at a 60^{o} angle to the magnet core centerline.

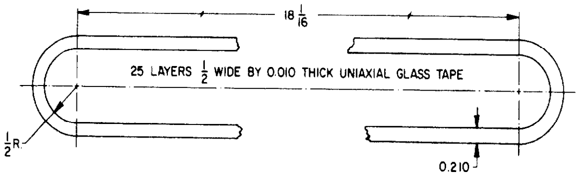
A given lateral force applied at a suspension cross section plane must equal the weight of the magnet core at the suspension before the magnet becomes unstable. This is shown in Fig. 1. For longitudinal forces restraint is provided elastically by the reaction of the 60^{o} inclined stabilizer straps at each suspension point. A complete analysis is done in Ref. 1.

Mechanical Design

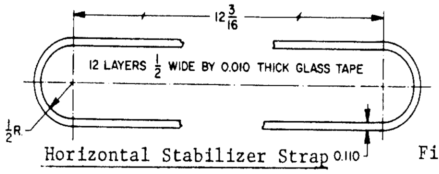
The suspension and stabilizer straps are made of uniaxial fiberglass tape which is supplied with a B-staged epoxy resin filler. This material has excellent mechanical properties which are as follows:

Tensile Strength	160×10^{3} psi
Elastic Modulus	5.7×10^{6} psi
Polymerizing Temperature	280^{o} F
Polymerizing Time	16 hours
Tape Thickness	0.010 inches
Tape Width	½ inch

Drawings of the straps used are shown in Fig. 3.



VERTICAL SUSPENSION STRAP



Horizontal Stabilizer Strap Figure 3

To select the appropriate cross section, a finite element stress analysis was done. This showed that the highest stress is on the inside radius at 20^{o} from the intersection of the straight sections with the curved ends. The stress concentration factor is 1.9 times the stress in the straight section. Since a magnet core weighs 12,500 pounds and there are four straps, each strap has a load of 3,125 pounds. The cross section area using twenty five turns of tape is 0.5 x 0.210 x 2 sq. inches. This yields an operating stress of 28,270 pounds/in.^{2}. The design load for the horizontal stabilizer straps is 1,500 pounds. The cross section area using twelve turns of tape is 0.5 x 0.110 x 2 sq. inches. This gives an operating stress of 25,900 pounds/in.^{2}.

Thermal conduction along the straps is important because thermal losses want to be minimized. A compilation of data on filamentary composites yielded a graph of thermal conductivity versus temperature for uniaxial fiberglass in epoxy as shown in Fig. 4. The area under the curve between T = 300^{o} K and T = 4^{o} K gives the thermal conductivity integral KΔT used in the equation for heat flow

$$Q = K\Delta T \times \text{Area/Length}.$$

The value of KΔT = 1.34 W/cm. The result of this calculation gives:

$$Q_{\text{suspension}} = 0.157 \text{ W (for four straps)}$$

$$Q_{\text{stabilizer}} = 0.121 \text{ W (for four straps)}$$

$$Q_{\text{suspension total}} = 0.278 \text{ W (for eight straps).}$$

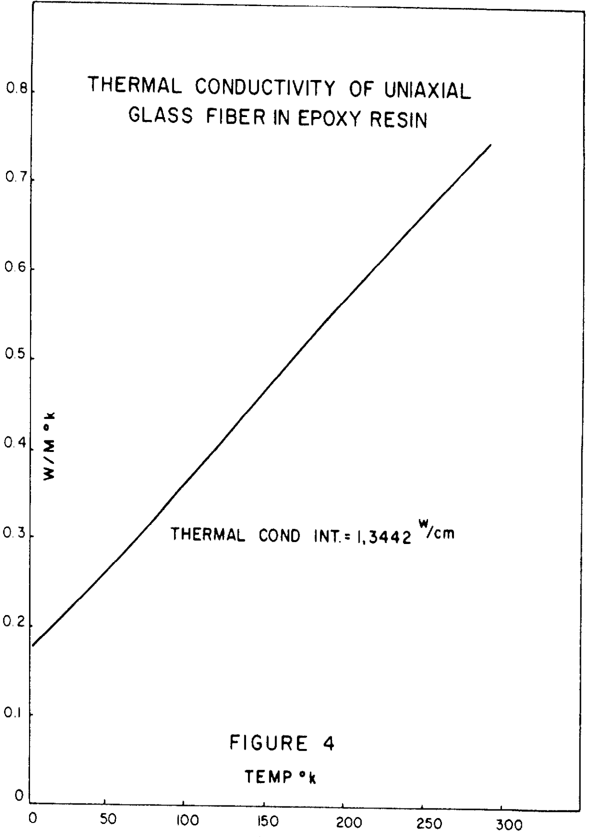


FIGURE 4

Fabrication

To fabricate the straps a different winding form is used for each kind of strap. These consist of a central mandrel with two side plates. This assembly is mounted on a winding head and the B staged epoxy tape is wound using a tension program which puts greater tension on the outside turns. Spring loaded compression bars are then placed along the long sides, and the ends of the inner mandrel are tensioned with end springs. The assembly is placed in an oven at 280^{o} F for one hour, taken out to retension the springs after the epoxy becomes liquid, and then placed back into the oven for the full curing cycle of 16 hours. After removing the excess epoxy and smoothing the starting and ending points of the tape, the strap is complete.

To insure that the load is properly applied to the strap, tight fitting spools are placed inside the strap ends by springing out the sides of the straps. The spool has a 3/4" diameter hole for attachment to the load ans support structure.

Performance Tests

Various tests have been performed to determine the performance characteristics of the suspension system, One test has been to check the breaking strength of the fiberglass straps in a tensile testing machine. The average breaking strength of the suspension strap is 17,500 pounds and the stabilizer strap breaking strength is 9,000 pounds. This gives a factor of safety of 5.6 for the suspension strap and 6 for the stabilizer strap, A typical curve of load versus elongation is shown in Fig. 5. It is interesting to note that there is no yielding as shown by the essentially straight line as the load is applied up to the breaking point.

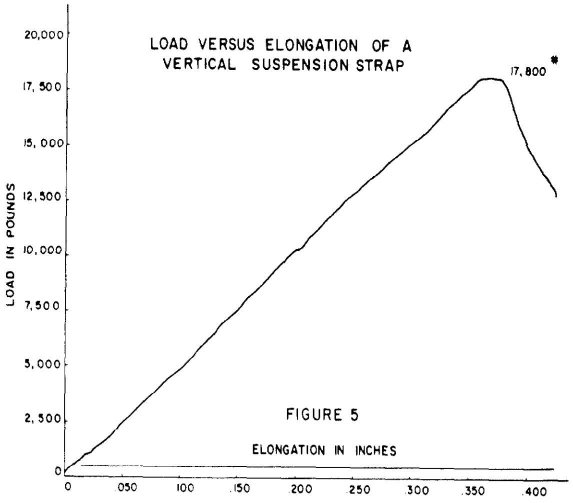


FIGURE 5

An Engineering Test Model was assembled to test the stability of the suspension system and to perform heat leak tests. This simulated a complete dipole assembly except that the superconducting coil was not installed. Crossed wire targets were attached to each of the vertical suspension points. These are viewed through a plexiglass window by a microscope in a moving carriage. Observations taken before and after cooling determine the motion of the magnet core when it is cooled down.

Heat leak of the whole magnet core was determined by attaching thermally calibrated ends to each end of the vacuum vessel. The cryogenic inlet and outlet had heat stations which were connected to temperature calibrated diodes. Temperatures of other points were also measured. By knowing the cryogen flow and the above temperatures it was possible to calculate the heat leak. The total heat leak was 4.5 W which included the suspension heat leak.

Magnet core position in relation to the vacuum vessel was measured through three cycles of cooling and warming. The results showed position repeatability of 0.005 inch. Further work is being done to obtain more information in this area.

In connection with long term position stability, creep tests have been underway at room temperature on both types of straps for over one year. Three straps of each kind have been linked together and loads of 1.3 times the design load have been placed at the lower end. Length measurements have been taken over the link pins connecting the straps. The results show no change in length with time. Strap fabrication and performance are described in Ref. 2.

Magnetic Measurements

After a magnet is completely assembled it will be cooled to operating temperature in a magnet test stand. Magnetic measurements will be made at operating temperature to determine magnet characteristics as well as the longitudinal magnetic axis and the axes of the poles. On the top of the vacuum vessel support boxes three plates are placed, one on one box and two on the other box. These will be used to locate a plane parallel to the magnetic median plane and at a fixed distance from it. In a plate on each box drill bushings will be located at a fixed horizontal distance from the magnet axis. These plates and bushings will be used to locate the magnet in the ring tunnel by standard survey techniques.

Magnet Position Adjustment

The magnet can be moved by means of an adjusting system beneath the support boxes. A three jack support with each jack under the level plates described previously is placed on the magnet stands under the magnet. On top of each jack is a low friction pad of glass fiber in teflon which permits the magnet to be moved easily in a horizontal plane. Pusher screws are arranged at each stand to permit lateral and longitudinal adjustment of the magnet. The vertical and horizontal adjustment arrangement is shown in Fig. 1.

References

1. ISABELLE Technical Note No. 5, December 1975.
2. ISABELLE Technical Note No. 95, February 1979.