ULTIMATE STRENGTH, LOW STRESS CREEP CHARACTERISTICS AND THERMAL
INTERCEPT METHODS FOR AN EPOXY FIBERGLASS TENSION MEMBER SUPPORT

MASTER

by

R. C. Niemann, J. D. Gonczy, J. A. Hoffman, K. F. Mataya,
P. Smelser and W. C. Young

Prepared for

International Cryogenic Materials Conference

Madison, Wisconsin

August 21-24, 1979

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

U of C-AUA-USDOE

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

Operated under Contract W-31-109-Eng-38 for the
U. S. DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

The facilities of Argonne National Laboratory are owned by the United States Government. Under the terms of a contract (W-31-109-Eng-38) among the U. S. Department of Energy, Argonne Universities Association and The University of Chicago, the University employs the staff and operates the Laboratory in accordance with policies and programs formulated, approved and reviewed by the Association.

MEMBERS OF ARGONNE UNIVERSITIES ASSOCIATION

The University of Arizona	The University of Kansas	The Ohio State University
Carnegie-Mellon University	Kansas State University	Ohio University
Case Western Reserve University	Loyola University of Chicago	The Pennsylvania State University
The University of Chicago	Marquette University	Purdue University
University of Cincinnati	The University of Michigan	Saint Louis University
Illinois Institute of Technology	Michigan State University	Southern Illinois University
University of Illinois	University of Minnesota	The University of Texas at Austin
Indiana University	University of Missouri	Washington University
The University of Iowa	Northwestern University	Wayne State University
Iowa State University	University of Notre Dame	The University of Wisconsin-Madison

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights. Mention of commercial products, their manufacturers, or their suppliers in this publication does not imply or connote approval or disapproval of the product by Argonne National Laboratory or the United States Government.

Introduction

Superconducting magnet cryostats require low heat leak, structurally sound supports. A suitable geometry is that of a tension member support, which supports the cold mass of the magnet relative to the structure of the insulating vacuum vessel. This geometry permits configurations that can resist dynamic loading and can result in a support system whose preloading is independent of temperature.

Support systems which utilize epoxy fiberglass tension members have been employed for the supports of the ZGS SSR Magnets (1, 2, 3, 4), the Michigan State University Superconducting Solenoid Cyclotron Magnet (5), and will be employed for the UTSI Superconducting Dipole Magnet.

A typical tension member support system is given by Figure 1.

The elements are as follow:

- The basic member is a link in which a composite is wound in a continuous fashion around a mandrel. The result is an element that uses the strength of the material fibers in their most advantageous way.
- To achieve the maximum strength of such a support member, the flexural and torsional load inputs to the link at its end must be minimized. A suitable configuration is a spherical bearing having a cylindrical outer surface, which functions as the central pin.

- The link is attached to the supported and supporting structures at its ends by means of a pin, which passes through the end bearings and engages into a clevis, which is fastened to the structures.

This paper presents the experiences gained in the U.S. SCMS application with emphasis on tension member material, ultimate strength, creep, and heat intercepts.

Material and Geometry

Several composites were considered for the U.S. SCMS tension links, among them glass roving, preimpregnated glass cloths of both unidirectional and bidirectional configurations, and wet layups. The material combination selected was NASA Resin 2 (6) and No. 143-75 glass cloth. NASA Resin 2 consists of Epon 828 (a bisphenol A epoxy) 100 pbw,⁺ dodecenyl succinic anhydride (a flexibilizing curing agent) 115.9 pbw, Empol 1040 (a high-molecular-weight tricarboxy acid) 20 pbw, and benzyldimethylamine (a cure catalyst) 1 pbw. This composite has a rated room-temperature ultimate tensile strength of 690 MPa in the fiber direction and 210 MPa in the cross-fiber direction. The links were coated with a layer of epoxy polyimide varnish after fabrication to prevent water migration into the material, thereby reducing the likelihood of stress corrosion in the glass fibers.

⁺Parts by weight.

The geometry of the tension member was a link wrapped around 0.095 m (3.75 in.) O.D. bearings at each end, 0.51 m (20.00 in.) on center. The build of the 0.070 m (2.75 in.) wide wrap was 0.016 m (0.63 in.). Integral LN₂ temperature heat intercept stations consisting of three 0.81 x 10⁻³ (0.032 in.) x 0.025 m (1.00 in.) copper tabs were located at mid-length of each side of the link.

Ultimate Strength

Prior to fabrication of the tension links, room temperature tensile mechanical property tests were conducted on samples of the 143-75 cloth/NASA Resin 2 composite. The cross-section of the test specimens was 0.003 m (0.13 in.) thick by 0.025 m (1.00 in.) wide. The test results were a room temperature tensile ultimate strength of 620 MPa (90,000 psi) and a Young's Modulus of 19,300 MPa (2.8×10^6 psi).

Room temperature tensile tests were also conducted on the tension links. The links were wrapped in a width which provided adequate material for a 0.025 m (1.00 in.) wide proof-link to accompany each 0.070 m (2.75 in.) wide actual link. Six proof-links were tested to ultimate load. During the tests, the specimens emitted random cracking sounds beginning at average area stresses of 47 MPa (6,800 psi). The ultimate tensile stress based on the average section area ranged from 342 MPa (49,600 psi) to 431 MPa (62,500 psi) and averaged 394 MPa (57,200 psi). The average stress concentration factor at the pin employing the abovementioned 620 MPa

(90,000 psi) tensile ultimate strength of the base material was 1.6 as compared to the analytically estimated value of 1.7 (7). All failures occurred at the pin section. The approximate time from zero to ultimate was 4 minutes.

A room temperature tensile test was conducted on a complete tension member assembly incorporating a full width tension link, spherical bearings, support pins, and clevises. The tensile stress at failure based on the average section area was 368 MPa (53,400 psi). The corresponding stress concentration factor was 1.7. The failure occurred at the pin section and is shown by Figure 2. The test specimen did not emit any cracking sounds prior to failure. The approximate time from zero to ultimate was 10 minutes. Post test inspection revealed extensive yielding of the pin hole in the 304 SST clevis assembly and slight bending of the 304 SST central pin.

Low Stress Creep

During installation, the tension member supports are adjusted to a tensile preload of 50% of the design load in order to prevent the tension link from separating from its support bearing and thus being impact loaded when contact is resumed. The U.S. SCMS application design load was 266,900 N (60,000 lb.) which required a preload of 133,500 N (30,000 lb.). The preload average area stress was 60 MPa (8,700 psi).

Since creep of the composite links results in a reduction of preload, a low level stress; i. e., 10-20% of tensile ultimate stress, creep test was performed. The test specimens were all fabricated from a U.S. SCMS link to a 0.006 m (0.25 in.) thickness. The links were statically loaded at room temperature by dead weight. The test apparatus is given by Figure 3.

The creep was measured by electrical resistance strain gauges. The orientation of the gauge on the link was in the principle direction of strain. The links were sealed against humidity by varnish. Varnish in the gauge area was removed by grit sanding prior to gauge installation. The installed gauges were sealed with a polyurethane coating. Two active strain gauges monitored each link. Apparent strain effects were reduced by employing a compensating gauge on an unstressed length of link material which was fastened to each link. The active gauges on each link were sequentially switched into an arm of a bridge circuit, the circuit containing the link's compensating gauge in its adjacent arm. Prior to taking strain data, the instrumentation was zeroed against a standard link that remained unstressed for the duration of the test.

The test results are given by Figure 4. Up to the 80th test day, the four specimens behaved in a manner as predicted. At this time, the No. 2 link data became irregular indicating a large decrease in strain. At the 112th test day, the other three test link data also became irregular. The inconsistency in the direction of change of strain was a concern. A careful inspection of the entire test arrangement resulted in the discovery of cracks

propagating from the heat intercept tab zones as shown by Figure 5. The inconsistency in the strain data was concluded to be a result of the non-uniform loading of the strain gauges due to crack propagation. The cause of the crack propagation has been proposed to be a combination of stress concentration at the tabs and a degradation of the mechanical strength of the NASA Resin 2 (8) due to the increase of temperature in the creep test area.

Heat Intercept.

To reduce the effective thermal conductance of the composite link between warm and cold ends, heat intercepts to an intermediate temperature heat reservoir can be employed at a point along the length.

The U.S. SCMS magnet cryostat employed heat intercepts, thermally coupled to the cryostat's LN₂ shield as previously described, at mid-length. The tension links were instrumented with Copper-Constantan thermocouples clamped and epoxy bonded to their surfaces. The data for steady state operating conditions are as follow:

LH _e ⁴ Vessel Pressure	= 10,340 Pa (1.5 psig)
Insulating Vacuum	≤ 5 × 10 ⁻⁶ Torr
LN ₂ Shield Temperature	= 78 K
Link Temperature at Heat Intercept	= 117 K
Link Temperature Midway Between Heat Intercept and Warm End Clevis	= 265 K
Warm End Clevis Temperature	= 290 K

A limited program was conducted to determine the thermal conductivity integral between several temperatures. Measurements were made both normal to and parallel with the cloth reinforcement. The results are as follow:

$$\text{Normal, } 300 \text{ K} \rightarrow 110 \text{ K} = 0.622 \frac{\text{W}}{\text{cm}}$$

$$\text{Normal, } 77 \text{ K} \rightarrow 22 \text{ K} = 0.065 \frac{\text{W}}{\text{cm}}$$

$$\text{Parallel, } 300 \text{ K} \rightarrow 110 \text{ K} = 0.713 \frac{\text{W}}{\text{cm}}$$

$$\text{Parallel, } 77 \text{ K} \rightarrow 22 \text{ K} = 0.072 \frac{\text{W}}{\text{cm}}$$

The values are in good agreement with those previously utilized for design calculations.

An improved heat intercept which would be reliable and compact, provide good thermal contact, minimize stress concentrations in the link, and be simple to fabricate and install was sought. A promising configuration employs thin copper foils interleaved between and wetwound with layers of the composite at a selected point along the link length. A scale version of this configuration has been fabricated for evaluation and test and is shown by Figure 6. This configuration permits direct soft soldering of the heat intercept connection to the embedded foils. Tests of the thermal effectiveness of this design are planned.

UTSI SCMS Tension Link

A tension member system will be employed to support the 136,000 kg (300,000 lb.) UTSI SCMS cold mass. The system incorporates four support assemblies at each end of the magnet. The support assembly geometry is given by Figure 7. Parallel tension links are employed to reduce the bending moment in the support pins to minimize pin diameter.

and permit a compact configuration. Each tension link will wrap around 0.15 m (6 in.) O.D. pins 1.22 m (48 in.) on center and will have a build of 0.032 m (1.25 in.) and a width of 0.11 m (4.25 in.).

The support assembly design load is 1,446,000 N (325,000 lb.) which results in an average area stress of 105 MPa (15,300 psi). A conservative value of 2 for the stress concentration factor at the pin results in a peak stress in the link of 211 MPa (30,600 psi). The links will employ a 143-75 S glass cloth which should result in a minimum increase of 25% in the room temperature tensile ultimate strength over the previously used 143-75 E glass cloth. The resulting safety factor based on peak stress at the pin is 3.75.

Heat intercept stations will be located at 0.30 m (12 in.) from the warm end pin center. Copper foils 2.5×10^{-4} m (0.010 in.) thick by 0.051 m (2.00 in.) wide will be wet wound into the link to minimize stress concentration due to change of section. The calculated heat flux to the LN_2 shield is 135 W and to the LH_2 vessel is 1 W.

A resin system having both good cryogenic and room temperature properties will replace the NASA Resin 2 system. An evaluation of several systems is currently in progress.

Acknowledgements

The authors would like to acknowledge the contributions of M. Kuchnir of the Fermi National Accelerator Laboratory for measurements of the composite thermal conductivity integrals and H. Tracey of

Geonautics, Inc., for advice in composite material selection and development of fabrication techniques.

References

1. J. R. Purcell, S. T. Wang, R. C. Niemann, K. F. Mataya, H. Ludwig, and J. A. Biggs, IEEE Trans. Magn. MAG-11 (2):455 (1975).
2. J. Bywater, C. Brzegowy, J. Dvorak, R. Fuja, H. Ludwig, K. Mataya, R. Moffett, R. Niemann, S. Wang, and J. Purcell, "Design and Operation of a Superconducting High Energy Beam Line at the Argonne National Laboratory Zero Gradient Synchrotron," paper presented at Applied Superconducting Conference, Stanford University, Stanford, California, August 1976.
3. R. Niemann, S. Wang, W. Pelczarski, J. Gonczy, K. Mataya, H. Ludwig, D. Hillis, H. Phillips, L. Turner, J. Purcell, D. Montgomery, J. Williams, A. Hatch, P. Marston, P. Smelser, V. Zenkevitch, L. Kirjenin, and W. Young, "Superconducting Magnet System U-25 MHD Facility," IEEE Trans. Magn. MAG-13 (1):632 (1977).
4. R. C. Niemann, S. T. Wang, W. J. Pelczarski, D. L. Hillis, L. Turner, M. G. Srinivasan, J. R. Purcell, D. B. Montgomery, J. E. C. Williams, A. M. Hatch, P. Marston, P. Smelser, V. B. Zenkevitch, and L. A. Kirjenin, "The US SCMS Dipole Magnet System for the Bypass Loop of the U-25 Facility," paper presented at Third U.S.-U.S.S.R. Colloquium on Magnetohydrodynamic Electrical Power Generation, Moscow, U.S.S.R., October 20-21, 1976.
5. H. G. Blosser, D. A. Johnson, R. J. Burleigh, R. C. Niemann, and J. R. Purcell, in Proceedings 7th Intern. Conference on Cyclotrons and Their Applications, Birkhauser, Basel, Switzerland (1975), p. 584.
6. L. M. Soffer and R. Molho, "Cryogenic Resins for Glass Filament-Wound Composites," NASA CR-72114 (1967).
7. R. C. Niemann, J. D. Gonczy, K. F. Mataya, and P. Smelser, "An Epoxy Fiberglass Tension Member Support for Superconducting Magnets," Advances in Cryogenic Engineering, Vol. 24 (1978).
8. R. E. Schramm and M. B. Kasen, "Cryogenic Mechanical Properties of Boron-, Graphite-, and Glass-reinforced Composites," Materials Science and Engineering, Vol. 30, No. 3, p. 197-204 (Nov. 1977).

LIST OF FIGURES

- Figure 1 Typical Tension Member Cold Mass Support Geometry.
- Figure 2 Typical Tension Link Failure Mode.
- Figure 3 Tension Link Creep Test Configuration.
- Figure 4 Tension Link Creep Test Results.
- Figure 5 Tension Link Crack Propagation.
- Figure 6 Improved Tension Link Heat Intercept.
- Figure 7 UTSI-CFFF SCMS Cold Mass Support Geometry.