Title
SOLENOID HAVING A HORIZONTAL AXIS AND A ROOM-TEMPERATURE APERTURE

Permalink
https://escholarship.org/uc/item/5qk5d66d

Authors
Meuser, Robert B.
Chamberlain, William H.
Hintz, Ronald E.

Publication Date
1968-04-01
Solenoid having a horizontal axis and a room-temperature aperture

Robert B. Meuser, William H. Chamberlain, and Ronald E. Hintz

April 1968

Berkeley, California
DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal 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. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.
SOLENOID HAVING A HORIZONTAL AXIS
AND A ROOM-TEMPERATURE APERTURE

Robert B. Meuser, William H. Chamberlain, and Ronald E. Hintz
April 1968
Solenoid Having a Horizontal Axis and a Room-Temperature Aperture

Robert B. Meuser, William H. Chamberlain, and Ronald E. Hintz

Lawrence Radiation Laboratory
University of California
Berkeley, California

April 1968

ABSTRACT

A solenoid having a horizontal axis and room-temperature aperture has been built. The overall length is 43 inches and the clear bore diameter is 4.25 inches. It contains 38,770 turns of Nb-48% Ti wire having a 0.015-inch-diameter core and a 0.030-inch-diameter copper sheath.

At the quenching current of 111 A, which is within about 10% of the short-sample value, the current density, based on the coil envelope, is 16.6 kA/cm², and the peak field is 65.5 kG.

INTRODUCTION

A solenoid having a horizontal axis and an accessible aperture at room temperature has recently been completed at the Lawrence Radiation Laboratory of the University of California. A summary of its characteristics is presented in Table 1. The solenoid was built for two reasons:

(a) to provide an experimental physics group with a solenoid with which to perform a neutron and proton spin experiment, and

(b) to provide the group associated with the study of the 200 BeV Accelerator an opportunity to gain experience in designing, building, and operating, on an actual physics experiment, a superconducting magnet having most of the characteristics of a beam-transport element.

Originally it was felt that the needs of the physics group could be satisfied by a conventional water-cooled copper solenoid, but to be reasonably economical of electric power it would have had to be 10 feet long, whereas it seemed reasonable to build an equivalent superconducting magnet less than half that length. Subsequently it was found that fitting all the apparatus for the experiment into the cramped space available at the 184-inch Cyclotron would have been virtually impossible with the longer magnet.

The winding configuration was designed to minimize the integral of $B_r dz$, and this resulted in the unusual field distribution shown in Fig. 1.
Table I. Summary of solenoid parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductor: Supercon T48B (Nb-48%Ti) wire, 0.015 in. diam core, 0.030 in. diam copper sheath.</td>
<td></td>
</tr>
<tr>
<td>Insulation: Turn to turn; oxide layer on copper sheath.</td>
<td></td>
</tr>
<tr>
<td>Layer to layer; two layers of 0.003 in. fiberglass cloth.</td>
<td></td>
</tr>
<tr>
<td>Short-sample characteristics:</td>
<td></td>
</tr>
<tr>
<td>Guaranteed min current at 60 kG</td>
<td>110 A</td>
</tr>
<tr>
<td>Maximum used in solenoid</td>
<td>&gt; 150 A</td>
</tr>
<tr>
<td>Minimum used in solenoid</td>
<td>120 A</td>
</tr>
<tr>
<td>Diameter of room temperature aperture</td>
<td>4.25 in.</td>
</tr>
<tr>
<td>Inside diameter of winding</td>
<td>5.2 in.</td>
</tr>
<tr>
<td>Outside diameter of winding at center</td>
<td>7.0 in.</td>
</tr>
<tr>
<td>Outside diameter of winding at ends</td>
<td>8.4 in.</td>
</tr>
<tr>
<td>Overall length of winding</td>
<td>35.75 in.</td>
</tr>
<tr>
<td>Overall width of cryostat</td>
<td>15 in.</td>
</tr>
<tr>
<td>Overall length of cryostat</td>
<td>43 in.</td>
</tr>
<tr>
<td>Total number of turns</td>
<td>38,770</td>
</tr>
<tr>
<td>Inductance (measured)</td>
<td>35 H</td>
</tr>
<tr>
<td>Current at quench</td>
<td>111 A</td>
</tr>
<tr>
<td>For a current of 111 A:</td>
<td></td>
</tr>
<tr>
<td>Max field at conductor (calculated)</td>
<td>65.5 kG</td>
</tr>
<tr>
<td>Max field on axis (calculated)</td>
<td>62.9 kG</td>
</tr>
<tr>
<td>Current density based on coil envelope</td>
<td>16.6 kA/cm²</td>
</tr>
<tr>
<td>Stored energy (approx)</td>
<td>200 kJ</td>
</tr>
</tbody>
</table>
Fig. 1. Field distribution and longitudinal cross section.
COIL CONSTRUCTION

Many small solenoids have been built at Lawrence Radiation Laboratory, in which copper-clad niobium-titanium wire with an oxide layer was used for turn-to-turn insulation and fiberglass cloth was used between layers to serve as electrical insulation and a permeable path for the helium, and to provide some helium hold-up in immediate contact with the conductor. A bulk current density of $55000 \text{ A/cm}^2$ at 60 kG has been achieved with this system, but only on small solenoids. These solenoids were not stable in the Stekly sense, but they nevertheless served their purpose well. We decided to try the same construction on the present magnet, both because it is economical and because it would furnish valuable experience to guide us in designing beam transport elements. Wire was purchased having considerably more copper cladding than used heretofore—a 3 to 1 copper-to-superconductor ratio. A small solenoid (5.0 in. i.d., 6.3 in. o.d., 5.1 in. long) was wound with the proposed conductor. The load line for the small solenoid was considerably steeper than that proposed for the large solenoid (Fig. 2), so as to constitute a severe test of the stability of the system. Tests indicated the stability to be adequate. More wire was added to the test coil, resulting in a lower load line, and again the performance was satisfactory. The current in both cases was within 10% of the short-sample curve (as measured along the load line).

As a result of the satisfactory results of the small-coil tests we decided to use the same construction on the large coil. Figure 3 shows the completed coil.
Fig. 2. Load lines and short-sample characteristics. Load lines are for the region of maximum field.
Fig. 3. Completed coil. Stainless steel cable covering the ends was later replaced by several layers of stainless steel wire.
CRYOSTAT

Design

The original concept included a vacuum vessel having a removable lid to which the entire cryogenic system was attached. That scheme was abandoned in favor of the present system, which employs a vacuum vessel with removable ends. It was felt that the latter scheme simplified servicing the internal components, and experience has shown that disassembly and reassembly are not difficult.

A single nitrogen-cooled baffle is as effective a thermal shield as several inches of very carefully applied multilayer superinsulation. Space between the bore tube and the cryostat was limited, and the desire for compactness, the many penetrations required, and the necessity for removing the insulation to gain access to the coil vessel made multilayer insulation very unattractive; therefore a liquid nitrogen baffle is used instead. Additional insulation is provided by a gas-cooled shield. Some multilayer insulation is used, but the extensive refinements necessary to make it completely effective were not employed.

The cryostat was designed to be reasonably economical of overall width, but the inside diameter of the coil vessel was made larger than necessary to allow it to be used later for a quadrupole or dipole winding. This requirement dictated that separate helium and nitrogen reservoirs be placed above the coil vessel, and it seemed most convenient to place the reservoirs inside the main vacuum vessel rather than in separate vessels.

Figures 4 through 7 show how the cryostat was made.
Fig. 4. Cryostat cross section.
Fig. 5. Helium reservoir and coil vessel.
Fig. 6. Nitrogen reservoir and shield installed in vacuum vessel.
Fig. 7. Cryostat with solenoid installed.
Mechanical Supports

The possibility of using large quantities of iron radiation shielding near the solenoid required the supports at either end to withstand large sustained unbalanced forces of 4000 lb in any direction.

The requirement that the coil remain in a fixed position ruled out some of the more flexible types of supports commonly used in cryogen-transport vessels, leaving a system of rods and struts as the only reasonable alternative.

The support system is shown in Fig. 8. Welded 6 Al 4 V titanium alloy struts, designed to withstand a 4000-lb compression force, support the liquid nitrogen shield and vessel.

Rods of A286 stainless steel, a precipitation-hardened alloy, isolate the helium system from the nitrogen system. The rigidity of the helium vessel permits the rods to be pretensioned so that they are never subjected to compression loading. These rods terminate at fittings that are cooled by effluent helium gas, and the fittings are in turn thermally isolated from the helium vessel by small struts.

Since the four LN-cooled tripods and the four gas-cooled tripods are statically determinate structures, the use of eight tension rods results in only two conditions of redundant constraint. This is one more than the minimum required for a pretensioned system, but it resulted in a completely symmetrical system, giving no change of the coil position upon cooldown.
Fig. 8. Mechanical supports. Only one end is shown. A longitudinal member, not shown, is attached to each LN system support point and to each He-gas-cooled terminal, forming a system of tripods.
Current Leads

The gas-cooled electrical leads have been designed with straight vertical flow passages of relatively large cross section (Fig. 9) so as to be resistant to obstruction and provide significant emergency-flow capacity. During normal operation the flow is viscous and the pressure drop is sufficiently low that buoyancy differences aid proper flow distribution among the flow passages.

Grade A nickel 0.010 in. thick was selected as the lead material because it has the best combination of electrical, thermal, and mechanical properties and can be readily formed and joined. Copper leads of the same length, for example, would have been only 0.002 in. thick. Three strands of superconducting wire were added to the lower half to ensure no Joule heating below 10°K.

PERFORMANCE

Cryostat

The following liquid helium boiloff rates were measured:

- Cryostat with current leads removed, 0.7 liter/hr,
- Current leads in place, no current, 0.8 liter/hr,
- Current leads in place, 100 A, 1.0 liter/hr.

Solenoid

The large solenoid was built and tested at various points during its construction. In its final configuration, with the shape shown in Fig. 1, it quenched at a current of 111 A when charged slowly (14 minutes to 100 A, 25 minutes more to 111 A). Later it was induced to quench at 80 A by charging, discharging, and recharging rapidly with reversed polarity. Subsequently it has been charged to 100 A several times. During the physics
Fig. 9. Current lead cross-section.
experiment the current will probably not exceed 75 A.

The short current decay time upon transition of about 1 sec indicates that the stored energy is dissipated throughout the winding.

The solenoid performed about as well in relation to the short-sample characteristics as the small test coils--there was no noticeable size effect.
This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.