**Title**
PRELIMINARY PARAMETERS OF A NEW 10-MEGAJOULE SUPERCONDUCTING MAGNET

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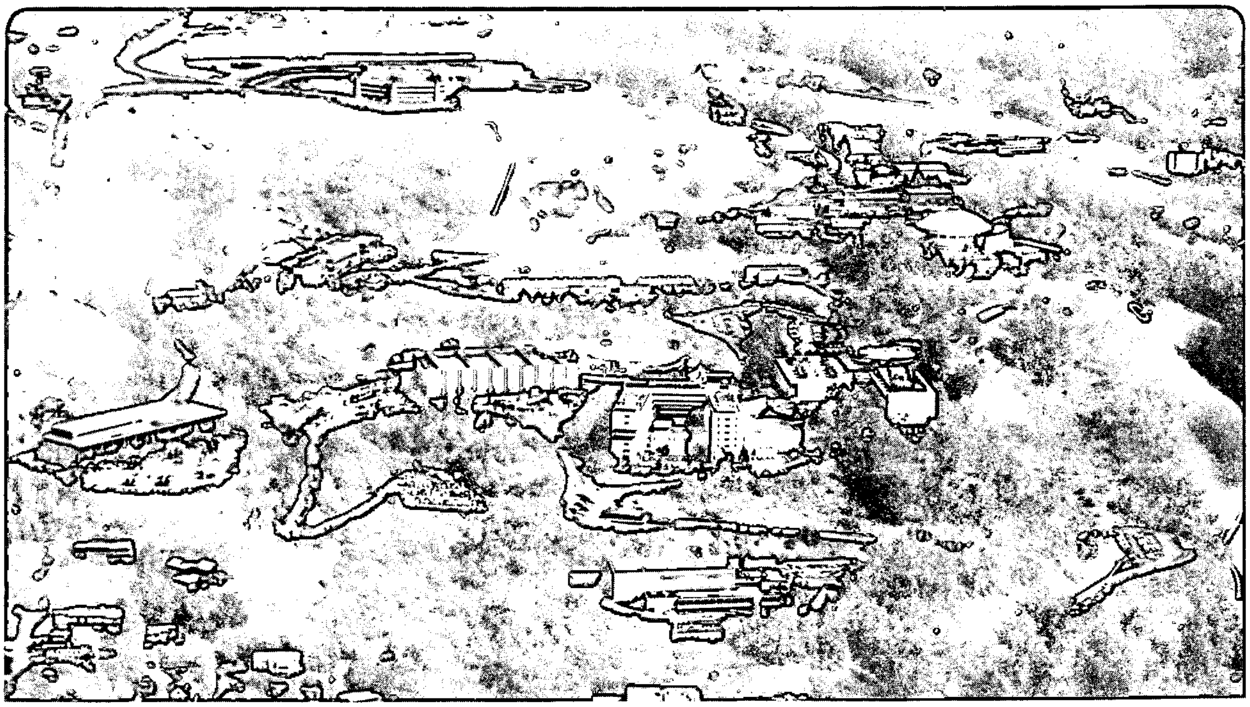

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PROGRAM — PROJECT — JOB

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SANDIA CRYOSTAT AND MAGNET

TITLE

PRELIMINARY PARAMETERS OF A NEW 10-MEGAJOULE SUPERCONDUCTING MAGNET

We have been asked to design a cryostat for the 2-meter-diameter C test magnet built by LBL in 1977. We have also been asked to do a preliminary design of a high current density solenoid with a design stored energy of 10 megajoules. The existing C magnet and the 10 megajoule magnet will provide a d.c. magnetic field for the Sandia pulsed MHD power supply for high-powered pulsed lasers.

The new magnet is almost identical in size to the old C magnet.[1] The coil length will be 0.7m and the coil inside diameter will be 2 meters. The current density of the new magnet must be high in order for it to fit within a horizontal bore cryostat designed for the existing C magnet. Therefore, the magnet will employ a quench protection system based upon the LBL shorted secondary circuit concept.[2] The new magnet will be cooled with forced two-phase helium just as the old LBL C magnet was.

The new superconducting solenoid magnet has the following parts: 1) An 1100 aluminum winding spool, 2) 14 layers of superconductor 1x3.6mm in cross-section, 3) A two-layer pure copper quench back coil wound with 1x3.6mm copper with a zero field resistivity ratio of at least 200, 4) Hard aluminum banding in a layer about 30mm thick, and 5) fined tube to carry two-phase helium used to cool the magnet. The copper quench back coil is the major new component in the proposed 10 MJ as compared to the existing C magnet. Figure 1 shows a cross-section of the proposed Sandia coil. As a comparison, Figure 2 shows a cross-section of the LBL C coil.

TABLE 1 compares the proposed new solenoid with the existing C magnet. The inside radius of the superconducting coil is the same for both coils. The length of both coils is also the same. The new 10 MJ solenoid must carry 2.3 times as much current as the existing C coil. The peak field in the new magnet will be about 5 Tesla compared to a peak field of about 2.2 Tesla in the old solenoid.

### a) The superconductor

The superconductor for the proposed new solenoid is similar to that selected for the TPC magnet.[3] There is one important difference. The new Sandia solenoid conductor has its matrix resistivity set so that the magnet will be protected from burnout during a quench <u>without</u> the use of an active quench protection system.[4] Quench back will be used to protect the new coil.

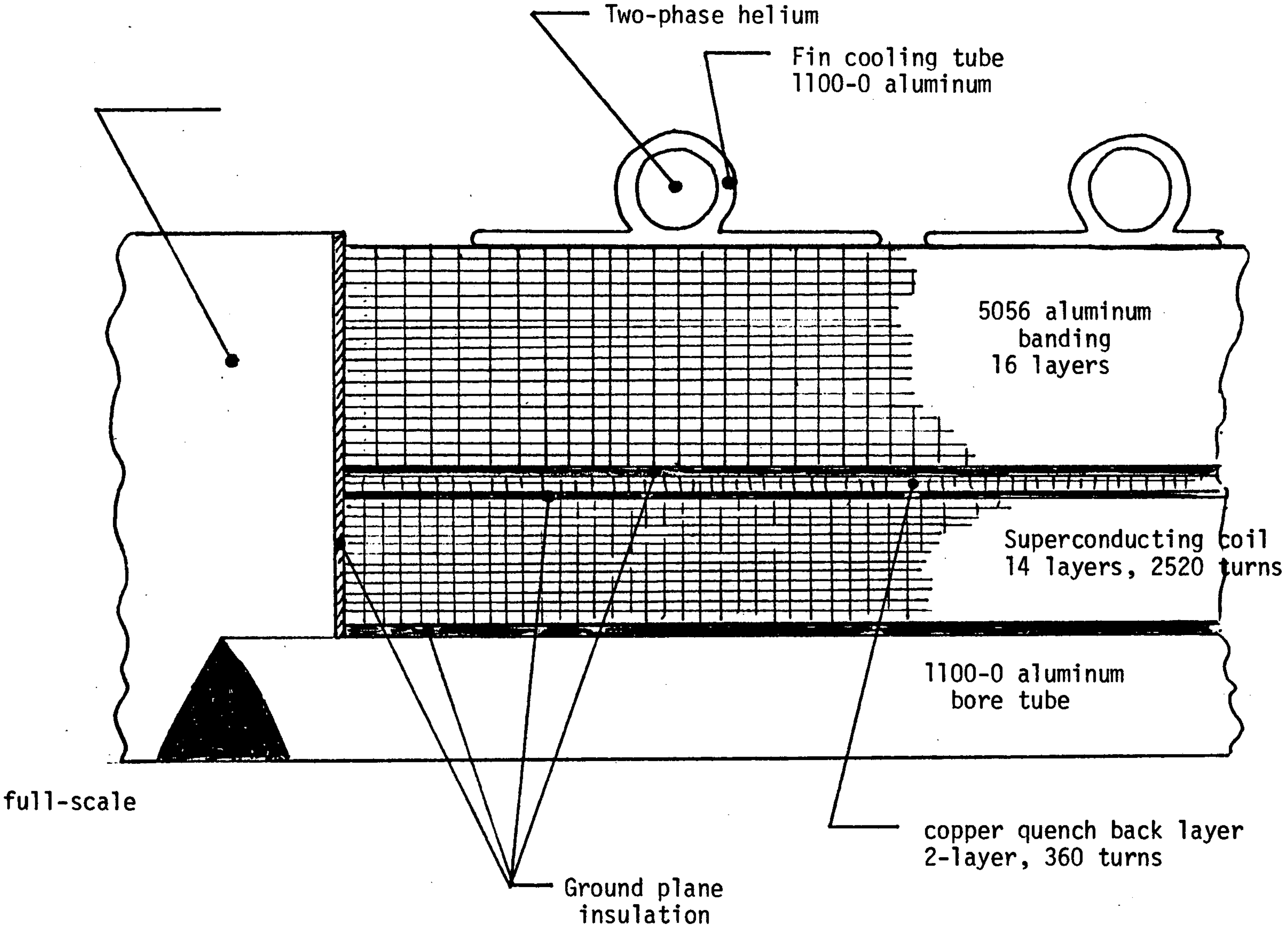

FIGURE 1. A CROSS-SECTION OF THE PROPOSED SANDIA COIL

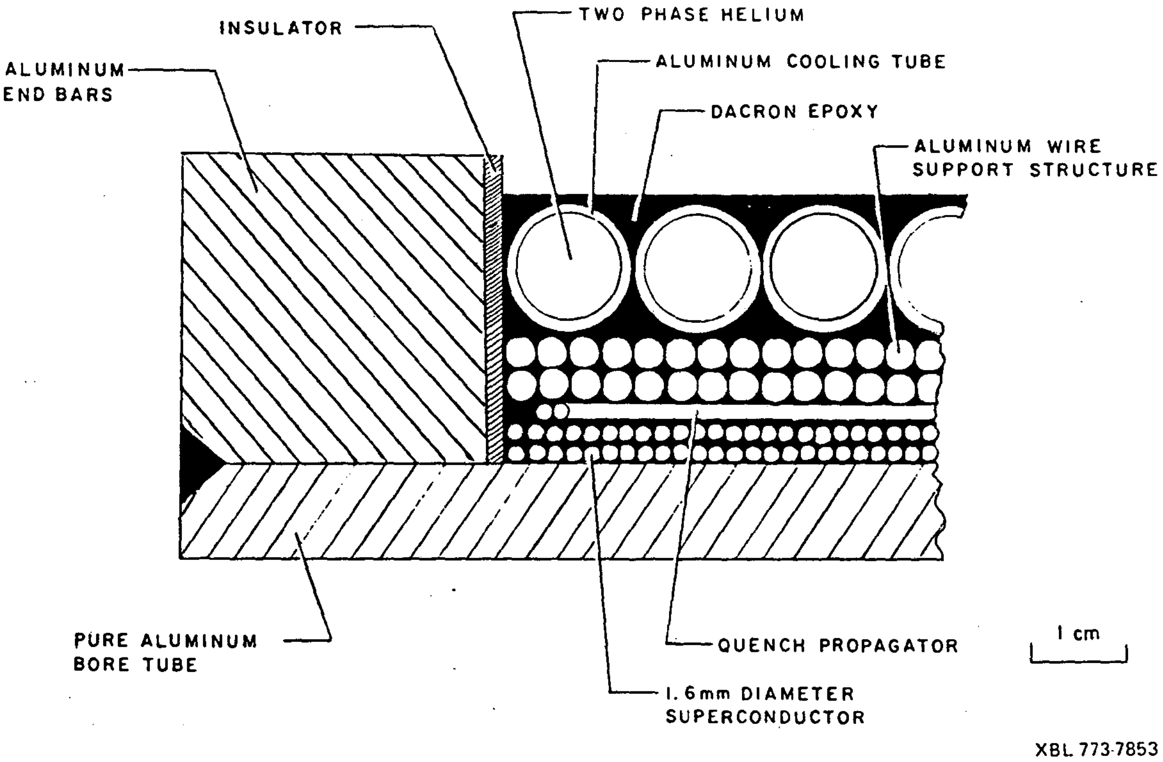

FIGURE 2. A CROSS-SECTION OF THE LBL C COIL

TABLE I. A comparison of the LBL C magnet with the proposed new ten-megajoule Sandia solenoid

| Parameter | (units) | Old C Magnet | New Magnet |
|---|---|---|---|
| Coil length | (m) | 0.697 | ∿0.7 |
| Inside radius of Coil $a_1$ | (m) | 1.001 | ∿1.0 |
| Coil thickness | (mm) | 3.35 | 21.90 |
| Number of layers | | 2 | 14 |
| Number of turns $N_1$ | | 860 | 2520 |
| Coil current $i_0$ | (A) | 1440* | 1115** |
| Matrix current density at $i_0$ J | ($\mathrm{Am^{-2}}$) | $8.14 \times 10^8$* | $3.19 \times 10^8$** |
| Stored magnetic energy E | (J) | $1.92 \times 10^6$* | $10.0 \times 10^6$** |
| Coil self-inductance $L_1$ | (H) | 1.847 | ∿16.1 |
| S/C matrix resistivity $\rho_1$ | ($\Omega$m) | $\sim 1.5 \times 10^{-10}$ | $\sim 5 \times 10^{-10}$ |
| Copper to S/C ratio r | | 1.8 | 1.8 |
| Number of turns in QB coil $N_2$# | | - | 360 |
| QB coil self-inductance $L_2$# | (H) | - | ∿0.34 |
| QB coil resistivity $\rho_2$# | ($\Omega$m) | - | $0.78 \times 10^{-10}$ |
| Bore tube self-inductance $L_3$ | (H) | $2.39 \times 10^{-6}$ | $2.37 \times 10^{-6}$ |
| Bore tube resistivity $\rho_3$ | ($\Omega$m) | $1.45 \times 10^{-9}$ | $\sim 10^{-9}$ |
| Magnetic moment at $i_0$ M | ($\mathrm{Am^2}$) | $3.90 \times 10^6$* | $9.02 \times 10^6$** |

* At critical current.

** At design current, the critical current is estimated to be about 1500A.

$J$ at $i_c$ = $4.29 \times 10^8\ \mathrm{Am^{-2}}$

$E$ at $i_c$ = $18.1 \times 10^6$ J

$M$ at $i_c$ = $12.1 \times 10^6\ \mathrm{Am^2}$

\# The old C coil has no quench back coil. Quench back occurs from the bore tube in this case.

The superconductor parameters are given in TABLE 2. The conductor given in TABLE 2 will be adiabatically stable, dynamically stable and stable against self field effects. The peak field in the new magnet is expected to be around 5 Tesla when it operates at design current. The operating temperature for the new magnet is expected to be around 4.5K. Using the conductor described in TABLE 2, one can expect the superconducting coil to have a critical current of around 1500A. Therefore the design current for the new magnet is expected to be about 75 per cent of the critical current along the load line.

b) The quench back elements

The proposed Sandia magnet would have two shorted secondary circuits. Quench back can be induced off of either circuit. The secondary circuits are the coil-winding bobbin made from 1100-0 aluminum and a two-layer circuit made from pure copper. It is proposed that the superconducting coil be wound directly on the coil bobbin. The two-layer quench back copper coil would be wound over the superconducting coil (see TABLE 3).

TABLE 2. Basic parameters for the superconductor for the proposed Sandia solenoid

| | |
|---|---|
| Matrix dimensions (uninsulated) | 1.0 x 3.6 with rounded corners |
| Nominal insulation thickness all around | 0.05mm triple Formvar |
| Copper to superconductor ratio | 1.8 |
| Number of filaments | >2000 |
| Filament diameter | <28μm |
| Twist pitch | ∿40mm |
| Critical current @4.2K and 5.0T | >2000A |
| Matrix copper resistivity @4.2K and 0.0T | $\leq 5 \times 10^{-10}$ Ωm |

TABLE 3. Secondary circuit parameters for the proposed Sandia solenoid

Winding bobbin

| | |
|---|---|
| Type of aluminum | 1100-0 |
| Resistivity at $4^{o}$K OT | $\leq 10^{-9}\Omega$m |
| Plate thickness before machining | 1 inch |
| Machined thickness | 19.1 mm |
| Bore tube outside diameter | 2000 mm |
| Bore tube length | 700 mm |
| Bore tube self-inductance | $\sim 2.37 \times 10^{-6}$H |
| Bore tube time constant at 4K and OT | ≥6.1S |

Copper quench back coil

| | |
|---|---|
| Type of copper | R101 |
| Resistivity at 4K and OT | $\leq 7.8 \times 10^{-11}\Omega$m |
| Copper dimensions[5] | 3.6 x 1.0 mm<br>w/round corners |
| Number layers | 2 |
| Number of turns | 360 |
| Coil inside diameter | 2048 mm |
| Coil length | 700 mm |
| Quench back coil inductance | ∿0.328 H |
| Coil time constant at 4K and OT | ≥6.4S |

The 1100-0 aluminum bobbin is expected to have a resistivity of about $10^{-9}$ ohm meters at $10^{o}$K. It is an energy absorbing circuit. When there is a quench at full design current, the aluminum bobbin is expected to absorb about half of the magnet stored energy. Quench back from the bobbin is expected to be longer than the quench back time off of the copper quench back coil.[4]

The two-layer, 360-turn copper coil is designed to induce quench back (where the whole magnet turns normal faster than through quench propagation) in a time short enough to prevent burnout of the superconductor.

The copper will have a resistivity of $7.8 \times 10^{-11}$ ohm or less at 10K and zero field. Magneto-resistance has been considered in the design. The proposed copper conductor is similar to the copper we purchased for the TPC magnet from Hitachi. The copper layer is expected to induce quench back in about 70 per cent of the time the winding bobbin alone would induce quench back.[4]

c) The aluminum banding

The layer of aluminum banding is designed to carry the magnetic forces when the coil is charged to full current. The total strain in the coil package when it is charged to full current is designed to be less than 0.15 per cent. The control of strain during charging is necessary if training is to be avoided.[6,7]

The banding layer can be wound from aluminum wire which has the same specification as that used on the TPC magnet.[8] This banding is 2.06 x 6.55 mm in cross-section and is made from 5056-0 aluminum. Whether or not the banding wire is insulated is subject to further study. The 2.06 x 6.55mm banding can be wound in 16 layers on top of the quench back copper coil.

d) Finned aluminum cooling tube

This magnet can be wound with superconductor, copper and banding before potting. Unlike the C coil, we propose that the cooling tube be applied after the coil is potted. This method of cooling tube application was used on the Cornell thin solenoid and it will be used on the new TPC solenoid.[9]

The TPC magnet finned tube could be used on the Sandia solenoid.[10] The fin width is 63.5mm wide with a 12.7mm ID tube attached to the fin. The proposed Sandia magnet would require 10 turns of this cooling tube.

The cooling circuit length is shorter than in the C magnet. Since the axis of the solenoid is horizontal, the number of turns in the circuit is of concern. Garden-hose oscillation and two-phase flow problems should be minimized when the new tube is used.

e) The electrical insulation for the new Sandia magnet will be built to a much higher standard than was used on the C coil. In critical areas such as the ground planes the insulation will insulate and form a barrier against chips.[11,12] Since the magnet is designed to use quench back as an important part of its quench protection scheme the voltages across the insulation are expected to be modest. In insulation system itself is designed so that a simple resistor could be put across the leads of the magnet as an active quench protection system. This resistor, which is about 0.25 ohms, will induce quench back in the magnet. The ground plane insulation will be designed to withstand at least 1.5kV.

The various insulation layers shall have the following properties:

1) Bore tube to superconductor: at least 1.0mm of fiberglass epoxy with a chip barrier plus 0.5mm of Formvar

2) Superconducting coil to copper coil: 1mm of fiberglass epoxy plus two 0.05mm layers of Formvar

3) Copper coil to the aluminum banding: at least 1.0mm of fiberglass epoxy with a chip barrier plus 0.05mm of Formvar

4) Layer to layer in the superconducting coil and in the copper coil: at least 0.4mm of fiberglass epoxy plus two layers of 0.05mm of Formvar

5) Turn to turn in the superconducting coil and the copper coil: two layers of 0.05mm Formvar

The layers of insulation will be laid down as the coil is wound; then they will be vacuum impregnated in epoxy resin. This epoxy resin becomes part of the insulation system.

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