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Items From the Construction of ESCAR*

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Introduction

ESCAR is an experimental superconducting accelerator which is being built at Lawrence Berkeley Laboratory to gain timely, full-scale experience in the construction and operation of a fully cryogenic accelerator. Its parameters have been described previously.[1,2] Construction is well along on several non-conventional items, which are reported here.

Dipole Magnets

Dipole Cryostats

In addition to being a helium container, the helium vessel for the dipole magnet supports the superconducting coil, provides a passage for helium flow, and forms the wall of the high-vacuum cold bore. The vessel is made of welded stainless steel; the bore tube wall and, to a lesser degree, the outer wall must be thin to permit the penetration of pulsed magnetic field with tolerable eddy current loss. Thicknesses of these walls are, respectively, 0.065 inch and 0.032 inch.

An end view of an assembled cryostat is shown in Fig. 1. The outer cylindrical wall of the helium vessel has been made off-center upward to provide a large area above the magnet coil for the passage of 100 grams/sec of two-phase helium. The six adjacent dipole coils in a quadrant will be mounted in a common outer vacuum vessel, their helium vessels being joined by flexible couplings that carry circulating helium, magnet current leads, and small leads for monitoring temperature, helium levels, and magnet voltages. Operating pressure for the helium circuit is a few psi, but to withstand the pressure pulse following a magnet transition or loss of insulating vacuum, the cryostat is made to resist a pressure of 110 psi.

Measurements on an assembled magnet and cryostat in a test stand showed the heat leak to liquid helium to be 3.8 ± 0.4 watts; of this, about two watts is attributable to the test end closures, leaving 2 watts as the leakage in the cryostat. This is agreeably low and well below the heat budget allowance of 5 watts per cryostat. No vacuum leaks to the cold bore or to the insulating vacuum were present and the magnet cooldown and filling proceeded without any problems.

Support and Alignment System

With the "warm iron" system used for these dipoles, the iron shield is well supported on a steel girder, but the magnet coil itself is enclosed in a helium vessel which is thermally isolated from the outside world. To firmly restrain and position this coil in the exact center of the iron shield with its dipole field vertical within a few tenths of a milliradian, a support system has been devised, consisting of fiberglass-epoxy compression rods extending from the room temperature vacuum vessel to the outside of the helum vessel. There are four at one end, three at the other and their loadings are monitored by strain gauges attached at the room temperature ends. With these, the coil is restrained in the six degrees of freedom and adjustment to null the magnetic decentering magnetic force insures that it is at the magnetic central axis of the iron shield. A small rotation is possible also. The system has proved to be precise, easily adjusted and monitored, and once adjusted maintains the adjustment through warm-up and cool down. For transport of the magnet, auxiliary support screws can be run in.

Magnetic Field Quality

The design field quality of ESCAR dipoles was governed by two major considerations. These were the eventual use of the machine with stored beams, and the desire to eliminate correction windings from the magnets themselves. After mechanical constraints on the design were decided, the coil configurations were optimized by computer to eliminate low-order multipoles. Tolerances were then calculated for various sub-assemblies of the design which would provide the desired quality. Measurements on completed magnets indicate that these tolerances have been held through the entire construction process.

Measurements are made on each magnet as part of their proof testing. A special nine-coil probe is inserted in the cryogenic bore and rotated in steps. This, with associated electronics and small computer, yields dipole field and harmonics to the 18th with a precision of a few parts in 10^5 of the dipole field, both at the ends and in the center. Also, the angular phase of the dipole signal with respect to vertical is measured with 5×10^{-5} radian precision, which information is then used to adjust a reference spirit level on the iron shield. This level may then be re-placed at any future time to orient the dipole field to the vertical.

Table I compares field quality as calculated and as measured after several transitions on an early magnet. The sextupole (N = 3) component is seen to increase from small initial values to about 3 parts per thousand during magnet training. This is attributed to compaction of the coil structure toward the median plane under magnetic forces. A more rigid, firmly constrained structure is being employed on later magnets.

Table I

Multipole components through N = 10, averaged over magnet length at 6.2 cm radius, shown as parts in 10^{-4} of the dipole component, N = 1.

Multipole N	Calculated from geometry	Calculated with Tolerances*	Measured after several transitions
2	0.0	3.1	5.3
3	0.2	2.1	27.6
4	0.0	2.9	2.9
5	0.2	1.6	8.1
6	0.0	1.9	1.7
7	0.0	2.0	0.2
8	0.0	1.3	0.8
9	0.3	0.8	2.0
10	0.0	0.5	0.9

* R.M.S. errors assumed: conductor placement 0.30 mm, sector placement 0.15 mm, quarter-coil placement 0.10 mm, centering in iron 0.10 mm, measuring coil placement 1.00 mm.

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Cryogenic System

Helium System

The general outlines of the ESCAR helium refrigerator and distribution system have been previously published.[3] ESCAR presents a load to the refrigeration plant which is summarized in Table II.

Table II

Estimated Heat Loads

Static:	
Magnets and Junctions	290 watts
Current Leads	55 watts
Cryopumps and Panels	120 watts
Distribution System	275 watts
Contingency	150 watts
Total Static Load	890 watts
Refrigerator Capacity	1450 watts
Remaining for Pulsed Operation	560 watts
Plus 3.0 grams/second warm gas return from current leads	

The refrigerator, being assembled now, is rated at 1450 watts refrigerating capacity at 4.2° K with 3 grams/second warm gas return. In the usual application, such a large refrigerator operates most reliably and efficiently with a steady or slowly varying load. A research accelerator is a variable load and one of the purposes of ESCAR is to develop experience in operating the two systems satisfactorily together.

The full gas-refrigeration-liquefaction performance and operating modes in cooldown and standby will be studied when the plant is assembled and run under load later this year. Plants similar to this are planned as modules for other laboratories.

Screw Compressors

A new feature of these plants is the use of rotary screw compressors in two-stage cascade. The first is rated at 200 H.P., compressing helium from 1 to 3 atmospheres. The second, rated at 800 H.P., compresses helium from 1 to 3 atmospheres. Full load is ~1 MVA. Both compressors have been run, with helium, for about 40 hours, with no major problems or adjustments. The cold box is to be delivered in May, when it and the compressors will be operated as a system, shown schematically in Fig. (2).

Oil Removal

Rotary screw compressors require oil not only as a lubricant, coolant and thrust-balancing pressure fluid, but as the principal rotor gas seal. Consequently, there are considerable quantities in the compressed helium, which will freeze out in the cold box unless otherwise removed. Opening and cleaning the cold box is a costly and highly skilled operation, and is to be avoided or deferred whenever possible.

Oil removal in this plant takes place in a large pressure tank, downstream of the compressors, at 300 psi. It is designed to reduce contaminants below 10 parts per billion. For operating economy, all parts are sized and designed to require infrequent renewal. In sequence, the gas stream initially passes through a molecular sieve which removes most of the water. Oil droplets, 1 μm and larger, are removed in a "coalescer", where they condense and are collected. Gas and vapor, with oil now at the 2-3 parts per million level then pass through a fiberglass mat, charcoal bed, another molecular sieve, another fiberglass mat and finally a fine mesh metal filter to remove any remaining particles.

Weir System

ESCAR is designed to house each superconducting coil in a pool-boiling cryostat with low pressure two-phase helium gas and liquid flowing through. The liquid level is determined by the opening to the pipe connecting each cryostat to the next, acting as a weir. All magnets are connected in series, with nearly 100% liquid entering the supply end and a mixture of gas and liquid returning to the refrigerator at the other end, with the proportions determined by the heat loads along the way. The flow is designed to be 100 grams/second.

This system is adaptable to either "cold iron" magnets with the iron shield in the helium bath, or "warm iron", with the iron outside the cryostat. ESCAR quadrupoles will use cold iron, the dipoles have warm iron. Cryostat dimensions are similar for either. The advantages are simplicity, low pressures and pressure drops, temperature regulation by the two-phase equilibrium, high capacity to remove heat. Cool-down is by means of cold helium gas, which is supplied more efficiently than liquid by the refrigerator. Liquefaction begins when temperatures have dropped sufficiently, filling one cryostat at a time in series until the ring is filled.

High-Current Leads

A new design has been developed to provide economical gas-cooled current leads with predictable characteristics. Tests of a developmental model revealed calculable and stable behavior and the example shown in Figure (3) is tailored to serve the ESCAR dipole magnets; the specifications are:

Stable operating range	0 - 2400 Ampere
Optimized current	2000 A
Voltage drop at 2000A	0.036 volts
Gas flow for stability, zero current	0.04 grams/sec
Heat required at zero current	1.0 watt
Gas flow for stability, 2000A	0.1 grams/sec
Heat required for gas flow, 2000A	1.2 mW/A, or 2.4 watt
Pressure drop at 0.1 gm/sec	0.3 psi

This tapered multi-plate design is adaptable to a wide range of current, gas flow, pressure drop and resistance. Leads of this type optimized for each application on ESCAR will minimize lead-cooling loads.

Cryogenic Roughing Pump

A cryogenic roughing and conditioning pump has been built and operated on a vacuum test chamber. It pumps by adsorption on a 4.2° K liquid-helium container surface, nitrogen shielded. The helium holding time is 12 hours. Utilizing these pumps, vacuum procedures on ESCAR will include:

For pumping down:

- Rough-pump to 10^{-2} torr with a well-trapped mechanical pump.
- Pump to less than 10^{-6} torr with the cryo-roughing pump.
- Cool the magnet bores and cryo-panels to cryo-pump to 10^{-11} torr.

For degassing cryopumped hydrogen:

- Raise the temperature of the surface to be outgassed (magnet bores) to about 40° K.
- Absorb the evolved hydrogen on pre-deposited Argon frost in the cryo-roughing pump.

1977 Tests

Twelve dipoles (two quadrants) will be installed at the ESCAR site this summer in a fully operational state. They will serve as an extended, realistic load for tests of the cryogenic helium plant and distribution system employing the series weir-controlled cryostat concept.

As satellite experiments:

- The high vacuum bore will be cleaned, pumped and monitored under site conditions.
- The magnet power supply and quench protection systems will be tested and placed in service.

References

1. T. Elioff, W.S. Gilbert, G.R. Lambertson, R.B. Meuser, ESCAR - First Superconducting Synchrotron, Storage Ring. IEEE Transactions on Magnetics, Vol. MAG-11, No. 2, March 1975.

2. T. Elioff, et.al., ESCAR Mid-Term Report, Lawrence Berkeley Laboratory Report LBL-4818.

3. R. Byrns and M.A. Green, The ESCAR Helium Refrigeration System. IEEE Transactions on Nuclear Science, Vol. NS-22, No. 3, June 1975.

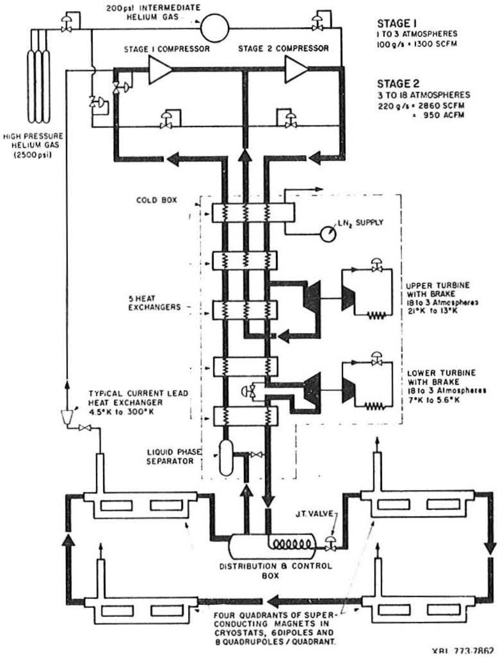

FIG. 2 - HELIUM PLANT AND SYSTEM

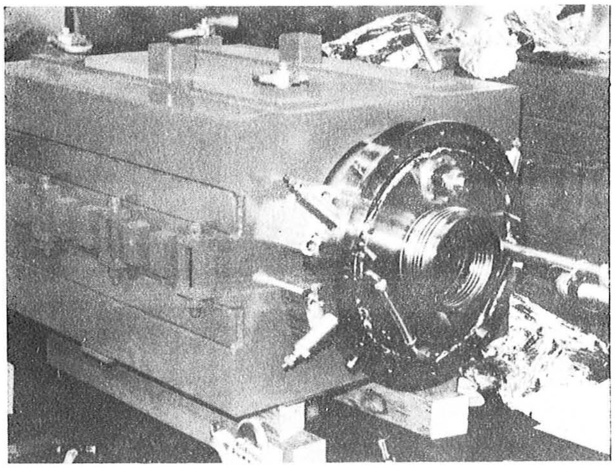

FIG. 1 - MAGNET ASSEMBLY, OPEN END OF CRYOSTAT

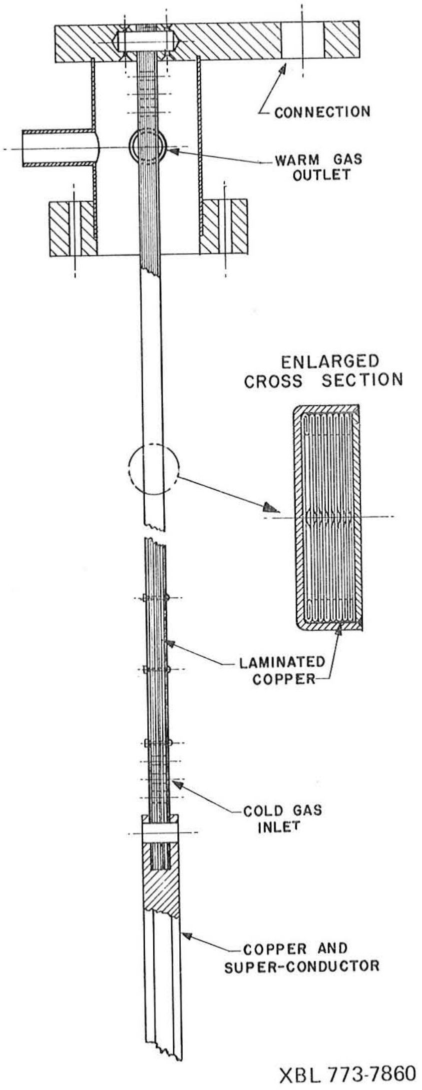

FIG. 3 - HIGH-CURRENT LEAD CONSTRUCTION