ESCAR - First Superconducting Synchrotron, Storage Ring

T. Elioff, M.S. Gilbert, G.R. Lambertson, R.B. Meuser

Lawrence Berkeley Laboratory
University of California
Berkeley, California

Introduction

The ESCAR (Experimental Superconducting Accelerator Ring) project is an accelerator technology development for which the primary goal is to obtain design and operational experience with a complete accelerator and storage ring system utilizing superconducting magnets. Full scale design effort began in July 1974, and operation is planned in 1977.

ESCAR will not only provide the experience of fabricating and operating an extensive cryogenic magnet system with a significant advancement beyond present experience, but it will also provide a comprehensive accelerator system from which can be learned the realities of the interaction between the new cryogenic elements and the many other components of an accelerator. The extent to which these components (e.g., rf, injection, vacuum, control systems, etc.) are compatible with the cryogenic features of the accelerator, and to which they force modifications of the design, will be determined.

The magnet system is designed for both pulsed and d.c. operation. The steady state operation will permit experimentation with high-current stored proton beams. In this area there are a number of unresolved issues which are important to the design of future high energy storage rings. The flexibility to carry out a program of beam experiments is incorporated in the design. Finally, the ESCAR system may prove suitable for an experimental program with high-energy heavy ions, or as a booster-injector for future high-energy proton systems.

Design Goals and Descriptions

The following parameters express the general design features of ESCAR.

Energy (Maximum)	4.2 GeV
Intensity	5×10^{12} protons
Pulse Rate	6/minute
Vacuum Pressure	10^{-11} torr
Number of Quadrupoles	32
Number of Dipoles	24
Dipole-Central Field (Maximum)	4.6 tesla
-Length	1.0 m
-Aperture (Radius)	6.5 cm

ESCAR is located at the rear of the existing Bevatron experimental hall, (see Fig. 1) which provides roof coverage, 30-ton-crane facilities, and heavy duty floor and foundation. Adequate power and water distribution systems are located in tunnels below the experimental hall. No major interference with the Bevatron-Bevalac program is anticipated. The existing Bevatron-50 MeV linac, in close proximity to the experimental hall, will be utilized as the proton injector for ESCAR.

The average radius of the ring is 15 m; it has 4 long straight sections, each 6 meters in length. The lower straight section is occupied by the injection, the right straight section contains the normal accelerating rf system, and the other straight sections are

available for experiments, beam dump system, monitoring and diagnostics. High-frequency cavities which might be used for longitudinal bunch compression are indicated as a future possibility on the left side of the ring.

Each quadrant, or cell, is a separated-function structure with focusing provided by 2 groups of 4 quadrupoles each. Six dipoles, each about 1 meter long, form the 90° arc of each quadrant. This arrangement provides for adequate straight sections and a loosely packed lattice structure, which is desired for diagnostics and general flexibility.⁽¹⁾

Superconductor and Testing

The dipole coil design uses a single-layer hollow cable that is compacted and flattened to a rectangular cross section. The aspect ratios of flattened cables⁽²⁾ we have been testing are 2 and 3, and we are awaiting delivery of cables with aspect ratios of 4 and 5.

For the pulsed service in ESCAR, we require a cable with NbTi filaments of 5 to 10 micron diameter and a doubling d/I₀ greater than 20 kg/sec. Determinations of short-sample characteristics (greater than 50 cm sample lengths) are made at fields up to 100 kg. Hysteresis losses and rate-dependent coupling losses in the cables are measured in magnetization tests. A final test of the cable's stability in a magnet winding is made by winding the test conductor into a small (approx. 6 x 16 cm) solenoid.

A most successful conductor, produced for us by Supercor, is a flattened cable of seven wires; each wire is 0.75 cm diameter and contains 3000 filaments, each of 10 μ diameter. This cable is flattened and compacted, without being soldered, to an aspect ratio of 2:1. In the solenoid test, this material reached its short-sample current (defined by 10^{-1} ohm cm resistivity) which corresponds to the exceedingly high overall current density of 35,000 A/cm² in the coil at a field of 64 kg. For ESCAR, the design current densities are 20,000 to 30,000 A/cm² at a maximum field of 55 kg.

Magnets and Cryostats

A preliminary design for the dipole magnets is shown in Fig. 2. Each dipole is 1 meter long and produces a design field of 46 kg. The coil is wound in layers. In each layer the conductors are grouped in sectors, the positions and widths of which are adjusted to minimize aberrations in the magnetic field. The number of layers required will depend on the current density and the aspect ratio of the conductor to be used. The cable is wrapped with an open spiral of epoxy-impregnated fiberglass tape, which acts as a spacer to permit permeation of the coil bundles by liquid helium. The resin is cured after each layer is wound.⁽³⁾ A cold beam tube encloses the evacuated bore and is the inner structural member that supports the coil. Spacers between the coil sectors and an outer clamp rigidly position the magnet conductors. Circular cylindrical structures are used in the coil region for their convenience in analysis and in fabrication.

Figures 2 and 3 show alternate designs having the iron, respectively, outside or inside the cryostat. With the iron outside, structural rings are shrink-

fitted onto the magnet coil, and the helium cryostat wall also gives stiffness to the coil package. With iron inside, the iron can provide the mechanical support but magnetic saturation becomes a troublesome factor in the magnet's performance. The final choice between these design alternatives will be made following further study. The winding of full size magnets has begun and prototype magnets are scheduled for early 1975.

A quadrupole design is shown in Fig. 4. In comparison with the dipoles, the field at the windings of the quadrupoles is lower and the coil construction will be simplified.

The cryostats of three dipoles or of four quadrupoles will be joined by a continuous, cold bore tube and by a liquid helium connection at the tops of the coil cryostats. Surrounding these are evacuated super-insulation and an 80° K temperature shield. The magnet cryostats connected in series through one quadrant of ESCAR serve as the helium transfer line, with two-phase helium at 4.4° K entering at one end and exiting at the other.

In addition to the series-cryostat circuit for liquid helium, a parallel helium distribution circuit must be provided around the ring. This will supply the cryovacuum system and may be used to bypass a warmed quadrant or straight section while maintaining a low temperature in the rest of the ring.

Vacuum System

The vacuum system is designed for 10^{-11} torr. The design will take advantage of the magnet cold bore temperatures (4.4° K), as this provides practically unlimited pumping capacity for all gases except hydrogen and helium. Even for these gases, because of the large area of cold surface available, the bore is expected to provide pumping for weeks of operation before saturation from cryodeposit accumulation.

The straight sections, which contain the accelerating cavities, injection and ejection systems, and diagnostic equipment, will have additional distributed cryopumps. These pumps will be specially constructed and cycled as needed to provide continuous pumping of all gases.

While a cold bore through most of the system provides excellent cryopumping, the surfaces surrounding a high-intensity beam are a concern with respect to gas desorption, the electrical impedances presented to the beam, and the potential need for ion-clearing electrodes. Consequently, various liners for the bore are being considered to shield the beam from cryodeposits if required. These vacuum system questions are an important part of the ESCAR mission. The cold bore system visualized here would greatly simplify the design and reduce costs of future high-energy proton storage rings.

While the design pressure of 10^{-11} torr is required to obtain proton beam-storage times of several hours, it also provides a pressure sufficiently low for very heavy ions (up to uranium) to be accelerated to more than 1200 MeV/nucleon without recombination problems. The heavy-ion output of the LBL-SuperHILAC (8 MeV/nucleon), presently used with the Bevatron (Bevalac), is in very close proximity to ESCAR and can readily be used as an alternate injector for ESCAR in the future.

Refrigerator

A cooling system of 1500 watts capacity at 4.4° K will be required for the ESCAR ring. Static losses, including cooling of current leads and cryopumping of

the straight sections, amount at 800 watts and, at 0.1 Hertz, pulsing losses require 700 watts. The selection of components for the refrigerator system is now in progress. We look forward to this opportunity for a realistic test of components for future accelerator applications.

Many individuals are participating in the ESCAR design. The physics group includes L. Smith, A. Garren, L.J. Laslett, W. Chupp, J. Peterson, J. Rechen, J. Staples, R. Thomas, and M. McAshan. The engineering group includes K. Lou, E. Hartwig, R. Acker, R. Avery, R. Byrns, W. Eaton, E. Hoyer, D. Hopkins, M. Green, R. Peters, C. Pike, J. Tanabe, F. Toby, F. Voelker, H. Vogel, and R. Wolgast.

References

1. R. Avery, et al, Experimental Superconducting Accelerator Ring (ESCAR), Proceedings of the IXth International Conf. on High Energy Accelerators, SLAC, Stanford, Ca., May 2-7, 1974 (to be published).
 2. Supercon Incorporated, 9 Erie Drive, Hattick, Mass. 01760
Imperial Metal Industries, Ltd., Kynoch Works, Birmingham, Great Britain.
 3. W. Gilbert, R. Mauser, and F. Toby, Proceedings of the International Conf. on Magnet Technology, Bill, Upton, N.Y., September 19-22, 1972.
- * Work supported by the U.S. Atomic Energy Commission.

Fig. 1 - Layout of ESCAR in the experimental hall.

Fig. 4 - Quadrupole magnet doublet