

UNICELL STRUCTURE FOR SUPERCONDUCTING STORAGE RINGS
G. Danby, B. DeVito, J. Jackson, G. Keohane, Y.Y. Lee, R. Phillips, S. Plate, L. Repeta, J. Skarlicka, L. Smith
Brookhaven National Laboratory, Associated Universities Inc.
Upton, New York 11973

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Abstract

Mechanically integrated, magnetically decoupled storage rings were designed for a heavy ion collider for 100 GeV/amu Au, at $B=2.7T$. New concepts were developed, including detailed engineering design and cost estimates. A "unicell" contains a half-cell of both rings within a single He vessel. The unicell design is optimized for economical mass production. Survey pads welded to the laminations provide external fiducials to locate the magnet cores. Roller bearing self aligning supports accommodate cool-down shrinkage. The design tolerates relative motion of components resulting from longitudinal shrinkage in the ~15 m long unicell without affecting performance. Magnetic and physical lengths are the same, eliminating waste space. "Achromatic" quadrupoles with sextupoles at both ends are located on a common precision beam tube which aligns and supports a pick-up electrode. The unicell accommodates longer dipoles compared to conventional designs, reducing B_{max} stored energy, and the volume of iron and superconductor. Applications to future machines will be discussed.

1. Introduction

Superconducting (SC) magnets and their cryogenic "packaging" introduce many complexities in accelerator design. But there are many advantages, some of which have not been fully exploited.

SC windings occupy such a small area that very short flux return paths can be used with iron dominated dipoles. It is not generally recognized that this is also true for quadrupoles, sextupoles and other correction magnets which can attain $B \geq 2.2T$ at the pole tips. The precision and simplicity of iron dominated circuits used in low field room temperature magnets is retained. The high current density makes possible compact quadrupoles and small, strong correction elements at low cost. These make possible a machine with a high degree of parametric control, very difficult with room temperature magnets.

A modern machine should have "cybernetic" capability: i.e., pick-up electrodes accurately aligned with each quadrupole, "on-line" computer orbit analysis and many feed-back corrector magnets.

Even with perfectly constructed and located dipoles and quadrupoles many distributed orbit and tune correctors are desirable for beam-wall, beam-beam and other effects. Then only highly stable location of elements is required; absolute location is unnecessary. It is easy to achieve positional accuracies of ~0.5 mm with standard construction techniques, well within the capability of correction magnets to correct the beam position and tune. The refined "survey" is done with the beam.

2. The Unicell Concept

A single cryogenic envelope is welded around all the magnets in a half cell of both rings, which is then encased in a heat shield, a blanket of superinsulation and a dewar, all supported as a unit in the ring--this is the unicell concept.

The first generation SC machine designs at FNAL and BNL had quadrupoles that, installed, cost almost as much as the longer dipoles. Unicell design eliminates separate dewars reducing quadrupole costs and saving space. For a given energy the dipole magnet can be longer and the field lower, reducing the cost per GeV. The unicell incorporates, for each beam in this order: a dipole, orbit correction magnets, a sextupole, a quadrupole and another sextupole, in an approximately 15 m long single cryostat (Fig. 1). The center-to-center beam spacing is 0.22m. The unicell concept reduces the number of dewar ends, the wasted space associated with them, and obviously reduces the costs associated with these ends. Magnets are designed so magnetic length = physical length. All available space is occupied by magnetic fields. The side-by-side dipoles (designed to be magnetically independent) share a pair of common Fe laminations which are split at the horizontal

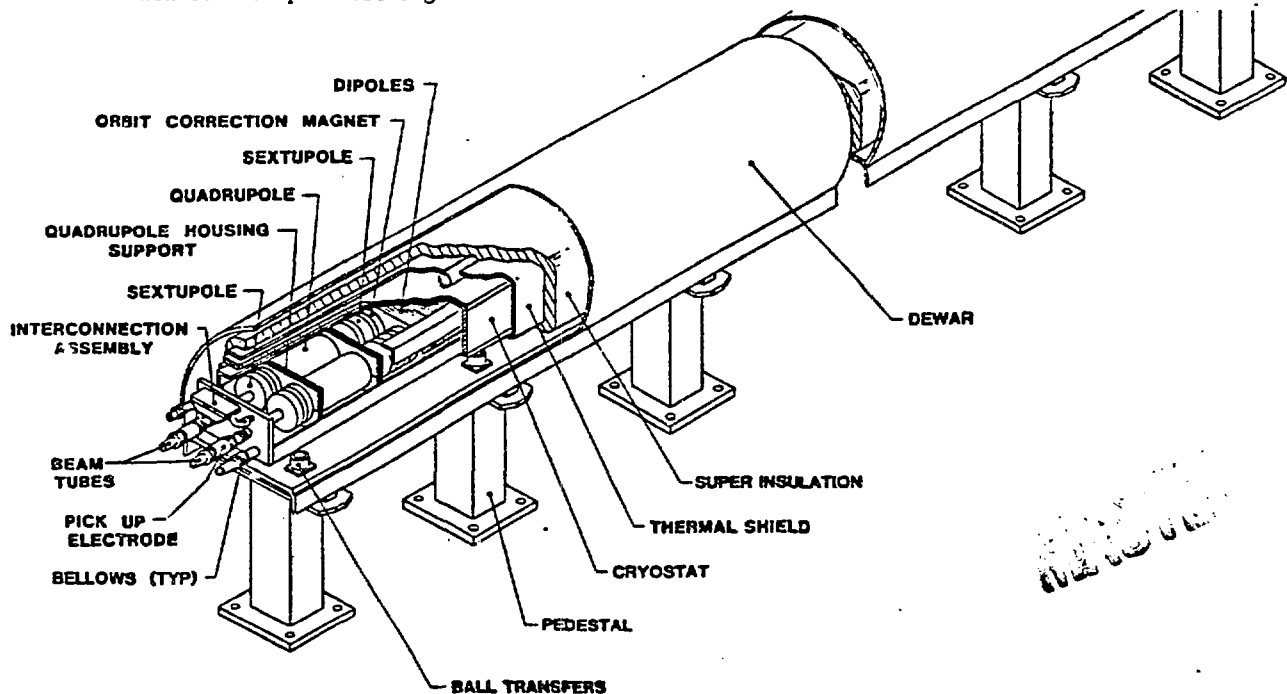


Fig. 1. Unicell Assembly.

* Work performed under the auspices of the U.S. Department of Energy.

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midplane.* A 10 cm access space is left to weld the curved dipole beam tube to the straight quadrupole beam tube. The 10 cm long correction magnet is then assembled around the welded section.

The cryostat fits tightly around the iron yoke and extends to surround the orbit correction magnets, the quadrupoles and the sextupoles. The survey pads penetrating the cryostat walls (see companion paper Fig. 2), are welded directly to the dipole laminations and the cryostat. They accurately transfer the magnet aperture coordinates to the outside surface of the cryostat. The portion of the cryostat containing the dipoles is curved to the required sagitta prior to welding. (See below under "Pacman.")

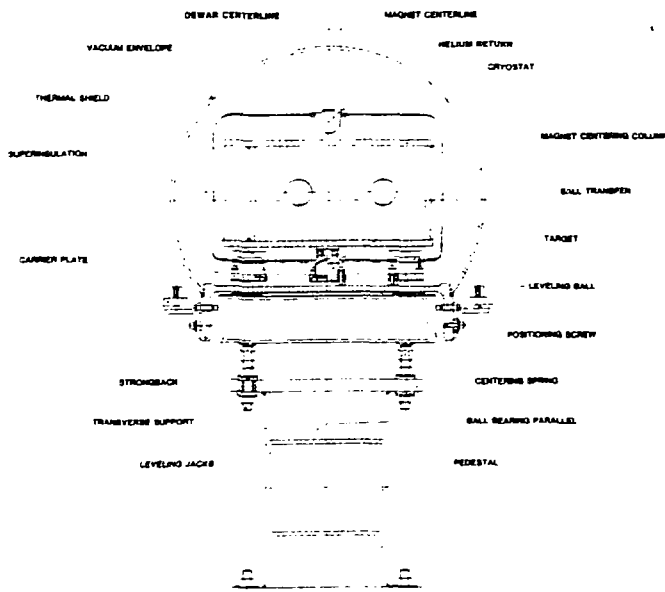


Fig. 2. HISR dewar assembly.

The side-by-side quadrupoles are supported by several block assemblies of specially punched dipole laminations providing an exact transverse fit in the cryostat (Fig. 1).

Extended sections of the beam tube through each quadrupole are machined to a prescribed radius to support and center the orbit correcting magnet, a pair of chromaticity correcting sextupoles and a precisely located pick-up electrode (PUE), all keyed for rotational alignment. The unicell elements of each beam are thus accurately and automatically internally aligned with respect to each other. Their absolute coordinates are transferred to the outside of the cryostat with high precision ($< 1/4$ mm).

The cryostat, supported on ball bearings, is anchored longitudinally by a locating ball on the magnet centering column (Fig. 2), only at the quadrupole end of the cryostat. The other end has a guide ball which slides longitudinally in a slot upon cooldown maintaining the correct radial coordinates everywhere along the length of the cryostat. Ball bearing supports are provided approximately every two meters of length. There are no internal bellows; they are located only between unicells. The cryostat is designed with a high degree of horizontal rigidity but with torsional flexibility so that slight adjustments to the vertical supports for height and rotation control do not couple into radial displacement. This approach depends upon successful sliding of surfaces in the longitudinal direction upon cooldown. The design of these magnets (window frame

* There are performance and cost advantages to orienting the magnets one above the other, but the lattice design for this HISR study mandated a side-by-side orientation.

geometry and "dry" construction techniques) permits this relative motion between the coils and cores. The transient differential shrinkage on cooldown, and curving during fabrication are accommodated. These properties are very important to the projected success of the unicell; the necessity to "see inside" a cryostat and make internal adjustments to various mechanical elements would destroy the simplicity of this design. The simplicity and economy of the unicell concept relies upon locating and controlling the large number of elements within it inherently by the mechanics of the construction. Survey is only required for a single structure, the cryostat.

3. "Pacman" Press for Unicell Construction

Pacman (Fig.3) is designed so magnets can be assembled and curved in a labor saving, cost effective manner. This device plus the unicell principle produces a window frame magnet at considerable saving compared to conventional cos θ magnets.

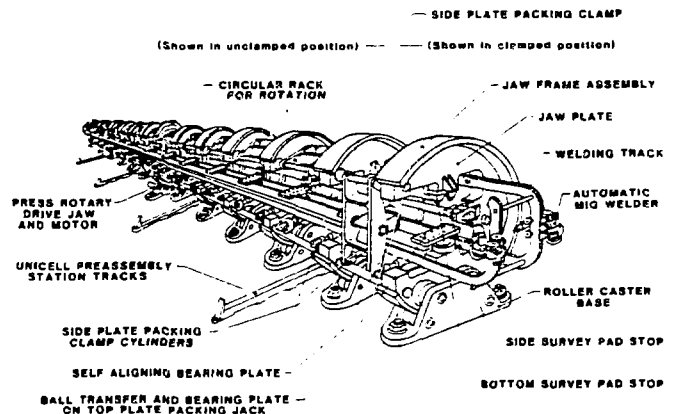


Fig. 3. "Pacman"

Component one, is a magnet assembly station, a long, massive, stable, precision aligned surface plate mounted on linear bearings where the unicell is assembled and encased in the cryostat. Slots accommodate retractable pneumatic jacks connected to stops to align and position the magnet yoke blocks and cryostat plates. The jacks retract when the cryostat bottom plate and the top yoke blocks are first placed upside down on the assembly station. The jacks and stops rise and rotate to position the unicell components during assembly. The assembly station has planar segments spaced to roll in and interleave with the jaw plates of Pacman. Ball transfer bearings on the segments allow transfer of the unicell into Pacman by hand.

Component two, "Pacman" (Fig. 3) is a long complex device that in profile resembles the opened jawed video game character. Jaw frame assemblies are spaced approximately every four feet with ball transfers for easy transfer of the unicell. Special roller-caster base assemblies bolted securely to the floor permit rotation of the jaw plates, all ganged together. Rotary position is accurately controlled. A system of hydraulic devices clamps the unicell. The cryostat side plates are clamped by a hinged lever which can be pinned to hydraulic cylinders at its other extremity. The lever has a self-aligning bearing plate that adapts to transient positions of the cryostat assembly. The straight section of the unicell, containing the correction magnets, the sextupoles, the quadrupoles and the PUE's, is precisely clamped in Pacman. The entire assembly is then rotated 90° before clamping the curved portion. Each jaw has a horizontal position stop which is adjusted precisely to conform to the horizontal design curve of the cryostat. Precision cylinders are pressed against the yoke and welded to provide survey pads for precisely locating the magnets (companion paper

Fig. 2). Smaller jacks press the cryostat plates onto the yoke sections. This assures the required accurate horizontal curved and straight (tangent) sections of the cryostat prior to welding. A unique advantage of the window frame design is that the curvature is only two dimensional. This greatly simplifies the problem of providing slip planes. After the cryostat and yoke are curved a vertical set of jacks clamps the bottom and top plates of the cryostat against the yoke sections. Finally, the computer controlled Astroarc "Mig" welding heads pass through the length of the pack press.

The unicell is transferred to a second assembly station, component three, a heavy duty table with ball transfer beams and hydraulic jacks mounted on its surface to clamp the position of the Unicell end plates for welding. This table is slotted in six locations to allow a magnet transporter access to the base of the half cell assembly.

4. Installation

The transporter serves as an assembly fixture allowing universal access to the cryostat and permits simple rapid assembly of heat shield components and superinsulation. Room temperature electrical and mechanical tests are performed. The transporter then carries the unicell to the ring for in situ installation on presurveyed ball transfer supports (Fig. 4). The unicell ends are then horizontally adjusted.

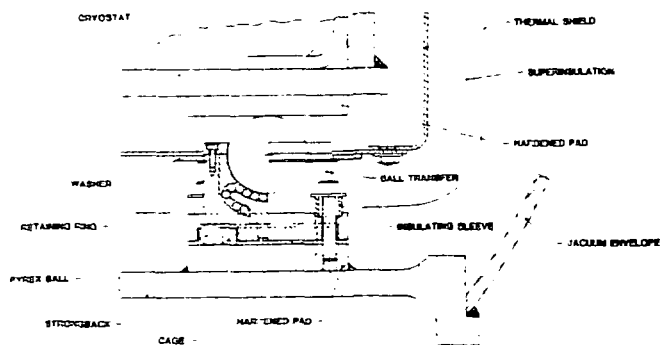


Fig. 4. Ball transfer and support assembly.

Unique to the unicell concept, all the magnets and PUE's in a half cell of both rings have been precisely located with respect to each other before the unicell is installed in the ring. The survey involves only one unit, the unicell, and can be checked in the future using external fiducials attached to the outside of the dewar.

It is expected that experience in the early part of the construction will prove SC full power tests are unnecessary on individual units because of the precise iron dominated fields (no stacking), conservative SC coils (no quench, no training) and absence of SC magnetization fields in the aperture. However, the capacity to perform integrated magnetic measurements on every unicell as assembled in the tunnel exists. Cooldown and pencil beam tests are performed on each superperiod progressively. Once a closed orbit is obtained the correction fields required to center the beam in every quadrupole will be established. Horizontal to vertical coupling will be studied and minimized. Polarized protons can be used early in the operation of the completed rings: their extreme sensitivity to horizontal fields can be used, together with imposed localized orbit distortions, for refined study of correcting magnet perturbations (this requires very stable magnets).

5. Simple Cryogenics

Minimum penetrations and low mass (with ball supports--Fig.4) give low heat load. Very low longi-

tudinal impedance and very high transverse thermal coupling permit high mass flow and large ΔT in cooldown. Conservative ultrastable "no quench" design, and no SC magnetization, permit large ΔT in operation and either 2-phase or 1-phase He flow.

6. Cost Summary

(k\$)	Arcs	Insertions	Total
Tooling	2,298.4	200.0	2,498.4
Dipoles	12,873.6*	3,510.0	16,383.6
Quadrupoles	2,505.6*	5,691.0	8,196.6
Correcting Magnets	576.0*		
PUEs, etc.	705.6	644.0	1,925.6
Installation & Survey	1,281.6	996.0	2,277.6
EDIA & Supervision	4,395.0	1,758.0	6,153.0
Total	24,635.8	12,799.0	37,434.8

* Includes prorated cryostat cost.

Insertions are straightforward, but expensive (large quadrupoles). Iron dominated narrow quadrupoles (uncoupled) are used near crossings.

7. Future Applications of these Design Concepts

The very large circumference weak focusing SSC is comprised of more than an order of magnitude more magnets with tighter tolerances than any existing accelerator. It is thus obvious that field stability is vital.

It is certainly not clear at this juncture that high B designs are less expensive than simpler, low B designs. The summary which follows supports the Texas low B initiative.

The low B, superferric design has many advantages that result in stability, design simplifications, and low cost:

- No SC magnetization--this provides large dynamic range and makes possible large dynamic aperture. Cos θ designs have sextupole and decapole aberrations at low fields that are strong functions of temperature, varying with time and location.
- Lower volume of SC--a reasonable increase over minimum requirements results in an ultrastable, no-quench design. SC costs dominate high B designs, requiring SC performance breakthrough.
- Very pure stable fields below 2T--dipole and quadrupoles do not require stacking, an important simplification for double magnets. This permits assembly in the tunnel.
- Uncoupled low B design--prevents unwanted aberrations in double magnets.
- No internal correction coils--very long dipoles can be economically broken into sections to insert saturation correction sextupoles, all in the same dewar.
- Time independent, highly precise fields--much easier to achieve with low B. The consequent large dynamic aperture inhibits high intensity beam growth. Many correcting magnets may be used for study and control of orbits, beam tune, coupling and emittance. A "beam transport" technique can be used for testing as the magnets are progressively assembled in the tunnel. Only minimal, room temperature, magnetic measurements are needed beforehand.
- Iron dominated, pure field quadrupoles precisely ($\pm 0.1\text{mm}$) aligned with the pickup electrodes--essential to the elimination of stacking.
- Simpler cryogenics with large He ΔT and no internal quench protection--results in fewer penetrations and reduced risk of cryogenic contamination. Generally simpler components mean less downtime and performance advantages.