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THE PROTON-PROTON COLLIDING BEAM FACILITY ISABELLE[*]

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ABSTRACT

This paper attempts to present the status of the ISABELLE construction project, which has the objective of building a 400 + 400 GeV proton colliding beam facility. The major technical features of the superconducting accelerators with their projected performance are described. Progress made so far, difficulties encountered, and the program until completion in 1986 is briefly reviewed.

INTRODUCTION

About one month ago Brookhaven National Laboratory celebrated the 20th anniversary of the Alternating Gradient Synchrotron. This venerable accelerator has been the instrument by which many significant discoveries were made. In order to continue its role as high energy physics center, studies for a proton-proton colliding beam facility were actively pursued at Brookhaven since the early 1970's. ISABELLE, as this Intersecting Storage Accelerator was baptized, made its debut at the 8th International Conference on High Energy Accelerators here in Geneva in 1971[1]. The story goes that the AGS construction was approved by the US Atomic Energy Commission six days after reception of Brookhaven's letter. This time it took more then six years and the writing of six design studies[2] before the new accelerator was recognized by authorizing Construction Planning & Design funds for Fiscal Year 1976 and 1977. Preliminary design was approved in FY 78 and authorization for construction followed then without further delay in FY 79[3].

From its inception, ISABELLE was intended to serve as a major high energy facility which implied the following design criteria:[4,5]

i) Available Energy - Originally conceived as 200 + 200 GeV storage rings, the energy objectives were increased to 400 + 400 GeV reflecting the expectations of the high-energy physics community as expressed by the 1977 Woods Hole panel. Equally important is ISABELLE's broad operating range covering the energies from injection at 30 GeV to peak field at 400 GeV.

ii) High Interaction Rate - Reaching a high luminosity remains ISABELLE's strongest asset, in particular now that two other higher-energy colliding beam experiments at CERN and FNAL are under construction. The luminosity at ISABELLE is projected to be 2×10^{32} cm^{-2} sec^{-1} in the standard insertions at top energy. At lower energy the luminosity decreases with beam height or the square root of energy. Modifications to the insertion layout should eventually allow luminosities of about 10^{33} cm^{-2} sec^{-1}. These luminosity levels can be achieved with 8 A beams in each ring; the concomitant beam-beam tune shift does not exceed in any case the recommended level of

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

¶) This status report was prepared by the author using materials, occasionally in verbatim form, generated by the ISABELLE project staff.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED about 5 x 10^{-3}. In order to assure long beam life time and low radiation background operation of ISABELLE for colliding beam experiments will use coasting unbunched beams. Even so, the expected interaction rate reaches about 40 MHZ resulting in a total particle production rate at top energy on the order of 1 billion per second at each crossing, clearly a nontrival detection problem.

iii) Experimental Flexibility - In colliding beam experiments the clear distinction machine/experiment disappears. An adequate number as well as an appropriate design of insertions thus becomes of paramount importance. Financial constraints restricted the number of crossing points to six. Each beam crossing will taken place in the center of 60-m magnet-free straight sections.

iv) Superconducting Magnets - Although a topic of considerable debate at the inception of ISABELLE, the use of superconducting magnets has been accepted by now as the best overall solution for highest-energy proton accelerators and storage rings and no further justification is here required. The optimum choice of peak field is, on the other hand, not so obvious. The relative ease with which 40 kG (i.e., the design value of the 200 GeV version) was reached and even exceeded$^{6)}$ suggested that 50 kG would be a responsible design value for the 400 GeV design. The machine size with a circumference of 3834 m, which follows from this choice, fits without difficulty on the Brookhaven site.

v) Expandability - Retaining the option of expanding the scope of ISABELLE by adding more rings, either for protons or electrons, is one of the basic design criteria. Presently under consideration is the possibility of an electron ring of about 12 GeV energy in a separate tunnel.

CONVENTIONAL CONSTRUCTION

The ISABELLE facility is located in the northwest corner of the Brookhaven site (Fig. 1). The complex encompasses an area of approximately 600 acres of which about one-half will be occupied by the main ring, experimental areas, access roads, and utility right-of-ways. The Long Island soil is mostly sand or gravel and conventional cut-and-fill construction techniques are well suited.

The magnet enclosure consists of a multiplate arch approximately 5 m in diameter erected on a continuous reinforced concrete slab. The 3800 meter enclosure is interrupted by the six experimental regions, located at the even clock positions. At the midpoint of each magnet enclosure sextant, there is an emergency exit consisting of an equipment alcove and crossover stairs exiting to the ring road. Approximately 118 meters on either side of the sextant midpoint there is an equipment alcove with an emergency escape ladder. The above three equipment alcoves per sextant, in addition to the areas in the support buildings, provide the necessary space for electronic racks and support equipment. Space for the rf cavities is provided in a special enclosure structure at the 5 o'clock sextant.

The largest and central service facility is the ISABELLE Service Building. This building is located at the 5 o'clock location on the ring and is the center of all machine operations. This structure contains about 50,000 square feet gross area and is divided into three main functions, i.e., cryogenic, main magnet power and rf, and the main control for the accelerator. Physical seperation of the compressor building was necessary in order to keep noise of the helium compressor at a minimum.

The experimental areas consist of a Wide-Angle hall at 6 o'clock, major facilities at 8 o'clock and 10 o'clock, and a Small-Angle hall at 2 o'clock. There are two open areas at 12 o'clock and 4 o'clock which initially will be hard stands without any detailed structures. Design of the experimental regions will take into account specific machine requirements, such as trenches for superconducting transfer lines and the ejection line in the Wide-Angle hall. At each of the experimental locations a support facility will be provided to accommodate those utility systems necessary for the magnet enclosure and hall environments. In addition, a modest size structure will be provided to house experimenter and machine support equipment as required. At each of the locations, an outside yard area is provided for the necessary apparatus (cooling tower, trailers, etc.) required in the experimental program.

The road network is essentially an interior perimeter road which follows a circular layout inside the ring and connects to each experimental area. The road interconnects with main laboratory road systems and has direct access to the AGS. Utility systems generally follow the road layout with all underground services being extended from the present laboratory facilities. Main power will be from an expanded 69 kV substation which presently serves the experimental areas of the AGS; a new 20 MVA transformer will be added.

Radiation shielding above the magnet enclosure is provided by 4 m of sand. The structural capabilities allow future increase to about 6 m. In addition, the sitework includes the provisions for muon shielding which is represented by the regular earthen lobes located around the ring circumference. These lobes vary in width from 15 m to about 100 m at the arc points between experimental areas. The height of the moun shield is about 4 m above beam height.

The architectural design services are being provided by Amman & Whitney from New York City. At present, design of the magnet enclosure, Wide-Angle hall, one open area, Small-Angle hall, and service building are complete. Conventional construction is scheduled to end by April 1983. Progress so far is impressive and no delays are expected.

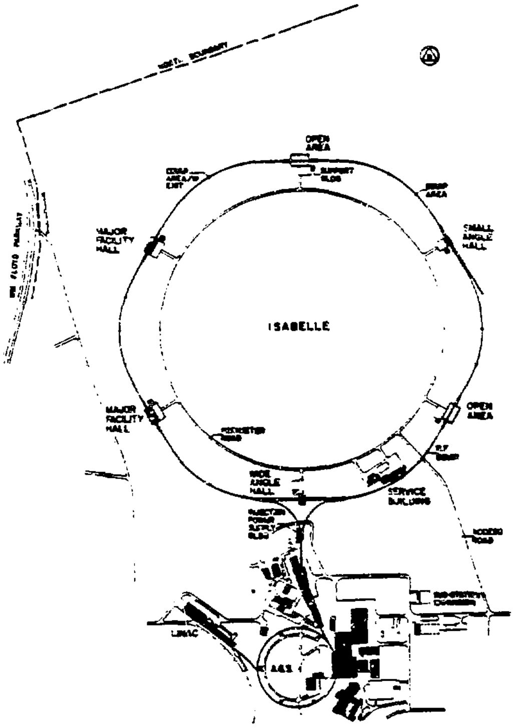

Fig. 1 ISABELLE layout.

GENERAL DESIGN DESCRIPTION

Ring Structure

The configuration of ISABELLE is essentially a hexagon with rounded corners. The machine consists of two identical rings for the accumulation, acceleration, and storage of proton beams. The two rings, identified as blue and yellow, are in the same horizontal plane allowing for intersections at six crossing points where the counter-rotating beams collide with each other. The two rings are magnetically separated to allow operation with unequal energies. Since the rings are to be filled from the AGS using synchronous beam transfer, their circumference was chosen as exactly 4-3/4 times the circumference of the AGS, or 3833.8 m. Almost half of the circumference is contained in the *six* insertions, the rest in the regular arcs. It has become customary to distinguish inner and outer arcs as well as inner and outer half insertions by their clock position. The ring structure has *quasi-six* fold symmetry which is only slightly broken by the inner/outer differences. It is thought prudent to start-up and operate initially with highest symmetry possible as provided by the standard insertions. Highest luminosity however will require non-standard low beta insertions.

The placement of the two rings side by side in a common tunnel is shown in Fig. 2. The circular tunnel structure has a width of 5 m and is 3.4 m high. The tunnel dimensions are tight but adequate as the experience with the First Cell test tunnel demonstrated. Transport of magnets alongside magnets already installed is facilitated by using special rail-guided vehicles. The ring seperation in the regular arcs is 95.2 cm from quadrupole center-to-center. ISABELLE beam level is 1.27 m above floor.

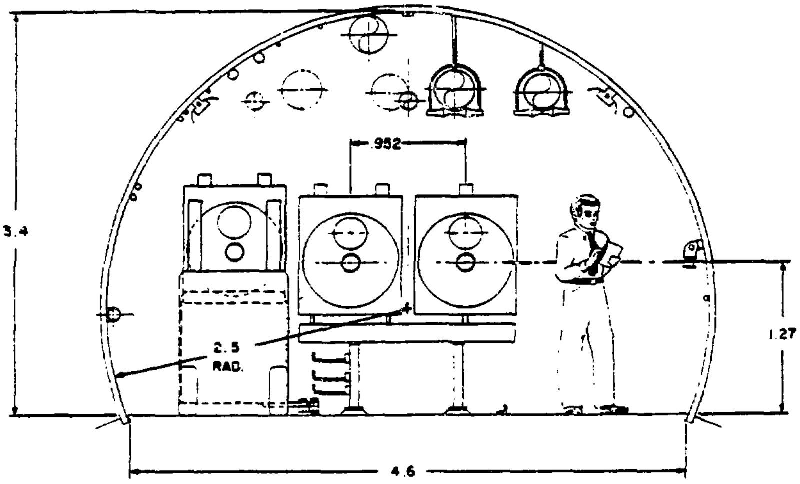

Fig. 2 Tunnel cross section. (Dimensions in m).

The ring configuration and the basic lattice parameters have remained unchanged since the first 400 GeV proposal[7]. The design of the magnetic focussing structure resulted from a compromise between aperture considerations and the desire to inject well above the transition energy[8]. Increasing the orbital frequency slip factor at injection helps to avoid the microwave longitudinal instability since minimizing the longitudinal coupling impedance has a practical lower limit. A further considerations is the fact that the revolution period together with the slip factor set the time scale for the longitudinal motion for the injection and stacking operations. The transition energy is 17.6 GeV resulting in a frequency slip factor of 1.8×10^{-3} at injection with 29.4 GeV. The tune of the machine is nominally 22.6, both in the horizontal and vertical planes. The contribution to the tune from the insertions is 9(i.e.,6x1.5) with the regular arcs providing the rest. Inner and outer arcs are constructed with identical separated function magnets. The resulting small gradient differences are corrected by quadrupole trim coils. Each arc contains 9 mirror symmetric regular cells with a QF/2 BBB QD BBB QF/2 configuration and designed for 90° betatron phase shift. The average cell length is 39.5 m, the effective length of dipoles 4.6 m and of quadrupoles 1.6 m. The average radius of curbature in the arcs is 381 m with the bending radius in the dipoles 267 m.

Experimental Insertions

The insertions determine the luminosity and other characteristics of the beam at the crossing points, the space available for experimental apparatus, and they are the location for beam injection/ejection. The inertions are thus decisive for the usefulness of the machine for physics experiments but at the same time they exert

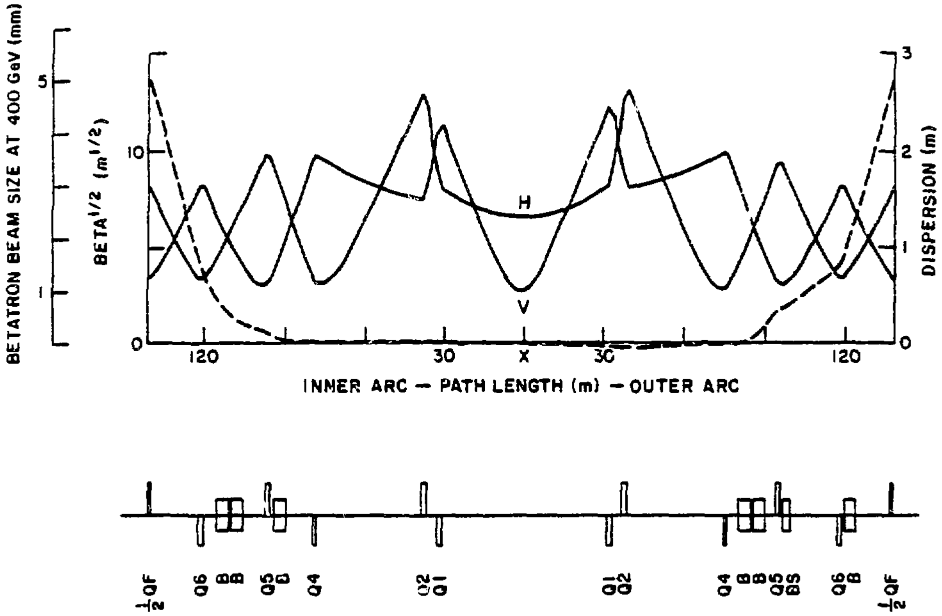

Fig. 3 Structure functions of standard insertion.

a major influence on design and performance of the accelerator itself. Decoupling the two aspects as far as possible is clearly desirable and can be largely achieved by using the concept of matched insertions having a phase advance of 3pi. Further improvements can be derived from 4pi insertions with one cell added at each insertion end and such a solution has been adopted. This concept allows changes in the betatron tune (obtained by adjustments of the phase advances in the regular arcs) or substitution of entire insertions without modifications to the standard insertions. The crossing angle of the standard insertion is fixed at 11.187 mrad and the total insertions length is 283 m. The free space between the nearest quadrupoles available for experimental equipment is 60 m. Each half insertions consists of an 80 m long drift space, interrupted by a longitudinally staggered quadrupole doublet in the middle, followed by three half cells, similar to the cells in the regular arc, arranged to make the crossing areas dispersion free. The structure functions of the standard insertion are shown in Fig. 3. Worth noting are the beta values at the crosssing point of 7.5 m vertically and 43 m horizontally. The beta functions reach conservative peak values of 151 m vertically and 172 m horizontally. The resulting interaction diamond dimensions at top energy are 1 mm height and 26 cm length, based on a normalized emittance of 15×10^{-6} rad.m. The luminosity of the standard insertion is 2×10^{32} cm^2 sec^{-1} at top energy decreasing with the square root of the energy. The associated beam-beam tune shift is 1.5×10^{-3} at top energy but is increasing with the square root of energy. Even at injection, these values are considered safe.

Beam Transfer

The AGS will serve as injector of 30 GeV protons for ISABELLE. The beam will be ejected from the AGS into the existing U-line to the north area by means of a fast bunched-beam extraction system (Fig. 1). The W-beam transfer line transporting the beam to the ISABELLE rings will branch off through an achromatic 2x10° bending section[9]. Within this bend, the beam level is lowered by 1.8 m and is then directed into either of the big-bend X and Y line, each providing almost 90° bending. Together the big bends are roughly equivalent to half of the AGS. All beam transfer magnets are conventional, with the bid bend using combined function magnets. Power consumption is kept to a minimum by limiting the vertical aperture to about 3.5 cm.

The beam transfer layout adopted is more demanding in terms of bending strength than earlier versions but it is advantageous because it completely by-passes the insertion region. A further design aspect is its capability of accepting a ± 1% momentum spread in the 90° bend, thereby opening the option of adding a future stacking ring.

The beam is injected into the outer arcs of ISABELLE utilizing the free spaces between magnets as shown on Fig. 4. The beam approaches the ring horizontally, about 2.5 cm above the median plane, and is brought above the injection orbit by means of a sequence of horizontal deflections, provided by two 3 m long current septa and a 3 m long Lambertson septum. A short vertical trim septum and the vertical fast kicker bring the beam to a vertical landing on the injection orbit near the junction of insertion and regular arc. The septum magnets will be pulsed with a millisecond pulse duration. The fast kicker will have a rise time to full amplitude of 150 nsec to permit successive insertion of five pulse trains from the AGS onto the same orbit. Design of the kicker, conceived as a shutterless device, is most demanding and model work has been started. In addition to the usual electrical requirements, these magnets must satisfy the severe vacuum and coupling impedance requirements.

At peak energy of the protons, about 40 MJ is stored in each beam. Serious damage to vacuum chamber and adjacent magnets could result if control was lost and the beam hits machine components. Therefore, the capability for fast single-turn beam extraction will be provided. Two options for an ejection system have been studied; one of them, the so called Q4 ejection, has been tentatively chosen and serves as basis for hardware development. In this solution the kicker magnets are located in the free space at Q6 and the first thin-septum magnet unit starts downstream of Q4 as shown in Fig. 4. Ejection is vertical with the beam passing about 1 m below the crossing point. The transverse beam dimensions are blown up to 37 cm^2 in a subsequent defocussing quadrupole and the beam is stopped in the beam dump[10)], which initially is conceived as a silicone carbide/sand block, (3+3.5)m x 1.1m x 0.6m. Notwithstanding the presence of the ejection beam tube, this arrangement seems to be superior on most accounts, except that the energy density deposited on the first septum takes it very close to the thermal limit. With a 0.5 microsec risetime of the ejection kicker and a 0.5 mm septum thickness, a beam loss of less than 5×10^{-4} is expected.

A related problem is the energy deposited in superconducting magnets by particles scattered out of the septum magnets. Recent work has generated considerable confidence in the computer programs used to predict the likely energy deposits and it should be possible to design a scraper and collimeter system which prevents quenching of magnets by scattered particles provided that septum losses of about 2.5×10^{11} protons at 400 GeV are not exceeded[11)].

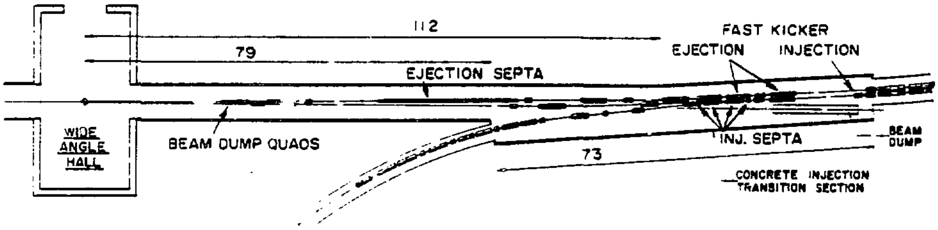

Fig. 4 Injection & ejection component layout. (Dimensions in m).

In support of the ejection system design, an AGS/ISABELLE task force has been making a study of the radiation threshold for quenching of superconducting magnets12). The experiment used 30 GeV protons thus simulating the situation at injection where most uncontrolled losses around the ring may be expected. In general, the results are consistant with enthalpy reserve considerations (few mJ/cm^3 are sufficient to quench a magnet at top field). The tolerable beam flux per magnet was found to be about 10^{11} protons at injection and extrapolation would indicate a value on the order of 10^9 protons at top energy.

Stacking and Acceleration

Filling the ISABELLE rings with 8 A proton current will be performed by stacking in momentum space, the method which is used at the CERN ISR. This solution permits optimizing AGS performance to obtain high stacking efficiency, requires no costly modifications of the AGS, and imposes no additional aperture requirements beyond what is needed for vacuum purposes. Other methods have been investigated, one involving a separate stacking ring13). The other, which would work best with the AGS converted to acceleration on its fundamental frequency, involves damping of coherent motion of injected bunches in the rf buckets of the ISABELLE acceleration system14). The design of the ISABELLE rf system permits retrofitting with either of these current-accumulation systems with minor changes.

In preparation for injection, the peak rf voltage in the AGS is reduced from 300 kV to approximately 65kV in order to match the AGS bunch shape to the buckets of the ISABELLE stacking rf system. The ejected AGS intensity is reduced from the nominal 10^{13} protons/pulse to 2.7×10^{12} to optimize phase space density (normalized transverse emittance 15×10^{-6} rad.m and 1.06 eV.sec longitudinal phase space per bunch). Eleven of the 12 AGS bunches are injected synchronously into waiting matched buckets of the ISABELLE stacking rf system. This procedure will be repeated untill 55 of the 57 buckets present on the injection orbit are filled. The injected beam is then accelerated in energy, slowly debunched, and deposited on the stacking orbit. Nominally 62 stacking cycles requiring a minimum stacking time of 10 min are sufficient to build up the total 8 A of stored beam. The largest aperture requirement, 67 mm at QF, exists during beam injection. One stacking cavity per ring operating at 4.45 MHZ is capable of providing the maximum voltage of 12 kV. However, a second wide band cavity with 1.9 kV capabilities will be provided for a longitudinal feedback system and could also serve for suppressed-bucket operation. To avoid longitudinal instabilities, the coupling impedance will be kept below $Z/n = 10$ Ohm by minimizing discontinuities in the vacuum chamber.

In order to accelerate the beam, it will be adiabatically rebunched by another rf system operating at the third harmonic, f = 235 kHz. The third harmonic was chosen in order to provide the option of bunched beam operation15) and to permit synchronous beam transfer from an optional stacking ring13). The peak rf voltage of 36 kV per ring will be provided by 3 ferrite-loaded cavities. The cavities are driven by 3x165 kW tubes operated as cathode followers to keep the coupling impedance below $Z/n = 16$ ohm per station. Acceleration time is nominally 8 min. At this ramp rate, eddy currents induced in the superconducting braid may result in uncomfortably high field errors and an acceleration over one-half to one hour is being considered. It was shown that fifth-order resonance crossings will not lead to appreciable beam blow up, regardless of the acceleration rate[16)]. The effect of rf noise is still being studied, but it appears to be manegeable.

Vacuum Systems

In the ISABELLE rings, there will be two completely independent vacuum systems[17)]. One, which operates in the low 10^{-11} Torr region provides the required clean environment for the circulating proton beam. The other system maintains an insulating vacuum of better than 10^{-4} Torr in the superconducting magnet vessels, since at this pressure the heat convection becomes negligible. Both vacuum systems for a full cell of magnets (6 dipoles and 2 quadrupoles) have been constructed, assembled, and tested confirming the design assumptions[18)].

The major decision in the design of the UHV beam vacuum consisted in opting for a warm-bore solution. Going this way made available the information on proton storage rings collected at the ISR thereby minimizing the technical difficulties and the required development work. At an earlier time, aluminum vacuum tubes were considered but later on stainless steel tubes were adopted because of their lower secondary electron emission[19)]. Basically, the beam vacuum system consists of a circular chamber with inside diameter of 8.8 cm pumped at 5.5 m intervals by titanium sublimation and ion pumps at 714 stations per ring. This arrangement has demonstrated to produce a hydrogen pressure of better than 3×10^{-11} Torr. Such a vacuum has been estimated to be adequate for operation when one considers beam life time due to nuclear scattering or multiple Coulomb scattering, beam neutralization by electrons from ionized residual gas molecules, and radiation background.

The beam tubes are fabriacted from 304 LN stainless steel with a 1.5 mm wall thickness and a 1 mm plated copper layer. Appropriate surface treatments including Argon glow-discharge cleaning are expected to practically eliminate the pressure bump phenomena (with the ISABELLE geometry allowing desorption coefficients of 4). The installed beam tubes are insulated with 20 layers of crinkled aluminized Kapton and 16 layers of NRC2 superinsulation filling the nominal 1 cm between vacuum tube and cold bore. The measured resulting heat load flowing into the 4 K superconducting magnets is less than 2 W per magnets.

The insulating vacuum is maintained below the 10^{-4} Torr limit by turbo molecular pumps, which should be capable of handling small He leaks as long as these are below the detection level at room temperature. Additional Helium pumping on cryogenic surfaces, to which activated charcoal is bonded, will be provided. The vacuum vessels rely on a completely welded construction with no gaskets and flanges at cryogenic temperatures.

SUPERCONDUCTING MAGNET SYSTEM

Magnets

The magnet system will be superconducting with the lattice structure assuming dipole magnets which are in the regular cells 4.75 m long and operate at 50 kG to achieve 400 GeV beam energy. The regular quadrupoles are 1.65 m in length and will operate with a gradient of 6.14 kG/cm. There will be a total of 732 dipoles (of which 12 are special magnets in the matching sections) and 348 quadrupoles (including 72 for the insertions) in both rings. Dipoles and quadrupoles are connected in series and will operate at a nominal 4 kA. The magnetic field is produced by superconducting braid formed into a single layer coil with an approximate cosine current density distribution (Fig. 5). The braid is made up of 97 twisted composite wires 0.3 mm in diameter, each containing about 500 superconducting Nb Ti filaments of 9 micron diameter. It is filled with an alloy of Sn-3 wt% Ag to give mechanical rigidity and is insulated with an epoxy-impregnated fiber glass tape 0.05 mm thick. The wires in the braid have a 0.01 mm thick Cu-10 wt% Ni jacket to decrease eddy current effects. The short sample critical current of the braid is specified as 4.9 kA at 50 kG and 4.2 K. The coil is shrink-fitted into a cold laminated iron core. The resulting interference fit of about 0.1 mm at helium temperature provides the necessary precompression of the coil.

The decision of adopting a 50 kC design field was at the time based on the performance of magnets in the Mark-series when MK-V exceeded 40 kG on the first quench and reached 50 kG with few training quenches$^{6)}$. The small number of training quenches was considered acceptable and the desirable safety margin was expected to come from lowering the operating temperature below 4 K and from conductor improvements. Construction of an industrial First Cell (6 dipoles + 2 quadrupoles) was initiated in 1978. The results from these magnets can be summarized as follows:

i) The quadrupoles performed as expected reaching the design current after few quenches. In the average the dipole performance was below expectations with first quenches at 37 ± 1.8 kG, reaching 42.4 ± 2.7 kG after training. The highest field of 48.5 kG was measured in one magnet after about 100 quenches.

ii) The static field quality over the good field aperture of 3 cm is acceptable with $dG/G = 2.4 \times 10^{-4}$ rms in the quadrupoles and $dB/B = 3.2 \times 10^{-4}$ rms in the dipoles$^{20,21)}$. Rate dependent effects are substantially above tolerance and, if uncorrectable, would require increasing the acceleration time to about one hour.

iii) Some of the dipoles were unable to absorb their own energy during quenches resulting in coil damage. Corrective measures such as changing spacer material to

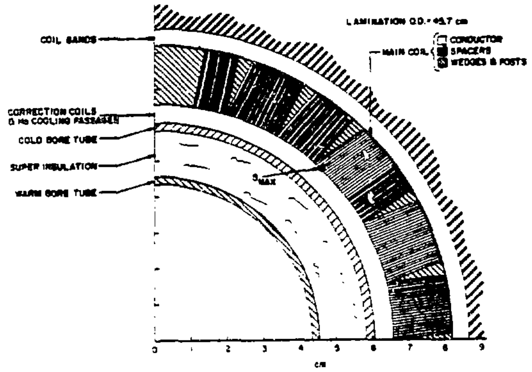

Fig. 5 Dipole coil cross section. (Dimensions in cm).

CuNi (instead of Cu) or improving quench propagation by a different turn sequence (e.g. as shown in Fig. 5) have been subsequently suggested and are under evaluation.

An extensive R&D program has been initiated in the last year to identify the sources of the magnet performance limitations. A detailed discussion of the program is beyond the scope of this paper, but one can say that great progress has been made in understanding the ISABELLE magnets. A series of R&D magnets is under construction to test ideas for improvement. Examples are the use of metal bands to increase coil prestress (and decrease coil motion) or the use of superconducting spacer turns to increase superconductor stability. Present production schedules point to the end of this year as the approximate decision date. Summarizing the magnet situation, one can state that the original 40 kG is completely in hand and no fundamental flaw in the design concept has been uncovered so far which would prevent the dipoles from reaching the full design field.

Refrigeration System

The ISABELLE refrigeration system must function in a variety of situations: normal operation, cooldown, bake-out of vacuum chamber, magnet quenching etc. The systems requirements are set by the normal operating condition with all magnets excited to full field. The design operating temperature for the superconducting magnets is 3.8 K with excursion to 4 K permitted during ramping of magnets. The most cost effective system to obtain this temperature is by means of a single refrigerator utilizing forced circulation of helium at supercritical pressure. The helium leaves the refrigerator at a pressure of 5 atm and a temperature of 2.6 K. The cryogenic distribution system feeds each sextant at its midpoint thereby cooling the 45 magnets of one half sextant in series22).

The estimated steady-state primary heat load at 4 K is 15.5 kW and the secondary heat load at 55 K is 36.8 kW23). Contributions to the primary heat load are made by the superconducting magnets (33%), the magnet power leads (21%), the helium distribution system (34%), and refrigeration requirements of experimental areas. The allowed load per dipole magnet is 4.6 W of which about 2 W is due to the warm bore. Measurements on the Engineering Test Magnet have demonstrated that these design values can be achieved at an insulating vacuum below 10^{-4} Torr. Magnets and transfer lines have heat shields at about 55 K, representing the secondary heat load. No nitrogen is used in the refrigeration system.

The refrigerator, which utilizes the Claude cycle, is designed for a 23.5 kW primary and 55 kW secondary capacity, i.e., a nominal 25 kW total. The magnet coolant is circulated in an essentially closed loop by a 3 kW centrifugal compressor operating at 3.5 K. The main refrigerator removes heat from the circulating coolant in a subcooler heat exchanger and replaces gas diverted for cooling of the power leads. The compressors will be of the oil-lubricated screw type, consuming a total of 16 MW electric power. Two steps of compression are required with 20 parallel units in the first and six in the second stage.

COST AND SCHEDULES

The project received authorization for construction in FY79. The construction time will span seven years following the funding pattern which the US Department of Energy projects for ISABELLE. The total funds released for the project through FY80 is 73 M$. The estimated cost in 79-dollars is 275 M$, of which 177 M$ is for the accelerator systems and 42 M$ for conventional construction with the rest for contingency (24 M$) and escalation (32 M$).

The superconducting magnet system imposes the most severe constraints on schedule planning because of its extended procurement time. The magnet factory at Brookhaven, in which the magnet components are assembled into complete units, has been started in June 1980 with delivery of the first quadrupole coils. Full magnet production rate (about one magnet per day) will be reached by end 1982. All magnets will be completed by April 1985. Another critical item is likely to be the refrigerator, which is expected to be operational in September 1983. Conventional construction is proceeding at an impressive pace. Completion of the main ring tunnel is expected for September 81. All other conventional construction will be completed by April 83.

For planning purposes, a sequence of steps in bringing the accelerator into operation were assumed. The first large-scale system test will involve the cool down of one sextant (January 1984). Beam transfer tests will start in March 1984. Ring installation will be completed in June 1985 and circulating beam in one ring is expected for September 1985. First colliding beams at low luminosities, but perhaps adequate for survey experiments, are scheduled for April 1986 and the project will be complete by July of the same year.

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