STATUS OF THE CALCUTTA SUPERCONDUCTING CYCLOTRON PROJECT

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A superconducting cyclotron with bending limit 520 is being constructed at this Centre. Several major components of the accelerator have been ordered and the fabrication has begun. In house fabrication of several special systems and components is also going on. The problems related to fabrication of certain cryogenic parts of the accelerator have been largely overcome. We are trying, as far as possible, to fabricate the components within the country to generate enough indigenous expertise for efficient development and operation of the cyclotron. It is scheduled to be commissioned in 2002. Progress made on various aspects of the machine will be described in this paper.

1 Introduction

The design of the Calcutta superconducting cyclotron[1] is similar to the machines operating at the National Superconducting Cyclotron Laboratory (NSCL)[2], MSU and Texas A&M University (TAMU)[3], College Station, in USA. The bending and focussing limits are 520 and 160, respectively. Light and medium mass heavy ion beams with energy between 80 MeV/A to ~10 MeV/A are expected to be available (Figure 1). A new building is being constructed for this cyclotron. Two experimental areas for heavy ion research and one for medical applications will be available in the first phase. Provision has been kept in the building and in the beam lines layout to bend the beam by ~180° to transport it for injection into the VEC - the existing K=130 room temperature at the Centre. Status of various systems and components is described in the following sections.

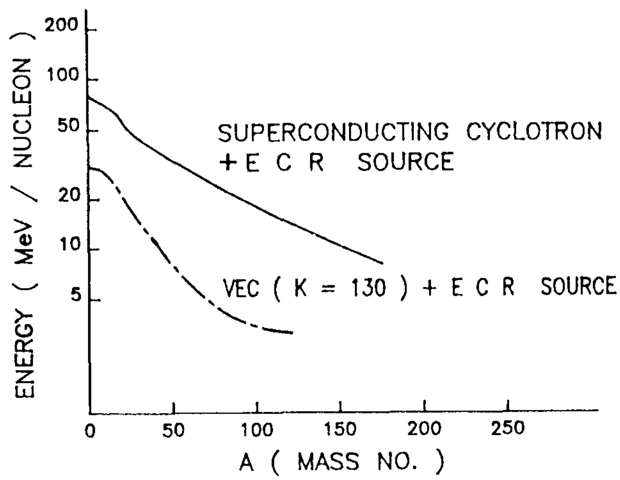

Figure 1: Energy/nucleon vs. mass no. for the heavy ion beam facilities at the VEC Centre.

2 Cyclotron Systems and Components

2.1 Main Magnet Frame

The magnet pole diameter is 142 cm with an extraction radius of 67 cm. Maximum hill and valley fields are expected to be 5.8 T (hill gap: 6.35 cm) and 4.3 T (valley gap: 91.4 cm), respectively, resulting in a maximum average field of 4.9 T. The main magnet frame is a pill box type structure, enclosing the cryostat and superconducting coil assembly. It is made of five major parts i.e. upper and lower pole caps, upper and lower return path rings and centre return path ring. Three pairs of spiral sectors are bolted to the upper and lower pole caps with appropriate fixtures. Maximum allowable carbon content in the forgings is 0.25%. However, variation of carbon percentage between upper and lower pole caps over 0.07% is not allowed. All the forgings will be subjected to stringent ultrasonic tests. Another important issue is the uniformity of magnetic properties over the surface of each pole cap. Samples taken from the pole caps will be subjected to magnetic tests at about 4 T field. Three fold symmetry is of particular importance.

Contract for fabrication of the forgings and complete machining of the 100 tonne magnet frame has been awarded to a public sector company who had earlier fabricated the magnet frame for the VEC. All parts of the frame are expected to be available on site towards the end of 1999.

2.2 Superconducting Coil

The coil is split into two parts, namely, α-coil and β-coil for proper shaping of the magnetic field radial profile. It is wound on a stainless steel (SS) bobbin as shown in figure 2 and will be operated in cryostable mode. In order to provide passage for liquid helium for direct contact with the superconductor in each turn, vertical spacers are used between each two layers of the coil. These spacers are made of fibre glass laminates (NEMA G-10) and are azimuthally distributed at 2° interval. Turn to turn insulation will be provided by using 0.1 mm thick mylar sheets. Glass epoxy spacers are provided between the α and β coils. Winding is done at a tension of 2,000 psi to prevent the conductor movement. Ten layers of aluminium banding will be wound at 20,000 psi around the coil after winding. The bobbin is then welded shut to form the liquid helium can.

A bunch of 500 NbTi filaments, each of 40 μm diameter, in copper matrix, forms the superconductor for the coil. The bunch, overall diameter 1.2 mm, is embedded in a slot along the length on the broader face of copper wire with 2.794 mm x 4.978 mm cross section. Copper to superconductor ratio for each filament is 1.3:1 while its overall value is 20:1.

An elaborate set up to wind the superconducting coil is under fabrication and is expected to be delivered on site by the middle of 1999. The set up incorporates mechanisms for straightening of the conductor, tensioning, cleaning, soldering, ultrasonic checking, dimension checking, insulation application etc.

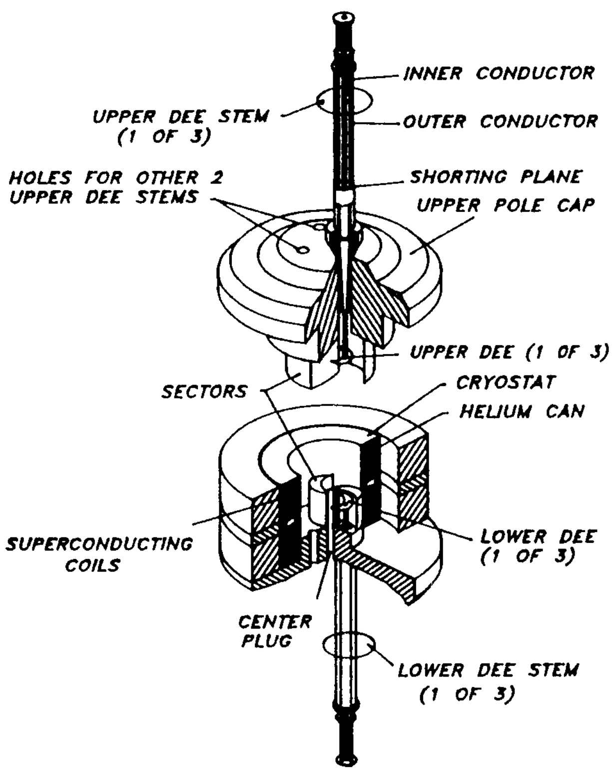

Figure 2: Various systems/components of the superconducting cyclotron - an inside view.

2.3 Cryostat and Cryogenic Transfer Lines

The liquid helium can is one major part of the cryostat. It will be made using special steel, SS 316L, with 12-14% Ni contents for better welding properties. This assembly, including the coil, is wrapped with several layers of super insulation and placed inside an annular space between two magnetic steel vessels. This annular chamber, called the coil tank, is evacuated to a pressure ~2×10^{-5} under normal operating conditions. The inner cylinder encloses the magnet pole piece. The outer cylinder enclosing the liquid helium chamber is in turn enclosed by the magnet frame as shown in the figure 2. In order to minimize outgassing, the coil tank walls facing vacuum are electroless Ni plated. A thin copper cylinder cooled by liquid nitrogen, called radiation shield, is placed between the coil tank walls and the liquid helium chamber. The radiation shield is wrapped with multilayer insulation. This shield along with the super insulation and coil tank vacuum serve to minimize the heat load.

Upper and lower bobbins are interconnected via thick SS plate having vertical penetrations for flow of liquid helium. There are several horizontal penetrations which provide access to drive the deflector components and the diagnostic probes in the acceleration region. Superconducting coil is held in position with the help of nine support links of which six are horizontal and three vertical. These links, made from scotch ply, are fitted with strain gauges for proper alignment of the coil when energized. The cryostat assembly is a very complex part of the cyclotron in view of special welding standards, several interfaces with other components and the need to minimize heat loads on liquid helium chamber. We have discussed with several manufacturers for its fabrication and assembly. It is difficult to make one agree to do this job at a reasonable price. A reliable manufacturer has finally been found.

The network of cryogenic transfer lines delivers liquid helium and liquid nitrogen to the cryostat and the cryopanels in acceleration region of the cyclotron. About 50 meters of delivers liquid helium transfer lines will be required as per our building plan. Both liquid nitrogen jacketed as well as vacuum jacketed lines will be used. In the liquid nitrogen jacketed lines there are four thin walled SS tubes inside a vacuum pipe. Two tubes carry liquid and gaseous helium and the other two carry liquid and gaseous nitrogen. All these four tubes are enclosed by radiation shield at 100K and multilayer insulation. The vacuum jacketed lines comprise of single thin walled SS tube wrapped with multilayer insulation inside a SS vacuum pipe. Since, the cryopanels are installed in lower dees, the cryogens are first transported to the basement below the machine and then pumped up. The pump cryostat, housing both liquid helium and liquid nitrogen pumps, is located in the basement. A special facility is being set up to fabricate the transfer lines at the Centre. Some prototypes have already been fabricated and are under tests.

2.4 Cryogenic Plants

Heat loads for the liquid helium plant include cryopanels (60 W), cryostat/coil assembly (38 W), median plane penetrations (8 W), current leads (6 W) and miscellaneous loads (8 W). A plant with refrigeration capacity over 200 W at 4.5K is being procured. In the liquid helium production mode, it will generate over 70 litres per hour with liquid nitrogen pre-cooling. Two 1000 litre dewars -one each for liquid helium and liquid nitrogen, will be located in the high bay area as buffer storage for the cyclotron.

2.5 Radiofrequency System

Three spiral dees will operate at a maximum of 80 kV dee voltage. Normal operating frequency for the system will range between 9 to 27 MHz. Three $\lambda/2$ resonators are inserted vertically, 120° apart, through the magnet pole caps (figure 2). Each of these ~20 m long resonators consists of two $\lambda/4$ cylindrical cavities tied together at the centre. They are symmetrically placed above and below the median plane. These cavities are short-circuited transmission lines terminated by the upper and lower dee halves. Each cavity has two portions. The portion nearer to a dee half comprises of coaxial inner and outer conductors made of OFHC copper. The outer conductor is cylindrical with uniform diameter while the inner conductor has tapered diameter. This portion extends slightly above and below the respective pole caps. The other portion is made up of hexagonal outer conductor and cylindrical inner conductor. Frequency tuning is carried out with the help of movable sliding short in this portion. Silver graphite buttons attached to Be-Cu contact fingers on the sliding short provide contact between inner and outer conductors.

Eimac 4CW 150,000E tetrode tubes will be used for each of the 3 main amplification stages. A phase difference of 120° is maintained between two successive dees. Two solid state amplifiers, each providing 300 W power output, will drive the main amplifier. Tuning of the amplifiers is carried out by movable sliding shorts similar to those in the resonators. Trimmer capacitor will do the fine tuning. RF energy is coupled to the resonators in the lower half through coupling the capacitor. The resonator assemblies are under fabrication at the Central Workshops of the Bhabha Atomic Research Centre, Mumbai. Prototype cavities will be ready by the end of the 1998 for experimental studies. The electronic part of the system is being fabricated by the RF group at the Centre.

2.6 Trim Coils

There are 13 sets of trim coils wound around the pole tips (sectors). These conventional coils will be fabricated using 6.35 mm square cross section copper conductor with central hole for water cooling. A spare pole tip has been ordered with the company fabricating the magnet frame. It will be used to wind the trim coils at the Centre.

2.7 Injection

Injection will be done externally along the magnet axis through the upper pole cap. A spiral inflector will be used at the cyclotron centre for inflection. We plan to install two 14 GHz ECR sources, both room temperature, in the high bay area. First design of the external injection line has been developed. Magnetic elements will be used on the line.

2.8 Extraction

Two electrostatic deflectors followed by 9 magnetic channels comprise the extraction system. The electrostatic deflectors are placed in two successive hills and are of angular width 55° and 43°, respectively. The electrodes are made of SS 304. The septum material is titanium while the spark anodes are made of tungsten. Magnetic channels are made of low carbon steel and each channel is a triplet of three bars shaped to match the beam orbit. Extraction takes place almost over one full turn. All parts of the extraction system are movable with the help of actuators. In order to compensate for the asymmetry harmonics introduced by the movable magnetic channels, compensating bars have been provided. Prototypes of the magnetic channels have been fabricated for field distribution studies.

2.9 Vacuum System

Figure 3 shows the schematic layout of the vacuum system for the superconducting cyclotron. Normal operating pressure in the cyclotron is about 10^{-7} torr. Pumping is severely conductance limited due to the compact design. Three 75 mm diameter pumping conduits have been provided through the upper pole cap for 3 turbomolecular pumps. These pumps are expected to evacuate the chamber to about 10^{-5} torr in ~4 hours. Three liquid helium cooled cryopanels will then take over the main pumping. These panels are mounted in the lower dee halves and are surrounded by liquid nitrogen baffles. A total of about 4,000 l/s pumping speed will be offered by the cryopanels. Narrow space between the copper RF liner and the untreated pole surfaces will be differentially pumped to maintain cleanliness and level of vacuum obtained by the cryopanels.

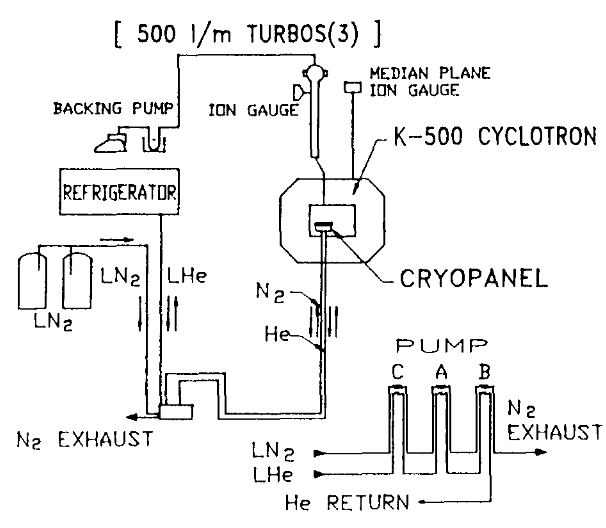

Figure 3: Vacuum system for the superconducting cyclotron.

2.10 Power Supplies

Two independent power supplies, each rated for 20 V, 1000 A (max.) with 10 ppm long term stability, will be used to energize the α and β coils. Up to 22 MJ stored energy is diverted on to a fast dump resistor in case of a quench or a catastrophic situation. The rate of current decay in such a situation is limited to a maximum of 5.3 A/s in order to avoid excessive mechanical stresses on the radiation shield in the cryostat. A slow dump system is used to discharge the current in normal and controlled operation with the current decay rate of 0.241 A/s. Trim coil power supplies, 18 in number, are rated for 30 V, 400 A (max.) with 30 ppm long term stability. A large number of power supplies with similar ratings will be required for the beam line magnets, ECR source and low energy injection line magnets.

Three identical amplifiers of the radiofrequency system use one 20 kV, 22.5 A anode power supply with fast crowbar protection mechanism. Further, 3 each of screen grid, control grid and filament power supplies will also be required to operate this system. Two deflector power supplies are rated for 120 kV, 2 mA operation. Major design and development work has been taken up for all types of power supplies. Several prototypes have also been fabricated and successfully tested.

2.11 Computer Control

At present our planning is to provide high-end graphic workstations as operator consoles. In the front-end/equipment layer of control, several PCs may be connected. The hardware interfaces may be add-on cards for PCs, PLCs and/or microcontrollers in view of their easy availability and in-house experience in their use. Operating system at the operator interface level will be UNIX, while LYNXOS or QNX is preferred for the front-end/equipment layer computers. It is also proposed to build up data bases for different cyclotron systems and parameters for effective on-line development. Several prototype computer control projects have been started at the Centre.

2.12 Beam Lines and Building

Figure 4 shows the layout of the beam lines proposed to be installed. There will be three experimental areas in the first phase. Cave no. 1 will have two beam lines while caves 2 and 3 have one beam line each. Experimental areas' extension is possible through either of the beam lines leading to the cave 1 depending on the building and land constraints.

Use of movable magnetic channels in the extraction system makes the beam exiting from the cyclotron with angular variation of $\pm 3^{\circ}$ in direction and with wide variation in the phase space properties. Therefore, powerful steering magnets need to be placed near the exit point to align the beam. The magnet/s must operate effectively in the high stray field environment. After aligning the beam, four quadruple magnets will be used to match the transverse phase space.

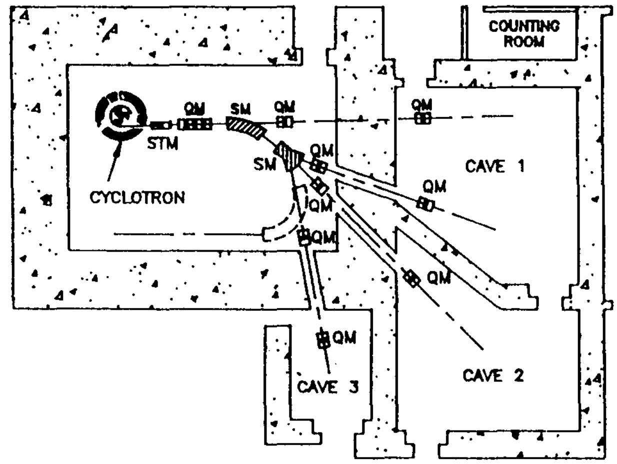

Figure 4: Beam lines layout for the VECC superconducting cyclotron facility

Detailed design of the new building which will house the superconducting cyclotron facility has been completed and the construction will begin shortly. Cyclotron vault is enclosed by 3.5 m thick concrete walls for radiation protection as per new and stricter international regulations. Detailed planning of the air-conditioning and other services has also been completed.

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