K-130 Cyclotron vacuum system

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Abstract. The vacuum system for K-130 cyclotron has been operational since 1977. It consists of two sub-systems, main vacuum system and beam line vacuum system. The main vacuum system is designed to achieve and maintain vacuum of about $1 \times 10^{-6}$ mbar inside the 23 m$^3$ volume of acceleration chamber comprising the Resonator tank and the Dee tank. The beam line vacuum system is required for transporting the extracted beam with minimum loss. These vacuum systems consist of diffusion pumps backed by mechanical pumps like roots and rotary pumps. The large vacuum pumps and valves of the cyclotron vacuum system were operational for more than twenty five years. In recent times, problems of frequent failures and maintenance were occurring due to aging and lack of appropriate spares. Hence, modernisation of the vacuum systems was taken up in order to ensure a stable high voltage for radio frequency system and the extraction system. This is required for efficient acceleration and transportation of high intensity ion beam. The vacuum systems have been upgraded by replacing several pumps, valves, gauges and freon units. The relay based control system for main vacuum system has also been replaced by PLC based state of the art control system. The upgraded control system enables inclusion of additional operational logics and safety interlocks into the system. The paper presents the details of the vacuum system and describes the modifications carried out for improving the performance and reliability of the vacuum system.

1. Introduction
A large room temperature K-130 cyclotron was commissioned at Variable Energy Cyclotron Centre (VECC), Kolkata in 1977. High vacuum is one of the basic requirements for preventing high RF voltage breakdown and loss of charged particles acceleration due to molecular collisions with residual gases. The vacuum system is thus one of the main subsystems of the cyclotron. The vacuum system has been operating since the cyclotron was commissioned. Initially, the cyclotron was used to accelerate light ions, viz., proton, deuteron and alpha particles using internal PIG ion source. Later, after development of an ECR ion source, heavy ions were accelerated during 1997-98. From 2007, the PIG ion source with modified central region was again used to accelerate the light ions for ultimate production of Radio-active Ion Beam. The requirement of high vacuum was stringent for heavy ion acceleration, where beam current were in the order of nano-amperes, compared to light ion acceleration where beam current were in the order of micro-amperes.
2. Vacuum system

The K-130 cyclotron has two major vacuum spaces to serve different functions.

i. A large lumped pumping system for cyclotron chamber (23 m$^3$) i.e. cyclotron vacuum system. The vacuum enclosure of the Cyclotron comprises the stainless steel Dee tank and the Resonator Tank made out of mild steel and copper cladded steel for acceleration.

ii. A distributed pumping system for beam transport line, i.e., beam line vacuum system. The beam lines carry the high energy beams after their extraction from the cyclotron to the designated destinations in the caves for experiments.

2.1 Cyclotron vacuum system

The cyclotron vacuum system [1] is further subdivided into two part i.e. Main vacuum system & Additional vacuum system. Both systems are shown schematically in Figure 1.

2.1.1 Main vacuum system

The main vacuum system has three major components of the high vacuum pumping system namely the 2.5 ton electro-pneumatically operated main gate valve, refrigerated Chevron baffle and fractionating oil diffusion pump having pumping capacity of 42000 l/s each for air. A pair of above three assemblies is suspended from the two large opening in the resonator tank. Chevron baffles over the diffusion pumps are cooled to -60°C with the help of Freon refrigeration units. There are two roots pumps (1000 l/s) and four mechanical pumps (50 l/s) for roughing of entire system as well as backing to diffusion pump. A set of roots and rotary mechanical pumps is used for roughing the entire system from the atmospheric to few microns before 889 mm diffusion pumps are used for high vacuum. Several HV valves and pirani gauges have been installed in fore line to provide maximum flexibility to change the operation sequence of system whenever found necessary.
2.1.2 Additional vacuum system

The addition vacuum system includes a 25 cm oil diffusion pump (2000 l/s) with its associated gate valve and baffle backed by a rotary pump (40 m³/h). This is located on the Dee Tank at extreme end to provide extra pumping close to the accelerating region. This was found necessary as the region where the ion beam circulates is far away from the main pumping ports, in addition, it has several impedances in its pumping path by way of the moveable RF panels and the Dee aperture etc.

2.2 Beam line vacuum system

Most part of the beam line is of cylindrical shaped. The beam transport lines running to 65 meters in length in four different channels are basically made of Aluminium tubes, 100 mm in diameter. Various beam optics and diagnostic elements are mounted on it. There are nineteen pumping units. Pumping units consisting of a combination of 10 cm diffusion pump (280 l/s); rotary pumps (5 m³/h) and gate valve have been installed at short distances apart along the length of the beam line to achieve a uniform vacuum throughout the length. Vacuum in the range of 10⁻⁶ Torr is found to be good enough to keep beam transport loss to a minimum. The locations of all pumping units are shown in Figure 2.

3. Reason for modification

After many years of operation, the cyclotron vacuum system components and its control system started malfunctioning. Moreover due to temperature cycling, a number of cracks were observed in the backing line. The maintenance became impossible especially due to non-availability of spares. This was disturbing the smooth operation of cyclotron. In order to increase the reliability and to achieve stable vacuum in the cyclotron chamber and the beam lines, some modifications were necessary. To reduce the down time, replacement with improved version of vacuum pumps, gate valves, vacuum gauges and PLC based control system were necessitated.

4. Modification scheme

Under the modernization program, the major task was to incorporate suitable modifications to accommodate specially the huge outer casing of 889 mm diffusion pump and similar size of high vacuum gate valve in vacuum system. In addition to these, many other modifications have been done in plumb line for installation of other components. Some of these activities associated with both vacuum systems are mentioned below.
4.1 Cyclotron vacuum system
In the process of improvement in vacuum system, we took a number of steps as given below.
A. The outer casing of one 889 mm diffusion pump has been replaced using the existing jet assembly. This was done because of multiple leaks on pump body.
B. Two new 889 mm high vacuum gate valves have been installed at inlet of main diffusion pumps. The old gate valves were not isolating cyclotron chamber from vacuum system to carry out maintenance in chamber at short notice.
C. Two 250 mm gate valves used at roughing port have also been replaced for proper isolation of system while chamber is at atmosphere.
D. Two 300 mm high vacuum gate valves used at inlet of roots pump were replaced because of severe defect in carriage assembly and recurring leak in old type of limit switch arrangement.
E. All manual gate valves at inlet of rotary pumps have replaced with electro pneumatically operated gate valves to enable the complete remote operation as well as incorporate auto operation of system.
F. One Electro-pneumatic, 25 mm right angle valve at inlet of each rotary pump as bypass valve for high conductance inlet valve to facilitate the controlled pumping especially at high pressure to prevent oil loss through exhaust port.
G. Four 100 mm and three 150 mm gate valves used in backing line have also been replaced to improve isolation to more option in the system operation.
H. One 889 mm chevron baffle has been replaced because of leak in its refrigeration line with a refurbished baffle. This baffle has two refrigeration lines. One line is being used keeping other at redundancy.
I. Temperature Sensor has put in boiler of both diffusion pumps to monitor oil temperature.
J. One pair of Freon units has been upgraded to improve better cooling of one chevron baffle that operate around -60°C regularly.
K. To monitor vacuum level at different locations of systems, several Pirani and Pirani-cold cathode combination gauges have been used in places of old gauges.
L. A residual gas analyzer has been installed to measure the gas composition, interpretation of gas data and for trouble-shooting.
M. The common operator control panel for both systems has been designed ergonomically. Relay based control system has been up-graded to PLC based control [2] of vacuum system. The PLC based system, hooked to LAN, with features like audio-visual alarm for various failures like system interlocks, field component, operational interlock, control hardware, communication etc is implemented to assist in both manual and automatic control of the vacuum system.
N. Many safety features have been incorporated into the systems, both at vacuum level and operation level to prevent operator’s errors such as turning on/off pumps in wrong sequence and opening the valve at the wrong time during process.

4.2 Beam line vacuum system
The following steps were taken to improve the vacuum:
A. Remote operation of all line gate valve located at different location have been implemented.
B. A 10 cm Isolation gate valve i.e. interface valve between Dee tank and beam line is operated from control console and it has been interlocked with pressure of both side.
C. Roughing line has been added in two pumping units i.e. one pumping unit in common line between Dee tank & switching magnet chamber and second unit located at switching magnet chamber.
D. Thermal switches have fitted at each diffusion pump to prevent overheating incase of cooling system failure.
E. A common roughing system for three high intensity beam line has been commissioned using a rotary pump, a main valve and another one valve for each beam line.
F. Remote display of vacuum level through the PC has been implemented even during cyclotron operation. For this several Pirani - Cold cathode combination gauges have been used at least one in between two line gate valves to monitor vacuum level as well as for trouble-shooting.

G. Two 150 mm pumping units for new vacuum chamber for the 159.5° analyzing magnet and three 100 mm pumping for 8 meter long beam line have been installed to facilitate the transport of beam to radio-active ion beam facility. Roughing line has been included in each of these newly installed pumping units to utilize the same rotary pump as backing and roughing pump. Three full range gauges have been used in this new part.

After implementing above changes in respective system, each system was operated separately and vacuum was achieved $\sim 5 \times 10^{-6}$ Torr in the beginning. Helium leak detector was connected for leak testing with fore line of diffusion pump. Cyclotron and beam line were leak tested with $2 \times 10^{-8}$ mbar l/s helium background and no leak was found. Now we are achieving regularly vacuum $\sim 2 \times 10^{-6}$ mbar in cyclotron chamber as well as beam line.

5. Performance after modification

Consequent to this refurbish, the performance of entire vacuum system has remarkably improved. Presently, the vacuum system is functioning smoothly. All interlocks have also been tested. All Vacuum components installed recently including the newly upgraded Freon units are performing well. Baffle temperature is operated at a temperature of about -60°C regularly. Vacuum level of the order of $10^{-6}$ mbar has also been achieved in resonator tank and beam line within reasonable time. The cyclotron chamber pump down curve is shown in Figure 3.

![Fig. 3. Cyclotron Chamber Pump down (With Two Diffusion Pumps)](image)

After implementation of changes in vacuum system and other sub-system, the cyclotron has been operated and beam of good intensity could be accelerated in the cyclotron. The achieved transmission of beam along the radius inside accelerator chamber is shown in Figure-4. Residual gas in the
cyclootron is regularly monitored by using a RGA. Fig. 5 shows a typical bar chart for normal operation of the cyclootron.

Fig. 4. Transmission curve for alpha (40 MeV) and Proton (10.5 MeV) beam

Fig. 5. Partial pressure of different gases during normal cyclootron operation at 4.7 x 10^{-6} Torr

6. Conclusions
New PLC based control system of cyclotron vacuum system has made the systematic operation of vacuum system more reliable. Auto start and shutdown of cyclotron vacuum system has been implemented and working satisfactorily. A PLC control system along with new MMI has been implemented. Online monitoring of vacuum level in different part of vacuum system as well as an accelerator chamber and beam line is helping diagnosis of system failure. The vacuum level in beam line at different locations is monitored through PC. Its vacuum system is operated with relay based control system.
Further improvement in vacuum system is planned by reducing gas loads in the beam line, reducing water leaks in the resonator tank, providing chilled water for cooling diffusion pump. Reduction of power fluctuations and a new PLC based control system for the beam line vacuum will improve the reliability of the vacuum system.

References
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