OPERATIONAL EXPERIENCE AND TESTS OF THE MILAN K800 CYCLOTRON VACUUM SYSTEM

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Abstract

The Milan K800 Superconducting Cyclotron has two main vacuum systems namely the acceleration chamber vacuum system and the cryostat insulation chamber vacuum system.

In this paper we discuss the special refrigerator cooled cryopump based on a Leybold split system developed for the operation into the RF cavities of the Milan Superconducting Cyclotron, together with the operational experience of the cryostat vacuum system.

The vacuum system of the acceleration chamber

Since the K800 vacuum system design is detailed reported elsewhere [1,2] we just recall the main requirements of the accelerator vacuum. The operative pressure in the acceleration chamber has to be in the 10^{-7} mbar range in order to limit to a few per cent the beam losses due to particles collisions with the residual gas. Moreover the operative pressure has to be reached in less then 1 day pumpdown, to let operative the machine for nuclear physics experiments at least the day after the end of a machine servicing.

Very low conductance for external pumping systems is one of the characteristics of compact accelerators. The Milan machine has less then 100 l/s of conductance for external pumping units. So that only an internal pumping system meets the operative vacuum requirements, letting the charge of forepumping the vacuum chamber to external pumps.

A large surface (> 50 m^2) is exposed to vacuum although the accelerating chamber is small (less then 1 m^3). Moreover the vacuum chamber is not a typical UHV environment: many parts can be cleaned only using solvents after their assembling and a backing process is not practical on most accelerator components. Furthermore elastomer sealing has been employed. The total estimated outgassing is about $2.3\cdot10^{-3}$ mbarls^{-1} at 10 hours since the pumpdown start.

A total pumping speed of about 25000 l/s on water vapour and about 2500 l/s on nitrogen and hydrogen together has been estimated to gain the operative pressure. High sorption capacity is also needed to compensate leaks and the hydrogen RF induced desorption.

The acceleration chamber is pumped mainly using split refrigerator cryopumps based on a Leybold split refrigerator system. In fact ,according to our requirements, Leybold has developed a 20 K refrigerator cryopump, compatible to our RF cavity design and able to work in the 5 T accelerator magnetic field [3].

The special refrigerator cryopump

The pump has the cold head with the moving piston assembled inside the dee accelerating structure and immersed in the 5 T magnetic field. On the contrary the motor driven valve assembly operates at 5 meters from the cold head, far enough from the accelerator magnet. Room temperature helium lines connect the two elements of the pump.

As reported elsewhere [1], the major difficulty of such an approach lies in the movement of the pump piston in the magnetic field due to the presence of eddy currents, stresses and power dissipation into the metallic parts of the piston . Computer calculation of the power dissipated in the piston and a 300 hours test inside the Milan AVF Cyclotron show that the split pump can operate in stress conditions worst than those expected inside the Superconducting magnet.

Notwithstanding this, a test of the pump in the real magnetic conditions is foreseen as soon as the first excitation of the Superconducting magnet will be performed.

The final version of the split pump has been extensively tested in our laboratory. A picture of the pump during laboratory tests is shown in fig. 1.

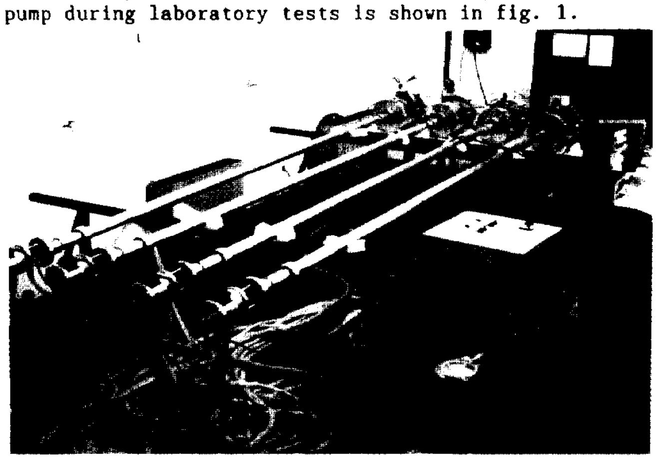

Fig. 1- The split cryopumps during the laboratory tests.

The new pump has doubled both first and second stage refrigerator power with respect to the prototype. So that larger pumping surfaces have been assembled, to increase of about 30 % the pumping speed and the sorption capacity for all gas. Tab. 1 shows the pump and the refrigerator characteristics which have been measured. Pumping speed has been measured at constant pressure ($1\cdot10^{-6}$ mbar) using the inverted burette method. Most of the lost of the cooling power observed in the first split prototype with respect to the standard pump, has been recovered using a gas distributor and a valve assembly with increased efficiency.

Table 1

First stage (80 K) cooling power	=	15.0 W
Second stage (20 K) cooling power	=	2.0 W
Cooldown time	=	80 min.
Second stage lowest temperature	=	11 K
Pumping speed:		
H_2O	=	10000 ls^{-1}
N_2	=	550 ls^{-1}
H_2	=	750 ls^{-1}
He	=	100 ls^{-1}
Sorption capacity:		
N_2	=	250 bar l
H_2	=	2.0 bar l

The cryopump-RF cavity matching

The main improvements with respect to the prototype are not restricted to the cooling characteristics. In fact, from the experience on the prototype, we decided to redesign most of the auxiliary components, in order to have a better matching of the pump with the RF cavity and to increase pump reliability, simplifying the assembling and maintenance procedures. Particularly in the final design the two major parts of the pump (cold head and gas distributor) are mechanically connected together by means of a stainless steel tube (O.D. = 80 mm), having a length of more than 4 m and including the room temperature helium lines. A sketch of the final version of the cryosorption pump cold head is shown in fig. 2.

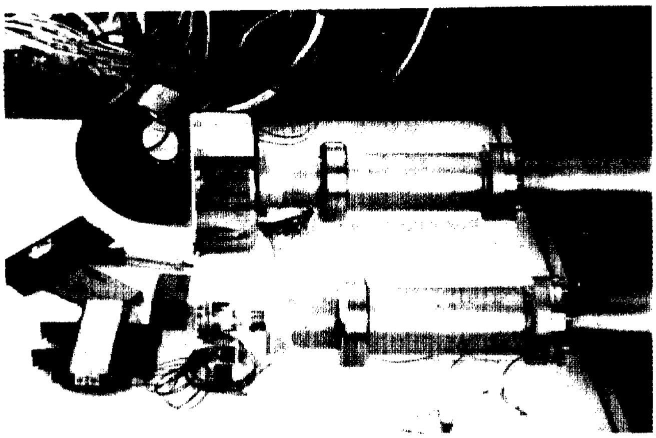

Fig. 2-The cold heads of two pumps: cryoplates, baffles, and the temperature sensors are shown.

The equalization of the symmetrical half RF cavities performed in the final RF design [4], (i.e. upper and lower half cavities are now identical and not just specular) gives the possibility to have a significant freedom in designing the vacuum system. In particular each of the six half cavities has an identical free passage (80 mm I.D.) connecting the external edge to the interior of the accelerating structure (dee). So that we have 6 possible regions to assemble cryopumps or any other useful component for the vacuum system.

In order to obtain the required pumping characteristics [1], the vacuum system design asks for the use of 3 split cryopumps (assembled into the upper half cavities) while the 3 lower free passage are used for turbomolecular pumping. So that turbomolecular pumps operate far from the magnet in order to experience a very low magnetic field [5]. In case of need, one or two of these pumps can be suppressed and the passage used for another cryopump or a liquid nitrogen panel. These two last solutions could be suggested to reduce the pump down time, increasing the water vapour pumping speed, and/or to have a spear cryopump already in place.

Fig. 3 shows a sketch of the final version of the pump assembled inside the dee.

Looking at the pumping cold surfaces assembled inside the dee it is mandatory that no significant temperature rise would be produced by the RF field. So that the 80 K radiation shield has been located 15 mm above the internal dee plane. Moreover computer calculations using an implemented version of SUPERFISH code has been performed on a simplified cylindrical model of the dee structure. Even if the calculations results show that the the RF power dissipated on the radiation shield is negligible, a 5 mm margin in the vertical position of the 80 K parts has been taken, in order to eventually reduce by a factor 2 the RF power heating the pump baffle, increasing the dee structure shielding effect.

Another problem which we had to investigate is that of the mechanical vibrations induced on the accelerating structure by the alternating movement (2 Hz) of the pump piston. Due to the high quality factor of the RF cavity, small mechanical vibrations of the dee, produce phase and amplitude noise on the accelerating voltage, i.e. beam energy spread. Since two high gain electronics feed-back loops are used to stabilize the accelerating voltage, the problem is limited to that of dumping these oscillations down to an amplitude small enough to produce a phase and amplitude noise well inside the feedback loops dynamic range. So that, in order to dump the induced vibrations the only mechanical connection between the pump and the cavity is at the cavity edge (very far from the accelerating electrode), while, at the dee entrance, an elastomer seal is used for centering and vacuum tightness, while spring contacts ensure electrical continuity. Pump reliability has been increased particularly regarding to its assembling and testing. The final pump can be completely tested out of the cyclotron and then assembled into the RF cavity without any helium refilling or refrigerator parts disassembling. This avoids the risk of contamination of the helium circuit with solid and gaseous impurities. When the pump has been fitted into the RF cavity only the connection to the cryoplates and the radiation shield has to be performed. In this way the time needed to operate the change of a pump working inside the accelerator, in a radioactive environment, has been strongly reduced.

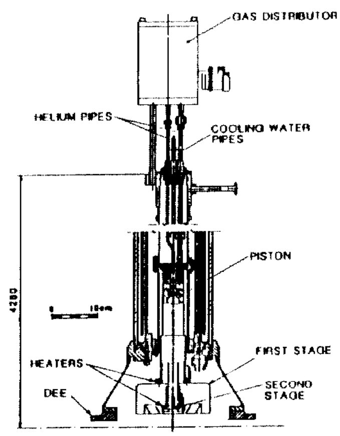

Fig. 3-A sketch of the final version of the pump assembled in the dee.

Moreover all the sealing, between the pump, the RF cavity and the cooling water lines, can be leak checked prior to the assembling of the RF cavity into the cyclotron. Finally, critical sealings have been designed to be easy differentially pumped.

Two compressors (RW5 by Leybold), connected in parallel with safety valves and control devices, supply the helium for the pumps operation. A control system switches on just one or both compressors, depending on the number of operative cryopumps. A maximum of 4 pumps can be operative at the same time. In case of a compressor failure the system is able to guarantee system operation at the price of a little increasing of the temperature of the pumping surfaces. A laboratory test has shown that 3 pumps can operate at less than 14 K with only one compressor.

The cryostat vacuum system

Inside the cryostat of the machine, vacuum provides thermal insulation among the room temperature parts, the LN2 shield and the liquid helium vessel.

The description of the vacuum system is extensively reported in [6], however we discuss the peculiar characteristics of the cryostat vacuum system. One of the peculiar characteristics of the cryostat vacuum chamber is to have large surfaces exposed to vacuum. In fact the reduction of the power incoming the cryostat has been performed employing a multilayer insulation and many parts of the coldest surfaces are covered by 20-40 layers of crinkled single aluminized mylar. The total surface of the multilayer insulation is about 1200 m^2. From first experimental results only the first layer of aluminized mylar has a relevant influence on the pressure in the vacuum chamber. Tab.2 shows the materials and the relatives surfaces directly exposed to vacuum. Literature indicates that for multilayer insulation good performances a pressure of about $1 \cdot 10^{-5}$ mbar is needed outside the insulation [7,8,9].

Table 2

Aluminized mylar	≃	20 m^2
Aluminum tape	≃	20 m^2
Epoxy protective varnish	≃	15 m^2
Nichel plated steel	≃	10 m^2

At these external conditions the interlayer pressure is probably 20 ÷ 100 times greater then in the vacuum chamber [10]. These conditions are generally accepted. Moreover a pressure of $1 \cdot 10^{-5}$ mbar was suitable for our cryostat, according to geometrical and conductance considerations.

Moreover such a large cryostat may have leaks from the helium vessel or from the LN2 shield undetectable at room temperature but relevant when the cryostat is cool. The vacuum system must be able to compensate this amount of gas incoming the vacuum chamber.

When the system operates in this way, a very long operative life is required. In fact maintenance operations or stops of the vacuum system force a warm-up of the cryostat.

Vacuum systems of large superconducting magnet cryostats must have an high degree of reliability due to the high cost of an air inrush in the vacuum chamber. A similar accident in our plant costs the loss of about 1200 liters of liquid helium and the need of a rapid discharging of the magnetic energy stored in the coils (nearly 40 MJ).

The accelerator fringing magnetic field (.5T close to the magnet) lies down severe conditions in the choice of the elements of the vacuum system.

A calculated map of the magnetic field out of the yoke [11] together with the position of vacuum plant elements is shown in figure 4.

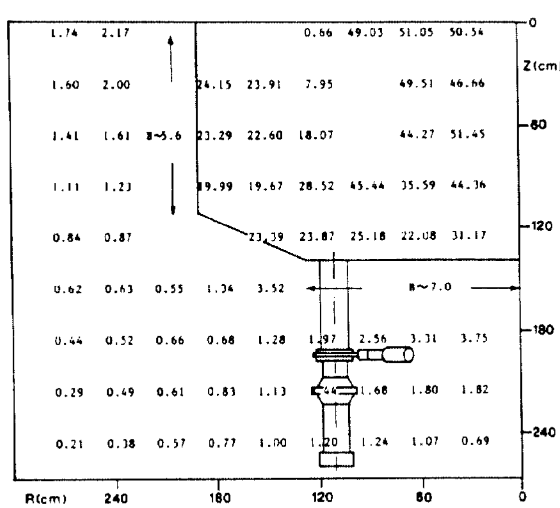

Fig. 4- Calculated map of the magnetic field out of the cyclotron yoke (B in KGauss). The position of vacuum plant elements is shown, too.

The composition of the residual gas after 50 and 1000 hours from the first pumpdown starting is shown in fig. 5, the total pressure being respectively $5 \cdot 10^{-4}$ mbar and $8 \cdot 10^{-6}$ mbar. Today, after about 4 months of continuous operation, the pressure in the chamber is below $5 \cdot 10^{-6}$ mbar.

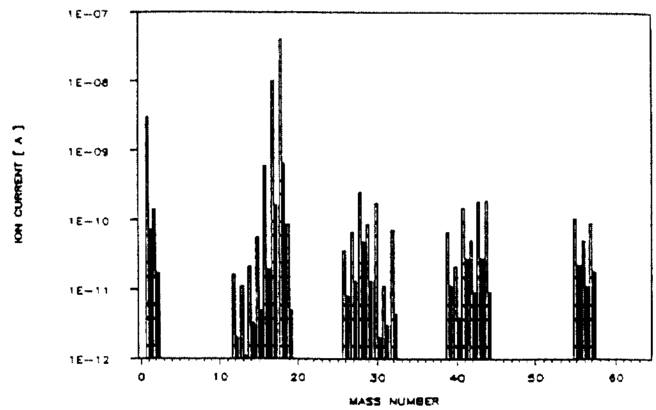

Fig. 5- Residual gas analysis after 50 h (dashed line) and after 1000 h (solid line).

Unfortunately, due to a delay in the scheduled operations, no informations about the thermal conductivity of the multilayer insulation, the cryostat helium consumption and the behavior of the pressure during cryostat cooldown are available.

Vacuum system control architecture

A microprocessor based station controls the vacuum systems of the Superconducting Cyclotron. It coordinates the activities of the major plants exchanges data with the other major components of the accelerator and with the operator console [12]. Close to the equipments, dedicated 8044 microcomputer boards and small PLC are connected on a Bitbus network. Transfer speed of data and commands between a Bitbus card and the master station is of nearly 100 message/s of 25 bytes. Local operation, using a dedicated keyboard, are possible for test and maintenance.

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