OPERATIONAL EXPERIENCE ON THE MILAN SUPERCONDUCTING CYCLOTRON CRYOSTAT VACUUM SYSTEM

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Introduction

The superconducting coils of the Milan K800 Cyclotron had been cooled-down at liquid helium temperature in November 1988[1]. Excitation tests were carried out in December and the maximum current (I = 1950 A) was reached in the first days of January 1989. Maps of the magnetic field at different points in the cyclotron operative diagram were measured from January to March 1989[2]. At the end of March 1989 the coils were warmed up to room temperature to allow the assembly of final parts of the vacuum chamber and to machine magnetic elements as dictated from the analysis of the magnetic map.

Inside the cryostat of the machine, a vacuum provides thermal insulation between the parts at room temperature, the LN_2 shield, and the liquid helium vessel[3]. The pumping system of this insulation chamber had been in continuos operation since January 1988 without any failure.

In this paper we discuss the characteristics of the pumping system of the insulation chamber and the experience gained on its operation under the influence of high magnetic field. Pressure measurements in the vacuum chamber with the cryostat at 4.2 K and during falling and rising of the temperature are discussed too.

General Description

The cryostat vacuum chamber has an hollow cylindrical shape, with an inner diameter of about 1.9 m, an external diameter of 2.6 m and an height of 1.7 m. The vacuum chamber is part of the magnetic circuit of the accelerator and is made of steel.

Designing the pumping system the main constraints have been arisen from the following items:

- large surface of steel exposed to vacuum;
- large extent of thermal insulation materials inside the vacuum chamber;
- influence of the magnetic field on vacuum elements.

To prevent corrosion effects and to reduce outgassing of the steel surfaces it was decided to protect them. Geometrical constraints suggested two different approaches for the inner and the outer shell. The inner one (surface ≃ 10 m^2) had been protected by a .02 mm chemically deposited nickel layer. The external shell (surface ≃ 15 m^2) was painted with a low outgassing epoxy varnish (Schramm 615-07/8130), nickel plating being not practical due to its large diameter.

The major source of heat flux into a cryogenic liquid in a double walled vessel is via radiation through the evacuated space between the inner liquid containing vessel and the outer vacuum enclosure at ambient temperature. To reduce the power entering the cryostat many surfaces were covered with a self adhesive aluminum tape (3M Scotch 425) in order to reduce the surface emissivity (Al tape surface ≃ 20 m^2). Moreover a multilayer insulation (30 layers) was wound around the liquid nitrogen and cryostat external shells (tot. surface ≃ 20 m^2). We wrapped about 600 m^2 of crinkled single-sided aluminized mylar in the multilayer insulation.

The use of such a large quantity of unusual materials forced us to investigate the consequences on vacuum requirements. Outgassing rates of the epoxy varnish (used to protect the cryostat external shell), of the epoxy resin (used to glow electrical wire to low temperature surfaces) and of the aluminum tape had been measured as data were not available in specialized literature. Test pieces were exposed to air for 48 hours before a measurement starts. The aluminum self adhesive tape was stuck on an aluminum plate. Results (reported in fig. 1) show an overall acceptable behavior: the outgassing rate is of the order of 10^{-8} $mbar \cdot l \cdot s^{-1}$ within 300 hours.

Analysis of multilayer insulation properties shows that the thermal conductivity approaches a constant value at pressure below 10^{-5} mbar (measured outside the insulation)[4)5)6)]. This value represents an upper limit for the pressure in the cryostat vacuum chamber.

Leaks are not unusual in such a large vessel and may be very difficult to investigate and eliminate[7]. The vacuum system must be able to compensate the amount of gas entering the vacuum chamber from leaks in the helium vessel or from the liquid nitrogen shield. When the system operates in equilibrium with leaks a very long operative life must be ensured.

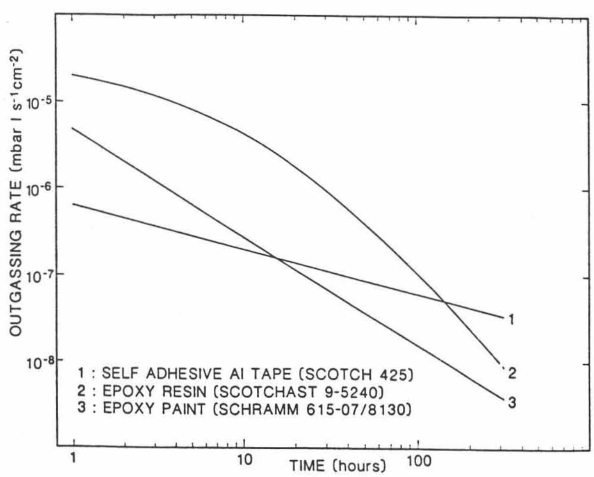

Fig. 1- Outgassing rate of some materials used in the cryostat vacuum chamber.

An high degree of reliability had been requested in vacuum plant operation. The loss of vacuum insulation, due to an air inrush in the insulation chamber, may produce the liquid helium boil-off and the quench of the superconducting coils if they are excited.

Plant Design

In order to fulfill the requirements so far discussed the pumping system had been designed in a redundant fashion with two identical and independent pumping plants, both operative at the same time, each one capable to maintain a pressure lower then $1 \cdot 10^{-5}$ mbar. Each pumping plant is composed of a diffusion pump, an high vacuum gate valve, a LN_2 trap, rotary vane pump and vacuum gauges. The effective pumping speed of each diffusion pump group is about 200 $l \cdot s^{-1}$ (for nitrogen). The chevron baffle is cooled using the cold nitrogen vapor living the cryostat LN_2 shield. Rotary vane pumps (30 $m^3 \cdot h^{-1}$) are located 6 m far from the magnet so to be not influenced by the accelerator magnetic field. No by-pass line is foreseen between the rough pump and the vacuum chamber, roughing being carried out trough the diffusion pump. This choice is due to the few pumpdown operations from atmospheric pressure required by the system. A sketch of the vacuum system is shown in fig. 2.

Figure 3 shows calculated[8] and measured value of magnetic field out of the yoke together with vacuum plant element positions.

Diffusion pumps have been chosen because they are able to operate in the expected magnetic field. Other pumps i.e. turbomolecular pumps can operate only in a few mT magnetic field [9] and therefore they must be more than 5 meters away from the magnet. This distance would reduce the pumping speed of a factor of 5 which is unacceptable for us.

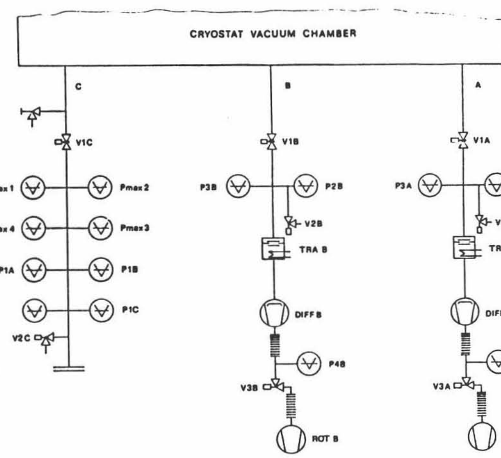

Fig. 2- Layout diagram of the vacuum system.

The filling of both diffusion and rotary vane pumps with the same fluid (perfluoropoliether Fomblin 18-8) ensures a long operative life of the plants, no back-streaming problems and no need of forevacuum traps.

The high vacuum valves are pneumatically actuated gate valves and they had been certified to work in a magnetic field up to .5 T. Solenoid valve (which control high vacuum valves) not operate above .05 T.

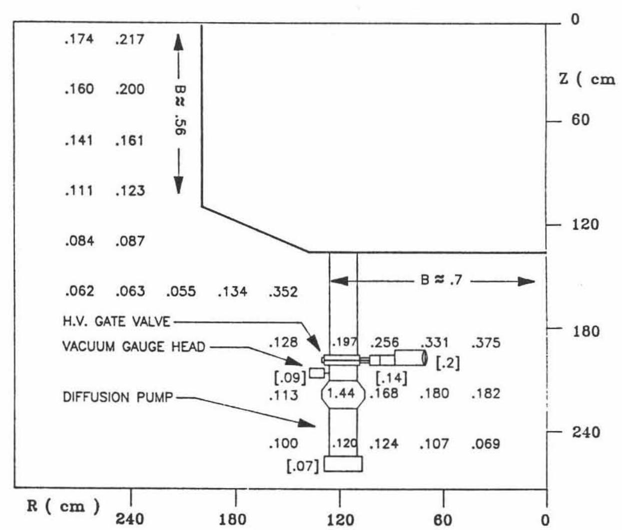

Fig. 3- Calculated and measured (bracketed) value of the magnetic field (in T) out of the yoke. Vacuum element position is shown.

The plant vacuum instrumentation consists of a combined Pirani-Penning system. Tests had shown that magnetic field influences the operation of vacuum gauges. A 0.05 T uniform magnetic field directed perpendicularly to the filament of the Pirani gauge produces a 10 % error of the reading in the range between 1 and 1000 mbar. This is the maximum error that we decided to accept. A shield (made of 3 mm thick iron tube) had been added to the Pirani heads that operate near to the magnet in a 0.15 T magnetic field. Penning gauges are located close to the Pirani gauge and are affected by the magnetic field that reduce the discharge current inside the gauge. The pressure reading is at least 2 order of magnitude lower than the one present in the vacuum chamber. Moreover tests had shown that Penning magnet loss residual magnetic field after few cycle in a .15 T magnetic field. This causes a malfunctioning in the gauge like the one above described. To avoid these problems our Penning gauges have been shielded by means of two coaxial iron tubes (thickness 1 mm).

Control System Description

The doublicated pumping plants require protective interlocks and a careful monitoring of their operations. As soon as a pumping plant fails it must be put into a safe state according to a known switch-off sequence, while the other one must ensure proper vacuum conditions. Faults must be recorded to allow an easy maintenance by the operator. Prearranged sequences for the startup of the plants have been defined to reflect the state of the vacuum chamber. Maintenance operations on elements of the vacuum plants (e.g. damage gauge substitution) must be carried out with extreme care when the cryostat is cool. Manual operations of any element must be consistent with conditions of the plant itself.

To fulfill the requirements so far discussed, a dedicated control unit had been designed.

The architecture of the computer control system for the Superconducting Cyclotron project consists of a set of control stations, each one dedicated to a functional partition of the accelerator and interconnected by an optical Ethernet local area network. The cryostat control unit has been considered as a subsystem of the vacuum control station which supervises its operations.

The main specifications we had to follow in the design of the control unit were to provide an high degree of safety in the functioning of the system. To grant this requirement we had both to reflect the doublicated nature of the vacuum system and to implement a redundancy level. A technical and economical analysis of the possible architectures suggested to use two identical control systems, each one dedicated to a vacuum plant, with a cross check protocol to immediately detect a failure. Such a structure allows to have two autonomous systems tied together by internal diagnostic capabilities.

The choice of the hardware had been bounded by the request to use elements typical of an industrial environment, which must be easily integrated in the architecture of the whole computer control.

Two choices seemed possible[10]: the first one was to implement a custom designed microcontroller based system, the second one to buy a small programmable logic controller (PLC). The requirement of having a program close to a sequence flowchart which can easily be read by a vacuum specialist and, especially, the short time available for implementing the system forced us to prefer a commercial PLC. A Westinghouse model PC-1100 had been chosen as the core element of each system. The PC-1100 contains a microprocessor and line-solver logic which provide the vehicle for program processing. Circuits are programmed into the processor from a reference ladder diagram by means of relay symbology. The PC-1100 and the related series of I/O modules are located in the same standard horizontal rack, as remote I/O are not supported.

Each plant uses 64 digital inputs, 48 digital outputs, 6 analog inputs and 6 power output lines. The overall number of I/O points takes into account those required for local operator interaction and maintenance operations.

Unlike the rest of the vacuum control system no interface devices had been inserted between the vacuum elements and the I/O modules. This choice had been due to the simplicity of the algorithms involved and to the need to reduce fault possibilities.

Control programs fits into 1.1 kwords of memory. To prevent accidentally loss of memory contents, a memory-safe program cartridge had been installed in each PLC. This module consists of EEPROM able to store ladder program and register contents. At power down the dynamic memory contents are stored in the cartridge provided that the ladder checksum and the end of program address in the cartridge agrees with that of the PLC. At power up the memory is up-loaded and then the processor starts to run.

The vacuum control station communicates with the cryostat control units by means of a gateway based on the popular 8044 μc. Data, commands and status informations are converted in the proper format and transmitted (or received) using 3 16-bit registers. We are now testing a new commercial gateway, still based on 8044, which communicates with the PC-1100 by using a custom RS-232 protocol.

Experimental Results and Conclusions

The vacuum system designed for the cryostat insulation chamber had been operative for more than 1 year. Influence of magnetic field on vacuum elements had been tested during the period required for mapping the accelerator magnetic field (≃ 30 days). The behavior of the vacuum elements and of the control system had been satisfactory. Design goals may be considered reached. Fig 4 shows partial pressure recording of some representative gases (water vapor, nitrogen and helium) during the cool-down procedure.

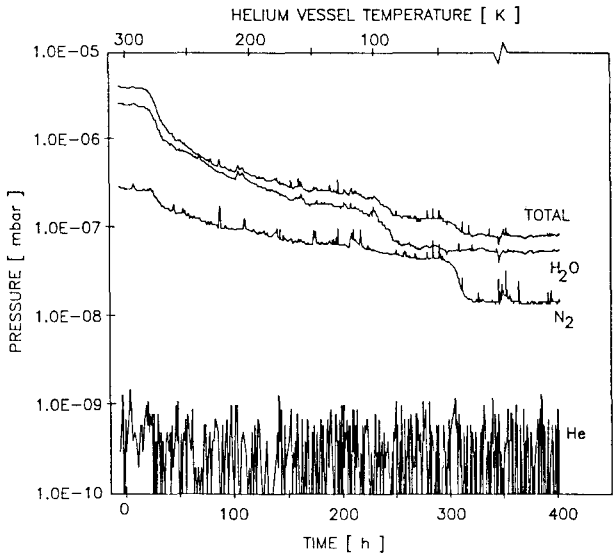

Fig. 4- Total, water vapour, nitrogen and helium pressure behaviours in the cryostat vacuum chamber during the cooldown procedure.

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