STATUS AND UPGRADE OF THE CRYOGENIC PLANT OF THE LNS SUPERCONDUCTING CYCLOTRON AFTER 25 YEARS OF OPERATION*

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Abstract

The Superconducting Cyclotron (CS) is a compact accelerator with three sectors with a wide operating diagram, capable of accelerating heavy ions with values q/A from 0.1 to 0.5 up to energies from 10 to 80 MeV/u. An upgrade of the CS superconducting magnet is in progress to extend the capability of the machine to high intensity beam facilities.

In this paper we describe the status of CS Cryostat and its Cryogenic Plant after 25 years of continuous operations at 4.2 K with the exception of the stop of about one year for the tenth test and the stop for restoring of the liquefier and the main issues happened during that long time. We describe the last complex and demanding procedure for the revamping of the He liquefier, its ancillary parts, other cryogenic parts of the CS, with special attention about the Piping and Instrumentation, gas analysis, Heat Exchangers, LN_2 transfer lines, Human-Machine Interface, vacuum system for thermal isolation, GHe recovery system and the optimization for the consumption of electrical power.

In conclusion we describe some hypothesis about the future upgrade of the Cryogenic system and the new Cryostat of the CS, in special way we analyse an approach to redefine the interconnection, piping boundary line and cryogenic diagnostic.

INTRODUCTION

The solution for the actual cryostat has been evaluated and the final decision was to include the superconducting coils in the helium bath. This solution, in principle, has then determined a macroscopic structural of practically forced cryostat.

DESCRIPTION

Below we will illustrate in detail the structure of the Superconducting Cyclotron and the relative plant. A detailed description of the cryogenic system can be found elsewhere [1].

Cryostat

The total of the actual cryostat is shown in Fig. 1. The entire complex is made of AISI 316L. It has an internal diameter of 1980 mm and an outer diameter a 2720 mm, with a height of 1740 mm for a total weight of approximately 4000 kg. The coils are realized with the system of the "double pancakes", stacked and subsequently and preloaded when in position. The coils inside the helium vessel are fixed to the annular structure (Median Plane).

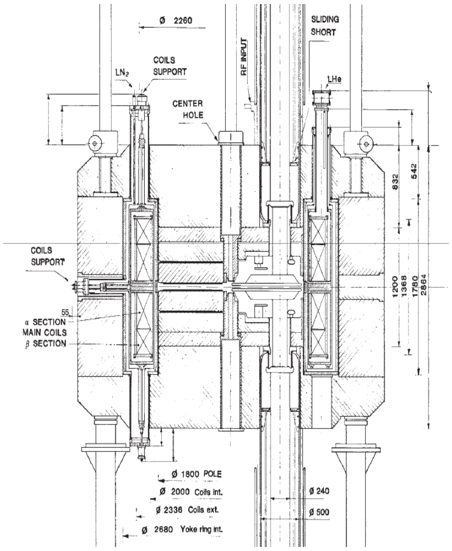

Figure 1: CS scheme.

Under the action of the weight, it is discharged on the inner wall in the case of the lower coil, and the maximum force of repulsion between the coils of 60 tons, the specific voltage stress applied to the tie rods is less than 20 kg/mm^2, and this force of container of helium, the latter with a thickness of 10 mm reduces the tensile stress at only 0.7 kg/mm^2.

The Median Plane has a thickness of 300 mm, corresponding to the separation between the coils. In it, three radial openings with an axial dimension of 200 mm are formed, which allow the passage of the beams and the housing of electrostatic and magnetic deflectors channels. The helium container is suspended from the vacuum chamber by means of vertical tie rods which therefore must withstand the total weight of the container and of the coils and the magnetic forces resulting from any asymmetry of the magnetic field.

An assessment of these forces in the event of a possible inaccuracy of mounting tolerable, up to about 0.5 mm, provides negligible values with respect to the weight of the complex coil-container of helium. The helium vessel has a weight of about 18,000 kg. There are 3 “upper” vertical tie rods made in titanium alloy (6% Al and 4% V) with a diameter of 18 mm immersed in the cold mass. Each of them in theory could support the total force applied to the structure (Fig. 1). Moreover there are 3 lower tie rods with a diameter of 6 mm to block the structure.

As you can see from Fig. 1, the tie rods have the task of supporting the entire structure, while the three lower links keep the coils in a fixed position.

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Plants

The cryogenic circuit is based on a Helial refrigerator delivering 180 W or 53 l/h of LHe at 4.3 K without LN_2 precooling and about 100 l/h with precooling.

PROBLEMS ALONG 25 YEARS

During these years of continuous operations, the plant was stopped by small failures, generally half a day long. The main causes of stop were: power line and water cooling plant failure (about 80%) and failure of the cryogenic plant. Only in June 1994, just during the first acceleration test, there was a serious stop due to a valve failure and consequent entrance of air inside cold box, causing the rupture of the bearings that support the turbines of the liquefier. The problem has been attributed to the plastic cap damage of a pressure reducer. Thanks to the plant supplier that was able to ship two new turbines in a short time, the liquefier was restarted after a 5 days stop, and after 7 day from accident we could supply LHe to the magnet.

In 2006, a warm up was made approximately from June 2006 to February 2007 for the ten years checks required by the law regulation (PED). In the first next cool down one of the insulation vacuum leak was manifested itself almost immediately. This leak had very particular characteristics: the reached stationary vacuum was two orders of size larger than what we had previously (from 10^{-7} bar to 10^{-5} bar). The leak singularity was the fact that over the next 6 months, peaks of 10^{-3} bar occurred for a period of a few hours, and then of course returned to the normal pressure value. These pressure peaks, at intervals approximately weekly, produced obviously the interruption of the CS activities.

To overcome this problem, a campaign of study was done and one of N_2 shields was isolated, because our system provides three independent shields N_2. This leak in the circuit of the insulating vacuum, was create a N_2 accumulation on the 4.2 K wall. When this N_2 accumulation became significantly large, it detached from its seat and it stop, at the 80 K wall, or at room temperature wall, vaporizing and creating the pressure peak.

The solution was found by isolating one at a time every shield and pumping on it with a rotary in the circuit to eliminate all the N_2 current.

These test results indicate a leak in the external shield and the inner shield, but the biggest leak in the second one. Because the independence of each of the N_2 shield circuits, it was possible to isolate the inner shield. This solution is still working and the circuit is currently under vacuum with a rotary pump and so the gap was reported to 10^{-6} bar.

Currently, to overcome these current pressure peaks, a warm-up to 80 K is necessary to clean the 4 K wall from condensed N_2. This 80 K warm up has made two times years.

LIQUEFIER REVAMPING

During these 20 years of operations, the entire liquefier system needed a general maintenance.

The main reasons necessary to the maintenance were:

1. PLC Obsolescence (MECI SYCLOP 1987)
2. Wear of the whole field instruments (valves, solenoid valves, temperature control, etc.)
3. Gas He leaks in the fittings of the refrigeration plant

About the PLC obsolescence, agreed with the liquefier manufacturer, it proceeded with the replacement and installation of a new PLC upgraded model used in those years (SIEMENS S7), in this way the manufacturer guaranteed the technical support.

Regarding the field instrumentation, we decided the total replacement of all components suppliers.

About the gas He leak, we proceeded to the piping complete replacement using the stainless steel fittings only for the two ferrule tube fittings (Fig. 2).

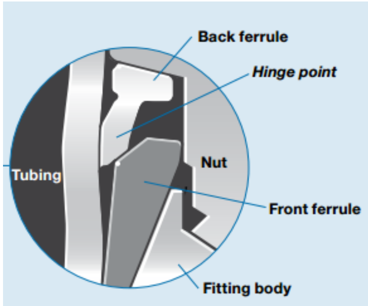

Figure 2: Two ferrule tube fitting system.

CS UPGRADE

The project to upgrade the Superconducting Cyclotron, whose objective is the increase of the intensity of light ions, is based on the application of a method of extraction from the one currently in place. Until now, the limitation on the intensity, of 1012 pps, is due to the current mode of the beam extraction with the aid of two electrostatic deflectors. This limitation can be overcome through the use of extraction by stripping that in the case of ions with mass <40 and for the energies of our interest has a efficiency close to 100%. A feasibility study on the beam dynamics along the extraction trajectories for stripping, confirms that a new extraction channel is needed. The new channel will be in addition to the existing extraction channel used for the extracted beams by means of electrostatic deflection and which will be maintained to allow the extraction of all the ion beams which may continue to be extracted with the current intensity.

The extraction by stripping implementation therefore involves the construction and installation of a new superconducting magnet to replace the current. The feasibility of the superconducting magnet has been established through a conceptual study that included magnetic, structural, thermal analysis and the estimated consumption of helium and liquid nitrogen.

Requirements to the cryogenic system were specified in terms of maximum consumption of the coolants, 20 l/h of helium at 4 K and 18 l/h of LN_2 at 77 K, which (by the enthalpy of vaporization) translates into 14.4 W and 805 W of heat loads at respective stages. The cooling scheme of the magnet is shown in Fig. 3. The upper and lower sets of alpha and beta coils are placed respectively in closed, annular vessels located symmetrically around the median plane of the cyclotron [2].

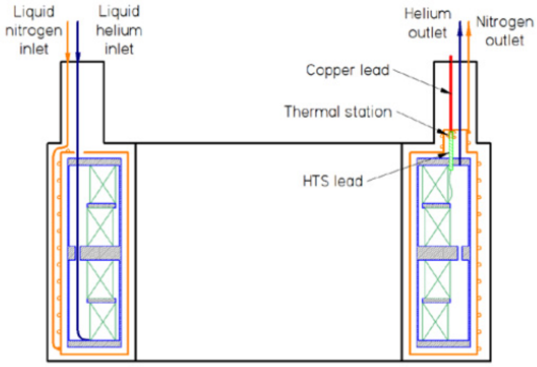

Figure 3: Cooling scheme.

Both sets of alpha and beta coils are cooled by immersion in boiling liquid helium bath at atmospheric pressure. The liquid is introduced by a transfer line directly connected to the magnet vessel, the one below the cyclotron median plane. The cryogen fill and vent lines are directed to a cryogenic plant through one of the three service chimneys at the top of the cryostat. Current leads protruding from the ends of the coils are directed to a set of hermetic feedthroughs mounted to the top plate of the upper magnet vessel, where they connect to high temperature superconductor current leads, which span the gap between the upper magnet vessel and a liquid nitrogen cooled thermal station, where they connect to conduction cooled copper leads which complete the link to room temperature. The instrumentation lead wires similarly exit the magnet vessel through hermetic connectors mounted to the top plate of the upper magnet vessel. The instrumentation wires are similarly heat sink to a LN_2 cooled thermal anchor before continuing out of the cryostat through one of the service chimneys. The cold mass is surrounded by an aluminium radiation shield, which is cooled by a forced flow of boiling liquid nitrogen in the tracers located at both the inner and outer surfaces of the radiation shield. All cold surfaces are covered with Al foil to reduce radiation heat loads. The radiation shield is covered with multilayer insulation (MLI) to reduce a heat flux from the room temperature walls of the solenoid vacuum vessel. Two pairs of 2 kA current leads are considered for both alpha and beta coils circuits bringing the total number of the current leads to four. Each of the leads is comprised of a room temperature (300 K) to intermediate (77 K) temperature optimized copper wire and a high temperature superconductor (HTS) lead between the intermediate temperature intercept and the 4 K end.

Tables 1 and 2 show itemized heat loads at both stages.

Table 1: Heat Load to Liquid Helium

Heat Load Source	Heat Load, W
Radiation from shield, 100% margin	1.0
Convection of residual helium gas	0.3
Conduction along support rods	0.3
Conduction along instrumentation wires	0.25
Heat leak through 4 HTS current leads	1.92
Heat dissipation in 8 x 2 joints	0.32
Nuclear heating	2.0
Total heat load to liquid helium	6.09

Table 2: Heat Load to Liquid Nitrogen

Heat Load Source	Heat Load, W
Radiation through MLI, 100% margin	40
Thermal conduction along support rods	6
Heat load through 4 current leads	340
Total heat load to liquid nitrogen	386

They comprise less than half of the respective liquid helium and liquid nitrogen specs. The remaining margin will be partially used to compensate losses in the transmission lines and in the helium liquefier [3].

The main difference with the current coils is the design of the cold mass. The existing coils consist of a set of wound double pancakes with pretension [1]. This solution is cryostable and it has worked very well. In the new coils design the maximum overall current density is 54 A/mm^2 instead of 35 A/mm^2 in the old design.

To simplify the construction process and to reduce the costs we choose to build the new coils epoxy impregnated (potted) using helium pooled cooling scheme. This choice is supported by the worldwide experience, for the construction of this kind of coil.

CONCLUSION

The current cryogenic plant as reported has shown a remarkable efficiency and reliability in the course of these 25 years, this results in addition to the excellent design are also due to maintenance work carried out by the LNS technical staff. CS Upgrade with a new cryostat and coils will change very little the actual configuration of cryogenic plant.

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