OPERATIONAL EXPERIENCE WITH THE SOLEIL STORAGE RING RF CRYOGENIC PLANT

M. Louvet, H. Dias, M. Diop, P. Marchand,
Synchrotron SOLEIL, L'Orme des Merisiers, Saint-Aubin - BP 48, F-91192 GIF-SUR-YVETTE CEDEX

Abstract

In the Storage Ring (SR) of the Synchrotron SOLEIL light source, two cryomodules (CM's) provide the required power of 575 kW at the nominal energy of 2.75 GeV with the full beam current of 500 mA and all the insertion devices. Each CM contains a pair of 352 MHz superconducting (s-c) cavities (Nb/Cu), cooled in a bath of liquid helium (LHe) at 4.5 K. A single cryogenic system supplies the LHe and liquid nitrogen (LN_2) for the two CM's.

INTRODUCTION

In the SOLEIL SR, four s-c cavities provide to the beam the required voltage of 3-4 MV and power of 575 kW at 352 MHz [1]. They are housed per pair inside two CM's, which are fed with LHe and LN_2 from a single cryogenic plant supplied by Air Liquide (AL). The order was placed in 2004 and the manufacturing took about 18 months. The full cryogenic plant was delivered by mid of 2005 and then it was installed at the SOLEIL site during the second half of 2005. Its commissioning with a single CM started beginning of 2006. The first cool-down of CM1 was successfully achieved in May 2006. Thereafter the SR has been commissioned and then operated for about two years with a single CM, which allowed storing up to 300 mA of beam current [2, 3]. The SR RF system was completed mid of 2008, with the implementation of the second CM, which allowed storing up to 500 mA [4].

CRYOGENIC REQUIREMENTS

Figure 1 shows a scheme of the SOLEIL CM and its cooling circuit. It contains two Nb/Cu cavities enclosed in their He tank; they are connected together with a central tube (Ø 400 mm) and to the ring vacuum chamber with extremity tubes (Ø 260 mm) made of double walls. Each cavity is equipped with an antenna type input power coupler (IPC) and two loop type high order mode (HOM) couplers, located on the central tube, and a mechanical frequency tuner at the other side. The LHe enters the CM through a phase separator and the two cavity reservoirs are filled from the bottom; they are connected together on the top by a common vessel, which recuperates the cold GHe. Part of this cold gas is returned back to the refrigerator while the rest is used to cool the extremity tubes and the external tube of the IPC's by circulating through their double walls. The IPC antenna is cooled by forced air circulation. Part of the LHe is derived from the cavity vessel and circulates through the HOM coupler loops while their bodies are conduction cooled at 4.5 K.

All these components are enclosed inside a LN_2 cooled copper thermal shield with layers of super-insulation, which reduce the radiated heat from the room temperature parts. The LN_2 is also used as thermal shield of the cryogenic transfer lines (CTL's) and in the refrigerator for improving its efficiency.

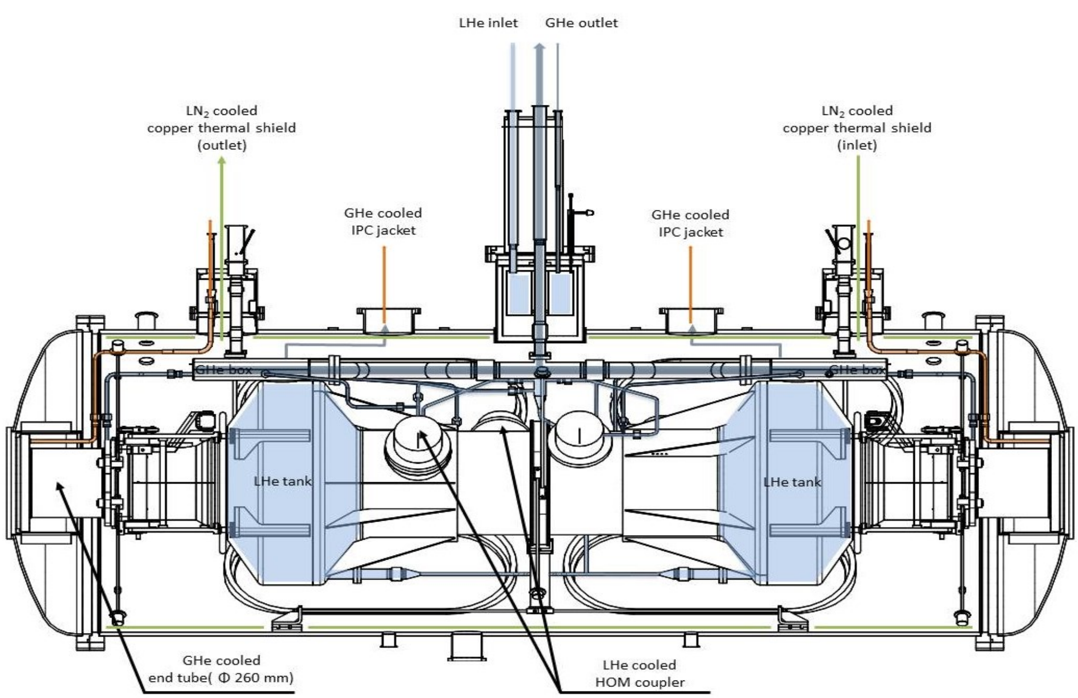

Figure 1: Soleil CM and its cooling circuit.

ISBN 978-3-95450-143-4

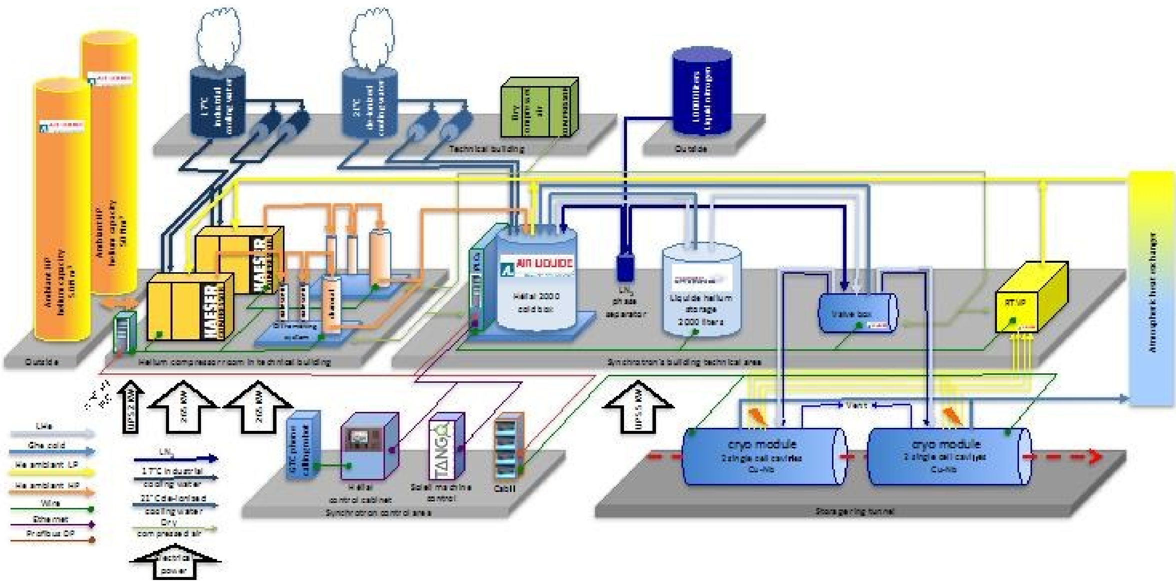

Figure 2: Cryogenic plant layout.

The estimated cryogenic loads for the CM and CTL are summarized in Table 1.

Table 1: Estimated Thermal Losses for one CM

Helium bath capacity	100 l (80% filling)
Losses at 80K	102 W
Static losses	39 W
Dynamic losses	60 W
Thermal transitions	14 l/h
CTL shielded LN2	3 l/h

For budgetary reasons, we chose to use a single cryogenic plant to supply both CM's with LHe and LN_2. Besides, the system was specified in order to provide a very high reliability and enough flexibility for enabling different modes of operation, like for instance, using one CM "at cold" the other one "at warm" (not supplied with He) and heated by the circulating beam.

CRYOGENIC PLANT DESCRIPTION

Figure 2 shows a layout of the cryogenic plant, which is based on the HELIAL 2000 from AL, operated in a mixed mode, liquefier/refrigerator.

Gaseous He (GHe) Compression and Storage

The He compression station, located inside a dedicated room of the utility building, ensures high-pressure (HP) 15 bara pure He production. It comprises two water-cooled and oil-lubricated screw compressors, specific for He, from KAESER; their characteristics are listed in Table 2. They are equipped with SIEMENS frequency drivers (FD's), which allow for smooth starts of the motors, electrical power savings and filtering of the mains fluctuations or short breakdowns. Each of them has its own oil removing system (ORS) from CIRRUS/AL with two coalescent units and charcoal pots, which restitute oil and composed organic volatile (COV) free He.

Two 500-meter GHe transfer lines, high and low pressure (HP and LP), connect the compression station to the rest of the plant. This distance was dictated by the need for proximity with the cooling water production and with the GHe storage as well as for avoiding vibration, noise and thermal nuisance.

Table 2: Compressor Characteristics

Suction pressure	1,05 bara
Exhaust pressure	15 bara
Mass flow rate	80 g/s
Max electrical power	265 kW
Frequency	25 - 50 Hz

The GHe is stored at ambient temperature and under high pressure (15 bara) inside two 50 Nm^3 tanks, located outdoors, nearby the compressor station. They are connected to a controlled valve panel, which is integrated into the ORS rack and manages the GHe expansion.

Figure 3 shows pictures of the compression station and the HP GHe storage.

Liquefaction and Distribution

A picture of the cryogenic area inside the accelerator building is shown in figure 4. The liquefier is a HELIAL 2000 from AL operated in closed loop, which exempts from having a purifier. Its LN_2 pre-cooling stage allows for more efficiency and compactness. The liquefaction cycle is based on a HP GHe main flow, cooled by a secondary flow passing through 2 serial turbo expenders and liquefied through a Joule Thompson (JT) valve.

The produced LHe is stored inside a buffer Dewar of 2000 liters at 1.5 bara, which feeds the CM's at 1.2 bara by natural flow. The LHe from the Dewar as well as the LN_2 from the phase separator are dispatched inside a cold valve box (VB) and fed into each CM through vacuum insulated and LN_2 shielded CTL's.

Figure 3: Compressor station and GHe storage.

The GHe above 17 K and the GN_2 are warmed up through atmospheric exchangers; the former is returned towards the compressor station through the LP line, the latter directly to the exhaust. The ambient gas are managed in the room temperature valve panel (RTVP) using controlled valves, mass flow controllers, pressure transmitters, pumping unit, …

Utilities

The utility requirements are listed in Table 3.

The cryogenic plant is powered from an uninterrupted power supply (UPS) unlike the compressors, which are too high power consumers (2 x 265 kW); they are powered from two different electrical loops, which provide some redundancy and maintenance flexibility.

Figure 4: Cryogenic area inside the accelerator building.

Two times 12 m^3/h of 17°C medium industrial water (MIW) are used to cool the compressors. The oil and He dissipation into the plate of the thermal exchangers is almost 2 x 225 kW.

The liquefier turbine brakes are cooled with 0.4 m^3/h of 21°C de-ionized water (DIW). It is the only cooling water of the cryogenic area inside the accelerator building.

Controlled valves are pneumatic. The consumption of dry compressed air (DCA) is ~ 25 Nm^3/h. The reliability and stability of DCA supply was recently improved by implementing a bank of pressurized N_2 cylinders as backup in case of network drops or shutdowns.

A 10 000 liter LN_2 tank, standing outdoors, feeds a phase separator, from which the LN_2 at 2.2 bara pressure is distributed towards the different parts of the plant.

Table 3: Utilities

$P_{electric}$	2 x 265 kW	3 x 400 V
$P_{electric\ uninterrupted}$	2 kW 5 kW	230 V
Dry Compressed Air	25 Nm^3/h	6 bar
DIW 21°C	0.4 m^3/h	6 bar
MIW 17°C	24 m^3/h 300 kW max	4 bar
Liquid Nitrogen	40 l/h Storage 10000 l	2.2 bara

Control System

A Programmable Logic Controller (PLC) S7-300 from SIEMENS, associated with an auxiliary unit connected via Profibus DP, manages the automated sequences for the liquefier, storage and compressor station. The functional analysis was initially performed by AL.

Another similar PLC, with a functional analysis from SOLEIL, controls the rest of the equipment.

The operator-to-machine interface, housed in the HELIAL control cabinet, is a standard operating panel from SIEMENS.

The local control units are linked to the SOLEIL global supervision system, TANGO, via an Ethernet network, allowing the operator to monitor data, remotely, everywhere on the site.

COMMISSIONING, OPERATION AND UPGRADES

Commissioning

The commissioning of the cryogenic plant started in spring 2006 and it was performed in two steps. At first, the system was tested, using the heater inside the Dewar in order to simulate the CM load. Under these conditions, performances largely beyond the specifications were quickly achieved (Table 4).

Table 4: SOLEIL HELIAL Performance

	Liquefaction mode	Refrigeration mode	Mixed mode
JT set point	13.5 K	12 K	12 K
Liquefaction rate	193 l/h	63 l/h	106 l/h
Refrigeration power	0 W	475 W	350 W
Dewar Pressure	1.3 bara	1.3 bara	1.3 bara

The second step consisted in testing and optimizing the parameters of a CM cool-down sequence. It was rather easy to cool down and maintain the cavities in s-c state, but difficulties were encountered with pressure instabilities inside the cavity helium tank, due to thermal oscillations. After bringing slight modifications in the

ISBN 978-3-95450-143-4

cryogenic valve box, the system has become very reliable and the pressure variations could be kept below ± 1 mbar, namely ± 0.1° in phase. Then the goal of storing up to 300 mA of stable beam, using a single CM, was quickly achieved and thereafter the SR RF system has run very reliably for about two years under these conditions.

The implementation of the second CM (CM2), in 2008, required a complete refitting of the cryogenic plant parameters. The new working point was easily settled but it revealed a wrong helium flow somewhere between the storage Dewar and the CM's. That was solved in readjusting the operating pressures of the buffer Dewar and of the CM's at 1.5 bara and 1.3 bara, respectively.

Operation

Since 2007, the cryogenic system availability has been excellent with 99.7%. It is worthwhile mentioning that a large part of its downtime, 0.2%, is due to a single event, an accidental shutdown of about 100 hours in 2010, caused by the fatal failure of the compressor controller. That event occurred just before a weekend and it turned out that the spare unit was not compatible!

Upgrades

Considering the compressor station as a strategic part for the reliability of the system and for facilitating its maintenance, a second set of compressor and ORS was implemented in 2010. However, it has been operational only since beginning of 2013, after replacement of the original electrical motor, which was malfunctioning. Since then it has run without any trouble.

As mentioned before, the availability of the cryogenic system itself is excellent. Nevertheless, there is still a significant amount of downtime due to utility failures, which induce rather long time for recovering the operational conditions, lowering the availability by about 0.3%. This recovery time has been already reduced from 6 down to 3 hours by optimizing the process of CM refilling with LHe. We still expect gaining another factor two from further optimization and automation of the process, which are being discussed with AL.

On the other hand, we have investigated the ways of improving the autonomy of the system. For this purpose, we planned to double the LHe buffer and HP GHe storage capacities, in 2014. That will allow almost 5 hours of autonomy under nominal operating conditions, with a running compression unit.

CONCLUSION

After an installation and a commissioning without any major issue, the first 7 years of operation with the SOLEIL cryogenic plant have been quite satisfactory. Its performance turned out to be significantly above the specifications, its operational reliability and availability are excellent [5]. The experience feedbacks at full operating conditions indicate ways of upgrading the system for even better reliability and availability.

ACKNOWLEDGMENTS

The authors acknowledge all the members of CEA, Air Liquide Advanced Technologies, Air Liquide France Industrie and SOLEIL, who have contributed to the success of the cryogenic RF system, with particular thanks to P. Brédy for his contribution to the technical specifications and his operational support.

REFERENCES

[1] P. Marchand et al, MOP064, this conference.
[2] P. Marchand et al, PAC 2007, p. 2050.
[3] A. Nadji et al, PAC 2007, p. 3002.
[4] J-M. Filhol et al, IPAC 2010, p. 2493.
[5] A. Nadji et al, IPAC 2013, p. 73.