Cryogenic System for Shanghai Synchrotron Radiation Facility

Anne Barbier 1, Jieping Xu2, Jian Cui 2, Annelise Machefel 1, Christophe Mantileri 1, Michel Maccagnan 1, Edouard Rogez 1, Mathieu Roig 1
1Air Liquide Advanced Technologies, Sassenage, 38360, France
2Shanghai Advanced Research Institute, Chinese Academy of Sciences, Pudong, Shanghai 201204, China

Abstract. The Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy light source built at Zhang-Jiang Hi-Tech Park in Shanghai, China. The RF power and voltage required for storing the electron beam are provided by means of three SC (superconducting) cryomodules, each containing one 500 MHz superconducting cavity. A cryogenic plant with cooling capacity of 650 W at 4,5 K (herein called SSRF-I cryoplant) supplied by Air Liquide advanced Technologies has been in operation since August of 2008 to provide cooling for the three superconducting cavities.

In order to further improve the performance of SSRF, the following SC devices are to be applied for the SSRF upgrade (SSRF-II):

1) 2 harmonic SRF (superconducting radio frequency) cavities with 1,5 GHz will run alternatively at 2 K (31 mbar).
2) One superconducting wiggler is to be used for one of the new-built beam lines, ultra-hard multi-functional beam line. The SC wiggler will be cooled by cryocoolers at 4,2 K region.

To support the operation of the new cavities, AL-aT (Air Liquide advanced Technologies) has designed, manufactured and started a new cryogenic system including a 2K system with equivalent cooling capacity of at least 650 W at 4,5 K and 60 W at 2K. The system is mainly constituted of a refrigerator HELIAL MF, an auxiliary 2 K cold box and of a 2 K warm pumping station.

This cryogenic unit has been started successfully at the end of 2018 and has proven performances both at 4,5K and at 2K.

1. Project description

The Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy light source built at Zhang-Jiang Hi-Tech Park in Shanghai, China. The SSRF consists of a 432 m circumference storage ring with operating energy of 3.5 GeV and minimum emittance of 2.9 nm-rad, a full energy booster, a 150 MeV electron Linac as well as dozens of beam lines and experimental stations. The RF power and voltage required for storing the electron beam are provided by means of three superconducting cryo-modules, each containing one 500 MHz cavity. The cavities, made of Niobium, are bath-cooled with saturated liquid helium at 4,5 K. A cryogenic plant with cooling capacity of 650 W at 4,5 K (SSRF-I cryo-plant) has been designed and manufactured by Air Liquid advanced Technologies and is in operation since August of 2008 to provide cooling for the three superconducting cavities.
In order to further improve the performance of Shanghai Synchrotron Radiation Facility (SSRF), the following devices are to be applied for the SSRF upgrade (SSRF-2):

1) two harmonic SRF cavities with 1.5 GHz will run alternatively at 2 K (31 mbar).
2) One superconducting wiggler is to be used for one of the new-built beam lines, ultra-hard multi-functional beam line. The wiggler will be cooled by cryo-coolers at 4.2 K region.

For the purpose of supporting operation of the above superconducting devices, a new cryogenic system (called SSRF-2 cryo-plant) with equivalent cooling capacity of at least 650 W at 4.5 K (including at least 60 W at 2 K) has been designed, fabricated and tested by Air Liquid advanced Technologies.

Additionally, the new cryo-plant can be used as the back-up of current 650 W refrigeration system at 4.5 K to support normal operation of the online three 500 MHz SRF cavities in case of any failure occurred to the current 4.5 K cryo-plant.

2. Cryoplant description

2.1 Technical specification and requirements

The new cryo-plant has to be designed for the following needs:

1) support operation of the 3rd-harmonic cavity at 2 K for long-term stable operation (~8000 hours / year)
2) serve as the back-up of the currently running SSRF-1 cryogenic system in case of any failure, to support the long-term stable operation of three 500 MHz single-cell SRF cavities at 4.5 K in order to ensure the normal operation of the SSRF, which provides the users with light source for experiments. Meantime, the 3rd-harmonic 1.5 GHz cavity must be kept cold at 4.5 K.

For normal operation mode the new SSRF-2 cryoplant will keep the 3rd-harmonic SRF cavity operating at 2 K. The SSRF-1 cryo-plant will support the three 500 MHz SRF cavities running at 4.5 K.

While the SSRF-1 cryo-plant is under maintenance or repair if mal-functioned, the new SSRF-2 cryo-plant will support the three 500 MHz SRF cavities running at 4.5 K and keep one 1.5 GHz SRF cavity at 4.5 K simultaneously.

In the same way, SSRF-1 cryo-plant will be used as a back-up in case of maintenance of SSRF-2 cryo-plant.

A switch valve box is required to switch automatically from SSRF-1 to SSRF-2.

The required performances for these operating modes are as followed:

- Minimum of 650 W / 4.5 K refrigeration with liquid nitrogen pre-cooling for refrigeration mode
- Minimum of 60 W / 2 K refrigeration
2.2 **Air Liquide advanced Technologies technical solution**

To fulfill the above specifications, Air Liquide advanced Technologies has designed and manufactured the following subsystems:

- One 4,5 K refrigerator including He compressor, oil removal system, gas management panel, 4,5 K cold box, on-line gas analyzer and control system
- One 3000 liters LHe dewar
- One auxiliary cold box including:
  - One phase separator, heat exchanger and Joule-Thomson valve to supply He at 2 K 31 mbar to SRF 1,5 GHz cavities
  - Automatic valves to switch from SSRF-1 to SSRF-2
- Process Vacuum Pump System (PVPS)
- Cryogenic lines interconnecting 4,5 K cold box, LHe dewar, auxiliary cold box
- One helium guard system to prevent air ingress into the circuits which are under atmospheric pressure
- One on-line analyser for nitrogen, water and hydrocarbons impurities measurements
- Control system

This new cryo-plant is interconnected with the old one so that each plant can be a spare for the other one in the degraded mode of operation defined above: one cavity 1,5 MHz and SSRF-1 cavities operating at 4,5K.

2.2.1 **4,5 K refrigerator**

![Figure 1: HELIAL MF cold box](image)

The cooling power required at 4,5 K is in the range of Air Liquide advanced Technologies HELIAL standard refrigerators.

HELIAL refrigerators can provide cooling power from 100 to 1000 W @4,5 K. The selected cryo-plant is an HELIAL MF using a KAESER ESD445 SFC as a recycle compressor.
The existing compressor Kaeser ESD441 previously used for SSRF-1 cryo-plant has been connected upstream of the oil removal system of the new refrigerator to be used as a spare compressor for SSRF2 cryoplant during the maintenance of the ESD 445 SFC.

A small compressor KAESER ASD57 was previously connected to the low pressure line of the SSRF-1 cryo-plant to recover the helium in case of cryo-plant shut down. This compressor has been connected also to the low pressure line of SSRF-2, it can be used either by one or the other cryo-plant, switch will be operated manually but position of valves is controlled by limit switch to avoid wrong operations.

2.2.2 Auxiliary cold box

The interconnections of the 2 cold boxes and the cavities are performed through the auxiliary cold box, which also includes a phase separator and the 2 K heat exchanger.

![SSRF overview of main equipment and interconnections through Auxiliary Cold Box (ACB)](image)

**Figure 2:** SSRF overview of main equipment and interconnections through Auxiliary Cold Box (ACB)

To operate at 2 K, the liquid helium bath in the operating 1,5 GHz cavity is pumped at 31 mbara by the process vacuum pumps system. LHe at 4,5 K 1,3 bara flows from the phase separator of the ACB through the heat exchanger and is expanded through a Joule-Thomson valve to the operating 1,5 GHz cavity. The He vapors pumped in the cavity flow through the heat exchanger.
in counter current and are sent back to the cycle compressor suction by the process vacuum pump system. This heat exchanger and the associated valves are included in the auxiliary cold box.

The design of the auxiliary cold box has also to take into account that each cryo-plant is a back-up for the other one in case of unexpected stop. This requirement means that it is necessary to have a common phase separator which can be filled by the two dewars alternatively or simultaneously.

In normal operation, which means one cavity 1,5 GHz operating at 2K and the three 500 MHz cavities operating at 4,5 K, the 2 dewars (SSRF-1 and SSRF-2) are connected to the common phase separator. Level in the separator and repartition of cold return to the two cold boxes will be automatically controlled. In case of trip of one cryo-plant, the selected cavity 1,5 GHz will operate at 4,5 K as well as the SSRF-1 cavities. In that mode, the ACB heat exchanger is bypassed.

Cool down of the phase separator can be performed by one dewar alone or by the two dewars on the same time.

![Auxiliary cold box](image)

**Figure 3:** Auxiliary cold box

### 2.2.3 Process vacuum pump system

The PVPS (process vacuum pump system) is constituted of 4 parallel trains of (roots blower / rotary vane pump assembly). Three pumps are used in normal operation and one pump is used as a hot spare (ready to start).

The upstream pressure of the PVPS can be controlled very precisely by a small by-pass valve and by variable speed control of the roots blowers.

The pumps have been designed for a flow of 3,6 g/s at 25 mbar.
2.2.4 PLC architecture

Process control to interconnect all the equipment was a major part of the project. The architecture chosen is as followed:

- One PLC is dedicated to the control of all the compressors,
- One PLC (existing one) to the control of the cold box 1
- One to the control of the cold box 2 and the auxiliary cold box
- One to the control of the process vacuum pump system.

2.2.5 Project schedule

Design and manufacturing of the plant started at the beginning of year 2017 and it was delivered in May 2018.

The interconnecting lines and erection were in SSRF scope as well as the electrical cabling. AL-aT performed erection supervision: one mechanical specialist, one electrical specialist and one commissioning manager were on site at different states of the erection. Due to this strong cooperation, first step was successfully performed during summer 2018 with the installation of the new cold box, cycle compressor, oil removal system, auxiliary cold box and PVPS and the inter-connection of these subsystems. Connections to the customer cavity and modification of the connection of cryo-plant SSRF-1 were performed in a second step during the first half of 2019.

Commissioning and performance tests of the new cryo-plant were performed at the end of year 2018.

3. Tests and performances

The two main operating modes have been tested at the end of year 2018 to validate the performances and the operation at 2 K.

The cooling power at 4.5 K was tested classically by using a heater installed inside the dewar and maintaining constant level. The guaranteed cooling power of 650 W was reached by the refrigerator with good stability during three days.
Performance tests at 2 K have been performed by injecting 60 W in the test phase separator of the auxiliary cold box which was pumped at 31 mbar. LHe level in the dewar was kept constant during the test, proving the cooling power at 2 K.

Figure 5: SSRF-2 performance test at 4.5 K

Figure 6: ACB view during performance test à 2 K
4. Conclusion
The new SSRF-2 cryo-plant was designed, manufactured and installed in eighteen months, thanks to a strong and efficient cooperation between SSRF and AL-aT.

The two performances tests corresponding to the main operating modes of SSRF-2 cryo-plant have been validated at the end of year 2018.

The 1,5 GHz cavities and the SSRF-1 cryo-plant are now connected to the auxiliary cold box. The final tests foreseen during summer 2019 will allow to validate the operation with the new cavities and the interconnection of the two cryo-plants through the auxiliary cold box.

Figure 7: SSRF-2 performance test à 2 K