

TEST OF THE SOLEIL SUPERCONDUCTING CAVITY PROTOTYPE ON THE ESRF RING

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Abstract

A cryo-module prototype housing two superconducting 352MHz-cavities was developed within the framework of the SOLEIL project design study phase. It is currently installed on the ESRF storage ring until the end of year 2002, in order to qualify the HOM-free operation. It will be tested with beam in the accelerating regime at 4.5K with the cavities cooled by liquid helium poured from Dewars. Four testing periods are programmed over the year, at the end of ESRF scheduled shutdowns. In order not to disturb the ESRF machine performances during the Users mode of operation, the cavities are maintained detuned at room temperature in a passive regime. The heat generated by the beam is then evacuated by a helium gas flow cooled by a heat exchanger. The main results of these tests as well as the possible improvements are described in this paper.

1 INTRODUCTION

In June 1996, a collaboration between CEA, CNRS, CERN and ESRF was launched to develop, build and test a strongly HOM damped SC cavity for the SOLEIL project [1]. The frequency of 352.2 MHz was chosen in order to benefit from possible CERN technology transfer, including the coupler design, and to open the design to a possible future implementation at the ESRF. The prototype was tested successfully at CERN in December 1999 with up to 7 MV/m of accelerating gradient [2].

It was now important to perform the next step in the development of this advanced HOM free cavity for light sources. In January 2000 it was thus decided to install it on the ESRF storage ring for one year in order to validate the design with beam at high intensity.

As reported in [2], several smaller technical problems were identified at CERN. The preparation of the ESRF tests necessitated some modifications, the completion of some missing components and further tests at CERN. The SOLEIL module was finally installed on the ESRF ring in December 2001.

For the limited test period, it was decided to feed the cryostat with liquid helium from Dewars. Tests with the cavity at 4 K are being carried out following the four shutdowns of March, May, August and October 2002. After one week of pre-cooling with cold helium gas, the first machine restart days are dedicated to the tests at 4 K. The cavity is then warmed up, kept on the ring at 300 K and cooled with warm helium gas for normal user operation, its resonance being thermally shifted off beam harmonics. The successful operation at 300 K with high beam

intensity, not initially foreseen in the cavity design, constitutes a major achievement. It opens the possibility of increasing the availability of SC RF systems if the ring can be operated with a reduced number of modules.

Also the cooling with LHe from Dewars has been a success: during the first two series of tests, the cavity has been kept stable at 4 K for about 17 hours. With the resonance de-tuned from the main RF frequency, 200 mA could then be stored without any problem. The SOLEIL cavity has also already accelerated beam at the last tests. During the remaining two test series, the cavity will be further conditioned and used to accelerate higher intensities. The tests will end in December 2002, as the space is required for a new beam line under construction.

2 THE SC STRONGLY HOM DAMPED SOLEIL CAVITY

The main design aspects that have been optimised for a reliable HOM free operation on high intensity rings are recalled [1,2]:

- On the 400 mm diameter beam tube, which connects two cells in a single cryostat, the HOM are effectively coupled with conventional couplers, which extract the power from the structure. As no ferrite absorbers are needed in the beam tubes, possible vacuum contamination is avoided.
- The open structure exhibits an excellent conductance for a very efficient vacuum pumping directly on the main tapers at each side.
- A high reliability is thus expected, which is essential for light sources. As an example, the ESRF provides beam with more than 96 % reliability and a total MTBF better than 40 hours [3].
- The CERN technology using Nb coated copper cells has been adopted for the SOLEIL cavity. It is the first application to a cavity designed for high beam current. Validating this choice constitutes another important issue for the beam tests at the ESRF.

3 INSTALLATION ON THE ESRF RING

3.1 Cooling System

Fig. 1 gives a schematic view of the cooling system that has been implemented at the ESRF for these tests.

For the operation at 300 K, the heat deposited in the accelerating structure is evacuated by means of helium gas (GHe). About 15 m³/h are pumped through the cryogenic lines to the cryostat and are re-circulated.

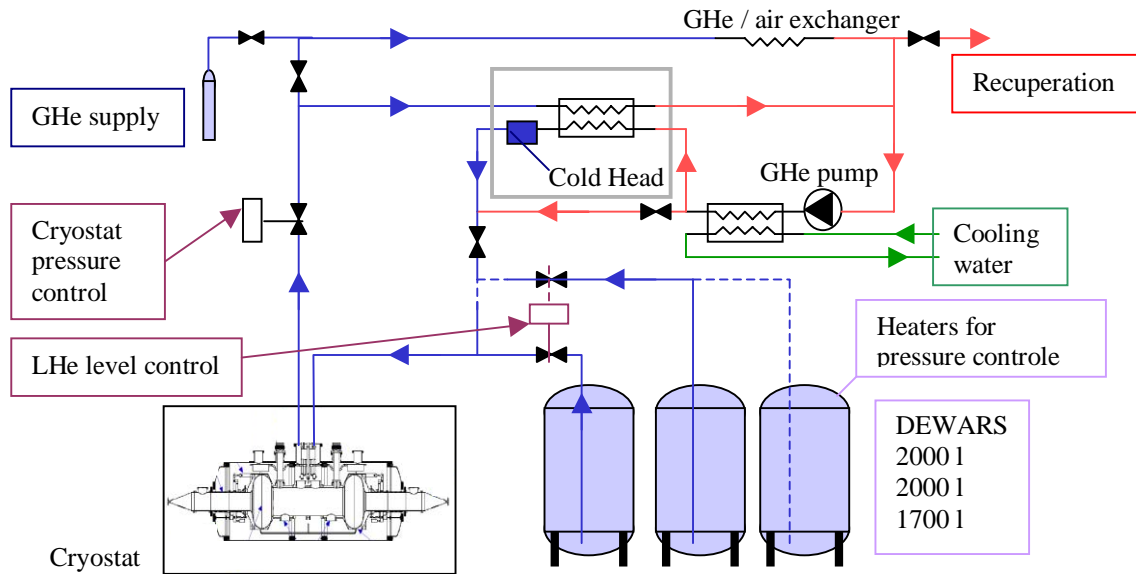


Figure 1: Liquid Helium (LHe) and Helium Gas (GHe) cooling circuits for the SOLEIL cavity at ESRF

The GHe/water heat exchanger after the compressor pump cools the injected GHe to 22°C and a GHe bottle keeps the pressure at 1140 mbar, above atmospheric pressure. With a modest consumption of about 2.8 bars/day, the bottle is exchanged every two months. The isolation vacuum is vented with a permanent small flow of dry nitrogen in order to add some convection and avoid any possible hot point inside the cryostat.

At the beginning of the one week long shutdowns, the cryostat isolation vacuum is pumped and the **pre-cooling** started. The GHe is then cooled by means of the cold head of a cryocooler, which extracts 280 W at 80 K. The gas incident on the cold head is pre-cooled with the cold return GHe by means of a heat exchanger built in the same cryostat. With a time constant of 36 h, the Nb/Cu cells reach their limit temperature of 110 K after six days.

The CEA and CNRS in Grenoble, who liquefy the helium, start filling 5700 l of liquid helium (LHe) into the Dewars about three weeks before the tests. The day before the machine restart, the whole LHe is available and the cooling to 4 K started. Details of the operation at 4 K are given in section 4.2.

3.2 Vacuum Configuration

In order to absorb the high frequency HOM above 1.5 GHz, which couple to the tapered transitions towards the vacuum vessel, these tapers are made of magnetic lossy stainless steel 430 and are water cooled. The main 500 l/s ion pumps are connected to the tapers, close to the accelerating structure. They are equipped with Ti sublimation pumps, which are regularly activated during machine interventions. On each taper, an isolation valve, a shielded bellow and a water cooled photon absorber are mounted. The absorber prevents synchrotron light from hitting the accelerating structure and is directly pumped with a 150 l/s ion pump.

Penning gauges are mounted on the tapers and on each RF power coupler. Their analogue signal is processed by the fast RF interlock system to cut the RF and protect the RF windows against sputter deposition of metal.

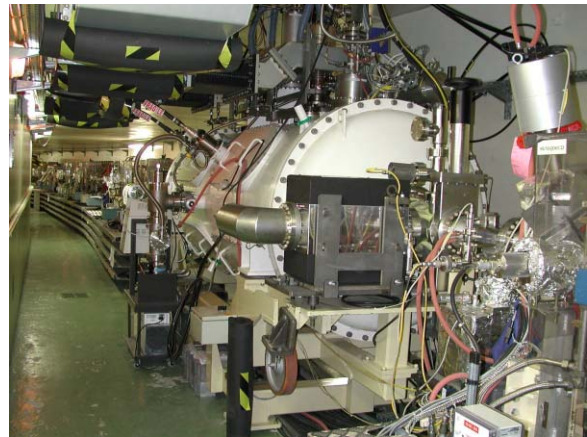


Figure 2: SC SOLEIL cavity on the ESRF storage ring

3.3 Connection to the ESRF 3rd RF Transmitter

The cavities have been installed in the straight section of cell 23 of the ESRF storage ring. A special waveguide feeder with waveguide switches connects the SOLEIL module to the 3rd RF transmitter instead of the existing normal conducting cavities 5 and 6 of cell 25. The standard RF control system design was easily adapted to monitor and interlock the SC cavity, and to integrate it into the ESRF control system.

The temperatures at several strategic points within the SC module are monitored and interlocked for the operation at 300 K, as well as the vacuum, the Helium gas cooling, the coupler air cooling, and other relevant parameters. When the system is switched to 4K operation, an interlock signal from the existing SOLEIL

cavity control cabinet is validated. This system was already developed by the CEA to control the cryogenic processes for the CERN tests [2] and was slightly modified for the operation with Dewars at the ESRF.

The existing software tuning system of the ESRF cavities was also easily adapted to control the resonant frequency of the two SC cells.

4 ACHIEVEMENTS AFTER 2/4 TEST PERIODS AT 4K

4.1 Passive Operation with Beam at 300 K

At 300 K, due to thermal expansion, the SC cells are naturally de-tuned by $1209 \text{ MHz} = 3.4 f_{\text{revolution}}$. This constitutes an excellent parking position, for which only little power is extracted from beam harmonics, including revolution sidebands in partial filling. Following a thorough computation of the HOM power distributed among the HOM dampers, the tapers and, to a small proportion, the warm Cu/Nb structure, the maximum total power to be extracted from the cryostat had been estimated between 200 and 300 W. This pessimistic analysis had been used to dimension the GHe pumps for up to $40 \text{ m}^3/\text{h}$ GHe flow. However, it turned out that with only $15 \text{ m}^3/\text{h}$ GHe flow, the measured temperature increase and the corresponding power dissipation are:

$\Delta T = 5 \text{ }^\circ\text{C}$, $P = 26 \text{ W}$ for 19 mA in single bunch fill

$\Delta T = 16 \text{ }^\circ\text{C}$, $P = 83 \text{ W}$ for 90 mA in 16 bunch fill

$\Delta T = 8 \text{ }^\circ\text{C}$, $P = 42 \text{ W}$ for 200 mA in uniform fill

Considering that the SC cavity had never been baked, the expected advantage of the open geometry results in a vacuum pressure as low as 10^{-9} , 10^{-8} and $3 \cdot 10^{-9}$ mbar in these three filling modes, respectively.

A maximum HOM power of 50 W was measured on monopole HOM couplers in 16 bunch at 90 mA. Finally, as expected from this strongly HOM damped cavity, no sign of HOM driven coherent multibunch instability was ever observed up the maximum ESRF current of 200 mA.

4.2 Cryogenic Cooling

To cool down from 110 K and saving as much LHe as possible by exploiting the evaporated cold gas, only a moderate flow of about 45 l/h of LHe is set for about 24 hours. The superconducting parts are then below 10 K and the bulky tuning system at about 30 K. A LHe flow of 200 l/h is then required for about 3.5 hours before the cryostat fills up with LHe. At this time, the first 1700 l Dewar is already empty. Including all the transfer losses, about 160 l/h, corresponding to a recuperation of 114 m^3/h or 117 W losses, are drawn from the Dewars in automatic mode keeping the LHe level stable in the cryostat. During the first series of test, the cavity remained in stable superconducting state for about 17 hours until the Dewars were empty. The unexpected high static losses may be explained by a degradation of the super-isolation following many manipulations during the development phase at CERN. Nevertheless, a cold radiation shield seems necessary for the final design.

4.3 Operation at 4K

The accelerating voltage has been ramped slowly up to 2.2 MV during the first two test periods. Not only the power couplers limit the conditioning speed. The coaxial line of one dipole HOM coupler also needs conditioning. The notch filter of this coupler is not perfectly tuned and transfers some fundamental mode power. The coaxial line will be inspected at the coming long summer shut down. In pulsed operation, 5 MV were obtained more easily. The HOM coupler design will be improved for better tuning and also better cooling for the next version of the cavity.

When de-tuning the cavity slightly, it was possible to store 200 mA in the ring: no instability and no increase in LHe flow were observed. This demonstrates that the HOM power is effectively coupled to the HOM loads.

With 2.1 MV from the SC module and 3.3 MV from the existing NC RF system, 6 mA of beam were stored with a lifetime of 17 hours for more than 1 hour. The loss per turn being 5 MeV, beam acceleration with the SOLEIL cavity has thus been demonstrated.

5 CONCLUSIONS

The test of the prototype SC SOLEIL cavity with beam at the ESRF is progressing well. During normal user service it is successfully operated in a passive mode at room temperature for any standard ESRF filling mode. A small Helium gas flow of $15 \text{ m}^3/\text{h}$ suffices to remove the small heat load generated by the beam. The cavity has been transparent to the normal ESRF operation. Within five months, the system has caused only two trips, which could not clearly be attributed to the cavity itself.

Although it requires a precise timing and limits the test duration, the operation at 4 K with liquid helium from Dewars has also been successful. Stable super-conducting state was achieved during 17 hours in each of the first two test windows. In passive operation at 4 K with up to 200 mA, no sign of HOM driven instability or any incidence on the helium consumption have been observed. Finally, first beam acceleration could be demonstrated using the superconducting SOLEIL cavity.

Two more test series are planned to further condition this prototype cavity and accelerate higher beam currents.

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