SUCCESSFUL RF AND CRYOGENIC TESTS OF THE SOLEIL CRYOMODULE

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Abstract

In the Storage Ring (SR) of the Synchrotron SOLEIL light source, two cryomodules will provide the maximum power of 600 kW required at the nominal energy of 2.75 GeV with the full beam current of 500 mA and all the insertion devices.

A cryomodule prototype, housing two 352 MHz superconducting single-cell cavities with strong damping of the Higher Order Modes (HOM) was built and successfully tested in the ESRF. Even though the achieved performance (3 MV and 380 kW) did meet the SOLEIL requirement for the first year of operation, it was decided to upgrade the cryomodule prototype before its implementation on the SR. Modifications of the internal cryogenic system as well as the input power and dipolar HOM couplers required full disassembling, reassembling and testing of the cryomodule, which were carried out at CERN. The refurbishment and test program, which was achieved in the framework of a collaboration between SOLEIL, CEA and CERN, is reported in this paper.

A 2nd cryomodule, similar to the modified prototype, shall be implemented on the SR by the end of 2006.

BRIEF HISTORY

During the SOLEIL Design Phase [1], it was decided that the RF system of the SR will rely on superconducting 352 MHz cavities in order to optimise the transfer of power to the electron beam and prevent coupled bunch instabilities that could be driven by parasitic HOM in the RF cavities [2].

In June 1996, CNRS, CEA and CERN concluded a collaboration agreement for the design, fabrication and test of a cryomodule prototype.

In December 1999, during the first power tests of the prototype at CERN [3], an accelerating gradient of 7 MV/m was reached with 120 kW (fully reflected) through each input power coupler (IPC).

In December 2001, the cryomodule was installed on the ESRF SR in order to validate the performance with high intensity beam. The results were quite satisfying : with 3 MV of accelerating voltage and 190 kW through each IPC, the cryomodule contributed to store up to 180 mA of electron beam at 6 GeV [4] (Fig. 1). On one hand, the achieved performance met the requirement for the first phase of operation (stored current of 300 mA and reduced number of insertion devices); on the other hand, these tests pointed out a few weak points that could be easily improved before the installation at SOLEIL.

Therefore, it was decided by the end of 2002 that, after a refurbishment, the prototype will become the cryomodule n°1 of SOLEIL, the only one for the first phase of operation. The full performance at 500 mA shall be achieved by implementing a 2nd cryomodule about one year later.

Figure 1: What the electron beam can see when entering the SOLEIL cavities

GENERAL CRYOMODULE DESIGN

A 3D-layout of the SOLEIL cryomodule is shown on Fig. 2. It consists of a cryostat containing two single-cell cavities, made of niobium deposited on copper and enclosed in their tanks where they are immerged in a bath of liquid helium (LHe) at 4.5K.

The HOM impedances are strongly damped thanks to four couplers of coaxial type, terminated with a loop (2 L-type for the monopole, 2 T-type for the dipole modes) and located on the central tube that connects the two cavities.

Both types of HOM couplers are made out of bulk niobium (RRR > 200), cooled with LHe circulating through the loops; their design is rather similar, except for two main specificities :

- different orientation of the coupling loops, as referred to the cavity axis (parallel for L-type, perpendicular for T-type);
- only the T-type HOM couplers, which stand closer to the cavity iris, are equipped with a notch filter for the rejection of the fundamental mode; an external mechanism and a single wave bellow allows to tune the filter, once the coupler is bolted on the cavity (Fig. 2).

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The HOM couplers are connected to external loads through coaxial lines housing a vacuum ceramic window; they are designed to extract up to 5 kW of power.

On the central tube connecting the 2 cavity cells, stand also the IPCs, 2 antennas of the LEP type, from CERN, which can transmit up to 200 kW, each.

The LHe from the Dewar, enters the cryomodule through a phase separator and then fills up the cavity He tanks from the bottom. On top of each cell a reservoir, acting as a second phase separator, collects the cold He gas (GHe), which is returned back to the refrigerator through the external transfer line. A small fraction of it is used to cool the 4-300 K transition tubes and the IPC jackets. A part of the LHe is also derived for the cooling of the HOM couplers.

Each cell has its own frequency tuning system, a mechanism, driven by a stepping motor which changes the cavity length within the limit of elastic deformation (range of ± 150 kHz; accuracy of ~ 1 Hz). The tuning assembly is housed inside the cryostat and works under vacuum and cryogenic environment.

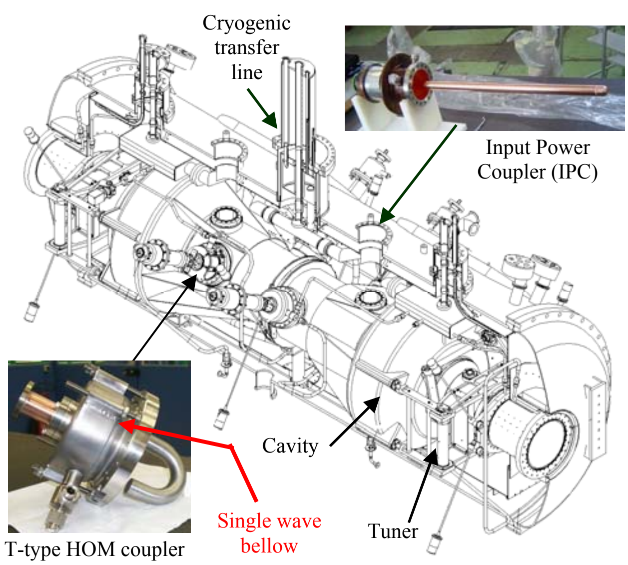

Figure 2 : SOLEIL cryomodule

CRYOMODULE PROTOTYPE TESTS AT ESRF AND UPGRADING TASKS

Summary of the Tests at the ESRF [4]

In 2002, four test periods were carried out with the cryomodule prototype in the ESRF SR. Each run allowed 17 hours of stable operation at 4K with LHe from Dewar. In October 2002, at the end of the 4th run, the SOLEIL cryomodule contributed to store up to 180 mA of electron beam at 6 GeV, by generating a peak RF voltage of more than 3 MV, with a power of about 190 kW through each IPC ; a RF voltage of 4 MV was simultaneously provided by the ESRF normal conducting cavities.

The ESRF tests have also pointed out a few weak points. In particular, undue high fundamental power (~ 2 kW instead of the expected 100 W) was coupled out through the T-type HOM couplers, due to the detuning of their rejection filter. Combined with a relatively poor cooling, it resulted in overheating that produced quench-like events with pressure bursts inside the He tank. Moreover, the total static losses were evaluated around 120 W, which is 50% larger than predicted.

In December 2002, the cryomodule was removed from the ESRF and transferred to CERN for a refurbishment, aimed at improving the previously mentioned weakness.

Upgrading of the Cryomodule Prototype [5]

For the T-type HOM couplers, which are located relatively close to the cavities, a notch filter is required to reject the coupling at the fundamental frequency. This filter is tuned by adjusting the gap between the stub and the coupler walls, thanks to a single wave bellow. Unfortunately, on the prototype, the bellow flexibility did not meet the initial specifications and thus prevented from tuning the filter. The design and fabrication process of the single wave bellow has been revised; after reshaping, it was machined and welded to the coupler bell. In order to improve the cooling efficiency, the LHe feeding connection was moved towards the cryomodule bottom.

For reducing the high static losses, a copper thermal shield, cooled by liquid nitrogen, has been inserted. Thermalisation straps anchored on the shield were introduced to draw heat out of the HOM couplers, the bulky tuning system, the coaxial lines, etc … The He circuitry was modified to accommodate the shield.

In order to better match the different possible operating modes of SOLEIL, the IPC coupling had to be increased : $Q_{ext} = 1\ 10^5$ instead of $2.2\ 10^5$, initially. For this purpose, the IPC antennas were cut and lengthened by 9.8 mm.

The standard instrumentation, used for the cryomodule prototype tests, had to be replaced with radiation-proof components. In addition, temperature sensors with wider operating range were mounted for proper survey of the cool-down from room temperature to 4K; each of them is mounted on a sensor holder.

SUCCESSFUL CRYOMODULE TESTS AT CERN AFTER REFURBISHMENT

The cryomodule refurbishment program required complete disassembling and re-assembling in a dust-free environment (Fig. 3). This was realised at CERN in the framework of a collaboration with CEA and CERN.

Figure 3 : Cryomodule in front of the CERN clean room

The cryomodule was dismounted during the last quarter of 2003. Then the cavities were rinsed and re-tested in a vertical cryostat. As shown in Fig. 4, the measured Q_0 of each cavity is larger than the specified value of 2 10^9 at E_{acc} of 6 MV/m.

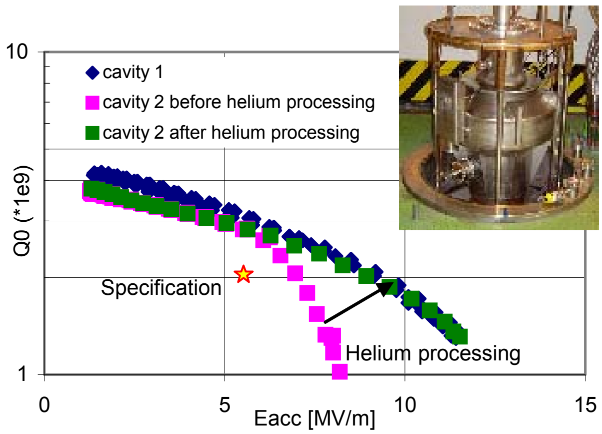

Figure 4 : Q_0 versus E_{acc} for the single cavities & cavity introduced into the vertical cryostat

After re-assembling in autumn 2004 (Fig. 5), the first cryogenic and RF power tests were carried out during December 2004, in spite of the missing T-type HOM couplers, which were not yet available.

Figure 5 : IPC and HOM coupler assembling inside the CERN clean room

The cryomodule was supplied in He from a CERN 18 kW liquefier, through a buffer Dewar (Fig. 6).

The tests demonstrated that the insertion of the thermal shield (Fig. 7) reduces the cryogenic losses by more than a factor of 2, from 117 W down to 51 W. The lower cryogenic losses allowed to regulate the LHe at 50% of the collecting box volume, insuring that the He fed into the HOM couplers is liquid.

The lengthening of the antennas well resulted in the anticipated Q_{ext} of 1 10^5 (± 1 10^4).

After mounting the T-type HOM couplers, the cryogenic and RF tests were completed in February 2005. Each IPC was conditioned up to 200 kW CW with full reflection and an accelerating voltage of more than 2.5 MV was achieved in each cell. This performance exceeds the requirements for the SOLEIL normal operation : 150 kW per coupler and 1.5 MV per cavity.

The notch filters of the T-type HOM couplers have proved to be easily tuneable and the rejection of the accelerating mode is -34 dB (instead of -19 dB obtained with the previous HOM couplers).

In addition, one could verify the functionality of the tuner, driven with the standard control unit of SOLEIL.

The cryomodule is now waiting at CERN for a few minor modifications before its final installation in the SOLEIL SR, scheduled for August 2005. An intervention is scheduled in June for the mounting of two HOM coaxial lines, which are still under repair as well as motor encoders, which are presently under tests at CEA.

Figure 6: Cryomodule in the CERN test facility

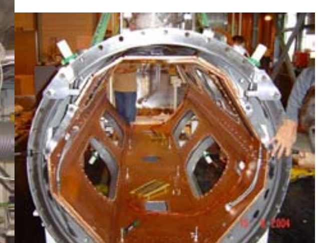

Figure 7: Thermal shield

GENERAL SCHEDULE

The two cryomodules will be supplied in LHe by a cryogenic plant with a HELIAL 2000 liquefier from Air Liquide. It is under fabrication and its installation is scheduled for June 2005.

Each of the four cavities will be powered from a 190 kW solid state amplifier, based on a technology developed in house [6].

The commissioning of the SR is planned beginning of 2006, using a single cryomodule powered with two 190 kW amplifiers. The 2nd cryomodule and two other amplifiers should be implemented about one year later.

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