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STATUS OF THE SOLEIL SUPERCONDUCTING RF SYSTEM

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Abstract

The 352 MHz SOLEIL SRF system consists in two cryomodules, each containing a pair of SC Nb/Cu cavities, cooled with LHe at 4K from a single 350 W cryoge-nic plant. In order to store 500 mA, a power of 575 kW and an accelerating voltage of 3-4 MV are required. The RF power is provided by 4 SSPA's, each delivering up to 180 kW. The original cavity input power couplers, which are LEP-type antennas, designed to handle up to 200 kW, were replaced by upgraded versions, able to transmit up to 300 kW CW. This opens the possibility to operate at full beam current with only one active cryomodule. The SRF system operational experience over the past ten years as well as the different upgrades are reported here.

INTRODUCTION

In the SOLEIL storage ring (SR), two cryomodules (CM's) provide the 352 MHz voltage of 3 - 4 MV and power of 575 kW, required at the nominal energy of 2.75 GeV with the full beam current of 500 mA and all the insertion devices. As shown in Figures 1 and 2, each CM contains two 352 MHz SC single-cell cavities, made of copper with niobium coating and cooled with liquid helium (LHe) at 4.5 K. Each cavity has its own frequency tuning, a mechanism driven by a stepping motor, which changes the cavity length. The HOM impedances are strongly damped thanks to four couplers of coaxial type, terminated with a loop (two for the monopole modes, two for the dipole modes) and located on the central tube that connects the two cavities. On the central tube, stand also the input power couplers (IPC's), CERN-LEP2 type antennas, which can transmit up to 200 kW CW. Recent R&D's led us to implement a new version, able to handle up to 300 kW CW.

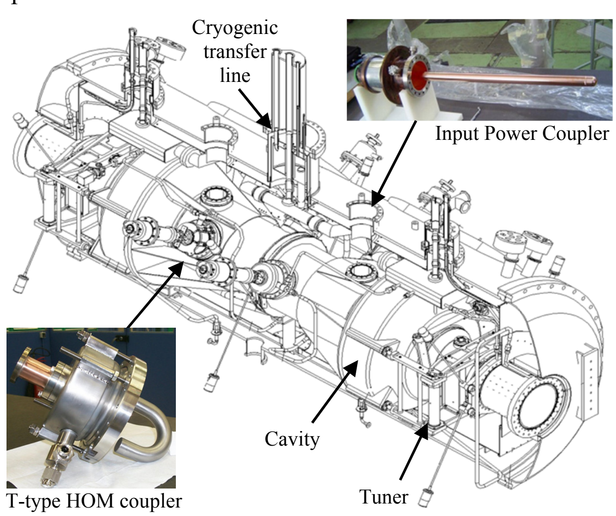

Figure 1: 3D-layout of the SOLEIL cryomodule.

Each of the four SR cavities is powered by a 180 kW SSPA, developed in house [1], which is a combination of four 45 kW towers; the tower itself consists in a combina-tion of 180 amplifier modules of 300 W with LDMOS transistors and integrated circulators.

A single cryogenic plant supplies both CM's in LHe and LN_2. It is based on a HELIAL 2000 unit from Air Liquide, operated in a dual liquefier/refrigerator mode [2].

One fully analogue low level RF system is dedicated to each cavity [3]. It comprises three relatively slow loops, which control the cavity resonant frequency and its acce-lerating field in amplitude and phase; besides a fast direct RF feedback copes with the Robinson instability at high current. This system can ensure a cavity voltage stability of ± 0.1% in amplitude and 0.03 degree in phase.

More detailed descriptions of the equipment, as well as reporting about the commissioning and phase 1 operation using a single CM can be found in references [4, 5].

Figure 2: CM1 in the SR.

OPERATIONAL EXPERIENCE AND UPGRADES

CM Frequency Tuner Issues and Cures

The SOLEIL SR RF system is in operation since 2006. Considering the difficulties encountered on the Super-3HC cavities at ELETTRA with a similar tuning system, which happened to get stuck after roughly fifty millions of motor steps [6], we were early aware of possible issues and therefore we came to operate at constant tuning and variable voltage during the injections [5]. Nevertheless, difficulties started after about two years of operation from repetitive jamming of the tuning mechanism. Fortunately, the impact on the user runs remained quite marginal.

Each cavity has its own tuner, aimed at changing its length. It consists in a double lever and a screw-nut as-sembly, driven by a stepper motor with a gear box. It is fully housed inside the CM, where it works under vacuum

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and at cryogenic temperature. The original version was using a standard screw, made of Copper - Beryllium with a MoS_2 lubricant coating, compatible with vacuum and cryogenic environment, coupled to a Harmonic Drive strain wave gear box.

The repetitive failures, in spite of a few cure trials (change in screw-nut threads and backlash), led us to develop a new version, based on more suitable components. Indeed the combination of a "planetary roller screw" (Fig. 3 - left) with a "planetary gear box" (Fig. 3 - right) was validated after an endurance run in the CryHolab test bench at CEA. The upgraded tuners were implemented inside each CM in 2009 and have worked for more than six years without any trouble.

By the end of 2015, one of the tuners began to behave differently from the others. For a same set point, the screw displacement was three times less than expected. During the January 2016 shutdown, this tuner was replaced and its inspection showed that one of the rings holding the peripheral rollers around the screw was broken. Fortunately it had no impact on user operation, but this led to backlashes and faster response of the tuner.

Although six years of lifetime could be considered as acceptable for such systems, we decided to use planetary roller screws without preloading (not needed with the planetary gear box) in order to improve the lifetime. A first one was implemented in April 2017 for validation on one cavity of CM2. This system will be extended progressively to all cavities in 2008.

Figure 3: Planetary roller screw (left) and gear box (right).

Towards More Powerful IPC's

The cavity IPC is another component of the CM which was subject to R&D. The original version was a CERN-LEP2 type antenna [7] consisting in a waveguide to coaxial transition with a doorknob and a cylindrical vacuum ceramic window (Fig. 4 - left). It was able to handle up to 200 kW CW. An improved version of this design (Fig. 4 - right), capable of transmitting higher power, was later developed by CERN at 400 MHz for the LHC [8]. That led us to conclude in 2011 a collaboration agreement with CERN and ESRF to develop a new 352 MHz version, based on the LHC design and capable of handling up to 300 kW. Two other events have motivated this decision. Firstly, problems of ceramic aging were encountered at the ESRF, where LEP type IPC's are also in use [9]. Secondly, occurrences of discharge were experienced in one of the SOLEIL IPC's, at a rate of about once a week, when operating above 120 kW; although that was not detrimental insofar as the beam current was limited at 430 mA in user runs, it could disturb the future routine operation at 500 mA. Furthermore the ability of feeding more than 250 kW per cavity will open the option of storing more than 450 mA using a single CM and consequently of taking benefit from the resulting redundancy.

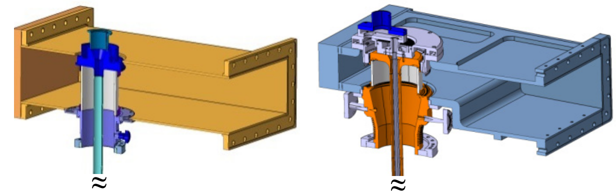

Figure 4: Original (left) and new (right) version of the SOLEIL cavity IPC.

Note that the antenna of the new IPC's is lengthened by 1 cm in order to double the coupling factor and hence match the standard operating condition at 500 mA, which is actually obtained with an overall RF voltage of 3 MV (750 kV/cavity) instead of 4.4 MV as initially predicted (Fig. 5). Operating at reduced voltage prevents from fast ion instabilities [10, 11].

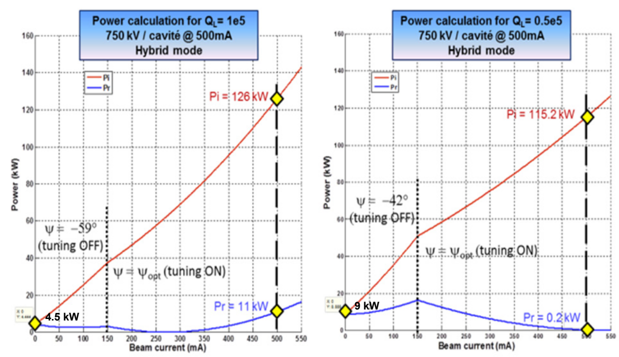

Figure 5: RF power versus I_{beam} with original IPC's (left) and upgraded ones (right) for V_{RF} = 3 MV (750 kV/cav).

In the summer 2013 shutdown, the first upgraded IPC, previously conditioned in the ESRF test-stand using a copper cavity from CERN, was mounted on CM1. This was achieved in situ inside the SR tunnel, using a hood with laminar air flow on top of the cavity. Then after only a few days of RF reconditioning the cavity could provide up to 1.5 MV with 150 kW CW in full reflection (no beam loading), limited by the power amplifier. As the maximum tolerated reflection on an individual SSPA is 80 kW, we have combined two of them to test the IPC up to 150 kW CW in full reflection.

End of August when restarting the operation with beam, we could store quickly up to 500 mA. Nevertheless, after about one week of operation, multipacting process occurred around 110 kW, sometimes triggering vacuum interlocks. During the user sessions, the corresponding cavity was operated below this level, compensating with the other ones. After two successive reconditioning during shutdown periods, the same scenario repeated itself: no problem at the beginning of the following run, then a kind of "de-conditioning" after a couple of weeks. This was cured by implementing a device which enables to generate a DC bias voltage at the ceramic window location, aimed at destroying the multipacting resonant conditions. The multipacting indeed fully disappeared when applying a DC voltage above 1 kV.

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The 3 remaining original IPC's were replaced with new versions in August 2014, January 2016 and January 2017, respectively. Each of them was tested up to 150 kW fully reflected (no beam loading), combining 2 of our SPPA's.

In November 2017, a power of more than 250 kW CW, from the combining of two SSPA's, was transmitted to the beam by one IPC of CM2 for several hours during a dedicated test session. In April 2017, the same experiment was repeated with the second IPC of CM2 which transmitted up to 270 kW CW and it is scheduled as well for the two IPC's of CM1 before the end of this year.

Combining the power from two SSPA's on a single cavity was made easier by modifications in the waveguide network as described below.

Upgrade of the Waveguide Network

In parallel to the IPC upgrade, the waveguide network was modified for a fast and easy combining of the power from two amplifiers into a single cavity. For this purpose, we have developed a new device that we called « Magic Switch ». It is a four ports (2 inputs & 2 outputs) waveguide component with a number of holes into which one can insert metallic posts (Fig. 6-a). Depending on the post configuration, one can transfer either each input power to each output or their sum to one or the other output (Fig. 6-b). Furthermore connecting two Magic Switches (Fig. 6-c), one can power one or the other CM with 270 kW per cavity from our four amplifiers, combined by pairs, which allows storing 450 mA using a single CM.

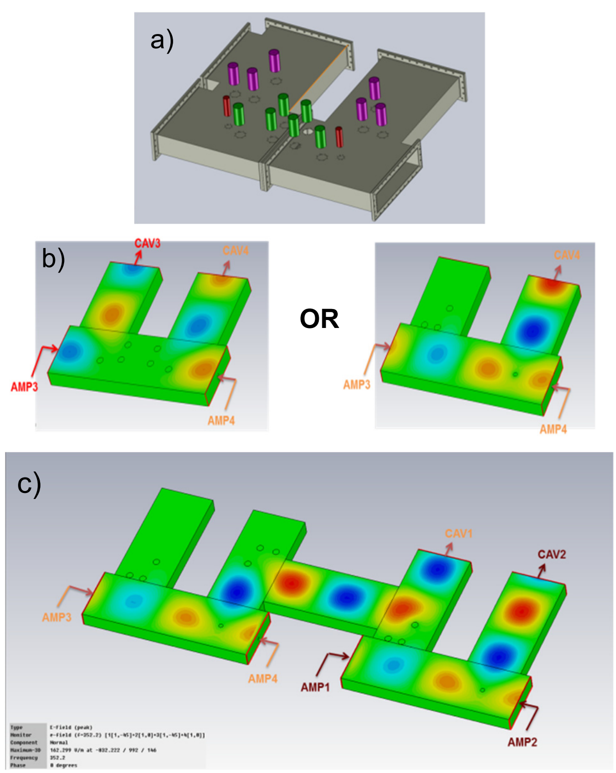

Figure 6: Magic Switch principle.

CONCLUSION

The RF system of the SOLEIL SR is quite innovative and challenging with the use of SSPA's and HOM free SC cavities, both developed in house. After more than 11 years of operation, it has demonstrated outstanding availability, reliability and flexibility [12]. Beam is routinely delivered to the users in two operation modes with top-up injection: 450 mA in multi-bunch hybrid mode (presently limited by fast ion instabilities) and 500 mA in multi-bunch uniform filling.

The difficulties encountered with the CM frequency tuners had only minor impact on the user operation and were quickly overcome by improving the initial device.

Cavity IPC's of higher power capability, have been developed. They are now implemented on the four cavities and are working quite satisfactorily when applying a 1 kV DC bias voltage, which cures the recalcitrant multipacting levels. By the end of 2017, all cavity IPC's should be able to feed more than 260 kW per cavity. Moreover modifications in the waveguide network with the insertion of "Magic Switches" opens the option of storing more than 450 mA using a single CM and consequently of taking benefit of the resulting redundancy.

Upgrades of the cryogenic system for improving its autonomy and reliability are also under way [2].

Emphasis is put as well on the success of the SSPA technology, which has demonstrated that it could advantageously replace the vacuum tubes in such application, thanks in particular to its extreme modularity and redundancy, along with the absence of high voltage which results in very low phase noise. It is fully expanding, now adopted by several other laboratories and taken up by the industry [12]. SOLEIL is thus involved in several collaborations and transfers of know-how. The French company, SIGMAPHI ELECTRONICS is SOLEIL licensee since December 2013.

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