COMMISSIONING OF THE SOLEIL RF SYSTEMS

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Abstract

The 352 MHz RF accelerating systems for the SOLEIL Synchrotron Booster (BO) and Storage Ring (SR) are being commissioned.

In the BO, a 5-cell copper cavity of the CERN-LEP type is powered with a 35 kW solid state amplifier.

In the SR, the required RF accelerating voltage (up to 4.4 MV) will be provided by two cryomodules, each containing a pair of superconducting cavities, specifically designed for SOLEIL. The parasitic impedances of the high order modes (HOM) are strongly attenuated by means of four coaxial couplers, located on the tube connecting the two cavities. The first cryomodule is already installed in the SR tunnel, while the second one is being constructed by ACCEL (Germany). These cryomodules are supplied in liquid helium from a single 350 W liquefier and each cavity is powered with a 180 kW solid state amplifier.

The RF system commissioning and first operation results are reported.

BOOSTER (BO) RF SYSTEM

In the SOLEIL BO, a single 5-cell copper cavity of the LEP type (352 MHz) provides the required RF voltage, which is ramped from 100 kV up to 800 kV at the injection rate of 3 Hz. The total needed power, up to 20 kW (15 kW dissipation into the cavity walls and 5 kW into the beam), is supplied by a solid state amplifier, capable of delivering up to 35 kW CW.

The solid state amplifier consists in a combination of 147 elementary modules of 330 W, with MOSFET transistor (VDMOS D1029UK from SEMELAB), integrated circulator and individual power supply. All components were designed in house and their fabrication was contracted in the industry. The description of the amplifier and its test results are detailed in reference [1].

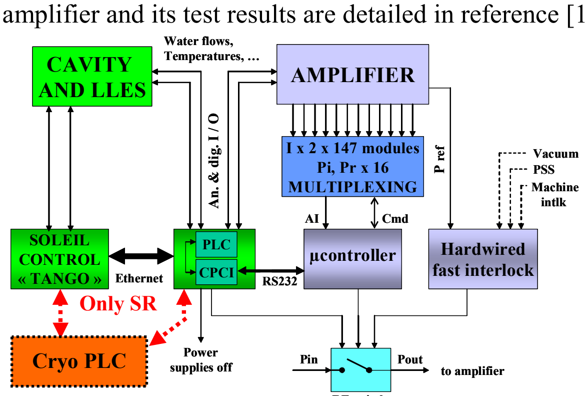
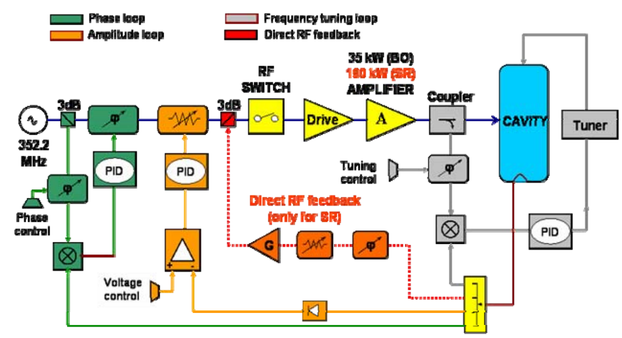


Figure 1: BO RF control system.

Fig. 1 shows a scheme of the BO RF control system. The amplifier parameters (transistor currents, incident and reflected RF power at the 2.5 kW stage) are permanently monitored by a µcontroller through a multiplexing system. A few signals (cavity reflected power and vacuum, personal and machine safety) are interlocked by a fast hardwired system. All the other "slow signals" from the amplifier, the cavity and Low Level RF system (LLRF) are monitored by a PLC, linked to the µcontroller via a RS232 link trough a CPCI board and to the SOLEIL TANGO world, via Ethernet. In case of fault, the RF power can be stopped by acting on the RF switch, which is located in the amplifier drive chain and/or by switching off the power supplies.

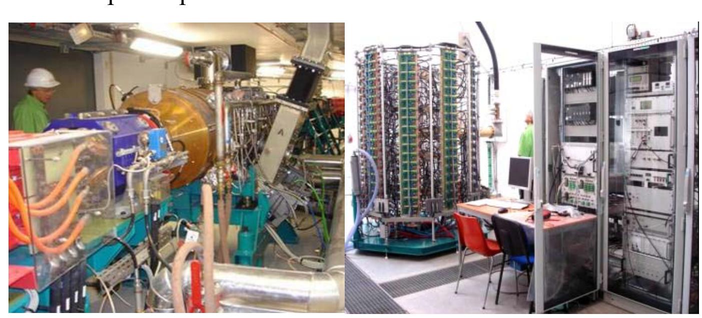
A conceptual diagram of the LLRF system (frequency, phase and amplitude loops) and its main performance are shown in Fig. 2.



	Amplitude	Phase	Frequency
Accuracy	± 0.25 %	± 0.4°	± 30 Hz
3dB bandwidth	10 kHz	7 kHz	5 Hz

Figure 2: BO LLRF diagram and performance.

The complete BO RF plant was installed on site in spring 2005 and commissioned in July. Up to now, it has run for about 2000 hours without any major problem. In particular the amplifier, which is the most innovative part of the system, proved to be quite reliable as well as very easy and flexible in operation. Only a single module failure has occurred, which did not perturb at all the amplifier performance.



The Fig. 3 above shows a) the cavity in the BO ring and b) the BO RF room with the 35 kW amplifier and the racks containing the control and LLRF systems.

STORAGE RING (SR) RF SYSTEM

In the SR, a RF voltage of 4.4 MV and a power of 600 kW at 352 MHz is required for the nominal energy of 2.75 GeV, the full beam current of 500 mA and all the insertion devices. That will be achieved using two cryomodules (CM), each containing a pair of single-cell superconducting cavities. Both CM are supplied in liquid Helium (LHe) from a single liquefier and each cavity is powered with a 180 kW solid state amplifier.

Only a single CM and two amplifiers will be used for the first year of operation with limited number of insertion devices and beam current below 300 mA. The second CM, presently being constructed by ACCEL GmbH, will be implemented by mid of 2007.

Cryomodules (CM)

A 3D-layout of the SOLEIL CM is shown in Fig. 4. It consists of a cryostat which contains two 352 MHz single-cell cavities, made of Niobium deposited on copper and enclosed in their tanks where they are immerged in a LHe bath at 4.5 K. Each cell has its own frequency tuning, a mechanism driven by a stepping motor, which changes the cavity length. The tuning assembly is housed inside the CM, where it works under vacuum and cryogenics environment.

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 2 cavities. On this tube, stand also the input power couplers, two antennas of the LEP type, from CERN, which can transmit up to 200 kW in CW.

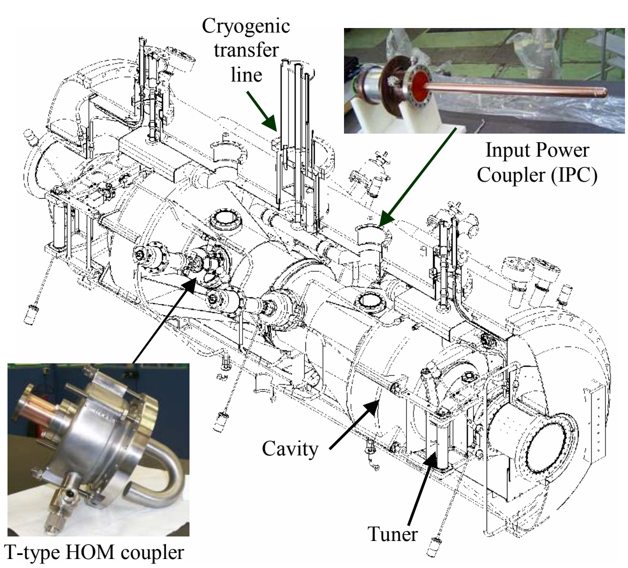


Figure 4: The SOLEIL cryomodule (CM).

After a campaign of tests with beam on the ESRF SR, the CM prototype was fully disassembled, significantly modified and then retested at CERN, in order to be used as the first cryomodule (CM1) in SOLEIL. Beginning of 2005, an accelerating voltage of 2.5 MV per cavity was achieved with 200 kW CW, fully reflected through each input power coupler (loaded Q-factor of 10^5) in the CERN area. The details of these different sequences are reported in reference [2].

The CM1 was transferred from CERN to the SOLEIL SR, end of Nov. 05 (Fig. 5). In May 06, after pumping, the cavities were cooled down to 4.5 K. Then each of the 2 cavities has been RF conditioned up to an accelerating voltage of 1.7 MV (4 MV/m) with a power of 80 kW CW fully reflected. We had limited ourselves at this level in order to not reflect too much power towards the amplifier. It took about 50 hours for conditioning each cell up to 80 kW with a frequency modulation of ± 10 kHz, rated at 0.1 Hz; at the end the cavity vacuum was a few 10^{-11} mbar.

Figure 5 : Cryomodule n°1 (CM1) in the SOLEIL SR.

180 kW Solid State Amplifiers

The SR 180 kW amplifier is based on the same principle as the BO one, extended to 4 towers of ~ 50 kW, as shown in Fig. 6. Its design is detailed in ref. [2].

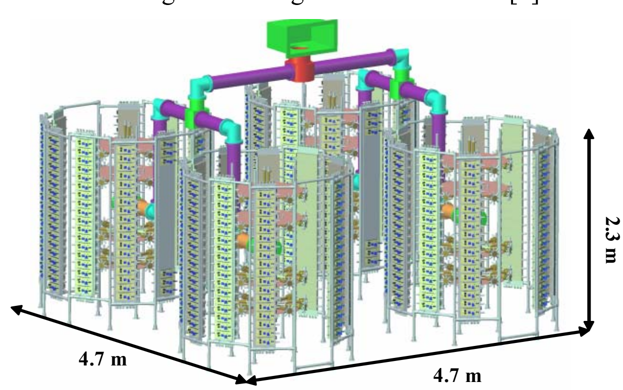


Figure 6 : SR 180 kW amplifier (724 modules of 320 W of which 42 in “stand-by”).

One of the main changes as compared to the BO is the use of a new type of MOSFET, the LDMOS LR301 from POLYFET, which can achieve better performance than the VDMOS D1029UK. The new LDMOS based amplifier module has been optimised in the frame of a SOLEIL-POLYFET collaboration work, after several iterations for matching the characteristics of the transistor itself and the associated circuit. The manufacturing and tests of the amplifier modules, as well as the power combiners and splitters, were then contracted to BBEF Electronics (Beijing). During the test of the first 50 kW tower (1/4 amplifier) with LR301-V3 transistors, we observed an unexpected high transistor failure rate (15 over 180, after 1000 hours of operation). This led us to launch the fabrication of another version, LR301-V4, with the aim of improving the toughness at the expense of a slightly lower gain (-1 dB). Since that reduced the failure rate by a factor of 3, we decided to go on with the LR301-V4.

Between May 2005 and March 2006, height tours were assembled and individually tested up to 48 kW. In April 2006 two amplifiers of four towers were successfully tested up to 190 kW into a dummy load (Fig. 7) and then they were connected to CM1.

Figure 7: 1st SR amplifier under power tests (dummy load).

Control and LLRF Systems

The LLRF system of each SR power plant (cavity and amplifier) is very similar to the BO one, but with the insertion of a direct RF feedback loop in order to cope with the Robinson instability at high current (Fig. 2). It is also the case of the control system, but with in addition the PLC for the cryogenic plant (Fig. 1) and a multiplexing system extended to the larger number of modules.

A fast digital FPGA based I/Q feedback, currently under development [3] will be implemented later on, in replacement of the actual analogue LLRF system.

Cryogenic System

A single cryogenic plant will supply in LHe both CM. It is based on the use of the HELIAL 2000 from AIR LIQUIDE, operated in liquefier/refrigerator mixed mode. The description of the system is detailed in ref. [4]. Fig. 8 shows the equipment located in the technical gallery of the accelerator building. The compressor plant is housed in a dedicated room of the utilities building (Fig. 9) and outdoors, stand the associated GHe buffers (2 x 50 m^3).

Figure 8: Cryogenic area in the technical gallery.

Figure 9: Compressor plant.

After completing the installation, in May 2006, the performance of the cryogenic source was evaluated, using the 2000 litre Dewar and its internal variable heater. One could reach more than 50 l/h of liquefaction and 400 W of refrigeration at 4.5 K, which is significantly more than specified. Then, on May 9th, one launched the cool-down of CM1. It took about 15 hours before reaching stable temperature and pressure conditions.

RF SYSTEMS STATUS AND SCHEDULE

After about 2000 running hours, the SOLEIL BO RF plant has demonstrated a good reliability and flexibility.

Only the half of the SOLEIL SR RF system (CM1 and its two 180 kW amplifiers with LLRF and controls) is presently installed. That is enough to achieve the required performance for the first year of operation.

The two first amplifiers were tested up to 190 kW into a dummy load and then connected to CM1 for conditioning its two cavities up to 1.7 MV with 80 kW fully reflected through each coupler. We limited ourselves at this level of power in order to avoid reflecting too much CW power towards the amplifier. With this level of power, one can store beam current up to 130 mA with accelerating voltage of 2.5 MV. Higher power and voltage (> 3 MV) will be achieved with increasing beam current up to 300 mA.

After a few weeks of SR commissioning, 20 mA were stored with 1.3 MV from a single cavity, powered up to 60 kW and then, up to 85 mA with 49 kW on each cavity.

The second half of the system, which is under fabrication, will be implemented mid 2007 for reaching the nominal operating conditions (4.4 MV and 500 mA).

ACKNOWLEDGEMENT

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