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STATUS OF SIRIUS STORAGE RING RF SYSTEM

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Abstract

The design configuration of the Sirius Light Source RF System is based on two superconducting RF cavities and eight 60 kW solid state amplifiers operating at 500 MHz. The current configuration, based on a 7-cell room temperature cavity, was initially planned for commissioning and initial tests of the beamlines. However, it will have to remain in operation longer than planned. Sirius has been operating in decay mode for beamline tests with an initial current of 70 mA. We present an overview of the first-year operation of the RF system and the preparations for the installation of the two superconducting cavities, which is expected to take place in 2023.

INTRODUCTION

In its design configuration the RF system for the storage ring will use two CESR-type SC cavities to provide the 3 MV gap voltage needed for the operation of the machine [1]. The installation of the system was programmed to be performed in two phases. The initial plan was to have the SC cavities installed since the beginning of operations. The main difference between the two phases would be the available RF power. The system would start with 120 kW per cavity and the available power would be doubled in the second phase. A third phase for the RF system would be the installation of a harmonic cavity in the storage ring, aiming mostly at increasing the beam lifetime for higher currents. However, changes were necessary in the course of the project and a decision was made to use a 7-cell normal conducting cavity for the commissioning and first year operation. The redesign of the RF system led to a three-phase installation program. Table 1 shows the current schedule for the completion of the RF system installations.

Table 1: RF System Installation Program

	Phase 1	Phase 2	Phase 3
Cavity type	7-cell NC	CESR	CESR
Number of cavities	1	2	2
RF Voltage (MV)	1.8	3	3
Beam current (mA)	50	250	350
E_{loss}/turn IDs (keV)	200	300	400
Number of SSA	2	4	8
RF Power/Cav (kW)	120	120	240
Time schedule	2019	2023	2024

Due to delays in the process of selecting and contracting the fabrication and installation of the cryogenic plant, there is an expectation that the installation of the two SC cavities may be scheduled for the beginning of 2023. The cavities are in final phase of production and will be ready for delivery in the following months. This means that Sirius will have to operate longer with the 7-cell cavity and efforts had to be made to reach stable operation for higher beam currents than originally planned.

RF SYSTEM INSTALLATION PLANS

The RF system currently in operation comprises the 7-cell cavity, a set of two 60 kW solid state amplifiers (Fig. 1) and a customized version of ALBA LLRF. The cavity was installed in a straight section originally planned for future installation of a harmonic cavity and a possible third SC RF cavity. The power of the two 60 kW solid state amplifiers is combined using a 2-way waveguide combiner designed at SOLEIL.

Figure 1: SSA towers of the storage ring RF plant.

We are currently in the process of designing and assembling the next two RF amplifiers that will be used with the SC cavities once they are installed in the machine. Small modifications are being made in the design of the amplifiers to make their installation faster and must also be implemented in the current SSA towers when they are relocated to the final position. The main modifications concern the interlock system of the amplifier which now includes a remote PLC unit that will be connected to the central RF plant interlock system. The design changes will make it easier and faster to redistribute the SSA towers when installing the last four towers. This is relevant since a different approach is being taken for the four next amplifiers. The main reason for that comes from the fact that the project of the RF system has extended over a too long period. That was mostly due to the need to adapt the progress of the project to the budgetary and cash flow conditions. As a result, only part of the components for the amplifiers was purchased in order to guarantee the necessary RF power for the early stages of operation of the machine.

The amplifier module used in the first four towers was designed about 10 years ago at SOLEIL. Sirius adopted an

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early version of the module, and the batch being used was produced by BBEF, in China. Since then, new transistors have been released for the UHF band. These new devices have higher gain, efficiency, and output power. This led to an effort to develop an amplifier module to be used in the last four amplifiers of the RF system. The new module is based on the BLF978P LDMOS transistor. Prototypes have been assembled and tested in the RF lab and special attention has been paid to the cooling of the critical components. More details can be found in the article dedicated to these new developments presented at this conference [2]. In bench tests the modules reached an output power of 850 W in the CW regime, with temperatures stabilizing at values suitable for reliable operation.

In addition, changes in the combination topology are being considered to include a cavity combiner and to eliminate the high-power coaxial cables from the setup. The higher output power per module will demand a smaller number of modules to achieve the 60 kW design power of the amplifier.

The 7-cell cavity RF plant will be deactivated for the installation of the SC cavities and moved to a new position to drive one of the new cavities. A second RF plant will be installed for the second cavity (Fig. 2). The topology of the plants is quite similar to the current one. Each plant includes a 300 kW circulator, a redundancy given that each amplifier module includes its own protection. For the final setup of the plants a magic-T combiner is being planned for the full combination of four SSA. However, alternatives are still being considered for this final setup.

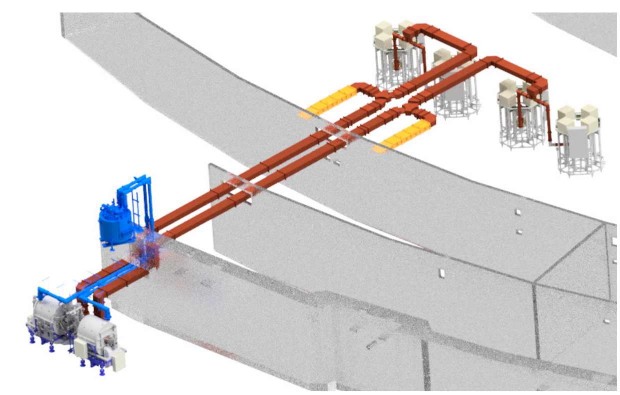

Figure 2: Layout of the RF system for the SC cavities in Phase 2.

Superconducting Cavities

The CESR-type SC cavities are in the final phase of production at Research Instruments. The first cavity is ready for delivery and was approved in the FAT performed in the last quarter of 2020. The second cavity is now being assembled in its cryostat and may be ready for acceptance tests by mid-2021.

Figure 3 shows the first cryomodule sitting in the RI testing area during preparations for the FAT. Since the cryogenic plant is planned to be ready for the cavities only in the beginning of 2023 the cavities will need to be carefully stored in the meantime.

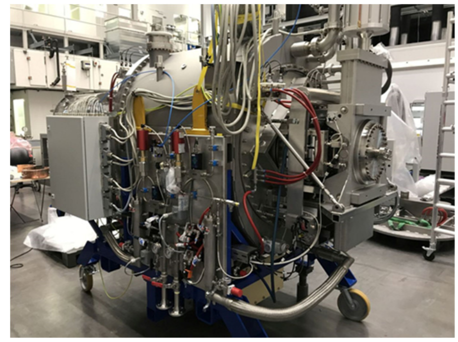

Figure 3: The first SC cavity cryomodule parked in a testing area for the FAT.

CURRENT STATUS OF THE RF SYSTEM

The RF system has been in continuous operation for more than a year. Over this period, it was necessary to commission the RF power plant, to fully condition the RF cavity and to fine tune the system for operation with beam. Most of the commissioning time was spent on conditioning the cavity. Sirius has a fully NEG-coated vacuum chamber and care was taken not to degrade the vacuum in the straight section.

Overall Performance

Since the installation and commissioning of the RF system the two SSA have operated for about 7500 hours with a reliability close to 100%. The SSA have not been the cause of any trip of the RF during operation, which have been mostly related to the cavity pressure or temperature. However, a considerable number of the modules had to undergo some sort of maintenance. For both storage ring SSA 12% of the modules had to be repaired, most of them due to failures in a pi filter in the gate drive circuit. These faults had no effective impact on the operation of the SSA towers and the filters are being preventively replaced during scheduled maintenances. The amplifier modules are based on the BLF578 LDMOS transistor. To date, only 2 out of a total of 264 transistors on the two SSA have failed during the initial tests of the SSA in the RF laboratory.

The electrical efficiency and the gain of the SSA towers have been measured, as displayed in Fig. 4.

The measurements were not performed at full power due to cooling system limitations, but it shows a compatible efficiency for an AB amplifier at 60% of its full power output.

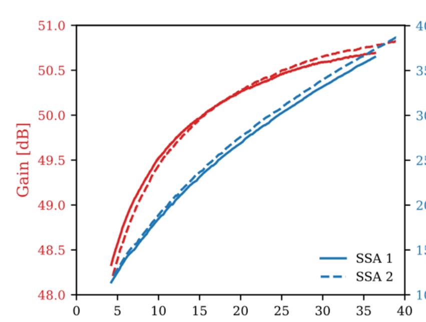

Figure 4: Sirius RF SSA towers efficiency and gain.

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The 7-cell Cavity

The 7-cell cavity (Fig. 5) is an old spare cavity from PETRA. The cavity has a shunt impedance of 28 MΩ. The cavity went through a baking procedure and was RF conditioned up to a power of 100 kW at DESY. It was shipped to Brazil pressurized with N_2 and was put under vacuum as soon as it arrived. The baking procedure was not performed after installation in the storage ring but the static cavity pressure was at 4×10^{-10} mbar at the time the RF plant was ready for the RF conditioning.

Figure 5: The 7-cell PETRA cavity.

The cavity was RF conditioned using pulsed RF, with duty cycle varying from 2% to 99%, and frequency sweep for increasing power level. The frequency sweep was very effective for conditioning the power coupler and plungers. The conditioning process was automated through scripts acting on the control variables, using of the protections built into the LLRF. The procedure is simple and easy to be performed. Fast conditioning may be needed when the cavity operating temperature is modified. Figure 6 shows a frequency sweep conditioning procedure.

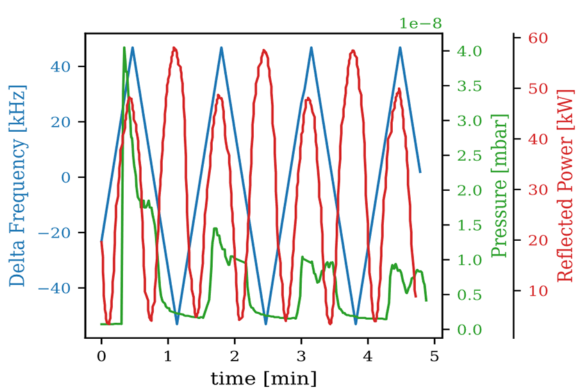

Figure 6: Cavity outgassing during RF frequency sweep conditioning.

A temperature control unit capable of regulating the cavity temperature between 25 and 50 °C was coupled to the cavity. Each of the cavity water circuits was equipped with a flow regulation valve and a water temperature sensor. It is therefore possible to adjust the power distribution between the cells. The temperature control is based on the central cell which is regulated within ±0.15 °C around the chosen temperature setpoint.

The cavity has a glass window overlooking the power coupler in which an arc sensor was installed and added to the plant interlock system. A temperature sensor was also installed to monitor possible heating of the window due to the cavity HOM at higher beam currents.

Stability Issues and Beam Current

Although the 7-cell cavity was planned to operate only during the initial operations of the beamlines with low beam current, it was necessary to look for ways to enable operation with higher beam current. The cavity has no HOM damping, but it is possible to search within the temperature control range for an operating temperature where the impact of these HOM is less harmful to the beam. Even more relevant, Sirius is equipped with a longitudinal bunch-by-bunch system designed to operate with a beam current of up to 100 mA [3]. By sweeping the cavity operating temperature, adjusting the parameters of the longitudinal bunch-by-bunch feedback system and by fine tuning the LLRF feedback parameters, it was possible to operate with beam stable conditions up to 70 mA. Efforts have also been made to improve the thermal stability of the accelerator tunnel, which is not yet within the tight ±0.1 °C design specification. The RF frequency is included in the closed-orbit slow orbit feedback (SOFB) and follows the tunnel temperature variations.

There are still a few limitations that are preventing the current to be increased. One of them is the increase in the temperature of the power coupler when the current increases and the forward power exceeds 80 kW.

Routine Operation

Sirius is currently operating in decay mode with current starting at 70 mA during beamlines friendly users run [4]. The gap voltage in the cavity is 1.6 MV and the control temperature 38.8 °C. Whenever the beam needs to be dumped a script running in the RF control makes sure it is done smoothly from the point of view of radiation protection and pressure monitors.

CONCLUSION

After one year the storage ring RF system has been operating smoothly. The amplifiers and the LLRF are very reliable, the cavity works as expected, and the whole system is being fine-tuned in line with the efforts to increase beam current.

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