SYNCHROTRON SOLEIL SUPERCONDUCTING RF STATUS

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Abstract

The RF system of the Synchrotron SOLEIL light source involves superconducting cavities and solid state amplifiers. Two cryomodules are needed to provide the maximum power of 600 kW, required with the full beam current of 500 mA, at the nominal energy of 2.75 GeV and with all the insertion devices. A prototype cryomodule, housing two 352 MHz superconducting single-cell cavity with strong damping of the HOM, has been built and successfully tested in the ESRF storage ring (3 MV and 380 kW).

Even though the achieved performance does meet the SOLEIL requirement for the 1st year of operation, the cryomodule prototype will be refurbished : insertion of a thermal copper shield cooled with liquid nitrogen, improvement of the HOM dipolar couplers, modification and lengthening of the fundamental power coupler antenna to achieve a Q_{ext} of 1.10^5. A second cryomodule will be built and installed about one year later.

Each of the four cavities will be powered with a 190 kW solid state amplifier consisting in a combination of 315 W elementary modules (about 750 modules per cavity). The amplifier modules, based on a technology developed in house, with integrated circulator and individual power supply, will be fabricated in the industry. A 40 kW solid state amplifier (147 modules) for the booster is being assembled and should be tested on a dummy load, before the end of 2003.

INTRODUCTION

Synchrotron SOLEIL is a dedicated high brightness synchrotron light source under construction at Saint-Aubin, near Saclay and Orsay in France.

During the SOLEIL Design Phase [1], it was decided that the SOLEIL RF system would be based on the use of superconducting 352 MHz cavities (fig.1) in order to optimise the transfer of power to the beam and prevent coupled bunch instabilities that could be driven by parasitic modes of the RF cavities [2]. Therefore, in June 1996, a collaboration agreement between CEA, CNRS and CERN was concluded for the design, fabrication and test of a cryomodule prototype.

In December 1999, during the power test at CERN [3], a full reflected power of 120 kW has been applied to each main coupler. With this power level, an accelerating gradient of 7 MV/m was reached.

In December 2001, the cryomodule was installed on the ESRF storage ring in order to validate the performance with high intensity beam.

As power source of the superconducting cavities, four options were considered : diacrode, klystron, IOT or solid-state amplifier [4]. The present performance of the RF power MOSFET's allows the use of the solid-state technology also in high power amplifiers [5]. The MOSFET's amplifiers are free from thermal runaway and secondary breakdown, which affect bipolar transistors, and they don't require periodical replacement like vacuum tubes. For these reasons, since November 2002, a new development program for a modular 352 MHz, 190 kW solid-state amplifier has been launched at Synchrotron SOLEIL in parallel with the development of a 40kW solid-state amplifier for the booster. The goal is to build low cost power amplifiers by combining a suitable number of independent modules.

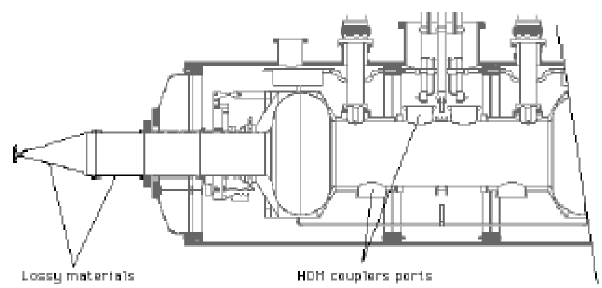

Figure 1 : SOLEIL cryomodule with HOM dampers.

CRYOMODULE TEST AND MODIFICATIONS

Brief Summary of the Tests at ESRF [6]

Four test periods have been carried out with the cryomodule prototype. In each test period, 17 hours of stable operation at 4K with liquid helium from dewars have been achieved. In October 2002, at the end of the 4th test in the ESRF, the SOLEIL cryomodule contributed to store up to 170 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 main coupler; a RF voltage of 4 MV was simultaneously provided by the ESRF normal conducting cavities. This level of performance, achieved in stable and reliable conditions, corresponds to the SOLEIL requirements for the first year of operation, starting in 2005 with a reduced number of insertion devices. The ESRF tests have also shown a few minor problems.

For the dipolar HOM couplers, the extracted power of

1650 W was higher than the hundred of Watts expected at 4 MV in CW. This undue high coupling of the fundamental mode is the consequence of an incorrect tuning of the HOM coupler notch filter.

Moreover, an overheating of the HOM couplers at high accelerating voltage was observed leading to some quench-like events, with pressure bursts on the LHe tank. The poor cooling efficiency was probably due an unfit design of the LHe circuit with the feeding inlet higher than the LHe collecting box.

The total static losses were evaluated around 117 W, which is significantly larger than the predicted value of 80W.

Multipacting was also observed in the main RF couplers around 4 MV, eventually leading to some pressure bursts on which the RF tripped. The fast vacuum interlock had been implemented to protect the ceramic from sputter deposition of copper. It is expected that further conditioning of the couplers will help to overcome multipacting up to 4 MV.

In December 2002, the cryomodule was removed from the ESRF storage ring. Based on the test results, the cryomodule will be refurbished before its installation and commissioning on the SOLEIL storage ring which is scheduled early 2005.

New Design and Modifications of the Cryomodule

On the dipole HOM couplers (fig. 2), the notch filter is tuned by adjusting the gap between the stub and the coupler walls, using a single wave bellow. Unfortunately, the bellow flexibility did not meet the initial specifications and thus prevented from tuning the filter. The design and fabrication procedure have been revised : the single wave bellow has been reshaped (fig 3) and it will be machined (instead of …) and welded to the HOM coupler bell. This new version should allow a proper tuning of the fundamental mode rejection.

Figure 2 : Dipolar HOM coupler.

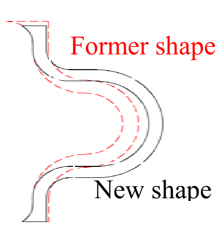

Figure 3 : Single wave bellow.

The HOM cooling efficiency will be improved : connection of the LHe feeding to the bottom of the cryomodule, allowing the LHe level to rise in the HOM feeding line as the LHe is rising in the cryomodule.

In order to reduce the high static losses, a copper shield cooled by liquid nitrogen (fig. 4) will be inserted. Thermalization straps anchored on the shield will be installed to draw heat from the HOM couplers, the bulky tuning system, the coaxial lines, etc… The helium circuitry will be modified to accommodate space for the shield.

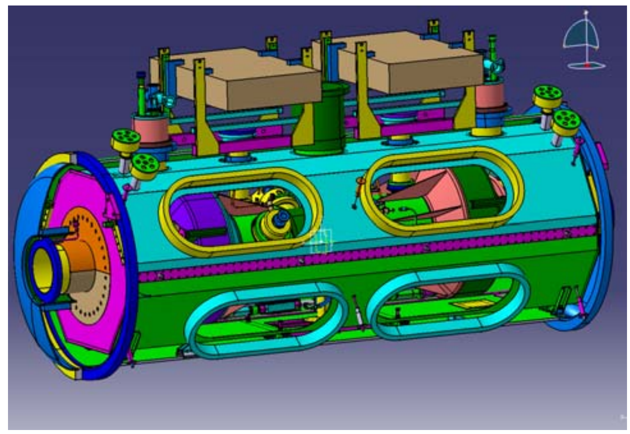

Figure 4 : Copper shield inserted in the cryomodule.

Two superconducting modules will finally be installed in the SOLEIL storage ring for the achievement of the revised requirements : nominal beam current (500mA), energy (2.75 GeV), losses from insertion devices (1150 keV) and accelerating voltage range between 3 and 5 MV. In order to better match these operating conditions, the power coupler will be modified for higher coupling to the cavity, $Q_{ext} = 1\ 10^5$ instead of $2.2\ 10^5$. For this purpose, the antennas of the fundamental power couplers will be cut and lengthened by 9.8mm, and the couplers re-conditioned to transfer more than 190 kW of RF power. This kind of modification had been successfully carried out in the past at CERN.

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

The cryomodule modification and tests will be performed in the last quarter of 2004 at CERN, in the frame work of a collaboration agreement between CEA, CERN and SOLEIL.

In parallel, the call for tender for the cryogenic source will be issued in October 2003. Beginning of 2005, we will start the installation and commissioning of the first cryomodule in SOLEIL. The order for the fabrication of a 2nd cryomodule, based on the improved design, will be placed early 2004.

SOLID STATE AMPLIFIER

Amongst the various alternatives which were considered, the selected solution for SOLEIL is the use of one solid state amplifier (200 kW) per cavity. The solid state amplifier is built from 315 W - 352 MHz elementary amplifier modules (fig. 5) which essentially consist of a MOSFET power transistor, an integrated circulator and an individual power supply of the DC/DC converter type.

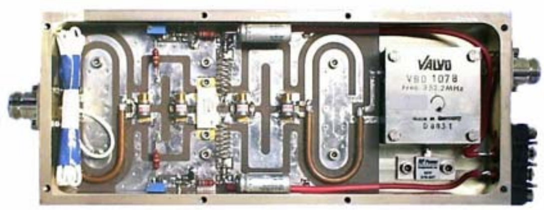

Figure 5: 315 W - 352 MHz amplifier module.

The specified module gain is higher than 11 dB with a tolerance of + 1.5 dB/- 0dB and a phase dispersion between the modules of less than 15°, at the nominal power of 315 W. The RF power splitting and re-combination schema is described in Figure 6.

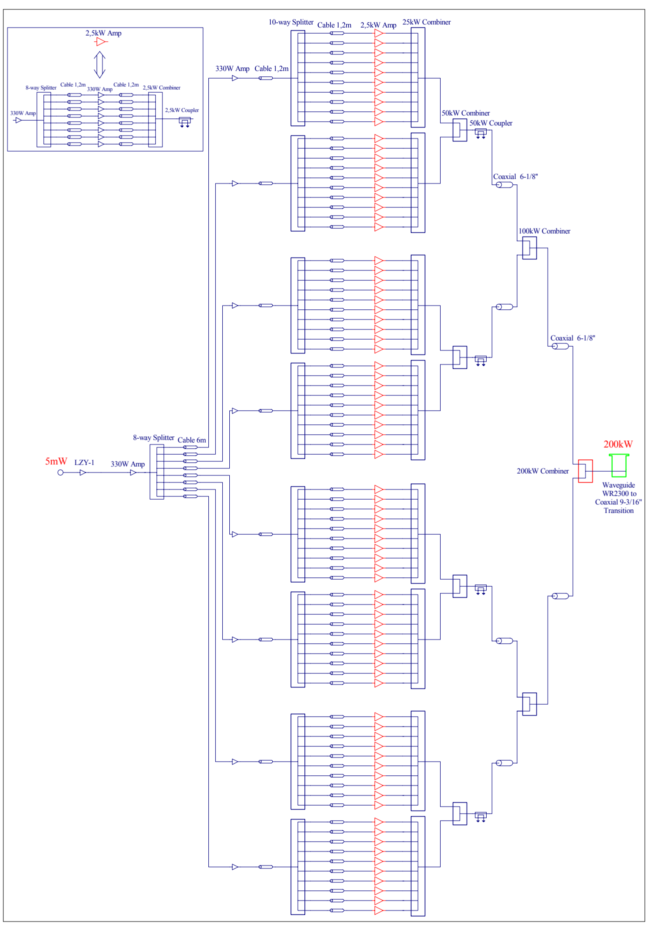

Figure 6: The RF power splitting and re-combination.

The total number of required modules for 200 kW is:
4x(10x18+2) + 1 pre-amplifier + 9 « stand-in » = 738.
The « stand-in » are spare modules which are already mounted on the amplifier, ready for operation if one of the modules from the first two amplification stages would fail.
The modules and the power supplies are bolted on water-cooled aluminium plates (« dissipators »), the amplifier modules on the inner side and the power supplies on the outer side.

For the two first amplifiers, some components (circulators, dissipators, …) are already ordered. Regarding the amplifier modules and the DC/DC converters, calls for tender are under preparation. All components for the 2 first amplifiers should be available in November 2004 for assembling. Their installation and commissioning in SOLEIL are scheduled for the beginning of 2005.

As a provisory back-up solution, we will use a 1 MW Klystron amplifier of the CERN-LEP type. By mid 2004, according to the status of the storage ring solid state amplifiers and the acquired experience on the booster 40 kW solid state unit, it will be decided whether the provisory back-up solution is installed or not.

ACKNOWLEDGEMENTS

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