THE RF SYSTEM OF THOMX*

M. El Khaldi, H. Monard, R. Marie, F. Wicek
LAL, Orsay, France
M. Diop, R. Lopes, A. Loulergue, M. Louvet, P. Marchand, F. Ribeiro, R. Sreedharan
SYNCHROTRON SOLEIL, Gif-sur-Yvette, France

Abstract

The RF system of the ThomX electron storage ring consists in a 500 MHz single cell copper cavity of the ELETTRA type, powered with a 50 kW CW solid state power amplifier (SSPA), and the associated Low Level RF feedback and control loops. The low operating energy of 50/70 MeV makes the impedances of the cavity higher order modes (HOMs) particularly critical for the beam stability. Their parasitic effects on the beam can be cured by HOM frequency shifting techniques, based on a fine temperature tuning and a dedicated plunger. A typical cavity temperature stability of ± 0.05°C within a range from 30 up to 70 °C can be achieved by a precise control of its water cooling temperature. On the other hand, the tuning of the cavity fundamental mode is achieved by changing its axial length by means of a motor-driven mechanism. A general description of the system and the state of its progress are reported together with some considerations of the effects of beam cavity interactions.

INTRODUCTION

ThomX is a Compton source project of hard X rays (45/90 keV). The machine is composed of a 50/70 MeV injector Linac and a storage ring where an electron bunch collides with a laser pulse accumulated in a Fabry-Perot resonator. The final goal is to provide an X-rays average flux of 10^{11}-10^{13}ph/s. The ThomX project [1] was recently funded and a demonstrator is being built on the Orsay university campus.

The proposed RF system for the ThomX storage ring is described in [2]. It consists in a 500 MHz single cell cavity of the ELETTRA type [3], powered with a 50 kW CW solid state power amplifier (SSPA), and the associated Low Level RF feedback and control loops [4].

When a bunch traverses a high Q resonator like a RF cavity, it excites its higher order modes (HOMs). The induced long term electromagnetic wakefields act back on the bunch over many revolutions and therefore can cause beam instabilities resulting in degradation of the beam quality or even beam losses.

In a low energy ring like ThomX, the natural damping time is so weak (~ 1 s) that a stationary stable condition can never be reached during the beam storage time, which is as short as 20 ms. On the other hand, it is sufficient to maintain the instability growth time larger than the beam storage time in order to keep at tolerable level the effect on the beam. That requires very strong attenuation of the cavity HOM impedances, typically by a few 10^3.

There are essentially two methods of coping with such HOM impedances, either a strong de-Qing of the HOM resonances [5, 6] or a tuning of their frequencies away from the beam spectral lines to prevent resonant excitations [7]. With the former it is difficult to reach attenuation factors larger than a few 10^2 over a wide frequency range. The latter, which consists in controlling the HOM frequencies, is better suited to a small circumference machine like ThomX, where the beam spectral lines spacing (16.7MHz) is very large as compared to the HOM bandwidth. As far as the HOM density is not too high and that they can be tuned far enough from the beam spectral lines ($\delta f >> f_{HOM}/Q_o$), it should be possible to reduce their effective impedances, R_{eff} (“as seen” by the beam), down to tolerable levels:

$$R_{eff} \approx R_s / (2Q_o.\delta f / f_{HOM})^2 << R_s \quad (1)$$

That led us to choose the ELETTRA type cavity which allows applying this technique in combining three tuning means. The HOM frequencies are precisely controlled by proper setting of the cavity water cooling temperature within a range from 30 up to 70 °C with a stability of ± 0.05 °C, while the fundamental frequency is recovered by means of a mechanical tuner which changes the cavity length. Besides, a movable plunger provides another degree of freedom for tuning the HOM frequencies.

In order to insure a fine control of the HOM frequencies, a good knowledge of their characteristics is mandatory. The main parameters of the fundamental and the HOMs have therefore been calculated using the Eigenmode solver of the 3D Electromagnetic HFSS [8] and CST MWS [9] codes and compared with the measured values on the cavity [10]. As it will be hard to cope with all these modes only by applying the tuning technique, one relies on the longitudinal and transverse feedbacks in order to bring additional damping.

STORAGE RING RF SYSTEM

The selection of 500 MHz as RF frequency leads to a quite good compromise in terms of cavity fundamental and HOM impedances, space requirements as well as the availability of RF power sources and other components.

500 MHz RF Cavity

One 500 MHz single cell cavity of the ELETTRA type, powered with a 50 kW CW SSPA, will provide the required RF voltage of 500 kV. It is made out of OFHC

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copper and equipped with 8 equatorial connecting ports: 3 large ones for the input power coupler, the pumping system, the plunger tuner and 5 smaller ones for vacuum and RF monitoring. It is water cooled by means of copper pipes, brazed on its external wall surface. Its temperature can be set within a range from 30 up to 70 °C with a stability of ± 0.05 °C by re-circulating the cooling water through an appropriate heat exchanger (cooling rack), similar to that was designed by the ESRF (figure 1).

Figure 1: Two of the ESRF cavity cooling racks.

The cavity cutoff tube (Ø 100 mm) will be connected to the octagonal shaped vacuum chamber by means of two 30 cm long tapers, made of 316 L stainless steel and bellows. The cavity assembly is shown in Figure 2.

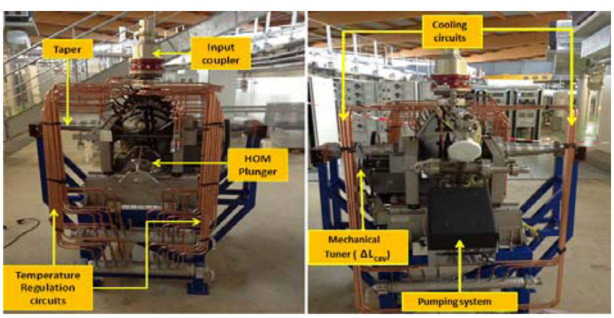

Figure 2: ThomX cavity assembly

500 MHz Solid State Power Amplifier (SSPA)

SOLEIL has functioned for about ten years with 352 MHz SSPAs, which were developed in house (1 x 35 kW in the booster and 4 x 180 kW in the storage ring). This experience has demonstrated that the SSPAs can advantageously replace the vacuum tubes in such an application, thanks to their inherent modularity and redundancy, the absence of high voltage and their extremely low phase noise. The R&D, carried out in the meantime at SOLEIL, has allowed improving the original design towards more compactness in doubling the power of the elementary amplifier module, while still reducing the thermal stress and improving the redundancy and the efficiency, for applications at 352MHz as well as any frequency ranging from 80MHz up to 1.5GHz [11].

The ThomX 50 kW SSPA (figure 3) consists in about a hundred of 500 MHz elementary amplifier modules, each containing a BLF578 LDMOS transistor and a circulator. They are mounted on water cooled dissipaters and can deliver up to 560W with a gain of 16.2dB (at 1dB compression) and an efficiency > 60%. The module output powers are combined by means of coaxial combiners for reaching up to 50kW. The 50V DC voltage is supplied to the transistors by 2kW - 220V AC / 50V DC converter units with 96% efficiency, which are combined in parallel.

The control system, developed by SOLEIL, relies on "MUX cards" containing a microcontroller and a CPLD, which manage all the monitoring signals to provide a fully stand-alone and self-protected operation of the SSPA. The MUX cards communicate with the local RF PLC or PC and with TANGO via Ethernet SNMP. The complete ThomX SSPA was successfully tested up to 50 kW into a dummy load at Soleil in March 2015. Its efficiency and gain versus output power for different DC supply voltage are shown in Figure 4. At 1 dB gain compression, the output power is 51.5 kW and the DC efficiency is 57% (AC efficiency is 54.5%) for a supply voltage of 48 V. Tests with high VSWR in CW and full reflection in pulse mode (any phase) were also performed.

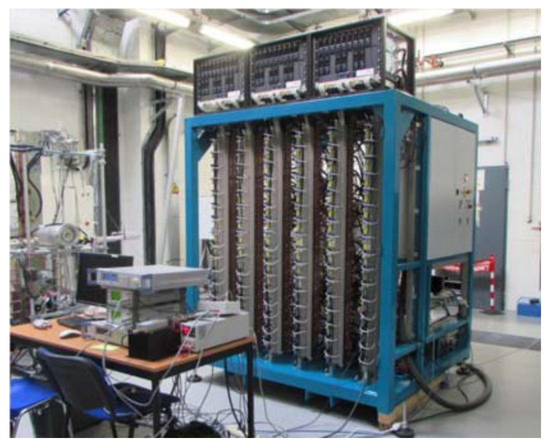

Figure 3: THOMX 50 kW SSPA under test at SOLEIL.

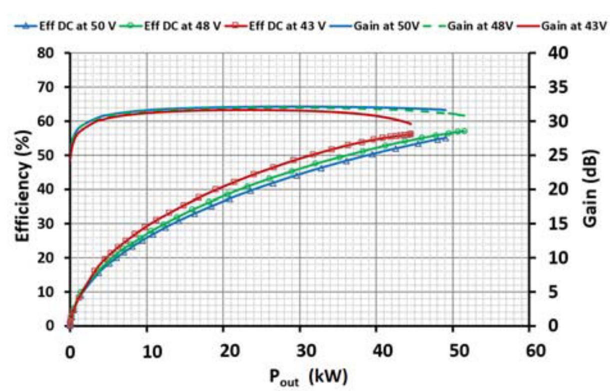

Figure 4: 500 MHz SSPA efficiency and gain vs. power.

Low Level RF and Feedback Systems

The task of the Low Level RF (LLRF) system is to control the amplitude and phase of the cavity accelerating voltage and its resonance frequency. The cavity voltage shall be controlled with typical stability of ± 0.2 % and

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± 0.2° by means of the conventional phase and amplitude loops of few kHz bandwidths. In addition a fast 1 MHz bandwidth longitudinal feedback (LFB) shall cope with the beam oscillations, caused by injection transients as well as by the longitudinal HOM excitations. It consists in a fast phase loop, combined with a high gain RF feedback acting directly on the accelerating cavity [4] as described in figure 5. According to computer simulations, such a LFB shall be able to provide the longitudinal damping of a few 10 µs, which is required to preserve the beam quality during its storage time of 20 ms with practical values of gain (figure 6).

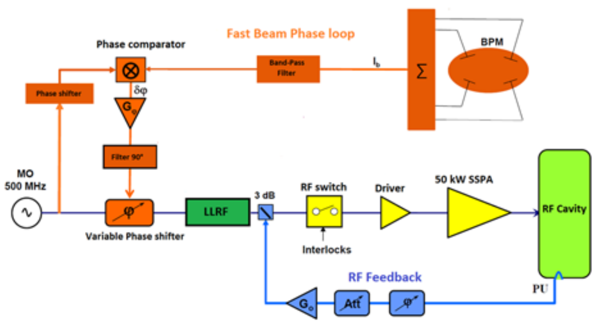

Figure 5: Schematic layout of ThomX LFB.

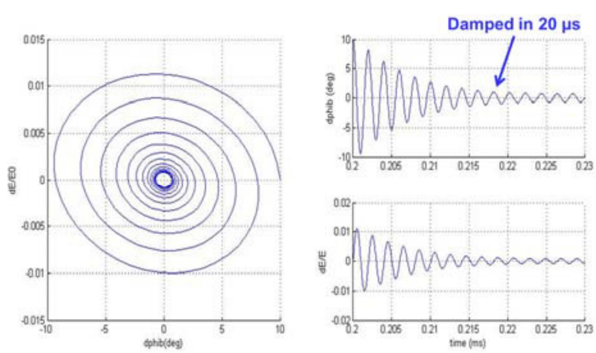

Figure 6: Damping of the energy and phase oscillations with the LFB ($\Delta\phi_{inj}$=10°, G_ϕ=50, G_φ=5, δ=150ns).

Besides, a transverse feedback (TFB), based on FPGA processing, similar to that used in SOLEIL [12], and acting on a dedicated 4 electrodes stripline kicker shall cope with the transverse oscillations in both planes, horizontal (H) and vertical (V).

In collaboration with the SOLEIL RF group, LAL has developed two versions of LLRF including LFB, PID controller and safety interlock system (figure7). The first version consists in separate analog control loops for frequency, amplitude and phase; the second version relies on the analog IQ modulation/demodulation technique. IQ regulation has the advantage of symmetrical I/Q signal paths, simpler nature of the electronics and wider phase control range.

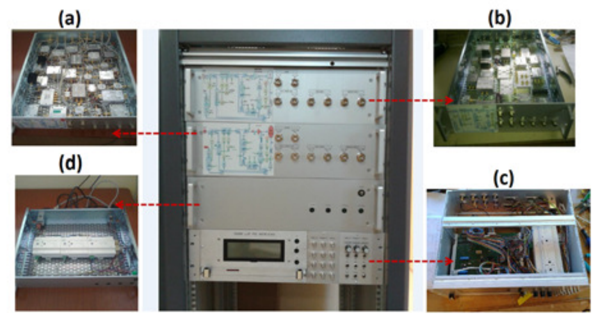

Figure 7: LLRF feedback and control systems; (a) LLRF (amplitude, phase & tuning loops) and LFB; (b): LLRF (IQ modulation/demodulation technique, tuning loop) and LFB; (c) PID controller and safety interlocks; (d) DC power supply.

CONCLUSION

The THOMX RF system is being completed; its integration and commissioning in ThomX is scheduled for 2017. At first, the RF cavity will be RF conditioned up to full power with its final SSPA in the casemate "shielded room" of the new IGLEX research platform located on the Orsay university campus. Then the complete RF system will be implemented and commissioned in the ThomX storage ring.

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