OPERATION OF THE SLS RF SYSTEM

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Abstract

The 500 MHz RF system of the Swiss Light Source (SLS) comprises five power plants, one for the Booster and four for the Storage Ring. Its installation and commissioning were performed during the year 2000 and so far it has proven to be quite reliable in operation. Presently, in the Storage Ring, one can store up to 320 mA of beam, without excitation of cavity Higher Order Modes (HOM). The design current of 400 mA was reached in spite of the weak excitation of one longitudinal HOM.

1 INTRODUCTION

The 500 MHz RF system of the SLS [1] comprises five power plants, one for the Booster and four for the Storage Ring (SR). Each of them essentially consists of a single cell copper cavity of the ELETTRA type, powered with a 180 kW klystron amplifier via a WR1800 waveguide line. The cavity power coupler is a coaxial line terminated by a coupling loop. The RF voltage is controlled by means of three regulation systems: phase, amplitude and frequency tuning (mechanical change of the cavity length). In order to cope with the Higher Order Mode (HOM) excitations that could drive multibunch instabilities at high beam current, two other frequency tuning means are used for the SR cavities: a precise control of the cavity temperature and a plunger.

The cavities with their input couplers, their tuning and cooling systems as well as the phase and amplitude regulation loops were supplied by Sincrotone Trieste, the klystrons by Marconi Applied Technologies (formerly EEV Ltd) and all the klystron DC supplies (cathode HVPS + auxiliaries) by THALES (formerly THOMCAST AG). The klystron cathode HVPS (46 kV – 7.5 A) is a Pulse Step Modulator, which consists of 68 HV modules connected in series and switched on/off by means of fast IGBT switches. The interlock system (PLD) and controls (VME/EPICS) were produced in collaboration between PSI and THALES.

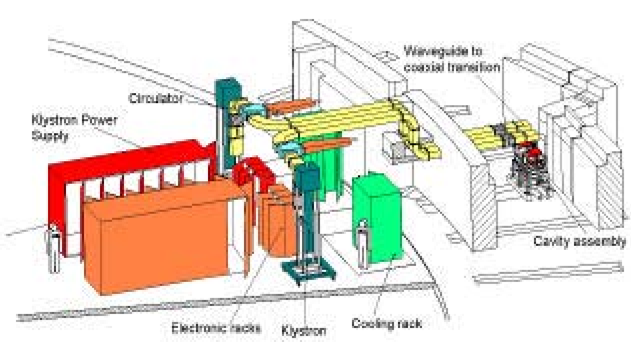

Figure 1: Storage ring RF plants 1 and 2

Figure 2: SR1 klystron

Figure 3: Booster cavity

2 COMMISSIONING AND OPERATION

During the year 2000, the five klystron amplifiers were installed and tested up to the maximum specified RF power of 180 kW (CW) into a dummy load. All of them could produce this power with a cathode DC supply of 45.5 kV and 6.5 A, that corresponds to an efficiency better than 60%.

After installation in the ring, the five cavities were first baked out at a temperature of 150 °C under pumping for about 24 hours and then RF conditioned up to a voltage of 650 kV (~ 62 kW of wall dissipation). The coupler loop position was adjusted for a coupling factor of 2 for the SR cavities (resp. 1.1 for the Booster). At the end of the conditioning process (about 20 hours), the vacuum pressure was around 10^{-8} mbar with RF and an order of magnitude lower without RF.

2.1 Booster RF Operation

The Booster RF plant (klystron amplifier, waveguide feeder line with circulator, cavity and regulation loops) was completed and put into operation for the Booster commissioning beginning of July 2000. The cavity RF voltage was cycled from 120 kV up to 500 kV at 3 Hz with a linear ramp (rise time of 70 ms, flat top of 100 ms) by modulating the reference voltage of the amplitude regulation loop. At this power level, the cavity vacuum pressure was 4 10^{-9} mbar without beam (2 10^{-8} mbar with beam). Under these conditions one could accelerate and extract at 2.4 GeV a charge of 1 nC, design goal for the Booster.

So far the Booster plant has run for about 6000 hours with practically no fault and the cavity vacuum pressure is now around 2 10^{-9} mbar in operation (with and without beam). A high reliability is essential for the continuous "top-up" injection, which became the routine operation mode of the SLS.

2.2 Storage Ring RF Operation

During the first two weeks of the SR commissioning (December 2000), three of the four SR RF plants were operational and, for the operation with beam, only two of them were simultaneously powered, each cavity providing an RF voltage of 600 kV (CW). With an accumulated beam current of only a few mA, negligible amount of RF power was transferred to the beam.

Beginning of 2001, the last SR plant was commissioned and the four cavities could be simultaneously powered for the operation with beam.

Typical cavity working conditions for a stored beam of 200 mA are shown in Table 1.

Table 1: Cavity working conditions with 200 mA in SR

Nb. of active cavities	Gap voltage [kV]	Incident power [kW]	Reflected power [kW]	Vacuum level [mbar]
4	550	71	1	5.10^{-9}
3	650	105	2	6.10^{-9}

It is worthwhile to note that at the beginning of the SR commissioning the cavity vacuum pressure reached about 1.10^{-7} mbar with only a few mA of stored beam and these vacuum conditions continuously improved during the operation.

So far, all SR plants have run for more than 4500 hours with very low failure rate.

The modularity of the RF system allowed us to operate up to about 300 mA using three plants out of four. This flexibility largely simplified the maintenance and upgrading of the system during the operation. One passive cavity was also temporarily used as "a diagnostic tool" for measurements of the synchronous phase and synchrotron frequency.

2.3 Higher Order Mode Tuning

In the SR, the interaction of the beam with a cavity HOM impedance can lead to Coupled Bunch Instabilities (CBI). The CBI growth rate, G_m depends on the frequency detuning between the HOM resonance and the coupled bunch mode frequencies:

$$G_m \propto \frac{I_b R_{sm}}{1+\left[2Q_m \dfrac{\nu_m - \nu_p}{\nu_m}\right]^2}$$

I_b is the stored beam current, R_{sm}, Q_m and ν_m are respectively the HOM shunt impedance, quality factor and frequency; ν_p $(p = 1,2,\ldots\infty)$ are the coupled bunch mode frequencies:

$$\nu_p = p.\nu_{rev} \pm \begin{cases} \nu_s & \text{longitudinal case} \\ \nu_\beta & \text{transverse case} \end{cases}$$

where ν_s , ν_β and ν_{rev} are the synchrotron, betatron and revolution frequencies, respectively.

The stability is ensured if the CBI growth rate is lower than the natural radiation damping rate.

Following the technique developed at ELETTRA [2], the HOM tuning is controlled via the cavity temperature, which can be set between 36°C and 70°C with accuracy better than ± 0.1°C. For any change of temperature, the tuning loop keeps constant the fundamental frequency by mechanical deformation of the cavity. The effective HOM frequency shift per degree is thus:

$$\tau_m = \left(\frac{\partial \nu_m}{\partial T}\right)_{eff} = \frac{\partial \nu_m}{\partial T} + \alpha_m \tau_0$$

$\alpha_m = \delta\nu_m / \delta\nu_0$, $\tau_0 = \delta\nu_0 / \delta T$ (open loop) and ν_0 is the fundamental mode frequency.

The HOM parameters of each cavity were measured at low power and used to calculate their frequency versus temperature; as an example, the longitudinal mode parameters of cavity 4 are listed in Table 2.

Table 2: Cavity 4 longitudinal mode parameters

Mode	**ν_m (40°C) MHz**	**α_m**	**τ_m kHz/°C**	**R/Q Ω**	**Q_m**	**R_{sm} kΩ**
L0	499.822	1.0	-9.4	86	13578	1168.
L1	948.046	0.62	-10.4	29	26453	767.1
L2	1058.485	-0.3	-19.2	0.9	6048	5.4
L3	1420.62	-2.29	-43.7	5.0	30224	151.1
L4	1514.216	-0.5	-32.2	4.3	4400	18.9
L5	1606.873	-3.83	-57.2	8.9	40888	363.9
L6	1874.467	-0.40	-33.6	0.4	37328	14.9
L7	1947.189	-2.3	-52.4	1.9	16884	32.1
L8	2071.967	-8.0	-100.	0.1	15000	1.5
L9	2123.04	-8.47	-107	7.9	29763	235.1

From the calculated HOM frequencies we could then compute the CBI growth rates and produce, for each cavity, temperature maps as shown in Figures 4 and 5. As an example, the graph in Figure 4 shows a large stable temperature window (53 - 59°C) for cavity 4 and that was experimentally confirmed in operation with beam. In the same way, a stable working point was easily found for cavity 1. On the other hand, only very narrow stable windows were found for cavity 2 and 3 (Figure 5) and that resulted in a weak excitation of a longitudinal HOM above 320 mA of stored beam. The situation could certainly be improved, using the plunger as third degree of freedom for tuning the HOM; this requires further investigations with dedicated beam time. Moreover, transverse and longitudinal feedbacks will be soon implemented that will contribute to damp the CBI.

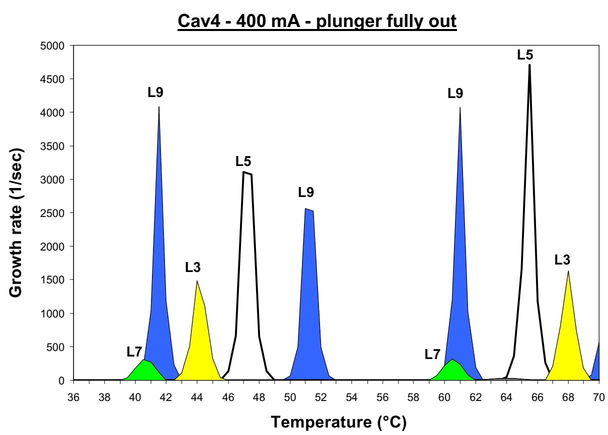

Figure 4: Cavity 4 HOM temperature map

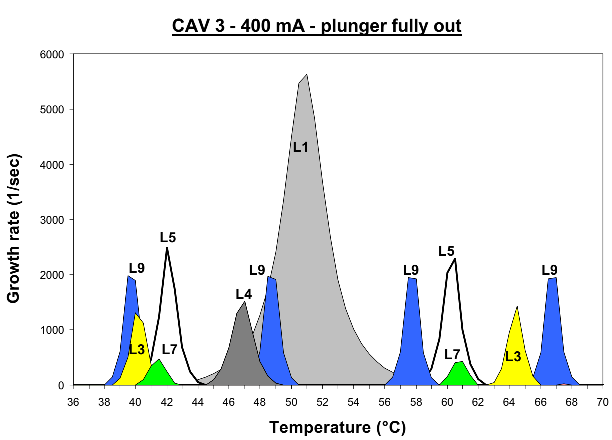

Figure 5: Cavity 3 HOM temperature map

3 UPGRADING

Insertion of filters at the output of the klystron HV switched power supplies significantly reduced the voltage ripple generated at high frequency, especially in the critical range of 4 - 12 kHz. Table 3 shows the ripple spectral components after filtering; the overall value is less than 0.6 $\%_{pp}$.

Table 3: Ripple of the HV switched power supplies

Klystron Voltage	Klystron Current	[1 – 2] kHz	[2 – 4] kHz	[4 – 12] kHz	> 12 kHz
38 kV	5.3 A	6 V_{rms}	4.5 V_{rms}	3.5 V_{rms}	23 V_{rms}
45.7 kV	5.3 A	5 V_{rms}	5 V_{rms}	3.5 V_{rms}	10 V_{rms}

The phase and amplitude loops were also modified for increasing their bandwidth up to 4 kHz. The residual RF phase noise, measured after these improvements, was less than $0.5°_{pp}$ in the frequency range 0-40 kHz.

It is also planned to complement the 500 MHz system described above with a third harmonic idle super-conducting cavity, which will lengthen the bunches and consequently improve the beam lifetime in the SR [3,4]. Thanks to this system, which should be operational in July 2002 [5,6], one expects at least to double the beam lifetime.

4 CONCLUSIONS

After more than one year of operation the SLS RF system has proven to be quite reliable. Presently, 320 mA can be stored without cavity HOM excitation. The design current of 400 mA was reached with a weak excitation of one longitudinal HOM. The suppression of the remaining HOM excitation at full beam current requires further optimisation of the HOM tuning on cavities 2 and 3.

The third harmonic superconducting cavity for bunch lengthening is being installed and should be operational in July 2002.

5 REFERENCES

[1] P. Marchand et al, RF System for the SLS Booster and Storage Ring, PAC99, p. 986.
[2] M. Svandrlik et al, Improved Methods of Measuring and Curing Multibunch Instabilities in ELETTRA, EPAC96, p. 1144.
[3] P. Marchand, Possible Upgrading of the SLS RF System for Improving the Beam Lifetime, PAC99, p. 989.
[4] M. Svandrlik et al, The SUPER-3HC Project : An Idle Superconducting Harmonic Cavity for Bunch Length Manipulation, EPAC2000, p. 2051.
[5] S. Chel et al, SUPER-3HC Cryomodule: General Layout and First Tests, these Proceedings.
[6] P. Marchand et al, Cryogenic System for the SLS Third Harmonic RF Cavity, these Proceedings.