UPGRADE AND COMMISSIONING OF THE LNLS RF SYSTEM

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Abstract

The RF system of the LNLS electron storage ring has been upgraded and is now in the final commissioning stage [1]. A second RF cavity was added to the system in order to prepare it for the power demands that the installation of insertion devices in the near future will bring about. Moreover, by increasing the available RF power we are also aiming at the possibility of attaining higher currents and longer lifetimes. In this paper there is a short description of the main characteristics of the system and of the most relevant aspects of its operation. The focus is on the commissioning aspects, with particular emphasis on the attempts to solve the instability problems that plagued the operation of the machine over the first months after the installation of the new RF system.

THE RF SYSTEM

The new RF system of the LNLS storage ring is not just a duplication of the previous system although that was the basic motivation for the upgrade. The whole low level RF system was rebuilt including the power amplification chain and the control loops. A second RF cavity has been added to the system, installed in the same straight section and 1.5λ downstream from the first one. Since each cavity is powered and controlled by completely independent RF stations, the accelerating fields in both cavities can be adjusted to the correct phase by shifting the phase of one station with respect to the other. Each of these stations has the three standard control loops: amplitude, frequency tuning and klystron phase.

Each station includes a 60kW UHF klystron tube with its pre-amplification chain and auxiliary systems, a high power circulator and one RF cavity. The RF cavities are single cell bell-shaped ELETTRA-type cavities operating at 476 MHz. The input power couplers connecting each cavity to the $6\ \ 1/8$” coaxial line are positioned such as to have $\beta \simeq 3$ and are inductively coupled to the cavities. Each cavity has its own independent heating unit that allows the temperature to be controlled between 40 and $75°C$ with no more than $0.1°C$ of temperature fluctuation in the whole range. The lateral ports of the cavity are cooled with water at $33 \pm 0.4°C$. The other two parameters that can be used for cavity tuning are the plunger position and the elastic deformation of the cavity. The axial deformation of the cavity in the elastic regime is used in the feedback loop that keeps the cavity tuned to the desired frequency whereas the plunger is used only for HOM shifting. Temperature and plunger position are used to set the operation point of the cavities.

COMMISSIONING

During the first months after the installation in the storage ring, the system was operated with just one active cavity, namely the old cavity with its new RF station. We were forced to that by difficulties in the power conditioning of the new RF cavity, which delayed the start of the commissioning of the whole system by two weeks. That prevented the second system from being ready for operation at the opening of the user run. The commissioning of that station was postponed and progressed at a slow pace during short maintenance shifts until June when the machine was shut-down for a 4-week period. The RF system performed reliably with just one cavity but the beam suffered from frequent instability outbreaks during the user runs. The effects of these instabilities could be sensed in some of the beam lines and were a major concern during the period. In the following sections we describe the main aspects of the commissioning of the new RF system as well as the main steps taken towards the understanding and solution of the problem.

Operation with a Passive Cavity

During the period it operated with just one active cavity the machine experienced several orbit stability problems, related to the parking position of the passive cavity. The attempts to eliminate the instabilities by changing the parameters of both cavities have proved to be not very effective. The search for a convenient operational point of the passive cavity was performed by scanning the parameters that can be used to control the cavity tuning: temperature, plunger position and axial deformation. One of the problems detected with the operation with a passive cavity was the necessity of performing large plastic deformations of the cavity in order to take the fundamental mode far off tuning. For the passive cavity the frequency loop is not active and frequency drifts due to small temperature variations of the cavity may occur. The main task was to find a setting of the cavity that would be free from the longitudinal HOMs for a reasonable range of temperatures.

The typical signature of the beam instabilities observed during the user runs is an orbit fluctuation measured only in the horizontal BPMs as shown in Fig. 1. The distortion

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pattern has the same 6-fold symmetry of the storage ring and shows up in the form of a fast transition between two states. For most of the user run periods small orbit fluctuations with amplitude of $\pm 3\,\mu$m were observed and could be detected at the most sensitive beam lines. However, larger amplitude distortions were sometimes observed even after a supposedly good operation point was achieved.

The origin of the orbit fluctuations was identified as being related to large amplitude dipolar longitudinal oscillations caused by the interaction of the beam with HOMs excited in the cavities. In fact, the second order term of the non-linear dispersion function $\eta_1(s)$ was measured and has the same profile observed in the BPM readings, as shown in Fig. 1. When a longitudinal dipole oscillation is present either by external phase modulation or by the influence of a HOM, the relative energy deviation is given by $\delta(t) = \delta_0 \cos \Omega_s t$. The closed orbit distortion is then

$$x_\epsilon(s,t) = \delta(t)\eta(s) + \delta^2(t)\eta_1(s) \quad (1)$$

Since the oscillation is fast (the synchrotron frequency Ω_s is of the order of 20 kHz) the BPMs measure only average positions

$$\langle x_\epsilon \rangle = \frac{1}{2}\eta_1(s)\delta_0^2 \quad (2)$$

such that the maximum amplitude of the oscillations is then given by

$$x_\epsilon^{max}(s) = \delta_0 \eta(s) = \sqrt{\frac{2\langle x_\epsilon \rangle}{\eta_1(s)}}\,\eta(s) \quad (3)$$

x_ϵ^{max} shows up in the detectors in the beam lines as an effective increase of the horizontal size of the beam. The same orbit distortions can be obtained by phase modulating the RF master generator that drives the RF stations at the synchrotron frequency.

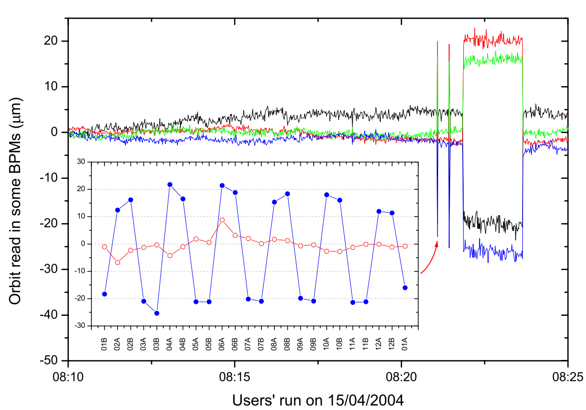

Figure 1: Orbit distortion caused by a Longitudinal CBI. The distortion occurs only in the horizontal orbit and has the same 6-fold symmetry of the machine.

Operation with Two Cavities

At the outset of the commissioning process, the klystron phase loops were still not operational. The first attempts to operate with both cavities failed due to a systematic unbalancing of the output power in both RF stations. In the course of the accumulation process the stations started to drift in phase one from the other culminating with the stations completely out of phase. The high voltage power supplies that energize the klystron tubes are an important source of phase fluctuation between the stations and this fluctuation ranges up to 8° for each station. When the klystron phase loop is turned on this amplitude is reduced to less than 1°. Another inconvenience is the dependence of the measured phase on the signal amplitude for the mixing based phase detectors used in the system. However, the main cause of phase drift is the excitation of HOMs in the cavities that may lead to cross-talk between them via bunched beam dilution processes [3]. When the klystron phase feedback is operating the system is less sensitive to phase drifts.

During the shutdown period, the control loops of both RF stations had their bandwidth and gain tuned and optimized so as to become less sensitive to noise. The commissioning of the several components of the new RF system has progressed steadily, although arcing in one of the high power circulators still happens when the beam is dumped at high current. The RF system is now operational with two active cavities and most of the commissioning time was spent seeking for beam stability.

Temperature and plunger scans of both cavities allowed the identification of regions where the cross-talk between the stations is absent or is under control. During the scans some parameters have been monitored that could result in a figure of merit for the operation point. The excitation of a HOM can be easily determined by the effect it has on the reflected power from the cavity and temperature oscillations in the cooled parts of the cavity like plunger and input coupler. A longitudinal CBM being excited has impact on the orbit and on the readings of photo-detectors positioned in the most sensitive beam lines. The count rate of a beam loss monitor, beam lifetime and phase between the cavities have also been monitored during the scans. From these scans, it was possible to determine the regions in the temperature vs. plunger parameter space where the excitation of strong HOMs can be averted. However, even though phase drifts ceased to be a concern, the same is not true for the orbit fluctuation problem which is still present. The amplitude of the fluctuations is very small ($\pm 2\,\mu m$) but can still be an annoyance for very sensitive experiments such as dicroism measurements in the UV beam lines.

HOM Mapping

The old cavity was installed in the storage ring without any previous measurement of the HOMs. The HOM screening for the new cavity had been performed only at room temperature before installation. A detailed survey of the behaviour of these modes with the cavity tuning parameters has been undertaken for both cavities *a posteriori* the installation in the storage ring. The identification of the potentially hazardous modes was possible by comparing them with the modes measured for the booster cavity, which had been fully characterized in the lab, and by checking the frequency shifts of the modes with those predicted from their simulated field maps. The procedure adopted is the same used for similar cavities operating at ELETTRA and ANKA[2] and consisted in the determination of the growth rate of the coupled bunch mode (CBM) instabilities with temperature and plunger position. By mapping the variation of the modes with these parameters, it is possible to determine the regions for which the growth rates are below the radiation damping rate of the oscillations. For the LNLS storage ring at high energy the radiation damping time is $\tau_s = 3.7\,ms$.

The results of the HOM survey showed a comfortable situation for the old cavity. The temperature range for which there are no dangerous longitudinal HOMs is quite wide. Unfortunately, the same is not true for the new cavity. A list of some of its main longitudinal modes is shown on Table 1. T_C is the critical temperature of the mode, defined as the temperature at which the frequency of the HOM matches the frequency of the CBM oscillation. The values of Q_L have been measured in the new cavity but those of R/Q are simulated values. The main problem with the new cavity is the longitudinal mode L1 whose critical temperature is just inside the temperature range of the heating unit. An attempt was made to shift that mode using the plunger already installed in the cavity but the extent of the plunger motion was not enough to accomplish the task.

Table 1: Main TM0 Modes of Cavity 2

Mode	**F** (MHz)	R_s/Q (Ω)	Q_L	T_C ($^\circ C$)	CBM n
L1	904.128	29.7	20000	74	133
L3	1356.89	5.4	4000	31	126
L5	1538.25	9.5	4000	54	34
L9	2040.125	8.2	25000	28	43

Longitudinal Coupled Bunch Instabilities

From the several temperature and plunger scans it was possible to identify the mode L1 of the new RF cavity as the main source of instabilities in the machine. The coupled bunch mode associated with this mode, CBM $\sharp 133$, is always present in the beam spectrum except in those regions where the growth time of other modes, such as CBM $\sharp 126$ associated to mode L5, are larger. HOM mapping was useful for the identification of the best operation point although these points were not good enough. Since it was not possible to find a passive way to create a glade in the cavity spectrum that would be free from instabilities, an active solution in the form of phase modulation of the RF fields at

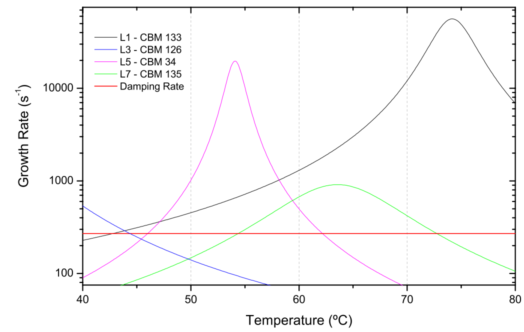

Figure 2: CBM growth rates for the new RF cavity in the best operation point for the plunger position, calculated for $E_0 = 1.37$ GeV and $I = 250$ mA. Notice the absence of a mode free region.

twice the synchrotron frequency was attempted with success. The phase modulation has a noticeable impact on CBM amplitudes (Fig. 3) and helps alleviate the orbit fluctuation [4]. Concerning the search for a passive solution to the problem, measurements indicate that modifying the current plunger installed in the cavity so as to increase its active range seems to be a promising way to shift away mode L1.

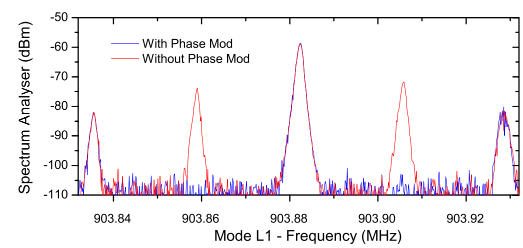

Figure 3: Effect of phase modulation on the dipole CBM mode $\sharp 133$.

Acknowledgments

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