# UPGRADE OF THE RF SYSTEM OF THE LNLS UVX STORAGE RING

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## *Abstract*

In this paper we describe the new RF system for the LNLS synchrotron light source which will double the RF power currently available to the beam. The efficiency of the injection system increased substantially with the installation of a 500 MeV booster synchrotron in 2001. That made possible the accumulation of much higher currents in the storage ring leading to the need for the increase of the available RF power. The upgrade of the current system includes the installation of a second RF plant and an overall reformulation of the low power and control circuits.

## 1 INTRODUCTION

The RF system of the LNLS 1.37 GeV storage ring consists of a single RF station comprising a 60 kW CW Klystron amplifier, a circulator and a single-cell cavity. In its current stage the system is able to maintain a maximum stored beam current of 300 mA with 370 kV of accelerating voltage. There are no insertion devices installed in the machine at the moment. A recently commissioned booster synchrotron [1] raised the injection energy in the ring from 120 MeV to 500 MeV resulting in great improvement in the attainable stored current. In addition, the better injection conditions now make possible the installation of insertion devices in the light source. One such device is to be installed next year. Moreover, the upgrade of the vacuum system is being prepared and is to be installed later this year. This will allow the machine to operate at higher currents. In order to account for the demands for RF power that the new operational scenario brings about, a new RF plant will be added to the current system thereby doubling the RF power available nowadays. The new system will allow us to store a 400 mA electron beam with 600 kV of accelerating voltage (and expected 10 hours beam lifetime at 0.3% coupling) with 4 insertion devices installed in the storage ring. Table 1 shows the basic relevant parameters of the LNLS electron storage ring.

Table 1 - Parameters of the Storage Ring.

| | | |
|---|---|---|
| Beam Energy, $E_0$ | 1,37 | GeV |
| Beam Current (Maximum), $I_b$ | 400 | mA |
| Revolution frequency, $f_0$ | 3,22 | MHz |
| Harmonic number, h | 148 | |
| Energy lost/turn (dipoles), $U_0$ | 113,99 | keV |
| Radiated Power (dip.)/100mA, $P_0$ | 11,4 | kW |
| Momentum compaction, $\alpha$ | $8{,}3\times10^{-3}$ | |
| Natural Energy Spread, $\sigma_E/E$ | 0.06 | % |
| Longitudinal damping time, $\tau_s$ | 6,2 | ms |
| Horizontal damping time, $\tau_x$ | 13,2 | ms |
| Vertical damping time, $\tau_y$ | 12,6 | ms |

## 2 TOPOLOGY OF THE SYSTEM

The main point we kept in mind when choosing the topology of the new system was to get the maximum yield from the system concerning the net power available to the electron beam. The power available should be able to withhold a 400mA beam at 1.37 GeV with four insertion devices installed in the machine (assuming 1.5 kW/100 mA radiated power for each ID). The choice was also based on guidelines related to the minimisation of the installation and maintenance costs of the new system. Four alternatives have been considered: (1) add a second cavity or (2) a second 60 kW klystron to the current system, (3) add a second complete rf plant and (4) add a second cavity and replace the current klystron by one with higher power output. The best cost-benefit trade-off is just to double the current system. A new RF plant, with a klystron amplifier feeding a single RF cavity, will be added to the system. That is expected to increase the available RF power from the generators to about 100 kW. The second cavity will be installed by the side of the cavity already in operation, in the same straight section of the ring. There is still room for a third RF cavity in the same section and the whole system is being conceived in a way to provide flexibility for future expansion.

### *2.1 High Power System*

The new system consists of two independent RF plants each one comprising an accelerating cavity, a high power circulator, a 60 kW UHF CW klystron and control circuits. Ancillary components such as filament and focussing lens power supplies are under construction in the lab. The 150 KVA high voltage power supply for the transmitter will be provided by a Brazilian vendor. Solid-state amplifier modules developed for the booster RF system, coupled to a commercial high gain amplifier, are to be used as preamplifiers to the high power klystrons [2]. The modules will be adjusted so as to supply just the 50 W necessary to drive the klystron.

The high power circulator can stand up to 75 kW forward and reflected CW power, has 6-1/8" coaxial ports and is matched to an 80 kW water-cooled 50 Ω load. The waveguide system uses EIA 6-1/8" coaxial transmission lines and is being assembled in the lab. Forward and reflected power flow is monitored at the exit of the klystrons and of the circulators.

The single cell, bell shaped ELETTRA type cavity to be installed in the machine is basically identical to the one

Table 2 - Parameters of the RF System

| | |
|---|---|
| Maximum current, $I_b$ | 400 mA |
| Insertion devices, $n_w$ | 4 |
| Klystrons, $n_g$ | 2 |
| RF cavities, $n_c$ | 2 |
| Fundamental frequency, $f_0$ | 476 MHz |
| Q (unloaded), $Q_0$ | 43000 |
| Shunt impedance, $R_s$ ($P=V^2/2R_s$) | 3.5MΩ |
| Maximum power per klystron, $P_g$ | 60 kW |
| Maximum power (cavities), $P_{gmax}$ | 100 kW |
| Power radiated - IDs (100 mA), $P_w$ | 1,5 kW |
| Power radiated - dipoles, $P_0$ | 45.6 kW |
| Total power radiated in the IDs | 24 kW |
| Total gap voltage, $V_{cy}$ | 600 kV |
| Overvoltage factor, q | 3,8 |
| Maximum coupling for cavity 1, $\beta_1$ | 1,5 |
| Maximum coupling for cavity 2, $\beta_2$ | 3 |

already in operation. The fundamental mode of the cavity is tuned to 476.066 MHz. There are two independent tuning systems. Besides the conventional tuning plunger the tune can be changed by elastic deformation of the cavity along the axial direction. A wide-ranging study of the resonant modes of the cavity is being carried out. All the HOM up to 2.1 GHz are being investigated. Measurements are being performed in order to map the variation of the resonant frequencies with temperature, and plunger and axis positions.

The temperature control system is under construction in the lab and will be able to control the temperature of the cavities to within ±0.1°C. The temperature set point can vary from 45ºC to 60ºC and control must be independent for each cavity. Temperature is an important parameter for the control of the instabilities caused by the HOMs of the cavity and may have to be set independently for each cavity. Such temperature stability is already achieved in the current system.

## *2.2 Low Level System*

The reference RF signal for both storage ring and booster RF systems is generated by a high stability, low-noise master oscillator operating at 476.066 MHz and located in the control room. A sample of that signal is used to generate timing signal for various accelerator components. After being split and conveniently amplified and monitored the drive signal is taken to the klystron amplifiers and to the control loops.

In order to save development time we initially plan to have the whole low power system based on purely analog devices. The present system has only two control loops, for frequency and amplitude. For the new one a phase-feedback loop is necessary for the phase balance between the two RF stations. Except for the phase control circuits all the other circuits work independently for each RF plant.

The amplitude loop compares the voltage measured in the cavity with a user specified reference voltage and adjusts an electronically variable attenuator to minimize the difference between those values. The loop has to keep the amplitude stability in a 1% range in order to counteract beam loading effects. The amplitude loop controls the accelerating voltage in the cavity gap by changing the input power to the klystron preamplifier acting on a voltage controlled attenuator. It has about 1 kHz bandwidth, which is well below the synchrotron frequency of 27 kHz.

The frequency loop controls the tune of the cavity by changing the plunger position and by deforming the cavity. It is essential for providing stability against thermal variations and for optimising power transfer efficiency from the generator to the cavity by keeping the adequate tuning angle. The RF signals from the cavity and from the amplifier are down-mixed to the 100-kHz range and the phase detection is performed with a HCT4046 PLL. The same phase detector is used in the phase loop. A mechanical phase shifter is used for coarse matching the phase between the two plants. The phase loops will act on each plant so as to keep the phase of the RF in the cavity fixed related to either the master RF signal or to a signal taken from the beam. The system is expected to keep the phase difference between the two plants and the reference to within 1°. This way we expect to compensate for variations in the RF power output, especially those due to fluctuations in the power supplies and klystrons. The lack of such phase control may lead to synchrotron oscillations that may be harmful for the beam besides degrading the beam quality.

A fast phase feedback loop for high beam loading compensation is planned to be installed in the future.

## 3 OPERATIONAL ASPECTS

The current RF system was originally designed to operate at 1.15 GeV (the design energy of the LNLS storage ring) and maximum current of 100 mA. As a consequence the power feedthrough was designed to have a small coupling factor, β=1.5, which is not optimised for high current beams. It is possible to operate the system with the two cavities set at different coupling factors but at the cost of losing power transfer efficiency, particularly at high currents. At 400 mA the reflected power from the cavity (with the present power feedthrough) to the circulator would be as high as 10 kW and that limits the maximum sustainable current to about 350 mA with four insertion devices installed in the machine. Besides, we would have to operate both cavities at different gap voltages. Since the synchronous phase is determined by the beam and by the total effective accelerating voltage it has to be the same for both cavities. Figure 1 shows the phasor diagram for the scenario with two cavities with different coupling factors. As the optimal tuning condition

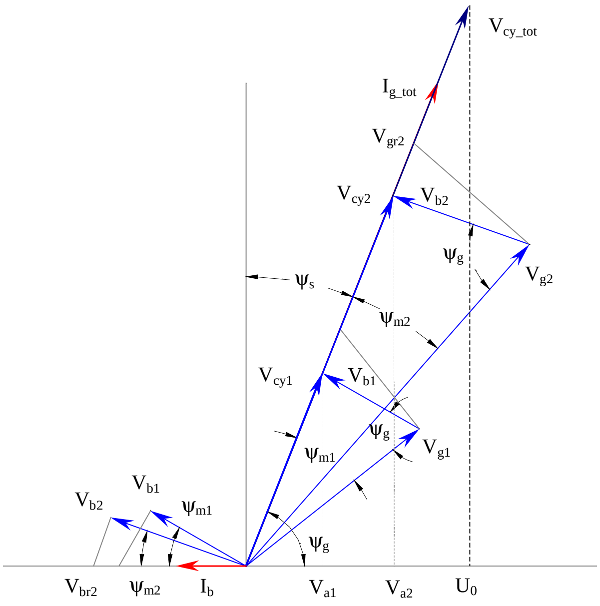

Figure 1 - Phasor diagram for the two-cavity system with different coupling factors: $V_{cy}$ = voltage in the cavity, $V_g$ = voltage of the generator as seen by the cavity, $V_b$ = beam induced voltage and $\psi_m$ is the optimum tuning angle.

for each cavity relates the phase of the generator to the synchronous phase according to [3]

$$\psi_g = \tfrac{1}{2}\pi - \psi_s \,,$$

— which maximises the energy flow from the generator to the cavity — the phase of the generator has to be the same in both RF plants. Once this condition is satisfied the voltages in both cavities are in phase and the total accelerating voltage is just the scalar sum of the individual voltages. The cavities can be treated independently and operational conditions can be obtained for the system. These conditions were obtained for the maximum expected beam current and for the net RF power available from the two klystrons, taking into account the effects of beam loading in the cavities. For each cavity the power required from the generator in order to maintain a certain gap voltage $V_{cy}$ for a given current $I_b$ is [3]

$$P_g = \frac{V_{cy}^2}{2R_s}\frac{(1+\beta)^2}{4\beta}\left[\left(\frac{\operatorname{sen}\psi_s}{\cos\psi}+\frac{2I_bR_s}{V_{cy}(1+\beta)}\cos\psi\right)^2+\left(\frac{\cos\psi_s}{\cos\psi}-\frac{2I_bR_s}{V_{cy}(1+\beta)}\operatorname{sen}\psi\right)^2\right]$$

where $\psi$ is the tuning angle of the cavity.

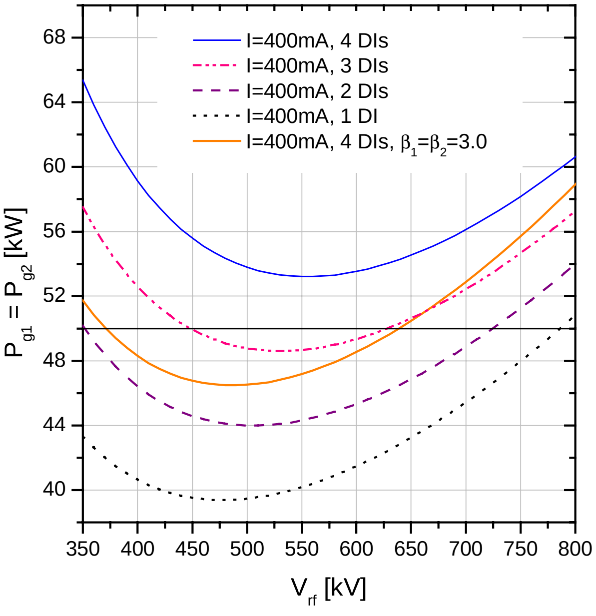

Figure 2 - Power demanded from the generators in the case in which power is the same for both cavities, calculated for different total RF gap voltages. The curves below the 50 kW line correspond to the valid operational conditions for the scenarios studied. Each ID radiates 1.5 kW/100 mA.

Given the maximum power available from the generator there is a limit for the beam current that can be held by the system. The power demanded from the generator depends on the gap voltage, on the coupling to the cavities and on the beam current. Obviously, the current can be sustained whenever the demanded power for both cavities is compatible with the available power. Coupling depends on the geometry of the feedthrough and cannot be changed during operation. Once the coupling is set it will be optimum for a certain operational condition (beam current). The power reflected from the cavity increases as far as the operational parameters are driven away from the optimum settings. With that in mind we can find the demanded power to establish a certain operational condition. Considering a given total gap voltage, a certain beam current $I_b$ and the operational condition in which the power demanded from the generators is the same for both cavities, it is possible to sustain the beam if this power is smaller than the available power from each generator. Figure 2 shows the calculations for some relevant scenarios. We can see that it is impossible to sustain 400 mA with 4 IDs without increasing the coupling factor of the old cavity. For the possible operational conditions we calculated the valid gap voltages and tuning angles for each cavity.

## 4 FINAL REMARKS

Most of the main components of the RF system are already in the lab and are now being characterised. As a result of the preliminary studies on the performance of the system a new coupler was ordered from ELETTRA that will raise the coupling factor to the old cavity to 3. The whole system will be put to operation in the second half of 2003.

## 5 REFERENCES

[1] P.F. Tavares et al, "Commissioning of the LNLS 500 MeV Booster Synchrotron", PAC2001.

[2] C. Pardine et al, “THE RF System of the LNLS Injector synchrotron”, PAC2001.

[3] H. Wiedemann, “Particle Accelerator Physics II”, 2nd ed, Springer-Verlag, 1999.