RF SYSTEM FOR THE ELETTRA BOOSTER SYNCHROTRON

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Abstract

The booster synchrotron now under design for the synchrotron light source ELETTRA will ramp the energy of a 4 mA beam from 100 MeV to 2.5 GeV with a repetition rate of 3 Hz. The design of the booster RF system is governed by the requirement of being as simple, conservative and reliable as possible, taking into account the high reliability required especially since the possibility of top-up injection in the storage ring is foreseen. The RF system will use ELETTRA type cavities. The total RF power required will be higher than 70 kW. Operating frequency will be the same of the storage ring (499.654 MHz). This will assure that the time structure of the bunch train at extraction from the booster will fit comfortably in the storage ring RF buckets. The low level electronics will include, apart from a phase shifter for timing adjustment and a fast switch for interlock purposes, a tuning loop for each cavity, an amplitude loop (which will also be used to ramp the cavity gap voltage) and a phase loop. A general description of the system and the status of the design are given here.

1 INTRODUCTION

Presently the beam is injected in ELETTRA at 1 GeV and ramped in the ring to 2 GeV. Despite the improvements to this procedure which has been implemented during these years, this has various consequences on the operation of the facility as time lost for the refill procedure, effects on the thermal stability of the closed orbit due to the thermal cycling, etc. For all these reasons an injection booster synchrotron is now under design study [1]. This can be conveniently located in the open space inside the storage ring building. Construction can be performed without major interference to the operation of the light source, up to the moment of connection. The booster will be designed to the maximum envisaged storage ring energy (2.5 GeV), although normally the storage ring is operated at 2 GeV (~80 % of user time) or at 2.4 GeV. The possibility of performing top-up injection is also planned.

2 OVERVIEW

The parameters of the booster RF system are listed in Table 1 [2]. The frequency of the booster RF system will be the same of the storage ring one (499.654 MHz) to assure the matching between the two machines. Notwithstanding the larger momentum compaction in the booster compared to the storage ring (4.3884E-2 compared to 1.606E-3), the rms bunch length in the booster will be only about 93 psec at 2.5 GeV, which could be easily accepted in the storage ring energy acceptance (470 psec at 2.5 GeV).

Table 1: RF system design parameters

Beam energy	2.5	GeV
Energy loss/turn (2.5 GeV)	417	keV
Beam current	4	mA
Momentum comp. factor	4.3884E-2	
Natural energy spread	7.45E-4	
Longitudinal damping time	2.38	msec
Energy acceptance	3.16E-3	
Repetition frequency	3	Hz
Harmonic number	198	
Revolution frequency	2.524	MHz
RF frequency	499.654	MHz
Number of cavities	2	
Overvoltage factor	2.15	
Total effective RF voltage	896.6	kV
Peak RF voltage per cavity	640.4	kV
Cavity power	30.45	kW
Beam power (per cavity)	0.834	kW
Total RF power per cavity	31.3	kW

The acceleration cycle will be repeated at a 3 Hz frequency. The RF voltage will be cycled at the same rate. At injection the RF system has to provide sufficient energy acceptance for the injected beam. However the overvoltage factor should be limited in order not to result in a too large bucket size. During acceleration, the RF voltage should increase with energy increase. Finally at the extraction energy, the RF voltage has to provide a sufficient quantum lifetime. A 1 sec quantum lifetime at 2.5 GeV requires an overvoltage factor of 2.15. Since the energy losses at 2.5 GeV equal to 417 keV/turn, this results to an effective RF voltage of 896.6 kV. Summarizing all these considerations, Fig. 1 shows the time dependence of the RF voltage during one acceleration cycle. A design quantum lifetime of 1 sec has been chosen in order to provide a sufficient lifetime for the extraction from the booster, keeping the requirements on the RF power in a reasonable range to save in costs, needs of space and electrical power and cooling. It must be remembered that, for the same RF voltage, at lower energies (which are the normal operating energies for the storage ring) the quantum lifetime would be much higher. Two ELETTRA type cavities are needed since, taking into account their typical transit time factor, the peak RF voltage is 1280.8. This value is higher than the maximum allowed in one cavity both for the electromagnetic field and for the dissipated power in the cavity walls (which would turn out to be more than 120 kW). An ELETTRA type cavity is the primary option, since the reliable operation of this cavity is well known, many of them have been built at ELETTRA and the know-how for their construction and operation is well established at ELETTRA. Nevertheless a comparative study was performed to see if by using a different normal conducting cavity (such as an optimized nose cone) there could be advantages. The results showed that while still two cavities were needed, the savings in RF power were not so large, while extensive R&D work is required which is not worthwhile both on the technical and costs side. The total required RF power for each cavity (taking into account a 10 % safety margin) turns out to be 35 kW per cavity. This could be realized either with a single 75 kW 500 MHz RF plant feeding both the cavities or with two 35 kW 500 MHz RF plants each one feeding a single cavity. For both the options there are high power RF tubes already developed.

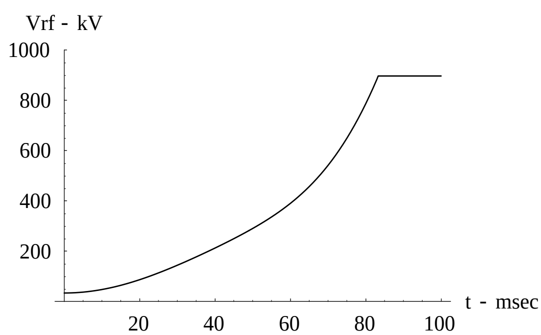

Figure 1: RF voltage during one acceleration cycle.

3 DESCRIPTION OF THE SYSTEM

3.1 RF Cavities

The two accelerating cavities will be of the ELETTRA type, therefore similar to the ones installed in the storage ring [3], [4]. The ELETTRA cavity (see Table 2) is a single cell cavity, resonating at 500 MHz with a bell shaped profile optimized to reduce multipacting phenomena. It is made of normal conducting oxygen-free copper.

Table 2: Cavity parameters

Cavity internal diameter	526	mm
Cavity length	480	mm
Quality factor	39000	
Transit time factor	0.700	
Shunt impedance	6.7	Mohm
Effective shunt impedance	3.3	Mohm
Coupling factor	1.03	

Radiofrequency power is fed to the cavity by means of a coaxial coupler with inductive coupling to the cavity. Vacuum to air transition is made with an aluminum ceramic window, brazed to the inner and outer conductor of the coaxial line. Low level pick-ups are installed for the low level electronics, control and measurement purposes. Cooling of the cavity is performed with cooling pipes brazed on the body of the cavity and connected in parallel circuits. Since for the currents accelerated in the booster, the cavities' higher order modes (HOMs) are not expected to excite multibunch instabilities, there will be no need of a dedicated cooling rack to stabilize the cavity temperature to ±0.05 °C as used for the storage ring cavities. Nevertheless a higher order mode frequency shifter (HOMFS) will be installed in each cavity to give the possibility to shift the HOMs frequencies at the cavity working point. Tuning of the fundamental mode is performed by means of an external tuning cage, which stresses or compresses the cavity longitudinally.

3.2 Power Plant

The power requirements can be satisfied either with a single 75 kW plant splitting the power to feed each cavity (option A) or with two 35 kW separate plants (option B). For both options the possibility of using klystrons or IOTs has been investigated. For option B the possibility of using solid state amplifiers has also been considered, but it was eventually discarded due to the extremely higher costs. Compared to klystrons, IOTs have the advantage of greater and constant efficiency, although they have a lower gain and then require a higher power pre-amplifier. On the other hand, klystrons have been used in a wide range of applications and operating conditions, therefore their reliability is well known. For option B, either klystrons or IOTs are available. For this case there is also the possibility of using the same 60 kW klystrons which are mounted in the storage ring RF plants. An IOT for option A needs development, while different manufacturers can provide a 75 kW cw klystron. Since it is not economically reasonable to develop a power tube for a single amplifier, for option A the IOT possibility most probably will be discarded. Before taking the final choice, a detailed comparative evaluation of the different options will be performed, taking into consideration both technical and cost contributions.

The driving signal to the power plant will be provided by the low level system. This will be a ramped RF envelope at a 3 Hz rate. Once injection in the storage ring is completed, the power plant will be set in a stand-by state, where RF drive is removed and the power tube beam current is reduced to a low value to minimize electrical power consumption and tube lifetime. The booster RF plant then remains in stand-by until the next storage ring injection is required. As usual a circulator will be used to decouple amplifier from cavity and the power transmission line will be most probably realized with a coaxial line system.

As well known, a decrease of the efficiency of the power tube can be expected with time. A calculation (see

Fig. 2) shows that even with a 10 % less power, the quantum lifetime at 2.5 GeV would be higher than 400 msec. This will allow operating the booster although at a lower efficiency, until the substitution of the tube would be possible.

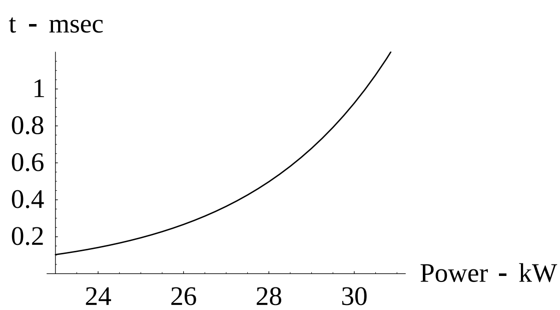

Figure 2: Quantum lifetime vs. RF power in one cavity.

3.3 Low Level

The low level system will be an upgraded version of the low level system of the ELETTRA storage ring RF system [5].

Each cavity will be equipped with a frequency loop to keep it tuned compensating for beam loading and temperature effects. The frequency loop works as a closed loop that drives the motor of the tuning cage to keep the cavity tuned to the required frequency. The loop makes a phase comparison between the samples of the cavity field and of the input power. The resulting signal, after having been processed by the loop electronics, is applied to the tuning motor drive unit. The parameters of the loop will be variable to optimize the performances of the loop. For example there will be the possibility of setting the sensitivity to 100, 500 or 1000 Hz and of offsetting the cavity frequency compared to the generator frequency.

Each RF plant will be equipped with an amplitude loop that will regulate the RF voltage according to the required waveform, provided to the loop as a reference voltage from the control system. The amplitude loop will be designed to maintain the RF voltage stable in a ± 1 % range through the entire operating range. Accordingly to the 3 Hz rate energy ramping, the RF voltage must be changed from almost 0 to the final value. At the same rate the RF power increases from a few tens of watts to the final value (31.3 kW adding the beam losses) and then drops back to the minimum after extraction. The amplitude loop will regulate the driving power to the amplifier by controlling a voltage controlled variable attenuator. Also for the amplitude loop there will be some flexibility in the choice of the operating parameters in order to allow a fine optimization, in particular to minimize overshoots at the end of the ramping cycle and interference with the machine synchrotron frequency. For example the loop bandwidth will be variable up to 4 kHz.

The phase stability of the input power to the cavity has to be within ± 0.5 degrees at each power level. For this reason for each plant a phase loop will compensate for phase changes in the RF plant due to the power amplifier, the circulator and the driving electronics. The phase loop makes a phase comparison of the samples of the plant driving signal and of the RF forward power after the circulator and it drives an electronic phase shifter. The loop will be designed to be sensitive to the amplifier power supply ripple, but insensitive to the synchrotron frequency. The precision of the loop will be ± 0.5 degrees for a phase variation of ± 30 degrees.

A fast RF switch will be used to cut the RF driving signal to the RF plant. The switch will be driven either by the operator or by interlock signals from the RF plant and from the machine interlock system. The switch will be a high isolation, absorptive, pin diode switch. Finally a remotely controlled 500 degrees at 500 MHz phase shifter will be provided for each plant to set the relative phase of the booster to the storage ring RF system and to the linac pre-injector.

4 SUMMARY

The design of the ELETTRA booster RF system is in an advanced status. While for the cavities and low level the design is almost defined, for the power plant still the choice between the two options is open. Where possible, the same components that are used in the storage ring will be adopted to save in spare requirements.

It must be noted that even in the two plants option, any failure would imply the interruption of the booster operation. The experience gained with the ELETTRA RF system [6] shows that power plant's failures are the ones requiring a longer fixing time. Therefore the possibility to upgrade the booster RF system, even in a second time, adding a spare RF amplifier will also be examined. This could be either kept in reserve operation (ready to be switched on, if needed, in a short time) or combined to the others to provide more RF power to the cavities to increase the lifetime.

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