INSTALLATION AND COMMISSIONING OF THE RF SYSTEM FOR THE NEW ELETTRA BOOSTER

A. Fabris, M. Bocciai, L. Bortolossi, M. Ottobretti, C. Pasotti, M. Rinaldi
Sincrotrone Trieste, S.S. 14 – km.163,5 , in AREA Science Park, 34012 Basovizza, Trieste, Italy

Abstract

The commissioning of the new booster of the Elettra synchrotron radiation storage ring started in Fall 2007. The RF system of the booster is made of a five cells accelerating cavity fed by a 60 kW 500 MHz power plant. The accelerating cavity voltage is ramped along with the booster energy at repetition rate 3 Hz. The cavity field is controlled by analog feedback loops on amplitude, phase and the resonant frequency. This paper describes the setting into operation of the system and its performances during the commissioning phase of the machine.

OVERVIEW

The new Elettra injector complex is formed of a 100 MeV and a 2.5 GeV booster synchrotron [1]. The complex is designed to operate up to 2.5 GeV beam energy, although presently storage ring energy for users' operation is either 2 or 2.4 GeV. Following the completion of the building and the installation of the components, Elettra was shut down during Fall 2007 to switch between the old linac injector to the new booster. During the same period the booster commissioning started with the goal of restart users' operation at Elettra at beginning of March 2008. This important milestone was met and the project was concluded on budget and on time.

The RF system has been designed taking into consideration the high reliability required especially in view of the possible top-up operation [2]. RF voltage is ramped with beam energy and the design quantum lifetime at 2.5 GeV is 1 second in order to keep RF voltage requirements in a reasonable range. The main design parameters of the system are summarized in Table 1 for the nominal and the low emittance optics [3].

SYSTEM DESCRIPTION

The requirements on the RF system can be satisfied using one RF plant powering a five cells cavity. The RF power budget allowed the possibility of re-using the power amplifier and other components released following the upgrade of one of the storage ring plants, with considerable savings in costs [4].

Cavity

The cavity is a five cells PETRA type cavity. The choice of the cavity has been mainly driven by the less total power required compared to the use of two single cells cavity. The cavity was acquired from industry.

Prior to the installation in the new machine, the cavity was thoroughly tested in the RF laboratory. In addition to the low power measurements, a high power conditioning was performed up to 54 kW, i.e. two times the design maximum operating power. This has allowed to partially clean the hardest multipacting thresholds, which were particularly strong in the range up to 8 kW.

Table 1: RF System Design Specifications

	Nominal	Low Emittance
Beam energy	2.5 GeV	2.5 GeV
Beam current	4 mA	4 mA
RF frequency	499.654 MHz	499.654 MHz
RF voltage	840 kV	730 kV
Cavity power	25.2 kW	19.1 kW
Beam power	1.9 kW	1.9 kW
Total power	27.1 kW	21 kW

Power Plant

The power requirements could be easily satisfied by the 500 MHz 60 kW amplifier available after the first phase of the upgrade of the storage ring RF system. The final stage of the amplifier is a 60 kW UHF TV klystron.

The amplifier is decoupled from the cavity by means of a 75 kW circulator. Also this component and the dummy load for the third port of the circulator have been obtained as a side effect of the storage ring upgrade. Power transmission is performed by means of rigid 6 1/8" coaxial lines.

Low Level RF

The low level RF system (LLRF) is based on the analog techniques that were originally designed for the storage ring RF system and upgraded during the years to cope with the advance of technology and the additional requirements of a five cells cavity [5]. Since the operation of the booster is ramped and some flexibility could be needed especially during the commissioning period, the system can work at almost any duty cycle up to cw and with different voltage waveforms.

Three loops have been installed: a frequency and field flatness loop, an amplitude loop and a phase loop.

The frequency and field flatness loop controls the two cavity plungers to keep the cavity tuned at the operating frequency and to correct excessive unbalance of the fields among the cells. In the first case the plungers are moved simultaneously in the same direction, in the second one they are moved in different directions. For tuning, the electronics compares the cavity field sampled in the central cell and the input power to the cavity. The sensitivity of the loop can be set so that a ±100 Hz frequency difference can be corrected. For balance, the fields in cells 2 and 4 are compared. The balance between the voltages in the two cells is kept in a ± 5 % range.

The amplitude loop controls the cavity gap voltage regulating the driving power to the amplifier. In this way the cavity voltage is set following the required waveform, which is provided by the control system. When working in cw the loop assures a ± 1 % stability of the voltage.

A phase loop keeps the phase of the input power to the cavity stable in less then a ± 0.5 degrees range. A 500 MHz mechanical phase shifter is used for the phasing of the booster RF to storage ring RF and pre-injector.

All the components of the low level system were tested prior to installation in the laboratory on the five cells cavity, thus allowing a full debugging prior to installation.

INSTALLATION AND SETTING TO WORK

All installation activities were performed during summer 2007. Since the booster building was built inside the existing storage ring, all the components had to be transported from outside using a dedicated crane running above the roof of the storage ring building. This has of course required a detailed and careful planning of all the installation activities.

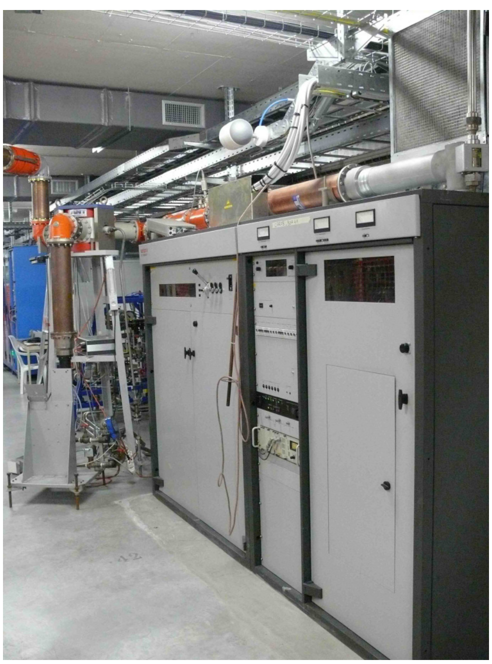

Figure 1: Power plant.

The power amplifier was set into operation and tested at its full power (i.e. 60 kW). All the other components of the power plant were tested at the same power. In particular the circulator was tested also with a short circuit on port 2 at different lengths. Ramped operation at 3 Hz was also tested in order to assure that the system was satisfying the requirements, especially in terms of reliability.

After installation in the machine, the resonant cavity was equipped with two 300 l/sec ion pumps mounted on cells 1 and 5. The pre-vacuum unit was installed on one of the free CF40 cavity ports. The cavity and its accessories were baked out prior to start in situ RF conditioning. The limit pressure reached after bake-out was 2.6 E-10 mbar. The conditioning to 54 kW took around 60 hours, but it must be noted that the vacuum interlock threshold was kept as low as 5 E-7 mbar for further safety margin. Final vacuum level at 54 kW operating power was 5 E-9 mbar. The multipacting thresholds already observed below 8 kW were still present, however the conditioning speed was greatly increased thanks to the previous operating hours in the laboratory. The conditioning was performed using the automatic conditioning rack developed for the tests of the Elettra cavities.

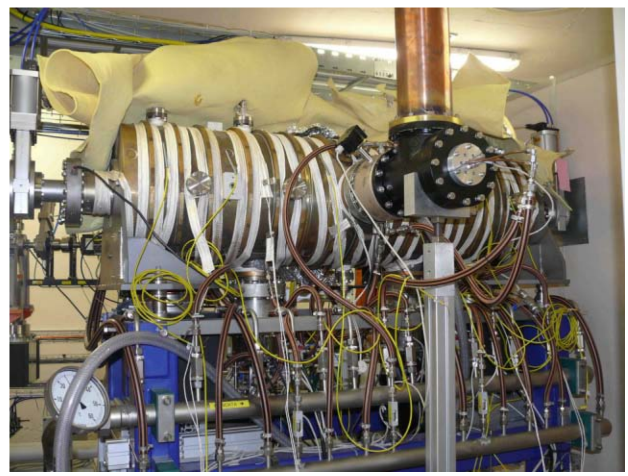

Figure 2: Booster cavity.

Setting to work of the LLRF system was quite straightforward. All specifications were met. The system was extensively tested in order to assure the required reliability both in the normal ramped operation and in cw mode. Different cavity voltage ramps were tested to allow flexibility in view of the commissioning. The unbalance of the cells voltage has been checked in the operating power range and it is well inside the required values even with the field flatness loop bypassed.

COMMISSIONING AND OPERATION

Commissioning of the new booster started at end of September 2007. The RF system was switched on few days later and the beam was captured the same day. Commissioning has then proceeded in order to assess and improve the performances of the machine in view of the planned first full energy users injection on March 3, 2008.

Parameters Optimization

The optimum voltage at injection has been calculated imposing the condition of proper matching between the linac pre-injector and the booster at injection energy, so that all the electrons are captured inside the stationary bucket [6]. This means that the following condition must be satisfied:

$$(\Delta E/E)_b = (\Delta E/E)_{RF}\cos(\Phi_m) \qquad (1)$$

where $(\Delta E/E)_b$ is the energy spread of the beam from the linac pre-injector (± 0.5 %) and Φ_m is the maximum phase length.

Eq. 1 is satisfied for a RF voltage equal to 33.7 kV. Experimentally an efficient capture was achieved at 40 kV, which is in good agreement with the theory also considering the calibration accuracy at low power.

At extraction, the voltage is determined by the value needed to assure a sufficient quantum lifetime. The 1 sec design value at 2 GeV is reached with 330 kV, while at 2.4 GeV 600 kV are required.

The energy ramp of the beam is performed according to a 160 msec sinusoidal ramp. The RF voltage is ramped as well to compensate the momentum variation due to the magnets ramping and the energy loss due to radiation, the latter becoming predominant at higher energies. Putting all together, this means that the RF voltage should follow the following equation:

$$V_{RF}(t) = V_0 + K_1 dB(t)/dt + K_2\left[E(t)\right]^4 \qquad (2)$$

where V_0 is capture voltage, K_1 is proportional to the maximum energy variation and K_2 takes into account the radiation losses and the condition on the quantum lifetime.

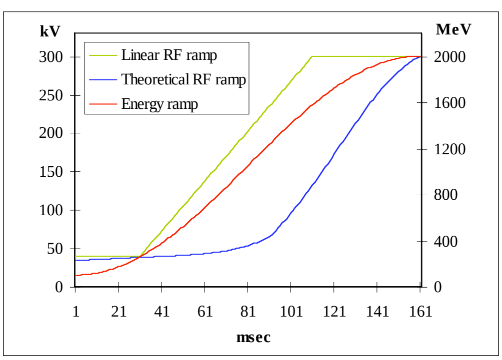

Figure 3: Energy and RF voltage waveforms.

The calculated curve for 2 GeV is shown in figure 3 (blue line). Operationally the theoretical curve has been approximated by a linear curve (green line) delayed with respect to the bending ramp (red line). This allows to easily change minimum and maximum voltage, as well as the other parameters such as the delay, risetime and flat top. Such a waveform has demonstrated to efficiently perform the ramping of beam energy, without adding in complexity.

Performances of the System.

The behaviour of the RF system during the first months of the commissioning and operation of the machine has been very satisfactory. The system has been reliable and easy to use for the operators.

Since at beginning of the commissioning, the cavity needed to be re-conditioned from time to time, an automatic conditioning program for the cavity was implemented in the control system, so that this procedure could be done automatically if needed. However with the increase of operating hours, this problem has disappeared.

The cavity and the RF system are installed very close to the injection point in the machine. At the beginning there were some trips due to the circulator arc electronics. Since the electronics was not shielded and injection was not yet optimised, the trips were correlated to possible radiation interference. With the progress of the commissioning and the implementation of a narrow shielding around the electronics, this problem has been solved. A visual inspection inside the circulator and coaxial lines has confirmed that the trips were spurious.

In parallel with the operation of the storage ring, the system has been kept in ramped operation on a 24 hours/day basis. This was done to test the performances of the system in view of top-up operation. The results have shown that the system satisfies the requirements of reliability needed for this operating mode.

CONCLUSIONS

The RF system for the new booster injector has demonstrated to satisfy the specified performances. The system has been installed, set to work and tested according to the foreseen time schedule.

The operating parameters have been optimised during the first months of operation. The flexibility of the system allows operation at different duty cycles and power levels. The tests have also shown that the system is perfectly suitable for top-up operation.

REFERENCES

[1] M. Svandrlik, “Overview of the Status of the Elettra Booster Project”, this Conference.
[2] A. Fabris et al., “RF System for the Elettra New Full Energy Booster Injector”, PAC’07, Albuquerque, WEPMN017, June 2007, p. 2083 (2007), http://www.JACoW.org.
[3] F. Iazzourene, “Elettra Booster Commissioning and Operation”, this Conference.
[4] A. Fabris et al., “Installation and Commissioning of the New 150 kW Plant for the Elettra RF System Upgrade”, PAC’07, Albuquerque, WEPMN016, June 2007, p. 2080 (2007), http://www.JACoW.org.
[5] C. Christou et al., “The Diamond Light Source Booster RF System”, EPAC’06, Edinburgh, TUPCH120, June 2006, p. 1296 (2006), http://www.JACoW.org.
[6] J. Le Duff, “Longitudinal Dynamics”, CERN Accelerator School, Benodet, 1999.