The R.F. System of ELETTRA.

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Abstract

The RF system of the ELETTRA storage ring has been fully commissioned and already used in normal operating mode. It consists of four independent power plants, each one feeding one cavity. The available RF power is 60 kW at a central frequency of 499.654 MHz. The RF driving signal is provided by a master oscillator which also drives the Linac injector. There also exists the possibility of working in an asynchronous injection mode. Installation of the plants started in February 1993 with the mounting of the power amplifiers. The tests on dummy load ended in July 1993, while starting from August 1993 the conditioning of the cavities took place. The RF system was set into operation right from the beginning of the first phase of the storage ring commissioning (October 1993). A detailed description of the complete RF system is given here.

1. INTRODUCTION

For ELETTRA a 500 MHz RF system using four identical 60 kW power plants each one feeding a cavity has been adopted [1]. In the nominal operation of the machine (see table 1), the required accelerating voltage is 1.7 MeV/turn at 1.5 GeV and 1.8 MeV/turn at 2 GeV. The power requirements per plant (beam losses plus power wasted in the cavity) are 37 kW for a 400 mA beam at 1.5 GeV and 52 kW for a 300 mA at 2 GeV. The driving signal for all the plants provided by the distribution system can be either synchronous or asynchronous to the Linac injector. Four control loops are installed for the control of the reference temperature, tuning of the cavity, amplitude and phase of the gap voltage.

Table 1. RF main design parameters

Energy (GeV)	1.5		2
Beam current (mA)		400	
RF frequency (MHz)		499.654	
Harmonic number		432	
Total losses (keV/turn)	97.6		286.1
Total voltage (MV/turn)	1.7		1.8
Number of cavities	4		6
Cavity unloaded quality factor		42000	
Cavity shunt impedance ($V^2/2W$) (MΩ)		7	
Power installed per plant (kW)		60	

2. OVERVIEW OF THE DISTRIBUTION SYSTEM

The driving signal for all the plants is provided by the same generator which drives also the Linac for the synchronous mode of operation, or by an independent generator for the asynchronous mode of operation. Both generators are located in the Linac klystron hall and a mechanical 4-ways switch allows to change the mode operation. The driving signal is then applied to a 20 W solid state amplifier via a fast switch (speed about 500 nsec) which is also used to dump the stored beam either for protection as part of the machine interlocks or for machine studies. The solid state amplifier has been built in house using a UTO 561 amplifier by AVANTEK as first stage and two MHW710-3 modules in parallel via a hybrid ring as second stage [2].

The transmission of the driving signal to the storage ring service area is performed by using 7 1/8" flexwell cables running along the transfer line. The signal is then split in eight channels, four of them are used to drive each of the present RF plants. Using the same kind of flexwell coaxial cables, the reference signal is supplied to each plant. The adjustment of the phase on a 360° range is performed by a mechanical phase shifter driven by a step motor. The regulation of the input level is accomplished with a voltage controlled phase free attenuator with a minimum changing step of the input level of 0.032 dB.

3. OVERVIEW OF A SINGLE RF UNIT

The ELETTRA RF system is composed of four identical units one for each cavity. Each RF system can be split into the following three subsystems:

-power plant;
-cavity;
-low level and control loops.

3.1 Power Plant

The power amplifier is derived from a commercial TV transmitter modified in order to achieve the required amplitude and phase stability [3]. In fact, all the components of the power plants have been designed in order to achieve a power stability of ± 1 % and a phase stability of ± 0.5 °, so that the control loops would be necessary only to cope with cavity and beam related effects. The amplifier has been designed and built by Harris Allied, Cambridge. The klystron used is a Philips YK 1265 capable of providing more than 60 kW cw RF power. The central frequency of the amplifier is 499.654 MHz and the bandwidth at -3 dB is ±2 MHz. To decouple the amplifier from the cavity and lower the shunt impedance seen by the beam even for passive cavities, a circulator has been installed equipped with a temperature compensating system to cope with the ferrite thermal effects. The coaxial circulator is made by ANT and it is capable of sustaining a forward and reflected power of 75 kW. The dummy loads of the circulators are rated at 80 kW. A 60 kW harmonic filter has been implemented at the amplifier output to damp the harmonics to less than - 60 dB compared to the fundamental avoiding possible damage due to multireflections of harmonics between the klystron and the circulator. The RF power transmission is performed via 6 1/8" coaxial components

3.2 Cavity

The RF cavities have been developed in house and have been built by local Italian companies. The brazing was performed at the INFN Laboratory of Legnaro, Italy. The 500 MHz RF cavities (fig. 1) have smooth shape and are made of oxygen free copper [4]. The nominal gap voltage at 1.5 GeV is 607 kV, thus leading to a total power wasted in the cavity fundamental mode of about 26.5 kW, being the measured shunt impedance equal to 7 MΩ. The measured unloaded Q is 42000. The cavities are water cooled by means of cooling pipes brazed on the cavity walls.

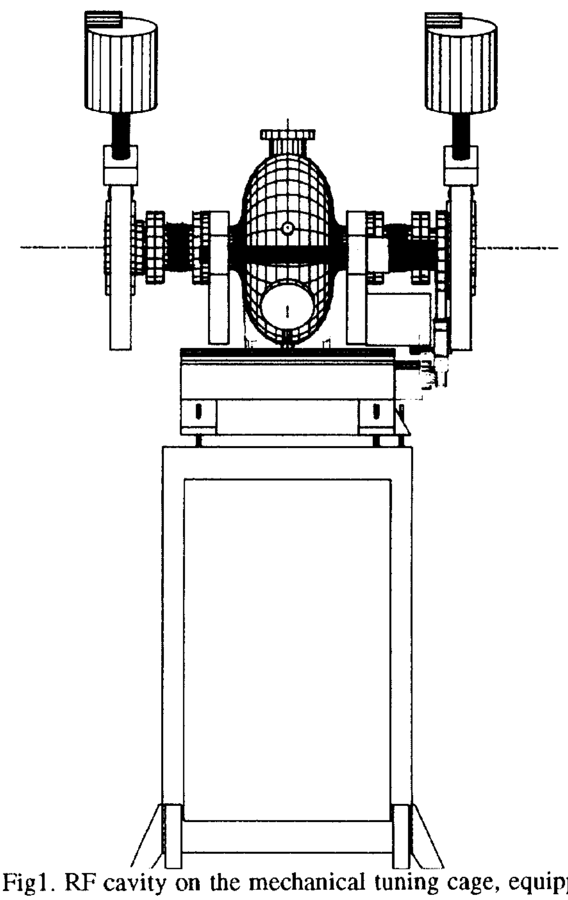

Fig1. RF cavity on the mechanical tuning cage, equipped with bellows and vacuum valves

The RF power is fed into the cavity via a coupling loop. The feedtrough is also copper made and water cooled. Besides the power coaxial feedthrough the cavities are equipped with two loops in order to pick-up signals for measurements and controls (low level loops, analog and digital signals for the control room).

The unit is connected to the vacuum chamber by means of a bellow and a vacuum valve on both sides. Therefore each unit can be considered indipendent from the rest of the machine, concerning bakeout or RF conditioning and maintenance.

The design of dedicated H.O.M. suppressors for the most dangerous modes has been carried on in parallel with the design of a new accelerating cavity with broadband H.O.M. suppressor [5,6,7].

3.3 Low Level and Control Loops

In order to ensure the required stability for the ELETTRA RF system operation, besides the control and the stabilization of the working temperature of the cavity, a mechanical tuning loop, an amplitude loop and a fast phase loop are implemented [8].

The cooling system controls the reference temperature of the cavity and keeps it constant under stable power conditions up to 0.05 °C. The reference temperature of the cavity can be varied to optimize the performances of the system. This also allows to move the most dangerous H.O.M. to avoid adverse interaction with the beam.

The tuning of the cavity is achieved by changing the axial length of the cavity by means of a mechanical tuner acting on the cavity necks [2]. The external tuning cage is driven by an ac motor. The frequency variation obtained is about 80 kHz for a variation of 0.1 mm (the beam loading is expected to be about 80 kHz in the worst condition). Within these limits the mechanical stress of the cavity remains below the elastic limit. The frequency stability is 100 Hz and the speed of the system is 700 Hz/sec. The choice of the speed has been done also to optimize the interaction with the temperature control loop.

The amplitude loop keeps the gap voltage constant in spite of the beam loading. The dynamic range is 30 dB and the maximum speed can be increased up to 50 µsec. The precision of the regulated gap voltage level is better than 1% [9].

The fast phase loop keeps the phase of the cavity constant better than ± 0.5°. The range of optimum operation is ± 20° and the speed is 10 µsec. Special care has been taken in order to prevent the amplitude modulation of the frequency signal due to the intervention of the phase loop.

All the main parameters of the plants' components and of the cavities are sent to the control room for remote control of the RF system [10]. A set of analog signals (samples of the gap voltage, input power and reflected power from the cavities, common driving signal) are also available in the control room for measurement purposes. All the safety relevant interlocks are directly connected either to the high voltage of the klystron or to the coaxial RF switch installed on each plant.

4. INSTALLATION AND COMMISSIONING OF THE PLANTS

The mounting of the four power amplifiers took three months starting from February to April 93. Setting in operation the amplifiers and their tests on dummy loads, followed by low level and high power tests of the circulators were performed from May to the end of July 93. Besides the test of the design performance of the components, all the plants were tested on dummy loads for about 36 hours at full power. The circulator were also power tested on a short circuit condition on the second port.

In the meantime the cavities were baked out and preconditioned using the RF power plant in the laboratory [11]. In August 93 the first cavity was assembled in the storage ring and put under vacuum, subsequently the other three were also installed. On site a second bake out was also performed, followed by a second power conditioning up to 36 kW cw and 60 kW peak power with 50 % d.c. (average power limited for thermal reasons). The bake-out was performed at 150 °C for 150 hours, the pressure at the end of the bake-out was better than 1.0 10^{-10} mbar for all the cavities. For operation the vacuum level trip was set at 1.0 10^{-7} mbar. After having achieved full power operation, each cavity has been operated for several hours to check the reliability of the system. The vacuum pressure at 35 kW at the end of the conditioning was about 4.0 10^{-10} mbar. Neither multipacting nor discharge phenomena have occurred during the whole conditioning. Thus no metalization of the ceramic window has taken place.

In parallel with the conditioning of the cavities, the work on the distribution system and on the low level and controls was proceeding. It must be noted that the time available for the cavity conditioning in site was limited due to interfering works of machine installation which were going on near the cavities. At start of commissioning one cavity was completely ready for operation [12] and this was sufficient to restore the beam losses at the working energy (1.1 GeV) at that time. During the periods between the commissioning runs, the completion of the conditioning and the completion of installation of the other plants took place. The second cavity was set into operation in January 1994, hence sufficient RF power was available for the operation at 1.5 GeV and 2 GeV obtained with the ramping implemented at the beginning of this year. The third cavity was set into operation in April 94 and the fourth in May 94. All the loops, except the phase loop have been set into operation. A prototype of the phase loop has been successfully tested on one cavity during machine commissioning in May and all the circuits will be installed within August this year.

5. CONCLUSIONS

The ELETTRA RF system has been completely installed (except the phase loops) and tested. All the four plants have been set into operation during the commissioning of the machine with satisfactory results (for a description of the performances of the system during the commissioning see [12]). During the next months the phase loops will also be set into operation and further investigation on Higher Order Modes and beam-cavity interaction will be performed. Studies on the mutual relation among the different control loops in real operation with beam are also planned.

6. ACKNOWLEDGMENTS

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