Commissioning and Operation of One Booster and Two Storage Ring RF Acceleration Units at the ESRF

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Abstract

The RF system of both Booster Synchrotron (SY) and Storage Ring (SR) have been fully commissioned and already used in a normal operating mode. The Booster RF accelerated a 5 mA beam from 200 MeV to 6 GeV in a reproducible way. The Storage Ring RF system was switched on right from the beginning of the first run of the storage ring commissioning and a beam was captured up to 50 ms (without accumulation).

For SY, one amplifier feeds two cavities in pulsed mode from 300 W to 550 kW in 50 ms. Presently, one amplifier delivers 350 kW CW to the four SR cavities in order to obtain 7.4 MV accelerating voltage. A bypass waveguide is used for the transmission to the cavities 3 and 4. The conditioning of the cavities was done in situ. The two SY cavities were conditioned together in pulsed mode, while the four SR cavities were conditioned together in CW. Both RF units are remotely operated with the nominal graphics application program.

Installation, commissioning and cavity conditioning was done in less than 14 months starting from January 1991.

1. INTRODUCTION

For the ESRF, a 352.2 MHz RF system [1] using 1 MW-CW klystrons and a modified version of the five cell LEP type cavities has been installed. In the nominal operation of SR, two identical amplifiers deliver a total of 1.1 MW to four cavities in order to provide 8.9 MV accelerating voltage and the 625 kW required to compensate the beam loading for 100 mA of stored electrons. The 7.3 MV needed for SY are obtained by feeding 550 kW from one amplifier into two cavities in a 10 Hz cycling mode.

2. OVERVIEW OF A SINGLE RF UNIT

The ESRF RF is composed of three identical units, each feeding two cavities. Each RF plant (table 1) can be split into the following four subsystems.

1. High Voltage Power Supply: The HVPS delivers a 100 KV, 20 A DC power regulated in the 1% range. It is composed of a classical cascade of step down and step up transformers between which is acting a 12 pulse thyristor AC controller. The modulating anode is polarised by a solid state power supply. A five ignitron crowbar located in the high voltage cage is able to switch off any arcing in the klystron in less than 10 µs. On top of this, a R//L snubber circuit limits the inrush current during the first 10 µs of the discharge before the crowbar comes effectively into action.

2. Klystrons: the 1 MW Thomson klystrons are the same as the ones used at CERN; 1 MW Circulators were also installed taking into account the LEP experience:

◊ temperature compensating system to cope with the ferrite thermal effect,

◊ harmonic E field antennas coupling out the TE01 waveguide mode in order to damp the multireflections of harmonics between the klystron and the circulator.

3. Cavities: For the two SY as well as the four SR cavities, the same modified design of the normal conducting five-cell LEP cavities without the spherical storage cavity was adopted. The difference is essentially the use of two LEP type input couplers which are designed for 130 to 150 kW RF throughput. This allows to feed up to 300 kW into one cavity and thus to meet the ESRF power requirements. The shunt impedance being 53.6 Linac-MΩ, 275 kW is coupled into one SY cavity at the peak of the 10 Hz cycle, i.e. 249 kW dissipation in the copper to obtain 3.65 MV and 26 kW for 10 mA beam loading. The average power dissipation is about 80 kW. Storing 100 mA in SR requires 242 kW CW to be fed into one cavity: 86 kW dissipated to obtain 2.15 MV and 156 kW for beam loading [1].

RF power distribution to the four couplers of a pair of cavities is made by means of three magic Tees. In order to validate the scheme of using two couplers per cavity, a power test was successfully performed at CERN during February 91; 170 kW CW (test without beam) and 300 kW in 10 Hz cycles were coupled into one ESRF cavity.

Device	Supplier	Characteristics
Master Source	Rhode& Schwartz	frequency stability 10^{-9}
Distribution network	Philips	high phase stability cable ± 0.1•/•c/100 m
HVPS	Siemens	100 kV, 20 A, ±1% stability in voltage
Mod Anode PS	FUG	100 kV, 15 mA max
Focus Coils PS	FUG	10 A 300 V
Filament PS	FUG	30 V, 25 A current regulated
Driver	Herfurth	200 watts output, 50 dB gain
Klystron	Thomson	1 MW CW, 352 MHz, 48 dB gain
Circulator	ANT	1 MW forward, 300 kW reflected power
Coaxial loads	CERN	300 kW dissipation
Waveguides	Mechanical Spec	WR 2300 type
Cavities	Interatom	5 cells, 2 couplers, 2.5 MV CW, 4 MV peak
Control	Herfurth	
amplitude	"	35 dB dynamic
phase	"	±1° accuracy
interlocks	"	500 signals
software	SCS CAP Gemini	

Table 1: Main parameters of one RF unit

4. *Control:* For the Booster amplitude control, a waveform generator triggered by the 10 Hz machine timing modulates the driver input of the amplifier while the modulating anode regulates the klystron current.

On SR, the anode modulator directly controls the sum of the four cavity voltages. In order to optimize the klystron efficiency, the drive loop is used to maintain the driver output close to the klystron saturation regime. The drive loop is then slower than the modulating anode loop.

Operation with drive modulation was easy to proceed because of high collector power dissipation capability of the Thomson klystron (1.8 MW with a water flow of 1600 l/mn). The phase at the output of the circulator is regulated by a fast analog loop.

On top of this, a slow software loop regulates the phase of the cavity voltage. A 35 db dynamic, 40 µs response time was achieved for the drive amplitude loop and a ± 1° degre precision for the phase loop. Loop switching, signal processing and system configuration are managed by a VME controller.

2.INSTALLATION AND COMMISSIONING

During 14 months from January 1991, the three RF units were installed and commissioned (fig.1). As no insertion devices are installed, SR voltage requirement is lower and only one klystron is sufficient to provide 7.4 MV accelerating voltage. To fit the installation planning and to keep a spare amplifier for tests, the four cavities were connected to one amplifier.

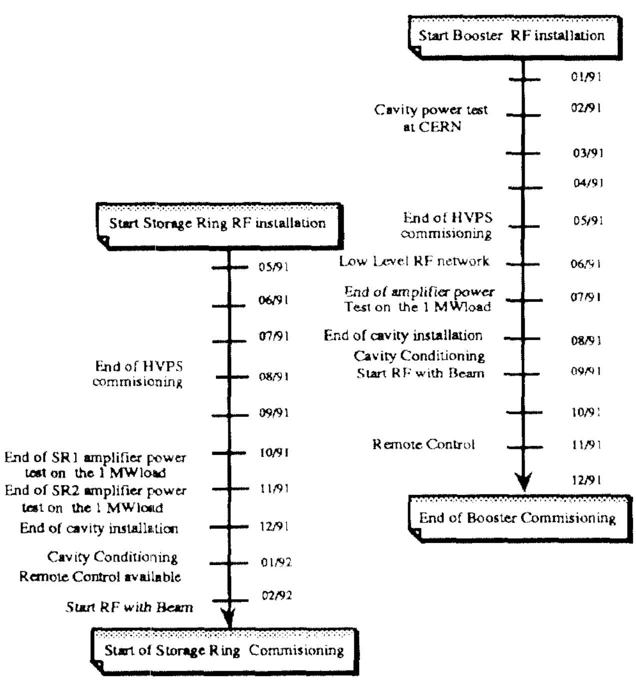

Fig 1: Installation and Commissioning Planning

The first amplifier was fully tested by Herfurth before delivery, with a HVPS of 30 kV, 20 A and was delivered to Grenoble beginning of april 1991. Each amplifier was fully preassembled and was installed within two weeks.

For each unit, we applied the same procedure. First, the HVPS was switched on a water load and tests were made up to 6 A, 50 kV. After this, a beam of 92 kV and 19 A was applied to the klystron in diode operation. Then the klystron was connected to the 1MW RF load, which allowed a complete RF commissioning of the amplifier and later on of the circulator. During that time, cavities and waveguide network were installed. One month before machine commissioning for the Booster (and two months for SR) the cavities were connected to the amplifier. Low power tests and conditioning then took place.

3. CAVITY CONDITIONING

An automatic cavity conditioning software measuring the vacuum in the cavities (two for SY and four for SR) and acting on the power with a dedicated algorithm was developped on a Personnal Computer connected to the Remote Serial Interface of the VME. The returned value was compared to thresholds: if one of the measurements was higher than 3 10^{-7} mbar, the power was decreased. If all pressures were below 2 10^{-7}, power was increased. Between these two values the power was kept constant. On top of this, the algorithm was acting on the derivate of the vacuum to cope with fast outgasing. Independently of this, an interlock tripped the RF if the pressure was higher than 10^{-6} mbar. Power steps in the 1MW range were 244 watts and the speed of the loop was 300 ms.

Multipactoring effects were seen at a CW power of 2 kW per cavity. This range was crossed by using smaller steps (2.4 W in the 10 kW range). No other hard point was seen, and full conditioning was achived within two weeks for SY and three weeks for SR.

For SR, the simultaneous conditioning of four cavities instead of two didn't induce more problems. But, since the process was done in CW, instead of the 10 Hz pulsing in SY, the conditioning speed was lower. The SR cavities were baked at 150°C and NEG pumps added to the two ion pumps. The average pressure is currently in the lower 10^{-8} range in all powered cavities.

4. LOCAL AND REMOTE CONTROL

The RF control is organised in three levels: the safety relevant control, the local system manager, the remote control (fig.2).

Interlocks are managed at three levels. First, the harwired controller provides a direct connection of the relevant interlocks to either the crowbar or the pin diode bus (response time lower than 10µs). Most of the digital interlocks are read by the PLC which controls the unit states (PLC cycle is 20 ms). On top of this, each RF unit is locally managed by an OS9 VME system which provides both a control of the plant and an intelligent man-machine interface (process cycle is 100 ms). Independently, the HVPS is fully controlled by its own PLC controller.

The three RF units are connected to the remote unix computers via the machine ethernet network. A first layer of the remote control is done by a device server which manages the connection to the local machine and the data transfer with the adequate format.

Connected to this, the application program, using a OSF/MOTIF widget set, controls the RF with an internal standard appearence for all control software in the control room. A single window gives access to the parameters which are used for routine operation (acceleration voltage, frequency, phase and states). With more sophisticated windows, specialised operators have access to signals, mode settings, and cavity detuning. An error window returns the status of the transmitters.

Local and remote control of both Booster and Storage Ring were fully operational for the machine commissoning.

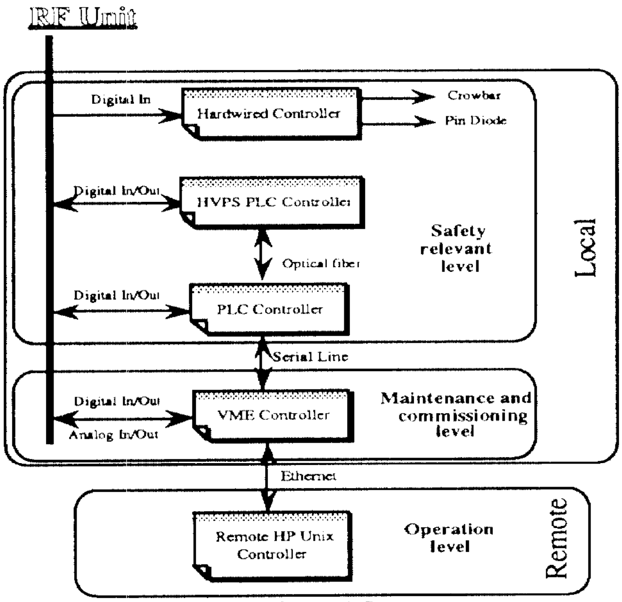

Fig 2: Control System

5. Operation with beam

Beginning of september 91 RF was switched on for the Booster commissioning [2]. An optimum value of the injection voltage was found at 300 W (0.1 MV) and a 300 kW peak power was sufficient to accelerate the beam up to 6 Gev to compensate beam losses. To keep the 1.4 overvoltage factor, the operationnal peak power was fixed at 530 kW (fig. 3). At the beginning, the amplitude loop was closed just after the circulator so that a constant beam loading drop of the accelerating voltage was visible from the injection time to the extraction point as a function of the current in the Booster. Then the amplitude loop was closed on the voltage sum from field probes on cells 3 of both cavities so that the constant beam loading during acceleration was compensated.

Some Robinson instability occurs in SY at injection when the accelerating voltage is rather low. Detuning the cavities by 20 degrees increased the accelerated beam by 1 mA. Then we applied a frequency shift of 8 kHz at injection during 25 ms with the master source in frequency modulation. The modulation function was given by a waveform generator triggered by the general timing. By using these two methods and switching on the Booster sextupoles, an accelerated beam of 9 mA was obtained (fig. 4). Since the same master source is used for all the RF units, the frequency shift cannot easily be used with a stored beam in SR.

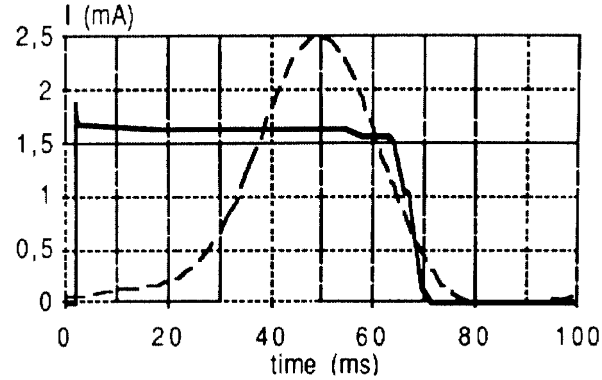

Fig 3: Boster Accelerating Voltage Waveform and Beam (Without Extraction)

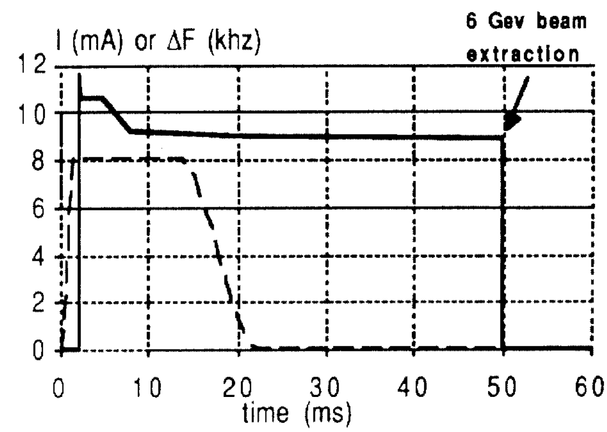

Fig 4: Accelerated Beam with Frequency Modulation

The main goal of the first storage ring commissioning period from the RF point of view was the setting of the frequency and the phase between SY and SR. Right from the beginning settings were not far from nominal values and a step to step program was sufficient to calibrate both. With the correct phase and frequency settings, and a total accelerating voltage of 7.4 MV, a stored beam of 50 to 100 ms was achieved (beam life time was limited by the large not yet compensated chromaticity of Sx = -116).

6. Conclusion

The ESRF RF Booster system has reached its design performance in the multibunch mode during the 6 Gev injector commissioning. The Storage Ring RF system was operational during the first phase of SR commissioning. A stored beam has been achieved and the RF is ready for accumulation. During the following months, High Order Modes and beam instabilities will be studied.

7. References

[1] J. Jacob and C. David " 352.2 MHz RF System for the ESRF", in EPAC'88 Proceedings, Nice.

[2] J.-M. Filhol et al " ESRF Booster Synchrotron Characteristics and Achieved Performances", in these proceedings.