COMMISSIONING OF THE THIRD RF ACCELERATION UNIT FOR THE ESRF STORAGE RING

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Abstract

After only two years of design, construction and commissioning, a new 1.3 MW transmitter feeding a third pair of cavities is now in operation on the ESRF storage ring. It allows each klystron and cavity feed-through to be run at moderate power even for high intensity operation at 200 mA, whilst still gaining in total accelerating voltage, from 8 to 12 MV. The third pair of cavities can also be used to modulate the RF voltage at the revolution frequency, thereby producing additional Landau damping of longitudinal multibunch oscillations, even for uniform filling of the SR. Finally, the additional RF unit provides the necessary redundancy to guarantee the operation of the ESRF at full performance in the event of a major intervention on one transmitter. For the new RF unit, a new control system, fully compatible with ESRF standards, was developed and will now be implemented to replace the obsolete version on the old transmitters. The planning and commissioning constraints imposed by the installation of this equipment on a running machine was one of the challenging issues.

1 INTRODUCTION

Four 352.2 MHz five-cell cavities and two 1.0 MW transmitters (upgraded to 1.3 MW in January 94) were initially installed on the ESRF storage ring (SR) for an operation at the design current of 100 mA at 6 GeV. During the SR commissioning, it was already possible to store higher currents and 200 mA of beam current have been delivered to the users in multibunch operation since November 1995. This resulted in pushing the power through the cavity input couplers to very high values and required operating the SR with both RF transmitters, each feeding one pair of cavities with up to 750 kW.

In early 1995 it was decided to construct a third RF transmitter (SRRF3) feeding a third pair of cavities [1]. Besides the reduced power load for the cavity couplers and a gain in redundancy, this third RF unit opens up other interesting new features.

2 DESIGN AND CONSTRUCTION

Based on the experience with the existing RF units, it was decided to construct the third RF unit using similar hardware for the large components. This includes the klystrons, the high voltage power supply (HVPS), the circulator, parts of the low level RF and the five-cell cavities [1, 2, 3].

The 100 kV - 22 A DC power supply (HVPS) for the third klystron was ordered in September 95 from Siemens who had already worked as a subcontractor for Herfurth, the supplier of the first turn key transmitters. This time, however, the HVPS was mounted and cabled under our responsibility : it was a very successful approach both in terms of cost savings and transfer of expertise to the RF crew. It also eased the implementation of an improved local control and of special measures against interference with the remaining RF equipment, especially concerning EMI shielding around the HV cage. The HVPS was ready as scheduled at the end of February 97.

The cavities 5 & 6 were installed, connected to the control and to the waveguide system and then reconditioned, as scheduled, during the three weeks of the normal 1997 summer shutdown. To meet the challenge of this tight schedule, ***the transmitter*** had been brought into operation on a dummy load and the cavities had been pre-conditioned in the power test-stand with the SRRF2 transmitter between May and July 97. During this period, only the SRRF1 transmitter was available to feed cavities 1 to 4, and a reduced SR beam current of 150 mA was served for synchrotron light production.

As the control system of the existing transmitters is becoming outdated and difficult to maintain or modify, ***a new control system*** was developed for SRRF3 and commissioned in parallel with the hardware [4]:

- The object oriented programming approach based on the separation between the transmitter and the cavities, which are themselves split into basic devices, proved to be very versatile for the development.
- The hardware protection is managed independently from the control software by a PLC for the slow interlocks and a hardwired system for the fast protections.
- The diagnostics tools included in the design are very useful for trip analysis and parameter follow up.
- The operator controls the RF system via an easy to use graphical user interface.

Some sensitive parts of the RF system, such as the ***arc detection*** system, have been redesigned in order to reduce the rate of spurious triggering.

Also the ***cavity vacuum equipment*** has been improved:

- The fast pressure interlock system, which is essential for the ceramics protection against glow discharges with subsequent sputter deposition of copper [3], has been doubled (two fast pressure detectors per cavity).

- The NEG pumps of the old design have been replaced by titanium sublimation pumps. This proved to be very efficient during RF conditioning and commissioning with beam, as it was possible to activate these pumps regularly, so that the vacuum could recuperate quickly after a strong outgassing.

Costs: From the 24 MFF foreseen, only 20.5 MFF have been spent, including building and infrastructure. Some larger components were found to be less expensive than eight years ago. Also the work performed in house helped keep the overall costs in check (the ESRF manpower costs are not included).

3 COMMISSIONING AND OPERATION

The new SRRF3 transmitter was ready for commissioning with beam on the scheduled date in August'97. After only four days, 160 mA could be stored and were then delivered for the first week of user service mode (USM). The maximum ESRF current of 205 mA was reached one week later and served routinely in the 4th week of USM.

As shown in table 1, the failure rate was higher during the commissioning period and the beam availability was reduced (90 % instead of the usual 95 %). After only three months of operation, the MTBF recovered and is steadily increasing.

	Before SRRF3	Aug'97 to Nov'97	Dec'97 to May'98
Mean Time Between Failure (MTBF) - part due to RF only	55.6 h	19.0 h	66.6 h

Table 1: Evolution of the Mean Time Between Failure.

During the three first months of operation, a lot of trips were caused by bursts of reflected power from the cavities, which were typically 50 µs long and as high as 300 kW at the peak. These events were mostly associated with outgassing and were probably due to fast detuning provoked by multipactor in one of the five cells. Continuous operation of the cavities was the only cure for these trips which now become less and less frequent.

In the early stage of commissioning, we were also confronted with high harmonic power generated by the klystron. The harmonics are fed back to the klystron by the reflection from the circulator, which is only matched at the fundamental RF frequency. Careful adjustment and positioning of matching elements (iris, post) allowed the harmonic power to be brought to an acceptable level.

A part of the early failures were removed gradually during the first three months simply by debugging the system.

The HVPS proved to be very reliable. For example, not a single spurious crowbar firing has occurred since the start-up.

4 NEW POSSIBILITIES WITH SRRF3

4.1 More flexibility and security

Table 2 shows the various configurations in which the SR has been operated since the commissioning of SRRF3. The fact that the maximum ESRF beam current of 205 mA can be stored without SRRF2 represents a large gain in flexibility and security. Klystron acceptance tests, cavity coupler conditioning and extensive R&D work requiring RF power can now be performed without restriction for the ESRF users.

It is planned to extend the waveguide network such that SRRF2 can replace either SRRF1 or even the booster RF system: SYRF. By doing this, we will obtain a level of redundancy that will allow SR operation to be safeguarded even in case of a major failure on any single transmitter.

4.2 Increase in cavity voltage

The third pair of cavities has allowed the cavity voltage to be raised from 8 to 12 MV with only a negligible increase in total power and still a reduction of the power per cavity coupler. However, it turned out that the associated gain in longitudinal acceptance did not show up on the lifetime which is presently limited by the transverse acceptance. Increasing the transverse acceptance of the SR is therefore one topic of machine physics studies to fully benefit from the enlarged longitudinal acceptance.

BEAM			*SRRF1 on Cav 1, 2, 3 & 4*		*SRRF3 on Cav 5 & 6*		
Storage Ring Filling	Imax	Vacc	Voltage	Max power	Voltage	Max power	Frequency
2/3 filling	205 mA	11.7 MV	8 MV	1100 kW	3.7 MV	550 kW	f_{RF}
2/3 filling	165 mA*)	8 MV	8 MV	1200 kW	*OFF*		(some beam induced voltage)
32 bunches	90 mA	9 MV	9 MV	1050 kW	0.8 MV	85 kW	$f_{RF} + f_o$ for HOM damping
single bunch	16 mA	8 MV	8 MV	600 kW	*OFF*		(some beam induced voltage)
homogenous filling	165 mA*)	8 MV	8 MV	1200 kW	1.5 MV	< 300 kW	$f_{RF} + f_o$ for HOM damping
*) SRRF2 transmitter is presently used for R&D and component tests, otherwise I_{max} could be 205 mA even without SRRF3							

Table 2: SR operation conditions achieved with SRRF3.

Since in single bunch and 32 bunch operation the lifetime is also Touschek limited, the optimum voltage was found to be close to 8 MV, for which the bunches are longest and the energy acceptance is not yet limited by the RF.

4.3 Landau damping of multibunch instabilities with cavities 5 & 6

For standard high intensity operation, only 2/3 of the SR are filled to produce strong transient beam loading, which leads to a voltage modulation at the revolution frequency f_0. The subsequent spread in synchrotron frequencies provides Landau damping of HOM driven longitudinal multibunch instabilities, a point of major importance for the ESRF [5].

An additional feature of the third RF system is the possibility to operate it at $f_{RF} + f_0$, such as to modulate the total RF voltage actively even for symmetrical fillings [6]. Figure 1 shows an experiment where the detuned fundamental modes of cavities 5 & 6 were used intentionally to launch an n=1 multibunch instability. The threshold current was increased by a factor 4 when applying a modulation voltage of 1.5 MV.

This scheme is employed for operation with 32 equally spaced bunches in the SR, where the optimum voltage of about 8 MV requires switching off cavities 5 & 6. As these are no longer temperature regulated, modulation is necessary to operate untroubled by multibunch instabilities at the nominal intensity of 90 mA.

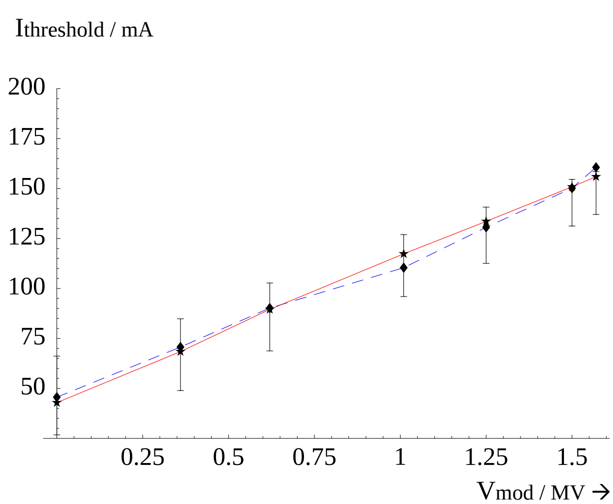

Figure 1: Threshold current for homogenous filling, applying voltage modulation with cavities 5 & 6 operated at $f_{RF} + f_0$ for Landau damping [6]
____ calculated - - - - experiment.

4.4 Basis for an upgrade of the existing transmitters

After the successful commissioning of SRRF3, the new control system is now fully validated. From the high UNIX level down to the hardwired fast interlock system, it had been designed taking into account the necessity of upgrading the existing RF units. Thanks to the existence of SRRF3, this work is now possible in parallel to operating the SR at full intensity.

Based on the clear separation between cavity and transmitter control, we are able to proceed in two steps. Here the strategy will be the opposite to the one applied for the construction of SRRF3. We will first transfer the cavities 1 to 4 from the initial to the new control system. This will take place in the next October shutdown. The upgrade of the transmitters will then take place one by one.

5 CONCLUSION

The third RF acceleration unit was successfully built and put into operation on the ESRF Storage Ring. It was fully designed by ESRF staff in order to best match the operation constraints and specificities, and to fit into the ESRF environment, taking into account the experience gained on the existing RF units. Performing such a design and construction work was very beneficial for broadening the knowledge and expertise of our RF group personnel. The project was completed within its budget and on schedule, and was managed so as to minimise the inconvenience for ESRF users. This was a challenging issue for a machine which delivers 5600 hours of x-ray beam per year.

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