OPERATIONAL PERFORMANCES AND FUTURE UPGRADES FOR THE ELETTRA RF SYSTEM

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The ELETTRA RF system is now in operation since 18 months and has demonstrated to be very reliable and flexible. Due to the independence of the four plants, the low failure rate did usually not cause interruption of machine operation. The low level control system has been completed in the last year with the installation of the phase loops. For the present operating conditions, i.e. maximum 250 mA at 2 GeV, no need for HOM dampers became evident, since, by accurate temperature tuning of the cavities, dangerous frequencies can be easily avoided. With the present scenario of insertion devices, a current of 400 mA with sufficiently good lifetime may be stored at 2 GeV in the multibunch mode. New upgrades of the system, like a slow phasing loop among the cavities are also discussed.

I. INTRODUCTION

The ELETTRA RF system is composed of four 500 MHz cavities distributed along the ring [1]. Each cavity is fed by an independent 60 kW RF plant. The RF system has been now operating for more than one and a half years. The operating hours vary from 4070 to 6560 depending on the plant. In routine operation the gap voltage of each cavity is set to 600 kV peak [2]. Injection is performed at 1 GeV at the nominal frequency (499.654 MHz). Beam energy is ramped to 2 GeV without acting on the RF parameters. At 2 GeV the RF frequency is shifted to 499.652 MHz for orbit and beam quality optimisation. RF system parameters for routine operation at 1 and 2 GeV are listed in tab. 1.

Energy (GeV)		1	2
Power loss (keV/turn)		16	255.75
Power to the beam at 200 mA (kW)		3.2	51.15
Number of cavities	4		
Total available RF power (kW)	240		
Power wasted per cavity (kW)		25.7	25.7
Peak cavity voltage (kV)		600	600
Total peak eff. voltage (MV)		1.68	1.68
Synch. phase angle (deg)		0.5	8.7
Syn. frequency (kHz)		15.7	11.0
Overvoltage factor		105.1	6.57
RF Energy acceptance		0.039	0.024

Tab. 1. RF Parameters in routine operation

II. PERFORMANCE OF THE RF SYSTEM

The general performance of the system since start of the commissioning up to now has been very satisfactory. The flexibility created by choosing independent plant has been very useful both in optimising the system itself and to guarantee a low failure rate. All the parameters of the plants are controlled to verify their operation. The gap voltage in each cavity is always monitored. The measured variation of the gap voltage is always well within the required 1 % stability range. The temperature of the cavities is optimised in order to lower interaction of the beam with HOM so to avoid multibunch instabilities [3]. The relative phasing of the cavities is obtained by equalising the input power to each cavity by means of a 360 degrees phase shifter which is placed on top of each RF plant. Slight modifications of the relative phases of the cavities are required from time to time during operation. These optimisations are in any case in the ± 1 degree electric phase range. The reason for these variations is due to changes in the ambient temperature in the service area.

The option of phase locking the signal generator, which was formerly used only to operate the RF system asynchronously to the linac, has been implemented. So now the RF driving signal can be either phase locked or free with respect to the linac signal generator which provides the machine main clock. In this way the storage ring RF frequency can be varied, once filled the ring with the required filling pattern, without altering the linac working frequency. A phase shifter is placed after the RF generator to optimise the phase of the RF bucket respect to the linac timing. The injection rate is strongly dependent on the relative phase of the storage ring RF and linac. It has been observed that the injection rate can be increased up to ten times by a proper choice of the relative phase.

Very few failures happened in the power plant (actually only five in eighteen months). The amplifiers' faults were mainly due to what can be considered mechanical reasons, however none of them regarded the RF chain. During the time needed to recover from these faults, the machine could be operated with the remaining three cavities with increased gap voltage to 650 kV, i.e. 1.37 MV total peak effective voltage. The only noticeable effect was a slight decrease in lifetime. Hence the choice of having four independent RF plants has proved to be very effective in minimising machine operation time lost due to failures in the RF system. Some circulators arcs have happened randomly. These are generally related to beam dumps at high currents. In fact in this case the tuning system needs some seconds to retune the cavity, while the amplitude control loop is keeping the gap voltage at the required level. This provokes an increase of the direct and reflected power that , depending on the phase relation between incident and reflected wave, could cause either an arc or most probably merely a disturbing signal in the arc detecting electronics. Vacuum trips have became very rare: as expected the number of faults has been vanishing with operating time. Random beam dumps caused by the ion pump interlocks have occurred for certain temperature settings of one cavity when ramping more than 200 mA at 2 GeV. These requests of beam dump are likely to be caused by an excited cavity mode which propagates through the tube where the ion pump is mounted. The mode which is suspected to be the cause of this effect is the tenth longitudinal mode whose frequency is close to 2.1 GHz. However this is not fully confirmed, but the flexibility of the temperature setting of the cavity has helped to avoid the repetition of the problem. Finally no faults have occurred in the low level system.

III. PHASE LOOPS OPERATION

The original design of the phase loops has been revised. With the former concept in fact, the closure of the loops on all the four plants generally provoked a reduction in lifetime or even beam losses. Furthermore injection seemed to saturate with all the loops in operation and problems with the ramping occurred as well. First of all the speed of the loop has been decreased to 1 msec, so to avoid perturbing interaction with the synchrotron oscillation period. The insertion of the loops has been modified so that now it is performed smoothly instead of abruptly. Finally the return signal of the loop is sampled at the directional coupler just before the cavity input coupler, since the main contribution to the phase variations comes from the klystron. With these modifications the phase loop system works satisfactory, not presenting any of the above mentioned problems. The possibility of implementing a fast RF feedback loop using the cavity voltage sample is under consideration even if at the moment it does not seem necessary being the phase stability of the cavity voltage already in the required range (± 0.5 deg.).

IV. CAVITIES' TEMPERATURE AND HOM SPECTRUM

Excitation of longitudinal multibunch instabilities by the cavity HOMs has been cured by shifting the HOMs' frequency away from overlaps with Coupled Bunch Mode (CBM) frequencies. This shift is obtained by a proper setting of the cavity temperature. This temperature can be regulated in a wide range (~30°C), at a constant cooling water flow.

The first nine monopole HOMs of the smooth shape ELETTRA cavities have been taken into account. For each mode only one resonance is present, since the cavities are single cell. Since no damping device is present, they are high Q resonances and their bandwidth is small compared to the interval between two subsequent CBM frequencies. Along with the wide tuning range this allows to select cavity temperatures at which harmful HOMs are sufficiently far away from CBM frequencies. The cavity temperature setting happens interactively from the general control system.

For an analytical approach to this technique the HOMs' frequencies should be known for the different operating conditions of the cavities and of the machine. Therefore the HOMs' frequencies are measured on the "cold cavity" (i.e. without RF power) at a given cavity temperature T_0 and accelerating mode (L_0) frequency. The HOM spectra characterisation is completed by measuring the coefficient τ, which gives the HOM frequency shift for a unitary change in cavity temperature at fixed L_0 frequency, and φ, which gives the HOM frequency shift induced by a unitary L_0 frequency change. The HOM spectrum characterisation is accurate and reliable. In fact the temperature stability of the cavity is within ± 0.05 °C and the accelerating mode frequency loop doesn't operate via an internal plunger but via an external tuning cage. Finally the temperature regulation loop operates in such a way that the fundamental mode frequency change from 0 to full RF power is little and can be measured. The corresponding little change on the HOMs' frequency measured without RF power, can be computed. It is equivalent to a shift in the temperature of the measurement, $T_0 + \varepsilon_w$. Typical value for ε_w is - 0.5 °C.

On the base of these data a "critical temperature" can be defined for each HOM and the corresponding Coupled Bunch Mode (CBM) [3]. Setting the cavity to this temperature maximises the coupling between that HOM-CBM pair. Computing the critical temperature for all harmful pairs, temperature settings can be sorted out where the coupling is minimised. Dependence on RF frequency, beam current, energy as well as RF voltage can be evaluated [3].

mode	fr (MHz)	Q	R/Q	R//	τ	φ
	T0 =43°C		Ohm	kOhm	kHz/C	
L0	499.654				0.0	1.0
L1	949.754	24562	34.7	851	-11.5	0.6
L2	1055.533	41265	0.5	20	-19.3	-0.3
L3	1421.287	40781	7.4	302	-43.0	-2.2
L4	1513.606	27953	6.3	176	-28.2	-0.3
L5	1600.458	13169	21.6	284	-41.6	-2.3
L6	1877.557	26911	7.2	194	-33.3	-0.1
L7	1948.013	40963	2.4	99	-52.6	-2.2
L8	2030.998	56767	0.7	37	-34.9	0.1
L9	2072.590	32956	24.7	813	-108.0	-8.3

Tab. 2: Longitudinal HOM characterisation for cavity S3.

As an example tab. 2 shows the characterisation of the longitudinal HOM spectrum for cavity S3. The HOMs' frequency and Q are measured as they would be seen by the beam. The computed value (OSCAR2D) for R/Q is quoted. The values in this table are used for the computation of the critical temperatures as it is discussed in [3].

V. NEW PARAMETERS FOR THE OPERATION WITH 400 mA AT 2 GeV

An effective peak voltage of 1.8 MV at 2 GeV was considered to be necessary in order to reach a reasonable lifetime. This estimate was based on certain assumptions about bunch lengthening (which means broadband impedance) and vertical emittance coupling [4]. This lead to the conclusion that with the foreseen layout, two more plants were needed for a 400 mA beam current at 2 GeV. From the experience with the machine, it became clear that these requirements could be slightly relaxed for the multibunch case. In fact in routine operation with 4 cavities at 600 kV peak gap voltage, i.e. 1.68 MV total effective voltage, the lifetime at 200 mA, 2 GeV is from 30 to 14 hours depending on machine optics. For this reason the parameters of the existing RF system are already sufficient to store 400 mA at 2 GeV with four plants (see tab. 3). Being limited by the total available RF power, the total voltage has to be obviously decreased so to allow sufficient power to the beam. However the slight decrease in RF voltage does not dramatically lower the lifetime. Up to now operation of the machine at 2 GeV is limited to 250 mA due to overheating problems of BPMs at higher current. These problems are now on the way to be solved, hence high current tests are foreseen to confirm if satisfying operation of the machine can be achieved without increasing the number of cavities.

		A	B	C
Power loss (keV/turn)		255.75	286.15	316.55
Total power to the beam (kW)		102.30	114.46	126.62
Number of cavities	4			
Total available RF power (kW)	240			
Power wasted per cavity (kW)		28	25	22
Peak cavity voltage (kV)		610	570	540
Total peak eff. voltage (MV)		1.70	1.59	1.51
Synch. phase angle (deg)		8.6	10.4	12.1
Synchrotron frequency (kHz)		11.1	10.7	10.4
Overvoltage factor		6.65	5.56	4.77
RF Energy acceptance		0.025	0.023	0.022

Tab. 3. RF Parameters at 2.0 GeV, 400 mA.

Notes: A. Bare machine.
B. Values calculated for presently planned ID.
C. Values calculated for two times the ID in B.

VI. FUTURE IMPROVEMENTS TO THE RF SYSTEM

The improvements which are under study are performed to further reduce the checks and actions by the operator.

It has already been mentioned above that the relative phases of the cavities need to be re-optimised from time to time. Normally this is done once a day and, if required, the correction is generally about 1 degree. The reason is thought to be due to variations in ambient conditions. In fact two cavities are placed in two different nearby sections of the ring and the other two are placed in the diametrically opposite position. RF plant driving signals are distributed via 7/8" flexwell cables running in the service area. This cables are for the moment not pressurised and are longer than 50 metres for two cavities. Their electrical length is obviously dependent on ambient temperature, pressure and relative humidity. Variations of these parameters have been observed in the service area. Another important parameter is also the ageing of the cables, but after eighteen months of operation this factor causes a minor effect. In order to avoid the action of the machine operator, a slow rephasing system is under study. This could be based either on the measurement of the input power to each cavity or on the measurement of the synchrotron frequency. The first method is actually more straightforward to implement. The measurement of the input power to the cavity is already acquired by the control system of the machine. The drawback of this solution is that it can be influenced by the slightly different input powers at the same gap voltage due to differences in the cavities and their matching to the line. However the error generated with this method is very low. A more precise system could be obtained combining the input power measurement with the measurement of the synchrotron frequency. The maximisation of the synchrotron frequency by phasing the cavities would assure that the gap voltages of the cavities are correctly phased with respect to the beam. A further improvement can be obtained by operating the distribution cables at a slight overpressure. Being the cables air filled, with the dielectric limited to an helical support, this should practically eliminate the effect of variation in ambient pressure and relative humidity. However the temperature dependence remains.

A phase discriminator will be added to measure the relative phase of the RF system driving signal to the Linac injector. This will allow to fix the phase between Linac and RF system to optimise the injection efficiency. The "good" phase will be then restored before injecting by means of a software command acting on the general phase shifter.

The vacuum interlock of the cavities is now based on a Penning gauge fitted in a tube brazed to the cavity. The possibility of adding a further interlock based on the derivative of the vacuum pressure is under study. In fact before a cavity trips, the increase in vacuum pressure in the cavity is very rapid. Therefore a system based on the derivative of the vacuum pressure would be more efficient to protect the system from eventual damages in the cavity or input coupler. This solution has been already adopted in other machines (e.g.. ESRF). Of course the interlock based on the pressure measurement has to be maintained as well.

VII. REFERENCES

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