CONSTRUCTION OF A THIRD RF ACCELERATION UNIT FOR THE ESRF STORAGE RING

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ABSTRACT

With four cavities powered by two 1.3 MW transmitters, the ESRF has successfully delivered synchrotron light to the users with 200 mA of stored multibunch beam, which is twice the initial ESRF target value. For this, the cavities and in particular the cavity input couplers have been pushed to their upper power limits. In order to provide high intensity operation by still operating the RF system at moderate power level, the ESRF has started the construction of a third 1.3 MW transmitter powering two additional five-cell cavities in the storage ring. This takes into account the steady increase of beam loading which results from the installation of more and more insertion devices. Furthermore, a total voltage increase from 8 MV to 12 MV will be obtained while still keeping the power constraints on the cavity couplers and the klystrons below the present values. This will result in a higher lifetime especially for high currents per bunch when the storage ring is operated in single and few bunch mode.

The system will be redundant and flexible enough to guarantee full beam performance with only two transmitters in operation. It will also be possible to keep any pair of cavities unpowered or to use them for Landau damping in order to obtain stable high current operation with homogenous multibunch filling.

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) to support an operation at the design current of 100 mA at 6 GeV. Already during commissioning, higher currents could be stored and the standard high intensity multibunch operation is now at 200 mA. Each of the two transmitters must then deliver 700 to 750 kW. However, although each cavity is fed through two input couplers, these are now operated close to their upper power limits. Note that longitudinal HOM driven multibunch instabilities showing up around 70 mA are suppressed with Landau damping obtained by filling only one third of the SR [1].

For periods of about 50 % of the year, one transmitter is disconnected from the SR to allow maintenance, pre-conditioning of new couplers on the cavity teststand, commissioning of klystrons and various component tests. At full klystron power, 175 mA can then be stored with the remaining transmitter connected to the four SR cavities [1]. During these periods, the SR is often operated in single bunch mode at 15 mA, in 16 bunch mode at 90 mA or in multibunch mode at a reduced intensity of about 150 mA.

In order to guarantee full availability of high intensity operation and to improve the reliability by limiting the nominal power load on the various RF subsystems, the ESRF is now constructing a third 1.3 MW transmitter feeding a third pair of cavities which will come into operation at the end of 1997. This will in particular allow:

◊ to lower the power transmitted through the cavity couplers,

◊ to still sustain high intensity operation in case of failure of either a transmitter or a pair of cavities, and when one transmitter is required for RF tests (no further need for an operation with only one klystron at full power),

◊ to increase the accelerating voltage for a better lifetime especially in few bunch operation and to account for the additional beam loading due to further installation of insertion devices, while still operating the klystrons and couplers at moderate power,

◊ to define a new operation mode with Landau damping of longitudinal multibunch instabilies for homogenous SR filling, by operating one pair of cavities at $f_{rf} + f_o$.

2 FUTURE OPERATION WITH A THIRD RF ACCELERATION UNIT

Table 1 shows the maximum current ranges and the power requirements obtained with four and with six five-cell cavities on the SR for different values of the accelerating voltage V_c. Typical synchrotron losses of 5 MeV/trun have been assumed and waveguide losses in the order of 10% were neglected for the calculations. The maximum coupling ß = 4 achievable with our couplers determines the current for RF matching I_{match} as well as the Robinson stability limit I_{rob}, i.e. the maximum stored current. P_{WdEq} gives the equivalent incident power that would produce the same peak electric field in the ceramic windows of the cavity input couplers as the sum E-field from the actual forward and reflected waves [1]. P_{WdEq} and the total required trans-mitter power P_g are given for 200 mA operation in table 1.

Vc [MV]	8	10	12
4 Cavities:			
I_{match} [mA]	**179**	280	403
I_{rob} [mA]	**299**	466	672
P_{WdEq} [kW] @ 200 mA	**177**	233	336
P_g [kW] @ 200 mA	**1301**	1488	1768
6 Cavities:			
I_{match} [mA]	120	**187**	269
I_{rob} [mA]	199	**311**	448
P_{WdEq} [kW] @ 200 mA		**115**	149
P_g [kW] @ 200 mA		**1312**	1464

Table 1: RF parameters for 4 and 6 Cavities on the SR

The following improvements will be obtained with a third RF unit:

◊ the nominal accelerating voltage will be increased from 8 to 10 MV without needing more total RF power,

◊ at the same time the power loading P_{WdEq} of the cavity windows will be reduced by 35 %,

◊ even for V_c = 12 MV, the cavity windows will be operated at less power than with four cavities at 8 MV: this will allow to increase the lifetime in single and few bunch mode with high currents per bunch,

◊ including waveguide losses, one ends up with a total required RF power of about 1500 kW at maximum, which requires only moderate power per klystron, even with one disconnected transmitter and one transmitter feeding four cavities,

◊ note that a 200 mA operation at low V_c = 8 MV will not be possible with six cavities, as the beam loading factor P_b/P_c (beam power over cavity losses) is too high to fulfill the Robinson stability criterion: this results from the large total impedance of six cavities; low V_c would therefore require to operate only four cavities as described in section 3.

The experience with four cavities indicates that, due to manufacturing tolerances, the HOM frequencies of different cavities are sufficiently spread in order not to interfere constructively for the build up of multibunch instabilities. No reduction of instability thresholds is therefore expected with the installation of two more cavities.

3 OPERATION WITH 4 POWERED AND 2 DETUNED CAVITIES

If one pair of cavities may incidently not be powered, it will nevertheless be possible to operate the SR at full performance as of today. This regime has been simulated for various frequency detunings Δf_d of the non-powered cavities. The voltage V_c that must be provided by the four powered cavities in order to obtain a total accelerating voltage V_{ct} = 8MV is shown in fig. 1 for Δf_d = ±50 kHz. Note that V_{ct} results from the vector sum of V_c and the beam induced voltage V_d in the detuned cavities.

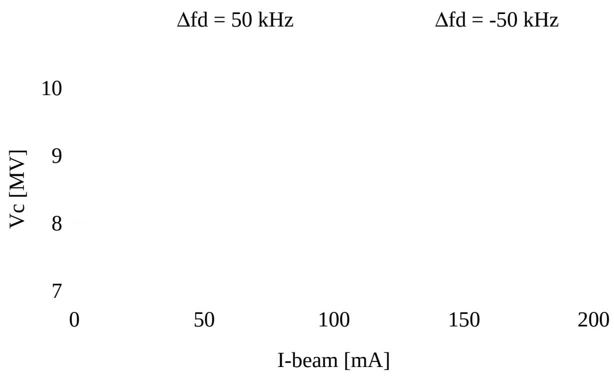

Figure 1: V_c required in the powered cavities to obtain a total accelerating voltage of V_{ct} = 8 MV

For both signs of Δf_d, at 200 mA, the two detuned cavities draw 139 kW from the beam, 28 kW being absorbed in the copper and 111 kW in waveguide loads. However, fig. 1 shows that a negative detune is more favorable. In this case the phase of V_d is such that the non powered cavities contribute to the longitudinal focussing V_{ct}. Therefore, less V_c is required from the four powered cavities. The opposite is true for a positive detune Δf_d.

The required total RF power at 200 mA is 1428 kW for Δf_d = -50 kHz and 1580 kW for Δf_d = +50 kHz: this has to be compared with Pg = 1301 kW in table 1 obtained for the same working point with only four installed cavities. Unfortunately, the tuning range of the existing ESRF cavities does only allow to set a higher negative detune. It therefore turns out that +150 kHz is the best choice requiring only 1359 kW of generator power at 200 mA.

Calculations have also shown that the Robinson stability limit is slightly reduced by the non powered cavities, but it still remains sufficiently far above 200 mA.

A test has been carried out at 5 GeV where the radiation losses of 2.4 MeV/turn allow to operate only two cavities at V_c = 4 MV: the experimental data were in good agreement with the theoretical predictions.

4 OPERATION WITH TWO LANDAU CAVITIES

In multibunch operation, longitudinal HOM driven instabilities are suppressed by filling 1/3 of the SR [1]. The induced peak-to-peak voltage modulation at the revolution frequency f_o = 355 kHz reaches 10 to 15 % at maximum current. The resulting spread in synchrotron frequencies then provides sufficient Landau damping to cure the instabilities. For 16 bunch operation a cavity temperature regulation to ± 0.2 °C is used to detune the HOMs off beam resonances.

One could also produce Landau damping for homogenous multibunch filling (which some users would prefer) and for 16 bunch mode by direct amplitude modulation of the cavity voltage. It is therefore planned to set up a special operation mode using four cavities for acceleration according to e.g.

$$V_c = 9 \text{ MV} \cos [2\pi f_{rf} t]$$

and making use of the third pair of cavities tuned to $f_{rf} + f_o$ and powered such as to obtain

$$V_{mod} = 2 \text{ MV} \cos [(2\pi f_{rf} + 2\pi f_o)t] \ .$$

This will result in a total phase and amplitude modulated accelerating voltage:

$$V_{ct} = 9\text{MV} \ \{1+m \ \cos[2\pi f_o t]\} \ \cos \ [2\pi f_{rf} t \ +m \ \sin(2\pi f_o t)]$$

with $m = |Vmod/Vc| \approx 2/9 \approx 22\ \%$.

Such a scheme has been tested succesfully at 5 GeV with two cavities providing Vc = 4 MV at f_{rf} and the other pair of cavities operated at $f_{rf} + f_o$. The SR was homogenously filled until a HOM driven multibunch instability developed and the injection saturated. The measured instability current thresholds obtained with four different values of V_{mod} are plotted in fig. 2.

The results look very promising since the Landau cavities allowed to increase I_{thres} by a factor 7. On the other hand, with 1/3 filling and the second pair of cavities tuned according to section 3, an even higher threshold of 175 mA was measured: the reason for this should be found in a different distribution of synchrotron frequencies. We also observed that homogenous filling yielded a two times higher lifetime at 100 mA than 1/3 filling: this is not yet explained.

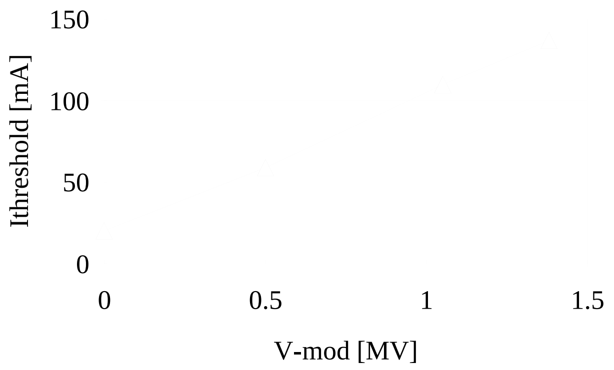

Figure 2: Damping of HOM driven longitudinal multibunch instabilities with Landau cavities operated at $f_{rf} + f_o$ (5 GeV experiment).

5 THIRD RF UNIT CONSTRUCTION

The existing RF transmitters had been delivered as a turn key system by Herfurth (FRG). They have been continously improved and upgraded since. Except for the high voltage power supply that has been ordered from Siemens, the third RF unit is being built in house. The same main hardware will be used as for the existing equipment (klystron and auxilliaries, cavities, waveguides, circulator).

However, a large part of the low level RF, the loops, the control hardware and the software have been redesigned. The present RF control system had been designed in 89/90 at an early stage of the ESRF project and could not fully integrate the final philosophy of the machine control system. It was therefore decided to totally rebuild it, in order to follow the ESRF standard and to use all the already developed tools. The system will be object oriented in order to provide more flexibility in the control of each sub-equipment.

Based on the six years of use of the present system, a new specification has been written after a complete review of the interlocks, loops, equipment states and diagnostics [2]. After commissioning of the third RF unit at the end of 1997, it is planned to upgrade the existing RF transmitters.

The long delivery components have already been ordered in 1995 and the new RF building is under construction.

REFERENCES

[1] “RF System Development for High Current Accumulation in the ESRF Storage Ring”, J. Jacob et al., in EPAC’94 Conference Proceedings, London, June 1994.

[2] “User requirements for RF control”, J. Meyer and J.-L. Revol, internal ESRF specification, June 1996.