A POSSIBLE RF SYSTEM FOR CERN RCS

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Abstract

As part of the LHC Injectors Upgrade (LIU) program at CERN the possibility of replacing the PSB with a new Rapid Cycling Synchrotron (RCS) is considered[1]. The requirements in terms of accelerating voltage (60 kV), frequency range (1.3 MHz – 9.6 MHz) and available space (4.7 m) make the RF system development quite challenging. The improved loss characteristics of the new FINEMET® type (FT3L) combined with a filter-like topology, allows achieving all the requirements. This paper describes the design of such a RF system

INTRODUCTION

As part of the LHC Injectors Upgrade (LIU) program at CERN the possibility of replacing the PS Booster (PSB) with a new 10 Hz, Rapid Cycling Synchrotron (RCS) has been studied.

Compromising among different parameters, the RCS circumference has been set at 4/21 of the PS (119.68 m) with a three-fold geometry and the symmetrical straight sections assigned to injection, extraction and accelerating structures respectively (fig. 1).

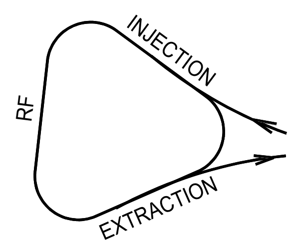

Figure 1: Lattice layout.

Beam injection from Linac4 will be at 160 MeV corresponding to a revolution frequency of 1.303 MHz that rises to 2.375 MHz at 2 GeV extraction.

To allow flexibility in choice of the PS filling patterns, operation should be possible at h=1 through h=4 so that the frequency range to be covered basically extends from 1 MHz to 10 MHz. Within this range, multi harmonic operation should be available at least at injection and during the first part of acceleration.

DESIGN CONSIDERATIONS

The main RCS parameters, from the RF system point of view, are listed in table 1. The wide frequency range, the fast cycling and the limited available space in the straight sections, suggest the use of high-permeability materials and Finemet® is the magnetic alloy of choice because of the high value of its figure of merit, $\mu_p Qf$, which translates into limited losses and high accelerating gradients. In addition, its very low quality factor, Q, allows the entire frequency range to be covered without any tuning system which would introduce, at the specified 10 Hz repetition rate, substantial additional complexity. Moreover, the wideband characteristic enables multi-harmonic operation.

Table 1: Main RCS System Parameters

Parameter	Value
Energy range	160 MeV to 2 GeV
Repetition rate	~10 Hz
RF voltage	60 kV
Revolution Frequency	1.3 MHz to 2.4 MHz
Harmonic numbers	h = 1 to 4
Frequency range	1.0 MHz to 10.0 MHz
Available length	2X2.35 m
Beam intensity	10^{13} ppp
Energy increase	~ 3 kJ
Required power	60 kW (50 ms acceleration)

The typical response of a Finemet® loaded resonator is shown in fig. 2 where the individual parallel equivalents R_P, L_P and C_P contributions are also plotted.

The first two terms (R_P, L_P) almost entirely depend upon the Finemet® core characteristics and drive the low frequency response. At high frequency the core contribution almost vanishes and the response is primarily driven by the resonator capacitance C_P. Unlike R_P and L_P this capacitance mostly depends on the resonator geometry.

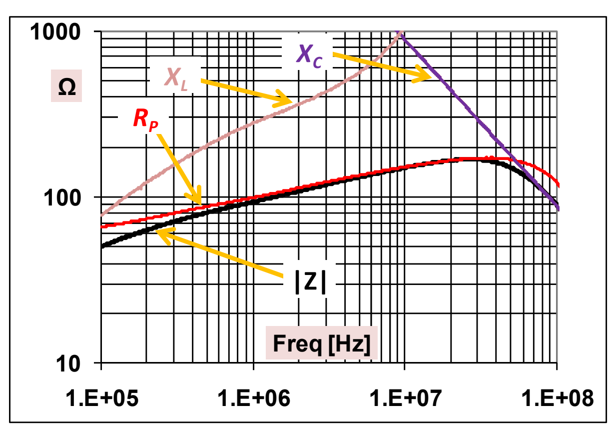

Figure 2: Response of a Finemet® loaded resonator.

A number of mechanical and electrical reasons suggest the use of many cores in each cavity. As one could expect, stacking more cores linearly increases the total impedance. But with this higher impedance the resonator capacitance becomes predominant at lower frequency (fig. 3) thus limiting the usable bandwidth. As the typical RF drive for such a resonator is a vacuum tube, this effect is magnified by the addition of the final stage output capacitance. To fight this effect and to fully exploit the Finemet® wideband response the total system capacitances must be somehow compensated.

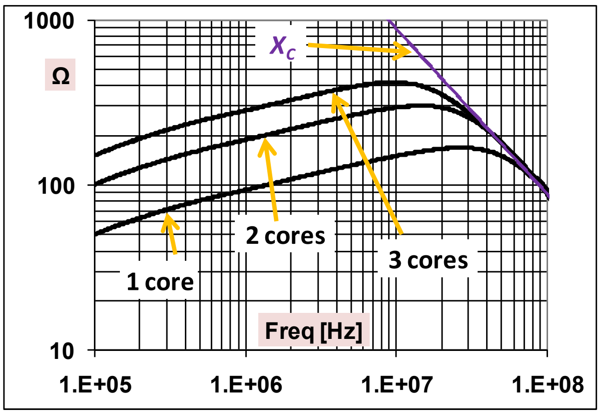

Figure 3: Response of stacked cores.

Considering the fact that the capacitances are mostly concentrated at the generator and at the resonator, such compensation can be achieved using a filter-like configuration (fig. 4). Although almost flat amplitude responses are theoretically possible with such a network, the lack of freedom in the choice of C_{Tube}, C_P and R_P imposes some compromises and typically ripples appear in the amplitude, phase and delay responses.

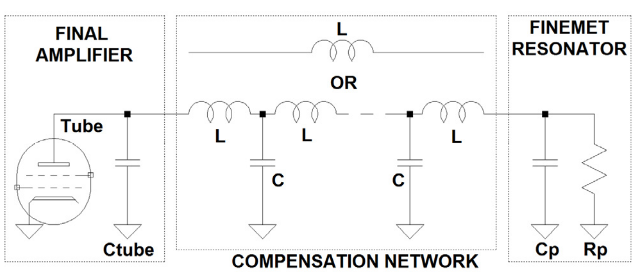

Figure 4: Compensation scheme.

SYSTEM DESIGN

The foreseen RF cavity (similar to the LEIR ones) is a coaxial resonator with the accelerating gap in the centre (fig. 5). Each cavity shall contain 6 Finemet® rings (OD=670 mm ID=305 mm, T=25 mm) and will be 0.5 m long.

From measurement of the new low loss Finemet® type FT3L samples, the $\mu_p Qf$ and Q values have been defined (fig. 6). As compared to the older FT3M material, losses are reduced by almost a factor 2. This allows a substantial voltage increase at constant power dissipation that is limited by the ring cooling efficiency. At the proven water cooling capabilities (620 kW/m^3 of Finemet®) the CW gap voltage will span from 7.2 kV at 1 MHz to 10.4 kV at 10MHz (fig. 7). Limiting the low frequency duty-cycle to ~75 %, a nominal gap voltage of 8 kV can be achieved over the whole band.

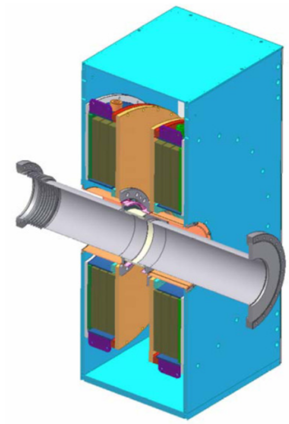

Figure 5: Cavity structure.

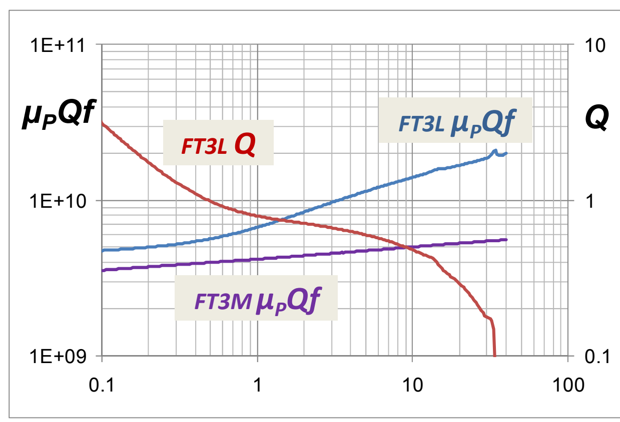

Figure 6: Finemet® FT3L and FT3M measured characteristics.

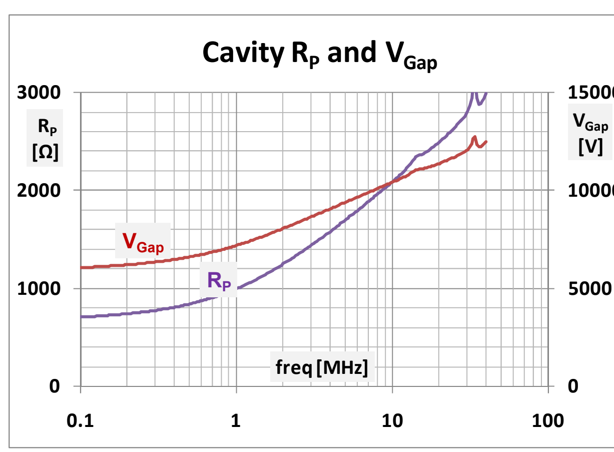

Figure 7: Expected cavity losses and voltage vs. frequency.

The cavity is basically a push-pull device with very loose coupling between the two cavity halves. This imposes a differential drive and thus a push-pull configuration for the final amplifier.

Each cavity will be driven by a push-pull final stage built around two 80 kW Thales tetrodes type RS1084CJ. This is a water cooled device widely used in the PS complex for which simulation and testing tools are readily available.

Simulations show that to cover the foreseen frequency range a 5-cells filter compensation network is required (fig. 8). The amplitude ripple is then limited to ≈7 dB and can easily be compensated by the low-level AVC system. Figure 9 shows the simulated response for the compensated and uncompensated cases.

To ensure sufficiently flat input circuit response, the grid capacitance is integrated in an all-pass network loaded on 50 Ω. The required driving power is provided by a solid-state, 1 kW, wide-band amplifier. Table 2 lists the main power stage and cavity characteristics.

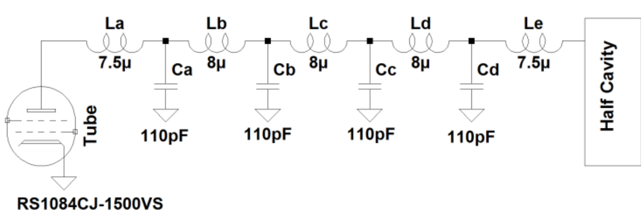

Figure 8: Final stage to cavity compensation network (One of the two push-pull sides).

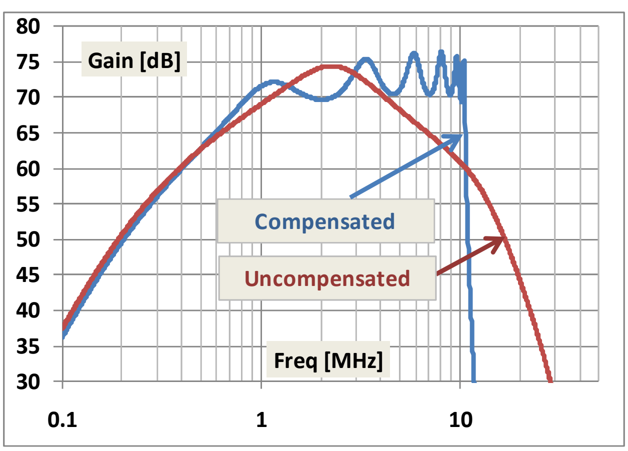

Figure 9: Compensated and uncompensated response.

The circuit configuration selected to cover the frequency range introduces wide phase and delay changes. This does not allow the implementation of a fast RF feedback loop for beam loading compensation. Alternative solutions must thus be devised. One candidate could be the feed-forward scheme sketched in fig. 10. It is successfully used in J-PARC[2,3] and proved its ability of reducing the beam induced voltages by more than a factor 10.

Table 2: Main Power Stage and Cavity Characteristics

Parameter	Value
Cavity Gap Voltage	8 kV
Frequency range	1.0 to 10.0 MHz
Cavity power	26 kW
Cavity length	0.5 m
HV supply voltage	8 kV
HV supply current	~20 A
Plate power dissipation	2 X 55 kW
Driving power	2 X 250 W
Repetition rate	~10 Hz
Number of cavities	8
Total cooling water	60 m^3/hr
Cooling water ΔT	15 °C
Total required electrical power	~1500 kVA

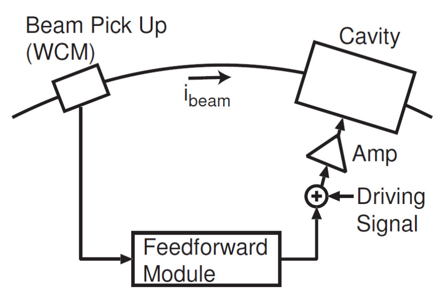

Figure 10: J-PARC feed-forward scheme.

THANKS

Thanks to Dr. Chihiro Ohmori for providing information about Finemet® and all useful discussions.

CONCLUSIONS

Despite the limited space dedicated to the RF system a solution has been devised to provide the 60 kV accelerating voltage required in the RCS under study at CERN. The solution is based on a novel Finemet® grade with improved loss characteristics. An atypical system capacitance compensation scheme allows covering the frequency range 1 to 10 MHz without tuning system and allows multi harmonic operation. A proven scheme for dealing with the beam induced voltages was also identified.

REFERENCES

[1] K.Hanke *et al*, Feasibility Study of a Rapid Cycling Synchrotron to replace the PS Booster, CERN, Geneva 2011.
[2] F. Tamura, J-PARC RF group, private communi-cations.
[3] F. Tamura *et al*, Multiharmonic rf feedforward system for beam loading compensation in wide-band cavities of a rapid cycling synchrotron, Phys. Rev., ST- Acc. Beams 14, 051004 (2011)