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STUDIES ON A WIDEBAND, SOLID-STATE DRIVEN RF SYSTEM FOR THE CERN PS BOOSTER

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Abstract

In the framework of the LHC Injectors Upgrade project (LIU) the PS Booster (PSB) will undergo in depth consolidation and upgrade programs [1]. The aim is increasing the extraction energy to 2 GeV, exploiting the potential of Linac4 and allowing reliable operations during the next 25 years. For the RF system, substantial improvements could come from the replacement of the existing narrowband, tuned systems covering the $h=1$ and $h=2$ frequency ranges (*0.6 ÷ 1.8 MHz* and *1.2 ÷ 3.6 MHz* respectively) with wideband (*0.5 ÷ 4 MHz*) Finemet® loaded cavities. The new system would be modular, allow multi-harmonic operation, use solid-state power stages and include fast RF feedback to compensate beam loading effects to some extent. A proof of principle system providing ≈*3.0 kV* accelerating voltage has been designed, constructed and installed in one of the PSB rings. This paper provides details on the design and measurements as well as information on the project status.

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GENERALITIES

The PS Booster (PSB) RF systems consolidation and upgrade programs aim at increasing the extraction energy to 2 GeV , the intensity beyond $2 \cdot 10^{13}$ protons and allow reliable operation during next 25 years. To achieve these goals a large amount of equipment has to be replaced or undergo heavy renovation such that almost a full reconstruction is required. Moreover, the integration of the cavity tuning and voltage servo controls into the new digital low level electronics would require a complete re-thinking of the low level and protection systems as well. The question of entirely replacing the systems, implementing modern technology, thus arises; in particular with the experience built over the last years in Low Energy Ion Ring (LEIR) where wideband, Finemet® loaded cavities have been put into operation [2, 3].

In this perspective a modular system, covering the *h=1* and *h=2* range without tuning (0.5-4 MHz), allowing multi-harmonic operation and being driven by solid-state amplifiers is presented here. It also includes a fast RF feedback loop contributing to the compensation of the beam induced voltage.

SYSTEM DESIGN

Among many substantial differences between Finemet® magnetic alloy and ferrites loaded cavities, two should be mentioned before coming to the discussion of the design: the low quality factor and high saturation field.

Exploitation of the first characteristic can be used to achieve a wideband frequency response. The second one allows maintaining linear response even at high accelerating gradients thus opening the door to effective and stable feed forward beam loading compensation techniques [4].

Configuration choice

Figure 1 plots the typical response of a Finemet® loaded resonator assuming a parallel *R-L-C* circuit equivalence. L_P and R_P drive the low and mid frequency response respectively; they mostly depend on the Finemet® characteristics. The system capacitance C_P mainly depends on the resonator geometry and influences the high frequency response. Any external contribution to C_P (i.e. final tube anode capacitance) will translate into an additional limitation of the high frequency response.

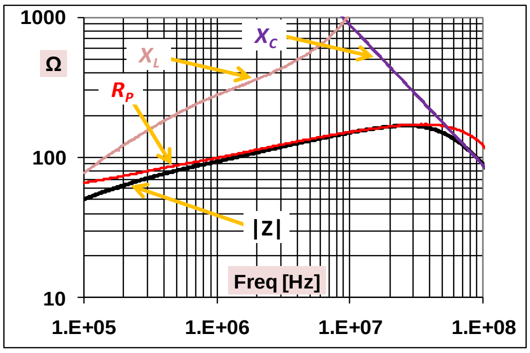

Figure 1: Finemet® loaded resonator typical response.

Stacking more cores (fig.2) has the effect of linearly increasing the low and mid band impedance but at the same time the high frequency cut-off decreases as the capacitive effects become predominant at lower frequency.

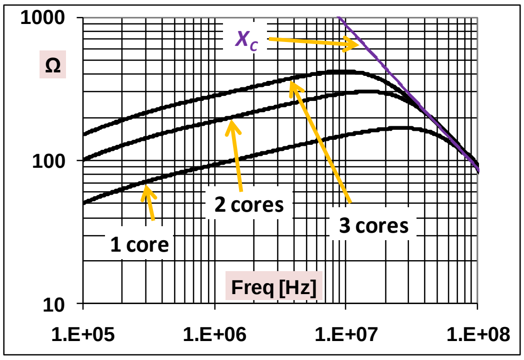

Figure 2: Stacked cores resonator response.

Full exploitation of the wideband characteristics thus suggests minimizing the number of stacked cores across each gap. For this reason the retained configuration is that of a basic cell composed of a gap with a core on each side (fig. 5a). This balanced configuration allows a better control of the even harmonic distortion that might be critical due to the wideband response. It also provides easy access to differential signals to implement a fast feedback loop in a push-pull configured power stage.

Basic cell design

The PSB has four superimposed rings with beam axis spaced by 360 mm. To fit within this vertical limitation the ferrite cores used in the existing cavities have an outer diameter *OD=330 mm*. The inner diameter, dictated by the vacuum chamber size is *ID=200 mm* and the width is *T=25 mm*. From data measured on a FT3L Finemet® sample the equivalent loss resistance R_P has been extrapolated for a core with dimensions given above (fig.3). Tests proved that power densities of 500 kW/m^3 with 50% duty-cycle can be achieved (T<100°C) indirectly cooling the core with a water cooled copper ring placed on one side (fig.4). One such core will then handle voltages spanning from *~350* V_P at *500 kHz* to *~470* V_P at *4 MHz* with a power dissipation of *~700 W*.

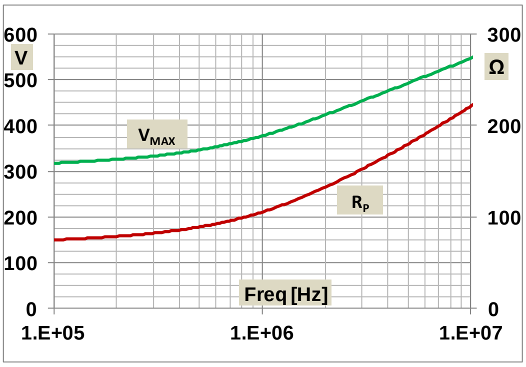

Figure 3: Performance of a FT3L Finemet® core (330/200/25 mm).

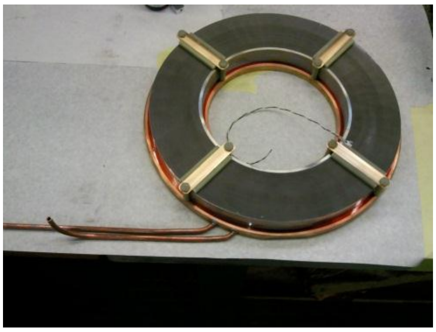

Figure 4: Core mounted on a cooling ring.

In first approximation, for the acceleration of the foreseen $2\cdot10^{13}$ protons to *2 GeV*, an equivalent amount of power has to be made available to the beam. This total power level (*~1.5 kW*) is just in the range of what a compact solid-state, Mosfet based amplifier can provide. In the prototype amplifier eight MRF151G devices are combined in the output stage. A 1÷3 transformer steps then up the voltage and matches to the nominal *50* Ω output load. Supplied with *40 V* DC the achievable output voltage and power on *50* Ω are *360* V_P and *~1.3 kW* respectively. The effective load presented to the amplifier in absence of beam is substantially higher than *50* Ω but the charge represented by the beam brings it down in the order of *35* Ω. Coupling two amplifier units in a single cabinet permits independently driving the two cores. With this compact assembly and using wideband techniques, the amplifier output stage delay can be kept short (*~13 ns*). Samples of the differential gap voltage can be fed back into a differential summing point to implement a fast RF feedback loop (fig. 5b). The differential summing point is composed of the final stage Mosfets paralleled gates. A high impedance input stage provides the driving RF current at the summing point.

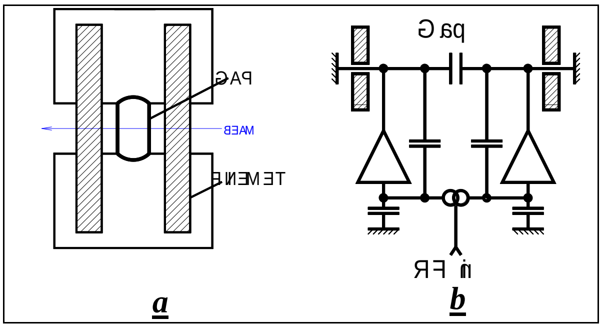

Figure 5: Basic cell configuration.

The open- and close-loop (OL, CL) responses as well as the loop gain (LG) of the single cell system are shown in fig. 6. The gap impedance seen by the beam is plotted in fig.7. Figure 8 shows an amplifier module.

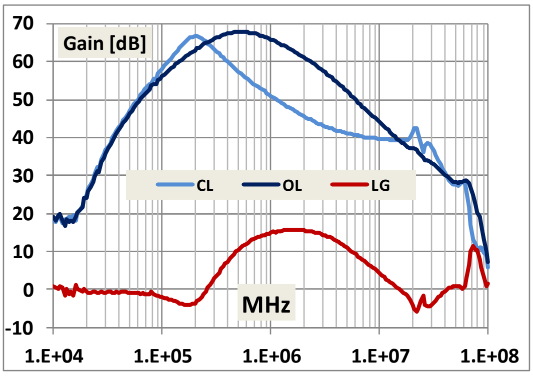

Figure 6: Single cell system response.

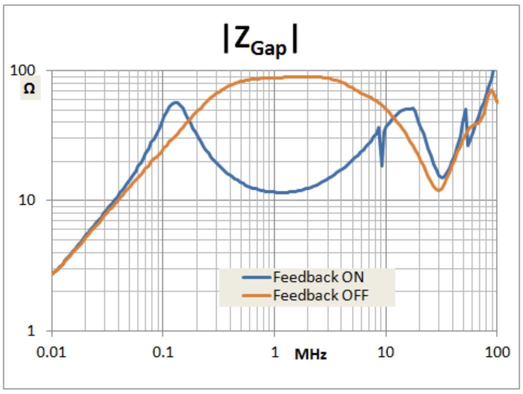

Figure 7: Cell equivalent impedance.

Figure 8: Double amplifier module.

3 KV - 5 CELLS SYSTEM

A prototype 5 cell system has been constructed (fig. 9 and 10) and is now installed in the PSB machine ready for testing (fig.12). Particular care has been taken in manufacturing the 5 gap vacuum chamber (fig. 11). Each cell is independently supplied and a common PLC based interlock supervises the operation. RF-wise, the beam control electronics see the ensemble as a cavity with a single driving point and accelerating voltage return. To avoid interfering with normal operation each cell is equipped with gap shorting devices.

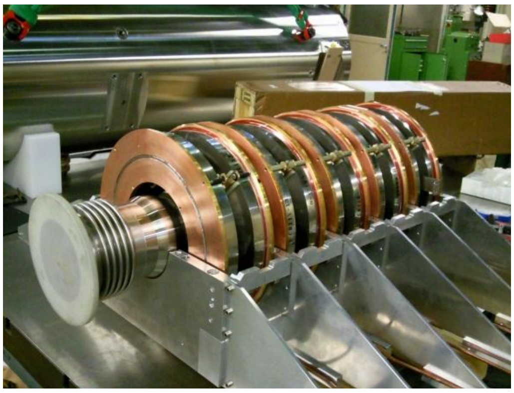

Figure 9: Open 5 cells cavity showing the cores and cooling rings.

Figure 10: Fully assembled system including the power stages.

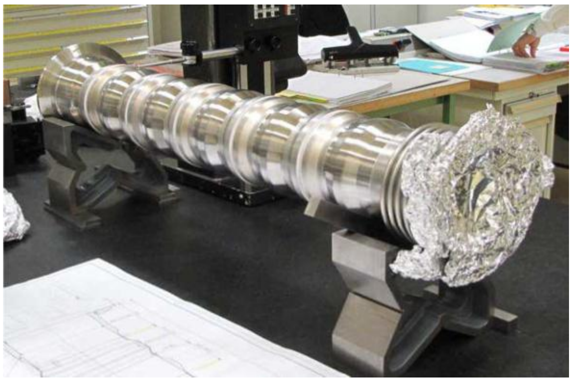

Figure 11: 5 gaps vacuum chamber.

The system provides an accelerating voltage in excess of $\approx 3.0\ kV$ that will be used for acceleration tests in addition to what is available from the existing RF systems. It will also be operated alone in the last part of the accelerating cycle where the required bucket height can be obtained with $3.0\ kV$. Due to the wideband gap impedance seen by the beam, the beam-cavity interactions are expected to be critical. Particular attention will be placed on this issue and the possible mitigation measures.

Figure 12: 5 cells system in the PSB Ring 4.

CONCLUSION

A wideband, solid-state driven prototype acceleration system has been devised, built and installed in one of the PSB rings. It covers the h=1 and h=2 frequency ranges and can be operated in multi-harmonic mode. During 2012 it will be tested to establish its limitations and will contribute to the beam acceleration during dedicated test cycles.

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[4] 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)