MEASUREMENTS AT TRIUMF ON A 80 MHZ CAVITY MODEL FOR THE CERN PS UPGRADE FOR LHC

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Abstract

The RF system of the CERN PS is being upgraded to bunch a beam that can be captured by the SPS 200 MHz RF system for injection into LHC. Two identical 80 MHz cavities are part of this PS upgrade program. At CERN, the cavity has been designed using SUPERFISH and MAFIA concerning its shape, tuning devices and amplifier coupling loop. TRIUMF has built a simplified full-scale, copper-lined, wooden model, designed such that the field patterns of the fundamental accelerating mode and the longitudinal modes agree closely to CERN cavity ones. The aim of constructing the wooden model was primarily to check the design of the capacitive tuners, the power coupling loop and the HOM dampers for the longitudinal modes up to 1 GHz. The results of the measurements were used to define the parameters of the tuners and a reliable model to describe the interaction of the coupling loop with the fundamental mode of the final CERN cavity. Four quarter-wave antennae are adequate to damp the first fifteen longitudinal modes. In order not to decrease the shunt impedance of the fundamental mode by more than 5%, three-element filters have been used with the antenna which damps the longitudinal mode at 256 MHz, 336 MHz and 912 MHz.

1 INTRODUCTION

The upgrade program of the CERN PS for the injection to LHC foresees the installation of some new RF system in the PS ring. A 40 MHz cavity has already been installed [1] and provides a beam with the required bunch spacing of 25 ns with a bunch length of about 8 ns. To match the SPS RF bucket dimensions the length of the bunch must be reduced to less than 5 ns. To achieve this aim two identical 80 MHz cavities will be installed in the PS in 1998. The bunch length reduction will be obtained with a 90° rotation of the bunch in the phase space.

The cavity is water cooled since it is operated nearly at CW (70 % duty cycle) due to the lepton cycle of the PS. Also, a heavy transient beam loading will take place during the LHC cycle and its dynamics will be too fast to be compensated by fast feedback or de-tuning method. A strongly over-coupled amplifier-coupling loop system was designed with PSPICE to cope up with the beam loading and to provide a consistent voltage step-up ratio between the amplifier anode and the cavity gap in a wide band around the cavity resonance. The value of the self inductance of the coupling loop and the voltage step-up ratio between the loop and the cavity gap was difficult to be evaluated reliably from MAFIA and SUPERFISH calculations.

In the frame of the collaboration between CERN and TRIUMF for LHC, a full scale cold model of the 80 MHz cavity has been built at TRIUMF to verify the design of the coupling loop and to develop a set of Higher Order Modes (HOM) dampers based on the quarter wave antennae as already done for the PS 40 MHz cavity [2]. To prevent the antennae from damping the fundamental mode, a coaxial three-element filter was developed to maintain the Q-factor loss within 5 %.

Two capacitive tuners are also foreseen to compensate atmospheric variation and deformation due to heating of the cavity walls during the start-up. The achievable tuning range has been measured. Figure 1 shows the shape of the CERN cavity with coupling loop and capacitive tuner.

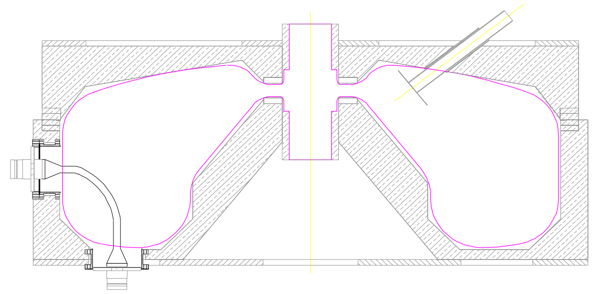

Figure 1. The CERN PS 80 MHz cavity shape (dashed line) and the TRIUMF wooden model with the coupling loop and the capacitive tuner.

2 AMPLIFIER COUPLING LOOP DESIGN AND MEASUREMENT RESULTS

Because of the proposed strongly over-coupled amplifier to deal with heavy transient beam loading, the amplifier coupling loop has to fulfill two requirements: voltage set-up ratio between the loop and the cavity gap close to ten, and a self inductance of the loop in the range of 130 - 160 nH. An approximate shape for the loop was found using MAFIA postprocessing capabilities, integrating the electric field along some different paths and relating the result to the integral on the cavity gap. The value for the self inductance was determined by measurements on different loops mounted on the TRIUMF model. The conclusion is that the cavity loop-system can be described by the circuit shown in figure 2, where the transmission line T2 represents the self inductance of the loop, and the Network Analyzer represents a current source shunted by a 50Ω load. The input impedance measurements on the TRIUMF wooden model is shown in figure 3. The error on the frequencies of the resonances between the PSPICE simulation of the circuit in figure 2 and the measurements is less than 0.2 %.

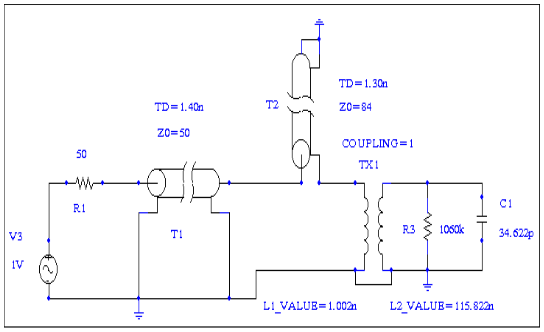

Figure 2. The equivalent circuit of the cavity-loop system

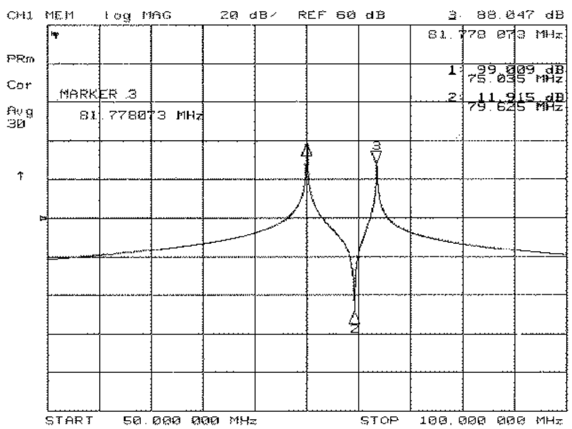

Figure 3. Input impedance measurement.

With the help of the measurements, an analogy between the loop and a strip line [3] was established which allows the dimensions of the loop to be determined. The difficulties in simulating such geometry with MAFIA or similar programs is thus bypassed.

3 CAPACITIVE TUNERS

Using MAFIA to design the capacitive tuners is also difficult to achieve because of the non symmetrical geometry and the dimensions of the tuners. The tuning range measured on the cold model was ±0.4 % for the 80 mm nominal stroke, which is about the half the value calculated by MAFIA. The error is essentially due to mesh problems.. It is interesting to note that the capacitive tuner stores essentially electrical energy. Thus, high voltage and low current associated with the tuners lead to two advantages : they are protected against multipactor problems and do not increase the ohmic losses.

4 HIGHER ORDER MODE DAMPERS

The wooden model built at TRIUMF was extensively used to design the higher-order-mode dampers for the longitudinal modes up to 1 GHz [4]. The physical location of the ports where dampers could be installed was predetermined from SUPERFISH and MAFIA calculations of the electric field configuration of the modes for the CERN 80 MHz cavity. Four loosely coupled capacitive probes (two at each side of the gap and 90 degree apart) at the gap in conjunction with in-phase combiners, provided a clear spectrum of the longitudinal modes and rejected most of the dipole modes. The Q of a particular mode was obtained by S_{21} measurement on a Network Analyzer. Four $\lambda/4$ antennae were constructed from standard 3/8” O.D (10.0mm) copper pipe and their position and length was optimized to provide the lowest Q for the modes under investigation. Although each antenna was optimized for a specific mode, it also damped other modes which had strong E-field in the close vicinity of the antenna. Table 1 shows the four antennae with their length and frequency of the principal mode being damped. All dampers were terminated with a 50 Ω load .

Table 1 : Antennae profile

antenna number	length cm	reference mode MHz
#1	28.0	255
#2	23.5	436
#3	16.5	538
#4	21.0	912

A 3-element high-pass filter was attached to antenna#1 because of substantial coupling to the fundamental mode at 79.64 MHz. The damping of the fifteen longitudinal modes up to 1 GHz by the four antenna is shown in figure 4. Antenna#2 required an angled flange to improve coupling to the fourth mode (436 MHz). Antenna#3 had improved coupling on the twelfth harmonic (910 MHz) by a 25 mm offset on the flange. It can be seen from figure 4 that the damping is very effective up to 800 MHz. Since, the field patterns of the fundamental accelerating mode and the longitudinal modes for both wooden model and CERN cavity were in close agreement, the loaded shunt impedance values for the CERN cavity could be scaled from the measurements. High-pass filters with an attenuation of >20 dB at 80 MHz will be used for antennae1,2 and 4 in order to keep loss of Q below 5% for the fundamental accelerating mode due to the antennae. All the four antennae will be water cooled since estimated maximum copper loss is 7 W (for a cavity gap voltage of 200 kV) for antenna#1 and consequently smaller for the other three.

5 TRANSMISSION LINE HIGH-PASS FILTER

The high-pass filter was designed with transmission line components instead of lumped capacitors or inductors. A prototype filter was successfully simulated on PSPICE and then constructed and tested by using the capacitive and the inductive characteristics of an open and shorted transmission line respectively [4].

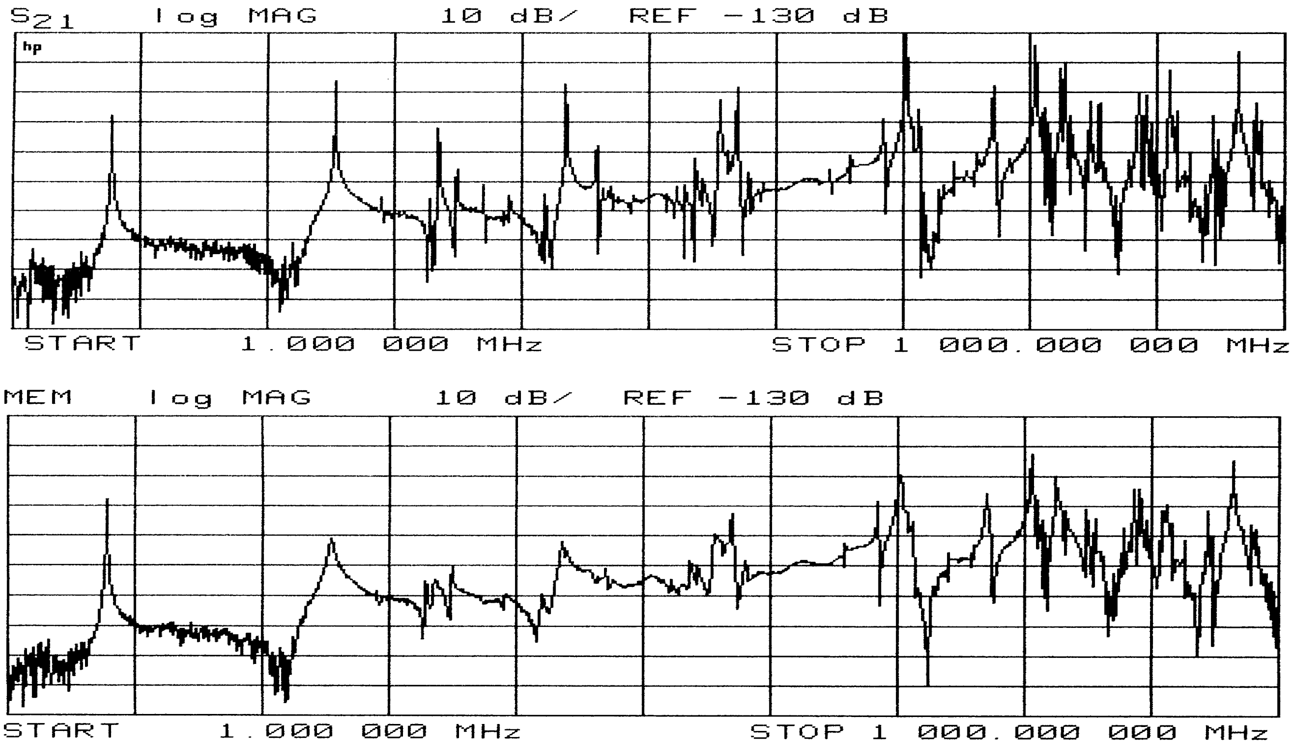

Figure 4. Frequency spectrum of the model cavity with (bottom trace) and without (top trace) HOM dampers

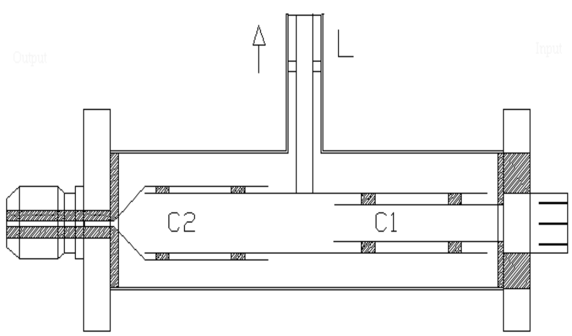

Figure 5. Transmission line design of filter

Figure 5 shows the prototype high-pass filter being built. The overall length of the filter is 30 cm and diameter is 8 cm. It is designed to withstand at least 7 kV at the input of the filter. The transmission line prototype provided an attenuation of 21 dB at 80 MHz . The insertion loss was more than 1.0 dB beyond 760 MHz. This was mainly due to poor rf connection of the input and the output flanges to the outer casing in the prototype.

6 CONCLUSION

The measurements done at TRIUMF on the wooden model has achieved the desired results. The capacitive tuner has been defined from model measurements. The voltage step up ratio of the coupling loop and the cavity gap, the shape and dimensions of the loop, and a PSPICE model was successfully developed to describe the cavity-loop system. The higher-order modes up to 810 MHz was effectively damped by the four λ/4 antennae. The desired value of loaded shunt impedance of 1 kΩ was achieved for most of the higher order modes. Also, the transmission line high-pass filter has been used for three antennae to reject the fundamental mode and thus maintained the Q loss below 5%.

7 ACKNOWLEDGMENTS

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