HIGHER ORDER MODE DAMPING OF THE CERN PS 40 MHZ CAVITY

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Abstract

TRIUMF has built a simplified version of a full scale copper lined wooden model of the 40 MHz CERN cavity for the PS upgrade program for LHC. SUPERFISH was used to design the wooden model so that the field patterns of the fundamental accelerating mode as well as the higher order modes were in close agreement with the modes calculated by MAFIA on the CERN all metal cavity. Extensive measurements have been done to identify the monopole and the dipole modes of the cavity model. The design goal was to damp the impedance of all the higher order modes up to 1 GHz to less than 1 kΩ and not attenuate the shunt impedance of the fundamental mode by more than 5%. Three λ/4 antennae terminated with 50 Ω were employed to damp all the monopole modes up to 850 MHz. One of the antennae uses an external matching circuit. The monopole dampers are being fabricated at TRIUMF to be tested on the CERN cavity with 300 kV and 600 kV gap voltages. MAFIA calculations on the CERN cavity show that most dipole modes can be damped by not copper plating a 30 cm radius part on the inside of the gap capacitor of the cavity. This enables the resistivity of the exposed stainless steel surface to be used to achieve damping.

1 INTRODUCTION

A new fixed-frequency RF system (40 MHz, 300 kV), is being implemented in the PS, as part of the LHC injector preparation. While a full metal 40 MHz cavity was being fabricated at CERN, a wooden model was constructed at TRIUMF to design higher-order-mode dampers, a power coupler and frequency tuners. SUPERFISH was used to design the wooden model so that the field patterns of the fundamental accelerating mode as well as the higher order modes were in close agreement with the modes calculated by MAFIA on the CERN all metal cavity. Extensive measurements have been done to identify the monopole and the dipole modes of the cavity model. From the measurements on the model cavity and MAFIA calculations, shunt impedances of the damped modes have been estimated. The higher-order-mode dampers which have been designed and constructed at TRIUMF, are to be installed on the 40 MHz CERN cavity.

2 HIGHER ORDER MODE DAMPERS

The design of the higher-order-mode dampers was restricted to damping the TM0 longitudinal modes (monopole modes) up to 1 GHz. One of the major constraints was that the Q of the fundamental mode should not be reduced by more than 5%. The physical location of the ports on the outer walls of the cavity were determined from SUPERFISH calculations of electric field configuration of the higher-order-modes up to 1 GHz. Figure 1 is the SUPERFISH plot of the electric field of the fundamental frequency of the CERN cavity.

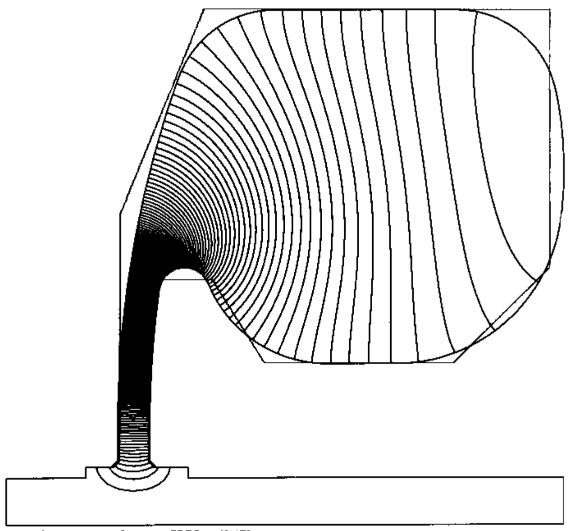

Figure 1 : SUPERFISH plot of 40 MHz cavity mode for the CERN cavity. Outline of the wooden model is also shown.

It is evident that the electric field is relatively weak at the rear of the cavity. A large number of higher order modes have strong electric fields in this area. One can couple to these fields without strongly perturbing the H-field of the fundamental mode. However, the modes at 260 MHz, 386 MHz, 442 MHz and 815 MHz have strong E-fields in the middle of the cavity and orthogonal to the gap axis. The E-fields of these higher-order-modes can be coupled by electric antennae but at the same time some coupling to the E-field of the fundamental mode is unavoidable. The modes are damped by inserting electric field probes ($\lambda/4$ antennae) at the dedicated ports for the dampers. The most dangerous mode is at 397 MHz which has an R/Q of 5.33 calculated at a radius of 7.2 cm and a shunt impedance of 120 kΩ.

2.1 *Design of HOM dampers*

Modes were identified by observing the phase of the particular resonance at the gap at a radius of 23 cm from the longitudinal axis of the cavity. This is done by using four loosely coupled capacitive probes placed symmetrically at this radius. The monopole modes could be identified by noting that the voltage signals on the probes were in phase. Quality factors for all the monopole modes with and without various antennae (terminated with 50 Ω) mounted on the cavity were measured. The lengths and the diameters of the antennae rods were optimized to provide the lowest Q for the modes. The length to diameter ratio is an important factor in designing a broad band antenna. Although each antenna was optimized for a specific mode, it also damped other modes which have strong E-fields in the same location. A total of three antennae were designed to damp most of the modes up to 850 MHz. Figure 2 is a photograph of the three antennae. The rods are constructed from OFHC copper and are supported by commercially available ceramic vacuum feedthroughs.

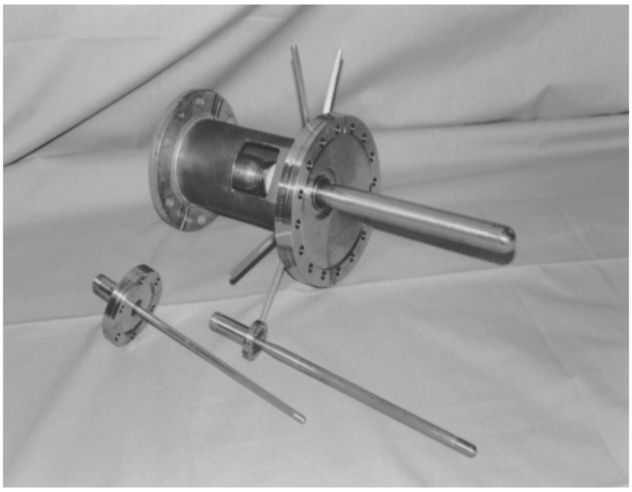

Figure 2 : Photograph of the HOM dampers.

Dampers are designated as D260, D504 and D650. D650 is located at the rear of the cavity and the other two dampers are at the middle of the outer radial wall of the cavity. D260 and D504 are mounted on 100 mm flange off-centered by 25 mm so that their position can be optimized for best damping. All the dampers are provided with removable tips of different lengths for fine tuning when installed in the CERN all metal cavity. Dampers D260 and D504 are designed with water cooling for the finger contacts and the antennae rods. No cooling is provided for damper D650. There exists a non cooled version of damper D504.

With a 5% loss of the fundamental Q due to the D260 damper, the peak voltage induced at the 50 Ω termination of this antenna for a gap voltage of 300 kV is less than 1 kV. The duty cycle of the rf is less than 0.1%. Average power dissipated in the 50 Ω termination is 4.0 W maximum. The other dampers couple less strongly to the fundamental mode and hence peak voltage and average power at the 50 Ω termination are significantly lower.

2.2 *Measurements*

An HP Network Analyzer was exclusively used for all damping measurements. No power coupler was installed on the cavity during these measurements. Loosely-coupled capacitive probes were used for Q measurements (S21 scattering parameter) of the cavity for the longitudinal modes up to 1 GHz. Figure 3 shows the frequency spectrum from 1 MHz to 1 GHz. The upper trace is for the cavity with no dampers and the lower trace is for the cavity with all the three dampers installed. Table 1 shows the undamped and damped Q and shunt impedance for all the monopole modes up to 900 MHz. The damped shunt impedance was computed from the R/Q obtained from MAFIA and multiplying this ratio by the loaded measured Q. It can be seen from the table that the shunt impedances for all the modes up to

Table 1 : Damping of monopole modes with three antennae.

f_{MHz}	Q_o	R/Q	Q_L	R_{shunt} (kΩ) loaded	Effective Antenna
39.478	12900	31.13	12200	380	
260.747	26100	1.29	<50	<0.07	D260
284.0	16200	0.01	<10	<0.01	D510
394.367	14500	5.33	410	2.18	D510
444.89	18700	0.92	<10	<0.05	D260
503.347	15860	5.82	<10	<0.01	D510
557.903	7700	0.01	6000	0.06	-
611.133	11150	1.08	410	0.44	D650
655.308	22800	0.51	460	0.240	D650
732.224	23000	0.85	10000	8.5	D650
774.713	9000	1.36	4900	6.66	-
813.656	16000	0.01	<100	<0.01	D260
862.611	4070	2.15	1800	3.87	D510
876.039	12450	0.79	<10	<0.01	D650

850 MHz are lower than 500 Ω with the exception of the higher-order-modes at 394 MHz, 732 MHz and 774 MHz.

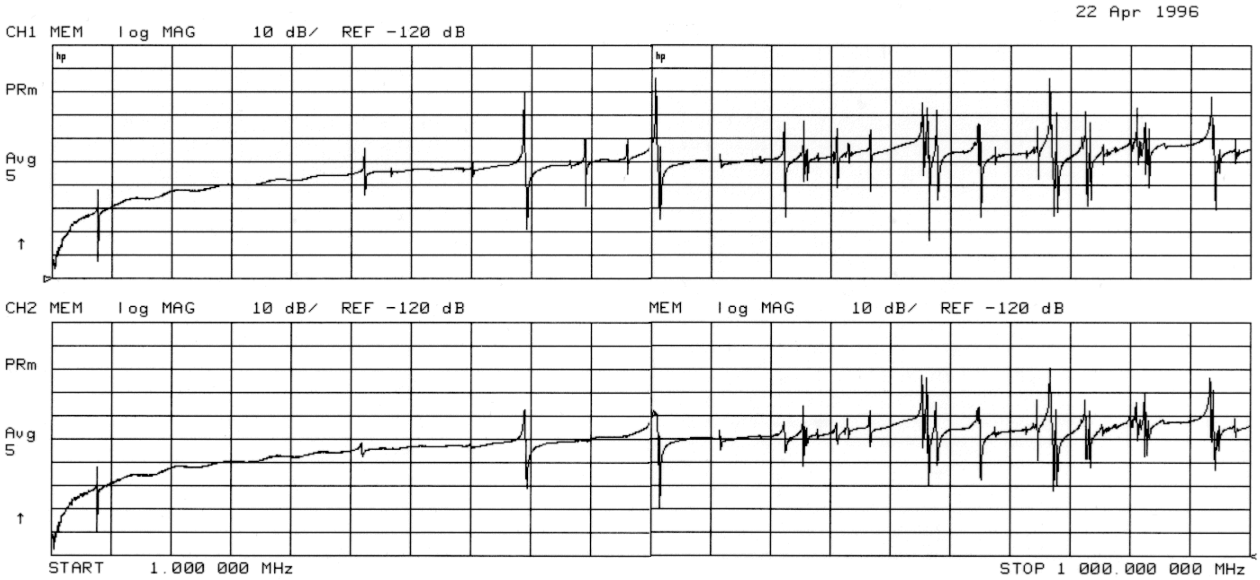

Figure 3 : Frequency spectrum of the model cavity with and without HOM dampers.

The shunt impedances are 2.18 kΩ, 8.5 kΩ and 6.6 kΩ respectively. The mode at 732 MHz could be further damped by installing a fourth damper near the accelerating gap in the cavity. Unfortunately, there is no port that could be provided to do this.

The mode at 503 MHz could only be damped when a reflective filter is installed between damper D504 and the 50 Ω termination. This filter is a capacitance input pi-filter.

2.3 Additional damping

A capacitive coupler is used to couple the power amplifier to the cavity to obtain 300 kV gap voltage. Measurements on the model have shown that this coupler attenuates some of the higher-order-modes. In particular, the Q of the mode at 394 MHz is reduced by at least a factor of three and by the same factor for the modes at 503 MHz and 732 MHz. Hence with the power coupler installed on the CERN cavity, the shunt impedances of the mode at the above frequencies will be further reduced by a factor of three.

MAFIA calculations on the CERN cavity show that dipole modes can be damped by not copper plating a 30 cm radius portion on the inside of the gap capacitor wall of the cavity. This enables the resistivity of the exposed steel surface to be used to achieve damping. This also helps to lower the shunt impedances of the 394 MHz and the 732 MHz longitudinal modes by at least a factor of 4 and 3 respectively. No external dampers have been developed to damp the dipole modes. Identification and measurements of the dipole modes are reported elsewhere [2]

3 CONCLUSION

The dampers which have been described in this paper have been tested on the wooden model. They have been optimized for best performance up to 850 MHz. They are ready for installation on the CERN cavity and are well within the time frame of the project.

4 ACKNOWLEDGMENTS

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5 REFERENCES

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