Title
Hom dampers for ALS storage ring RF cavities

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HOM DAMPERS FOR ALS STORAGE RING RF CAVITIES.

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Abstract

The main source of narrowband impedance in the Advanced Light Source (ALS) are higher order modes (HOMs) of the two main RF and three third harmonic cavities. These HOMs drive longitudinal and transverse coupled bunch instabilities, which are controlled using active beam feedback systems. The dominant longitudinal HOMs in both systems are TM_{011}-like modes with the R/Q factor an order of magnitude higher than all other longitudinal modes. To reduce the growth rates within the range of the longitudinal feedback system (LFB), these modes were tuned away from beam resonances by means of cooling water temperature control (main rf system), and the combination of two tuners (third harmonic system). To improve the reliability of the longitudinal dampening system, we have built and installed E-type HOM dampers for the fundamental and harmonic cavities. We present the design, commissioning and performance of the HOM dampers in this paper.

INTRODUCTION

The ALS storage ring 500 MHz RF system uses two re-entrant accelerating cavities apertures coupled to a waveguides for providing power. Originally, each main RF cavity was equipped with the HOM damper located in this waveguide as shown in Fig. 3, which resulted in moderate damping of some HOMs. From operational experience there were still three HOM main cavity modes that were gave instability growth rates beyond the damping rate of the longitudinal feedback (LFB) system [1] and required careful tuning to maintain beam stability. The most important modes are TM_{011} mode (highest R/Q factor) at 0.81 GHz and two others at 2.35 GHz and 2.85 GHz. The longitudinal symmetry of two out of the three modes of interest (0.81 GHz and 2.85 GHz) were an "odd" type, which indicated that an E-type damper located at the cavity equator was the best choice for a HOM damper (there was one port with the 48mm diameter available for HOM damper installation). In the 1.5 GHz third harmonic cavities, only one longitudinal mode (TM_{011} at 2.32GHz) presented problems. This mode was damped with a similar HOM damper.

E-TYPE HOM DAMPER BASICS

The simplest E-type HOM damper consists of a pick-up probe and resistive termination. The damper will reach optimum performance when $Rd=X_{pr}$ (maximum power dissipated in the termination resistor).

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$$P_{n_{MAX}} = \frac{1}{4} I_n^2 \cdot X_{C_{pr}} = \frac{1}{4} I_n^2 \frac{1}{\omega \cdot C_{pr}}$$

In reality some length of the coaxial transmission line has to be introduced between the HOM antenna and the termination resistor. By having the termination load impedance different from the characteristic impedance of the transmission line one can achieve an enhanced damping effect at particular frequencies. The equivalent electrical schematic of the basic E-type damper terminated into resistive load is shown in Fig.1.

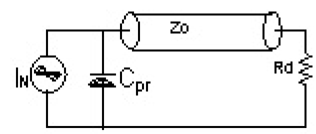

Fig.1

where: *Cpr*-total probe capacitance
I_n – displacement current induced in the HOM antenna for a particular cavity mode (for probe port shorted).

$$I_n = \omega_n \times \varepsilon_0 \iint_S E_n \cdot dS$$

DESIGN PROCESS

MAFIA 3D frequency and time domain processors have been used to determine the required size and the penetration of the HOM antenna into the rf cavity. Our goal was to damp the TM_{011} mode to the level where the growth rate was well within the damping ability of the LFB without dissipating significant fundamental frequency power in the HOM damper. The best damping effect has been achieved with the 19mm copper rod penetrating the rf cavity by 70mm. The "cold model" has been build and installed on the spare cavity in our test stand facility. The cold model was equipped with the sliding piston, which allowed further optimization of the geometry of the damper. Figure 2 shows the dependence of the loaded Q of the TM_{011} mode as a function of the penetration of the antenna into the rf cavity.

The total fundamental frequency power dissipated in the HOM damper for a 70mm antenna penetration is approximately 500W (for 50kW cavity cell power). More than 99.9% of the fundamental frequency losses in the HOM damper are due to eddy current losses induced on the surface of the antenna by the RF cavity field.

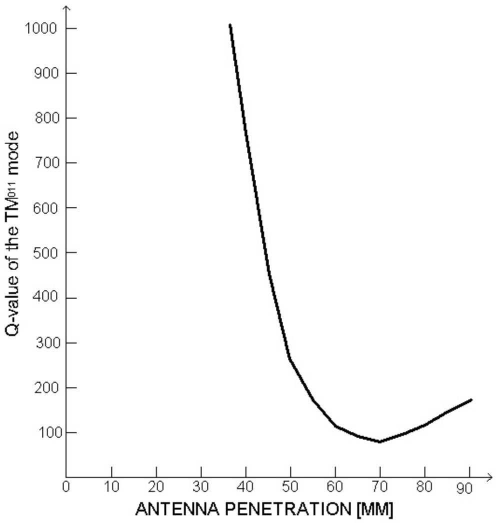

FIG.2

The required power handling capabilities of the termination resistors for the worst scenario of single bunch 30mA circulating current with all HOM modes tuned to the adjacent current spectral lines has been calculated and 150 W termination resistors have been chosen accordingly.

The same technique has been used while designing the HOM damper for the third harmonic cavities. The optimum performance of the third harmonic cavity damper was achieved for an antenna with a 10mm diameter and a 25mm cavity penetration. In this case the loaded Q of the TM_{011} mode dropped from 15000 to 60 with the fundamental frequency losses in the HOM damper of about 100W (for 5kW cavity cell power).

DAMPERS LAY-OUT

The cross-section of the ALS RF main cavity and HOM damper is shown in Fig 3. It consists of 180mm long antenna, supporting coaxial structure, two 50Ω termination ports and the vacuum bellows. The antenna and the two rods connecting the coaxial supporting structure to the vacuum feedthrough are made of OFHC copper. All other parts are made of stainless steel. Additionally, the coaxial supporting structure is nickel plated, to increase the rf losses to the HOM modes, which are not strongly coupled to the dampening resistors. Terminated ports are located 281mm from the shorted end of the HOM main supporting structure (3/4λ for TM_{011} mode and 0.5λ for fundamental TM_{010} mode). Vacuum bellows allow us to minimize the coupling of the fundamental mode to the HOM damper, and to optimize the damper performance over all frequency spectra.

The HOM damper antenna and the coaxial supporting stem are water-cooled. The damper is located on the movable table, which allows position of the antenna with all six degrees of freedom. Fundamental frequency coupling factor to the HOM damping port is lower than –60dB.

In the third harmonic cavity case the optimization of the position of the antenna in the cavity is not as critical since there is only one monopole mode required to be damped and the cavity cell power is a factor of 10 lower than in the main cavities. For these reasons bellows have been excluded from the damper layout, and the damper is directly attached to the cavity flange without any additional support. Over the next few months we will install a second identical damper on each third harmonic cavity, which will damp the second (horizontal) component of the "odd" dipole modes.

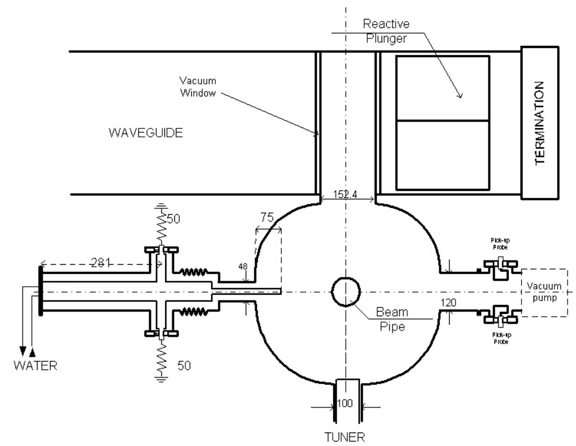

FIG.3

PERFORMANCE

The results of the measurements of the longitudinal HOM spectrum at fundamental frequency cavity before and after damper installation are shown in Table1.

Without damper			With damper		
F	Q	R_{sh}	F	Q	R_{sh}
MHz	-	kΩ	MHz	-	kΩ
499.6	40400	5000	499.8	40000	4960
809	**38700**	**1970**	**810.6**	**100**	**5.1**
1026.6	8250	9.9	1027.1	940	5.9
1310.8	10300	159	1327.8	280	4.3
1353.4	4000	39.2	1379.5	110	1.1
1554.1	5600	41.4	1560	940	7.0
1808.5	2850	13.1	1806.5	240	1.1
1883.7	1650	4.6	1886.2	540	1.5
2130.4	16800	58.8	2129.6	7200	25.2
2271.6	1800	6.8	2274.3	1500	6.5
2350	27500	99	2348.1	16300	58.7
2850	33500	142	2850	5360	22.8

Table1

We've been investigating an impact of the HOM damper on the few most important dipole modes. The results of the measurements are given in Table2.

Mode	Without damper F_H	Q_H	F_V	Q_V	With damper F_H	Q_H	F_V	Q_V
	MHz	k	MHz	k	MHz	k	MHz	k
1-M-1	707	36.2	708.4	46.5	723	2.8	709	44.2
1-E-1	810	51.1	796	0.9	811	48.3	796	0.9
1-M-2	1122	7.4	1123	38.1	1102	2.1	1123	38.1

Table2

One could notice the positive effect of our E-type damper on the horizontal component of the "odd" dipole modes. The dampening effect of the vertical component of the 1-E-1 and some other "even" modes is the result of the "waveguide" type HOM damper installed in the rf power waveguide and coupled to the cavity via rf power coupler.

There is only one "odd" longitudinal mode "trapped" inside the third harmonic cavity (TM_{011} mode), which was effectively damped by single HOM damper installed in April 2003. The cross-section of the ALS third harmonic cavity with two E-type HOM dampers is shown in Fig 4.

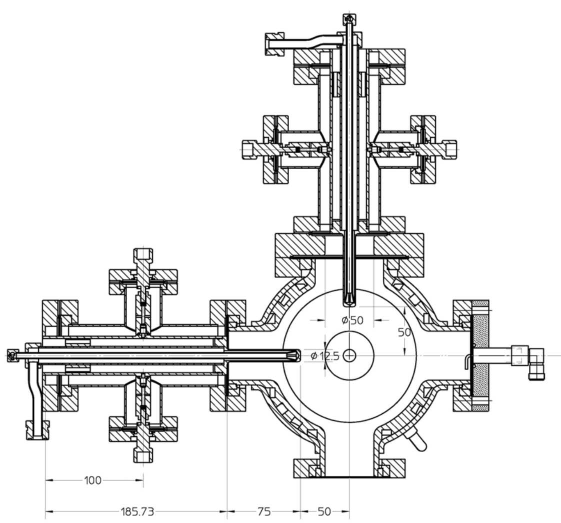

FIG.4

CONCLUSION

The installation of the HOM dampers on ALS rf cavities was an immediate success. Now, the ALS storage ring can operate with the 312 bunch filling pattern (with help from the third harmonic cavities Landau damping effect) without the Longitudinal Feedback System closed. For the 276 bunch beam pattern due to the significantly higher phase transient effect the LFB system is still required, but it can operate with significantly lower gain.

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