A CAVITY WITH CIRCULAR WAVEGUIDES FOR HOM DAMPING+

F. Schönfeld*, E. Weihreter, BESSY, Berlin, Germany
R. Apel, H. Henke, Inst. f. Theoret. Elektrotechnik, Technische Universität Berlin

1 ABSTRACT

The suppression of multibunch instabilities driven by higher order modes (HOM) of the rf-cavities is one of the challenges of third generation synchrotron radiation sources. A cavity with three radial waveguides for HOM-damping has been proposed by Concaurio and Arcioni. We have studied a very simple configuration based on a 500 MHz pill box with three circular waveguides. Numerical simulations and measurements of a low power model cavity are presented.

2 INTRODUCTION

Multibunch instabilities driven by HOMs of the accelerating cavities are the cause of potential performance limitations for high luminosity e^+e^--rings and for high brilliance synchrotron light sources. Various strategies may be adopted to cope with these limitations, such as the use of ‚single mode‘ cavities with inherently low R/Q for all modes, damping of the HOMs using suitable coupling systems, detuning of the HOMs by temperature, control of the cavity or by additional tuners, and the use of feedback systems.

The ‚ideal‘ cavity for an electron storage ring resonates only in the fundamental mode with a high shunt impedance, whereas the impedance of all other modes is negligible. Much effort has been spent in several laboratories to develop adequate cavities compromising low HOM impedances with a high shunt impedance of the accelerating mode. Many of these cavity designs are based on the idea of a single trapped mode resonator (STMR) of Concaurio and Arcioni [1] to extract HOM energy via three broadband waveguides where the cut-off frequency of the waveguide (WG) is low enough to couple to the lowest HOM, but high enough to keep the fundamental mode trapped.

3 GENERAL CONSIDERATIONS

WGs with a rectangular cross-section have been adopted for many HOM damped cavity projects [2]. These offer the advantage that for a given cut-off frequency the cross-section area of the WG can be minimized by choosing a high aspect ratio or by introducing a ridge. From the manufacturing point of view, however, the combination of rectangular WGs with a rotationally symmetric cavity is relatively complicated. WGs with a circular cross-section fit more naturally with structures of rotational symmetry. On the other side comparatively large WG diameters have to be accepted to obtain a sufficiently low cut-off frequency to cover also the lowest HOMs.

In principle elliptical WGs or ridged circular WGs could be used to reduce the cross-section, sacrificing however substantially the engineering simplicity related with circular WGs. Another possibility is to use smaller circular WGs together with single mode damping antennas for one or a few of the lowest HOMs.

4 MEASUREMENTS

For simplicity we have built a pillbox like model resonator (462 mm in diameter, 276 mm in height) from sheet aluminum fitted with 3 circular WGs in radial direction (see Fig. 1). Commercial foam absorber material (type LS) from ESCOMP for low power applications was cut into cones of 620 mm length and inserted into the WGs at sufficient distance from the cavity boundary to limit the reduction of the fundamental mode Q_o to about 15%. The WGs are mounted with special flanges for the ease of measurements with different WG diameters.

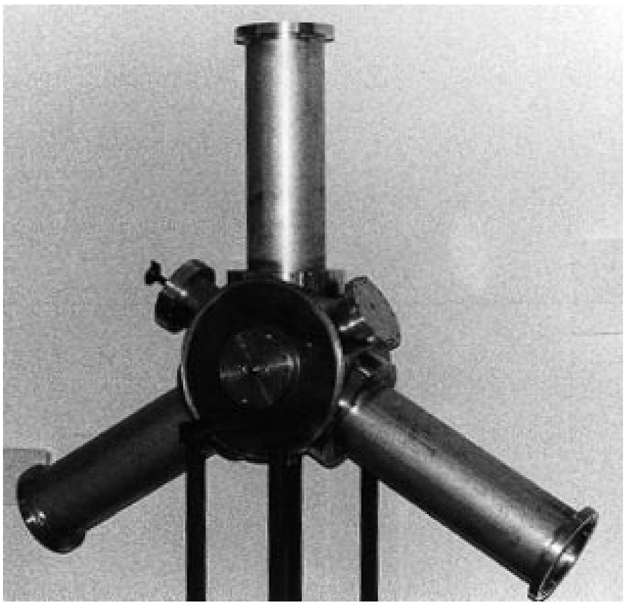

Fig.1: Low power model cavity for HOM damping measurements with 3 circular WGs.

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* present address: Siemens AG, ECPOT, Berlin

HOMs were excited with the help of small capacitive antennas introduced on axis into the cavity for monopole modes and off axis for dipole and quadrupole modes which couple to the axial field E_z. To characterize the 'naked' cavity without the WG absorbers, the unloaded Q_o has been determined for all observed HOMs in the frequency range up to 3 GHz. Measurements of the coupling factors β_1 and β_2 of both antennas in reflection and the determination of the loaded Q_ℓ in transmission give $Q_o = Q_\ell\ (1 + \beta_1 + \beta_2)$. After mounting the WG absorbers to the cavity the loaded Q_ℓ of the STMR has then been measured for different WG radii (r = 75/100/130 mm). All measurements were performed with a PC controlled setup including a HP 8753D network analyser.

Much effort has been paid for the identification of the HOMs, which can be classified in good approximation in TM_{mnp} eigenmodes. With the help of electric and magnetic field probes inserted through small holes on the cavity periphery (3 mm ø), the orientation and the relative strength of the fields can be obtained. In addition perturbation measurements pulling a needle shaped bead through the cavity in axial direction gave information on the longitudinal distribution of the E_z field component.

theoretical			measurements				
TM	pillbox		resonator		damping system		
mnp	Q_0	$\frac{R_s}{Q_0}$	f_0	Q_0	Q_{l1}	Q_{l2}	Q_{l3}
		[Ω]	[MHz]				
Monopol Modes							
011	28341	4058	736	10237	8863	4380	918
020	51347	0.50	1140	16639	5207	23	21
012	36104	8.45	1194	10979	1797	124	132
021	37125	28.36	1263	13382	1000	92	89
022	41458	29.16	1575	12828	232	222	32
013	43115	2825	1703	19553	287	257	181
030	64290	6.78	1787	32066	305	249	201
031	45153	6.54	1868	15503	298	264	84
023	46586	17.59	1989	14680	84	74	21
032	47777	0.77	2092	21049	248	200	180
014	49316	1.25	2229	18876	128	127	57
033	51376	7.13	2419	17756	75	20	73
040	75046	2.18	2436	31115	71	31	51
024	51795	10.12	2454	16886	58	38	23
041	52185	3.13	2495	18158	134	183	23
042	53948	8.12	2667	17504	92	101	98
015	54889	0.65	2761	21466	39	25	21
034	55410	9.87	2813	30408	41	30	32
043	56551	2.56	2930	17807	31	31	35
025	56551	6.07	2945	23420	152	123	108
Dipol Modes							
110	42780	11.05	792	13699	9171	1510	190
111	32366	23.13	960	14006	10779	2069	247
112	38298	6.25	1344	12151	918	624	764
120	58257	8.63	1468	22577	602	486	35
121	41327	0.65	1565	13095	251	31	31
113	44642	1.88	1811	18143	219	210	54
122	44640	9.94	1826	13555	54	23	37
130	69708	0.30	2101	28706	84	54	32
131	48669	13.49	2170	15849	177	169	171
123	48920	9.67	2193	17410	201	149	189
114	50232	0.71	2312	17307	98	115	99
132	50809	3.19	2366	19870	172	122	93
124	53490	6.30	2622	19218	79	81	70
133	53869	0.24	2659	18041	34	35	40
140	79773	5.41	2752	37712	110	148	117
141	55330	69.00	2805	2220	38	34	27
115	55560	0.31	2829	29138	30	27	28

Tab. 1: Results of Q-measurements of the lowest monopole (m = 0) and dipole (m = 1) TM_{mnp}-modes for the 'naked' 500 MHz model cavity and for the STMR with different WG radii of 75, 100, and 130 mm.

Table 1 summarizes the experimental results for the 'naked' resonator and for the STMR. Also theoretical Q_o-values for an ideal pillbox are included for comparison. The measurements for the STMR show that the loaded Q's are gratifyingly small (between a few 10 to about 300) at frequencies significantly above the cutoff of the WG (f_{co} = 1170./878./676. MHz for a WG radius r = 75/100/130 mm). On the other side the efficiency of the WG absorbers is reduced at lower frequencies, as expected, keeping more and more modes trapped with increasing WG cutoff frequency. For a WG radius of r = 130 mm the results indicate that circular WGs may be an interesting alternative to other STMR-schemes with more complicated WG structures. Figure 2 demonstrates the effective damping of all m = 0,1 modes observed up to 3 GHz.

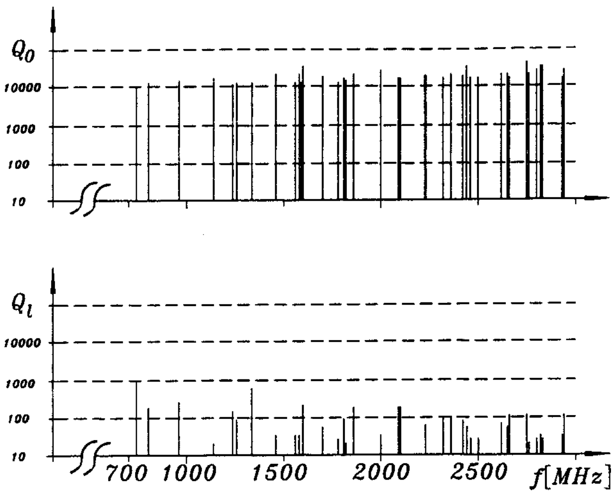

Fig. 2: Q-values for the 'naked' resonator and for the STMR using 3 WG absorbers with r = 130 mm.

5 NUMERICAL CALCULATIONS

For the optimisation of a STMR it is helpful to have numerical simulation techniques at hand. Two different methods developed by Kroll and Yu [2] and by Slater [3] have been applied to calculate the external Q for an open cavity which can then be compared with the measurements using the relation $1/Q_{ext} = 1/Q_\ell - 1/Q_o$.

As shown in Fig. 3 for several modes of the r = 130 mm case, the theoretical models agree fairly well. The measured Q_{ext} values are generally larger than the theoretical predictions, which may partially be attributed to the imperfectness of the absorbers. Except for the lowest mode (TM_{011}) there is a qualitative agreement between theory and experiment which allows to use the simulations in the design process with some care.

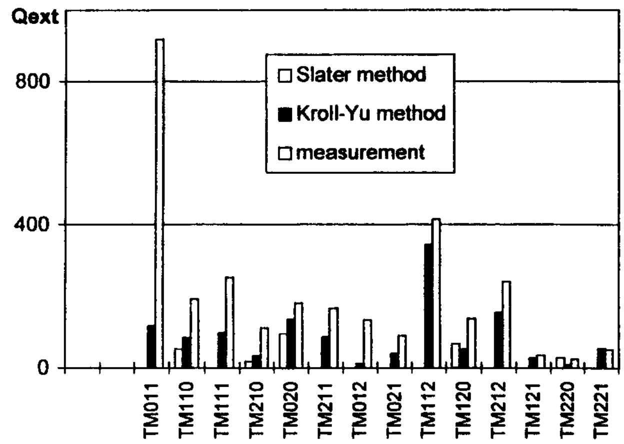

Fig. 3: Comparison of theoretical and experimental results for a STMR with circular WGs (r = 130 mm).

6 SIMULATION OF A HOM-ABSORBER

The absorber used for the above experiments can neither be used at high power levels nor under UHV conditions. Starting from the design of a rectangular WG absorber developed at SLAC [5] we have simulated a circular WG lead with the tapered absorber shaped as an inverse truncated cone (see inset in Fig. 4). This configuration has the advantage of a moderate field strength at the surface of the absorber material and allows effective transfer of the generated heat to the metallic WG boundary. Figure 4 shows the preliminary results of a geometrical optimisation using MAFIA to calculate the reflection coefficents for the first three WG modes. With the parameters D_1 = 26 cm, D_2 = 12 cm, ℓ_{abs} = 50 cm, ℓ_g = 15 cm the reflection is in the 10% range for frequencies well above the cutoff of the respective mode, which looks promising. The simulation is based on the properties of AlN-40% Si given in [6]. This material is a lossy dielectric ceramic with a specific outgasing rate below 10^{-10} torr · ℓ/cm^2 · s) compatible with the necessary UHV vacuum conditions. It can be brazed to a copper surface without previous metalisation.

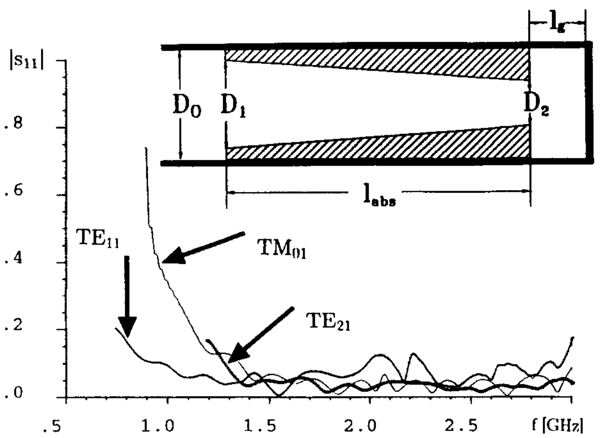

Fig. 4: Reflextion coefficient S11 for the first three WG-modes.

As an alternative to putting rf absorbing material into the vacuum, a circular WG to coax transition with a broadband ceramic window and an external load has been considered too. An outline design of such a transition is given elsewhere in these preceedings [7].

7 CONCLUSIONS

The concept of a simple HOM damped resonator based on a pillbox with three circular WG absorbers allows to reduce the Q-values from typically 10000 to a few 100 and below, a level competitive with other HOM damping schemes. This offers interesting possibilities for the design of rather simple STMR structures. Numerical techniques for the calculation of the external Q are accurate enough to help in the design process.

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