DEVELOPMENT OF HOM DAMPED COPPER CAVITY FOR THE ESRF

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Abstract

At the ESRF, HOM driven longitudinal coupled bunch instabilities are currently avoided up to the nominal beam current of 200 mA by precisely controlling the cavity temperatures and thereby the HOM frequencies of the existing five-cell copper cavities. A bunch-by-bunch feedback is presently being commissioned in order to increase the maximum stored current. In parallel, normal conducting strongly HOM damped cavities are under study to possibly replace the five-cell cavities. The design is based on a scaling of the single cell EU cavity [1]: a pillbox geometry with nose cones and three attached ridge waveguides loaded by ferrites for effective HOM damping. We report on the electromagnetic simulation making use of the 3D codes HFSS and GdfidL. They allowed optimizing the shape of both cavity and dampers, including electromagnetic absorbing material with frequency dependent parameters.

INTRODUCTION

Strong damping of Higher Order Modes is one of the strategies developed to avoid instabilities for electron beam currents far above 200 mA at ESRF. For this, a cylindrically shaped 352.2 MHz strongly HOM damped single cell cavity has been numerically optimized, taking into account technological constraints for both aluminium prototype machining and final copper structure production. The starting point was a scaling of the EU cavity. As next step, RF measurements on the aluminium prototype should reveal the points to reconsider.

The target is to be able to store an electron beam of 500 mA under stable conditions, even with the feedback off [2]. In order to obtain the nominal accelerating voltage of 9 MV and transfer the required 2.5 MW of beam power, 18 strongly HOM damped normal conducting cavities will have to be installed. Including some safety margin, we require that the HOM impedances remain below a value giving an instability threshold at 1A for 18 identical installed cavities.

NUMERICAL CODES

Three electromagnetic numerical codes have been used to optimize the structure. The 2D code Superfish [3] is perfectly adapted to calculate the eigenvalues and RF solutions of simple symmetrical cavities. The 3D codes GdfidL [4] and HFSS [5] are finite element solvers used to simulate more complicated geometries.

GdfidL can be used for eigenvalue computations in frequency domain and for wake field calculations in time domain. In the study of strongly damped HOMs, it has been shown that the Fourier transform of the wake field gives an accurate description of low Q impedances [6]. When the damping is low, as it is intended for the fundamental accelerating mode, the corresponding wake extends over several km and can therefore not be computed accurately in time domain. So, in order to quantify the effect of the HOM dampers on the accelerating mode, GdfidL is operated in frequency domain.

At BESSY, the EU cavity has been optimized using MAFIA [7]. A comparison between GdfidL and MAFIA is also presented at this conference [8]. HFSS is well adapted to S parameter calculations and was therefore used to optimize the dampers. Both GdfidL [9] and HFSS can solve complex structures including absorbing materials like ferrite.

STRUCTURE DESCRIPTION

The single cell cavity body is based on the EU model with nose cones to increase the shunt impedance. As shown in Fig. 1, three dampers are disposed at 120° in angle from each other in order to guarantee sufficient

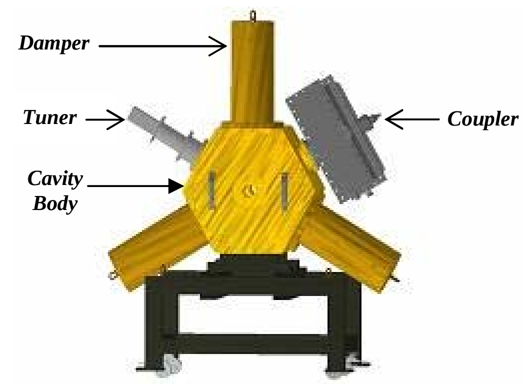

Figure 1: Drawing of the complete damping structure

coupling to HOMs with any polarization. Moreover, the dampers are shifted transversely: one in the front plane and two in the back plane to ensure a more efficient capture of HOMs.

As shown in Fig. 2, the dampers are built from ridge waveguides (RWG) terminated by a matched absorber. The portion of RWG of length L with a fundamental mode cut off frequency f_c = 440 MHz constitutes a high pass filter to couple the HOMs to the absorber and leave

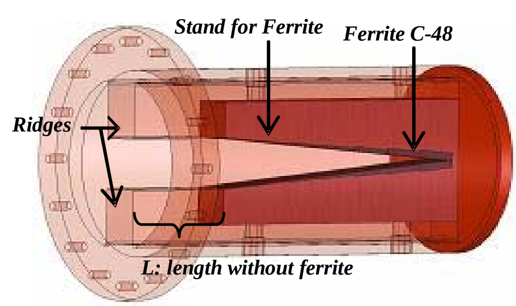

Figure 2: View by transparency of ferrite loads in a Ridge Waveguide *(RWG Damper)*

the accelerating cavity mode undamped. The termination consists of a section where the ridges are tapered and loaded with absorbing Nickel-Zinc ferrite C-48 to absorb the incoming HOM power with a minimum reflection.

CAVITY BODY OPTIMIZATION

The optimization of the perfectly symmetric basic cavity shape was carried out with the 2D Superfish code. At first, a simple scaling of the cylindrical EU cavity has been evaluated. It was then modified to maximize the quality factor Q_r and the impedance R_s/Q_r of the fundamental mode at 352.2 MHz. Numerical computations with GdfidL have been made in parallel to confirm the Superfish results as presented in table 1. They are compared with the impedance of one cell of the existing five-cell ESRF/LEP cavity.

Table 1: Simulations comparison for two kinds of cells

Cavity type (Copper)	*Simulation tools*	*f_r (MHz)*	*Q_r*	*R_s/Q_r (Ω)*
Optimized cell	Superfish	352.222	49844	148.98
	Gdfidl	352.171	51180	149.14
LEP cell	Superfish	352.182	47864	138.31
	Urmel [10]	353.500	47300	142.40

DAMPER OPTIMIZATION

Ferrite shapes

Many shapes of ferrite have been evaluated with HFSS to obtain the lowest reflection coefficient for the incoming HOM waves over a broad frequency range. Figure 3 shows a comparison of $|S_{11}|$ obtained for three different ferrite shapes between $f_{c\ (RWG)}$ at 440 MHz and 1 GHz.

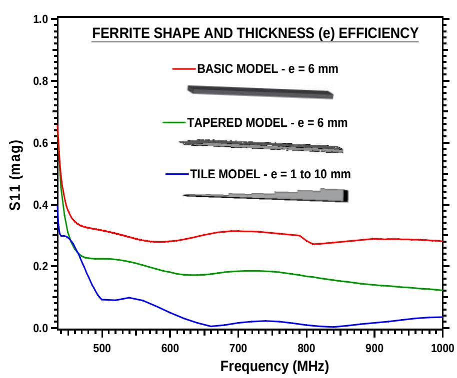

Figure 3: Reflection coefficient study with HFSS for three ferrite shapes

The *basic model* is a simple 6 mm thick rectangle of ferrite that covers entirely the skew ridge. It gives the highest reflections. The *tapered model* has the same shape but with a tapered extremity on the cavity side yielding considerably lower reflections. The *tile model* consists of a succession of ferrite tiles with stepwise increasing thickness *e*, the first tile having a tapered extremity too. It shows the lowest reflections. It has also the advantage of a homogeneous distribution of the power absorption along the structure. This ferrite shape has therefore been chosen for the first damper design.

Determination of the Length without ferrite

The length L of the unperturbed section of RWG in Figure 2, which is below cut-off at 352.2 MHz, determines which fraction of the accelerating cavity mode power is absorbed and how much its impedance is affected by the dampers.

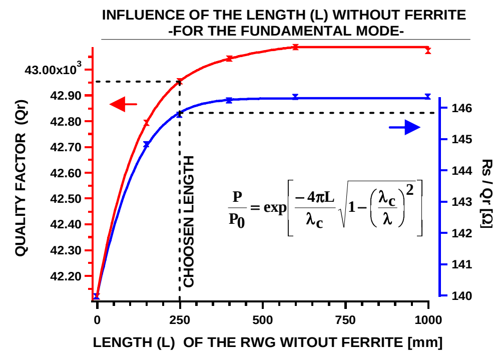

Figure 4: Eigenvalue computations (meshing 2 mm) to evaluate fundamental mode absorption in Dampers

By using GdfidL as eigenvalue solver, simulations of the cavity equipped with three Dampers, have been carried out by varying the length L. The *tile model* was assumed. The results in Figure 4 show that if L remains above 250 mm, both the quality factor and the shunt impedance of the accelerating mode are only slightly affected. A length L = 250 mm has therefore been chosen for the first aluminium prototype. This corresponds to a fraction $P/P_0 \approx 0.07$ of transmitted power at 352.2 MHz.

COMPLETE STRUCTURE EVALUATION

The next step consists in the evaluation of the assembly of the cavity with three dampers loaded successively by the *basic* and the *tile* type ferrites in order to evaluate the real efficiency of HOM damping in each case.

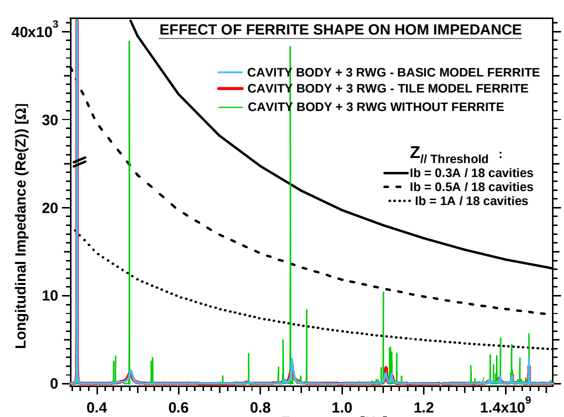

Figure 5: Time Domain simulation for ferrite efficiency comparison (600 m wake / 2 mm meshing)

Figure 5 gives the longitudinal impedance $Z_{//}$ obtained with GdfidL operated in time domain and subsequent Fourier transform of the wake. To confirm the damping effect of the ferrite, the results of a simulation for ridge waveguides without ferrite absorbers are also shown. The impedance is indeed much higher than for the ferrite loaded dampers. As expected, the *tile model* with stepwise increasing thickness of the ferrite tiles yields the lowest HOM impedances, which are moreover well below the reference curve for an instability threshold at 1 A. The only remaining higher peak belongs to the undamped accelerating mode.

Figure 6 shows the results for the even more realistic model of a cavity fully equipped with three dampers loaded by the *tile model* ferrites, a piston tuner, an input power coupler and a port for a field probe. This simulation indicates that the HOMs are so well damped, that even with 18 such cavities on the ring, the threshold for longitudinal coupled bunch instabilities would be far above the design target of 1 A.

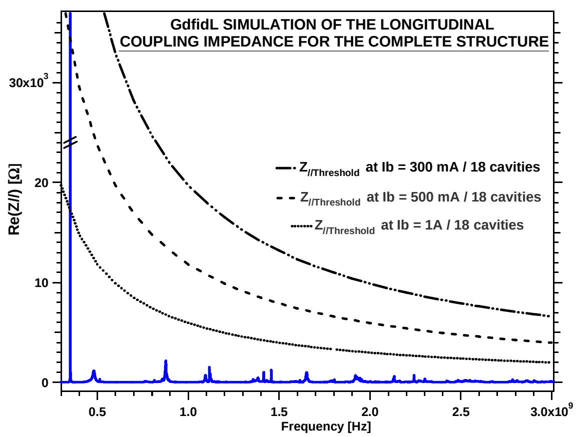

Figure 6: Time domain simulation to evaluate HOM absorption for the complete copper structure

The addition of all the auxiliary components (dampers, tuner, coupler, field probe) lead to frequency shifts for all the modes and in particular the fundamental mode. The size of the cavity body had to be readjusted in order to tune the accelerating mode close to 352.2 MHz. Results obtained with GdfidL (2 mm mesh size) as eigenvalue solver for this last body scaling are given in table 2. The field perturbation from the dampers generates a strong frequency shift but affects only slightly the impedance. The influence of the other components is of the same order for R_s/Q_r and negligible for Q_r and f_r.

Table 2: Eigenvalue computations of the Complete Structure with GdfidL

Structure	***f_r (MHz)***	***Q_r***	***R_s/Q_r (Ω)***
body scaling	359.408	47682	149.779
body scaling + 3 dampers	352.100	42954	145.756
Complete structure	352.358	40798	141.186

OUTLOOK

A low power aluminium prototype is presently being produced in order to check experimentally the main HOM frequencies, quality factors and shunt impedances, as well as the damping efficiency for different ferrite shapes. The prototype dampers will also be used to study the influence of unavoidable gaps between the ridges of the dampers and corresponding ports of the cavity body. A kit with different gap geometries has been designed for an experimental optimization, as these small details are not well resolved in simulations due to meshing limitations.

CONCLUSION

By means of a set of 2D and 3D electromagnetic simulation codes, a first prototype of a strongly HOM damped single cell cavity for the ESRF has been designed. The computations indicate that with 18 such cavities on the storage ring, longitudinal coupled bunch instability thresholds would be far above the targeted value of 1A. Aluminium prototypes for experimental verification and further optimization have been ordered.

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