NEW PLUNGER DESIGN FOR THE HOMFS OF THE ELETTRA-TYPE CAVITY

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Abstract

The Higher Order Mode Frequency Shifter (HOMFS) of the ELETTRA-type cavity has been improved by designing a plunger that can work without RF contacts. These were necessary in the original design to isolate the plunger housing from any RF field excited by the cavity fundamental or HOM mode. The used RF contacts have shown good electrical behaviour, but, in case of frequent movement, the internal surface of the cavity port in copper might be scratched due to the strong mechanical force which is applied. The new plunger has a modified profile that attenuates the field penetrating into the cavity plunger housing, therefore avoiding the RF contacts. The design and the power tests on a prototype are described.

1 INTRODUCTION

Coupled Bunch Instabilities due to the beam interactions with the cavity HOMs are cured in ELETTRA by means of the mode shifting technique. The parameters which are used to shift the HOM frequencies are the cavity temperature and the HOMFS position. The HOMFS is a plunger which is dedicated to HOM frequency shifting, while the fundamental mode frequency tuning is done by changing the cavity axial length [1].

In the initial design the HOMFS was equipped with RF contacts to avoid any overheating of the plunger housing. These contacts provide good RF behaviour, with satisfying current transmission. The strong mechanical force on the cavity port, however, in case of several cycles could scrape the port surface. Usually this is not a problem for the HOMFS, which is rarely moved once the optimum position is found, but it could prevent use of the plunger in other applications. Therefore a new, RF contact-free design has been developed.

The first experiment was done having simply removed the contacts. As expected the overheating effect on the plunger housing is significant. With the plunger in the “fully out” position, the external temperature of the stainless steel flange of the housing achieved 70 °C after one hour operation at 52 kW. In an intermediate position a temperature of 90 °C was rearched at a power level of 30 kW. The high pressure level, close to the interlock value of 1.0 10^{-7} mbar, prevented any further increase of the power level. Furthermore the bellow showed visible deformation due to the high temperature gradient.

The data of this experiment have been acquired as reference data for the new design. MAFIA simulations have been performed to determine the coaxial mode causing the overheating of the plunger housing and how to overcome the problem. The design has been completed with thermal studies and finally a prototype of the new plunger has been built and tested on an ELETTRA type cavity. The design and the test results are described here.

2 NEW PLUNGER DESIGN

2.1 Electromagnetic behaviour

First we simulated the old design of the plunger, without RF contacts. The overheating of the plunger housing can be caused by the $\lambda/4$ resonances in the coaxial line which results from the gap between plunger and port on the cavity, line that is short circuited by the vacuum flange. An other possible reason can be the penetration in the same coaxial line of the coaxial HOM TE_{11}. This mode is below cut-off at cavity working frequency, 500 MHz, but, with the old plunger geometry, the attenuation in the line is insufficient and allows some few watts of RF power to be dissipated in the plunger, which provoke the overheating of the plunger housing.

The attenuation in the coaxial cable for the TE_{11} mode is given by the formula (1),

$$\alpha = \frac{2}{r_o + r_i}\sqrt{1 - \left[\frac{\pi}{\lambda}\left(r_o + r_i\right)\right]^2} \qquad (1)$$

where r_o and r_i are the external and internal conductor radii respectively and λ is the wavelength at the working frequency. In our case the external conductor is the cavity port, thus r_o is fixed to 42 mm. The free parameter is the plunger radius, r_i, which has to stay equal to the nominal value, 40.5 mm, for a given length l, sufficient to guarantee the full tuning range. Beyond that length, which is fixed to l = 34 mm, the internal radius has been varied.

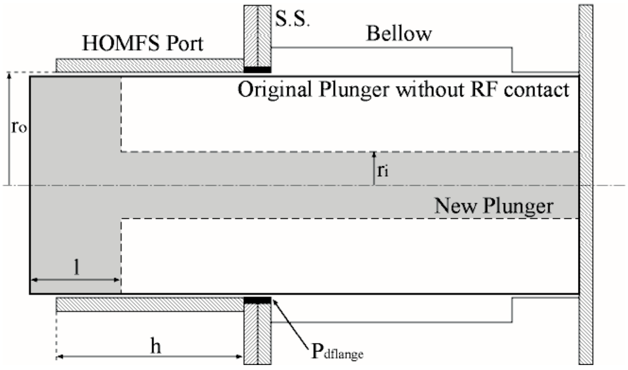

Figure 1: Old and new plunger geometry.

In figure 1 the geometry of the original plunger, with RF contacts removed, and of the new plunger are compared. Table 1 shows the MAFIA results for three different values of r_i, in the two extreme positions of the plunger: 0 mm (“fully out”) and 40 mm (“fully in”).

Table 1: MAFIA results, assuming 60 kW cavity power

r_i [mm]	α [Np/m]	position [mm]	P_{cav} [kW]	P_{HOMFS} [W]	P_{flange} [W]
40.5	21.9	0	60.0	150	3.3
		40	60.0	1100	17.3
29.5	26.0	0	60.0	100	1.5
		40	60.0	1030	12.0
12.5	34.7	0	60.0	97	0.2
		40	60.0	900	0.5

The last row in table 1 shows that with r_i equal to 12.5 mm the power dissipated on the stainless steel vacuum flange at a distance h = 70 mm from the cavity is reduced by a factor greater than 100, compared to the starting case with r_i equal to 40.5 mm. The value of 12.5 mm is a good compromise between field attenuation, mechanical strength (the plunger is made of copper) and space to host the the water cooling channels inside the plunger rod.

The magnetic field distribution is shown in fig. 2 for the plunger geometry with r_i = 12.5 mm.

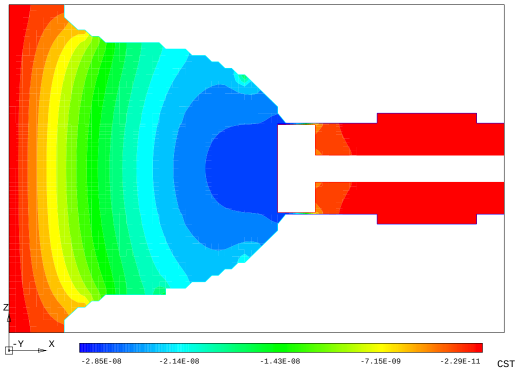

Figure 2: 500 MHz magnetic field distribution: red for minimum field, blue for maximun field

The investigation of possible resonances for the modified plunger geometry has then been performed. The resonating structure is given by the gap between the plunger and the cavity port or the plunger housing, which is short circuited on the vacuum flange closing the structure. In table 2 one can find the frequencies for the first four resonances in this resonant structure.

Table 2: Resonances in the plunger housing

Mode	Plunger "fully out" [MHz]	Plunger "fully in" [MHz]
TEM_λ/4	98.4	114.5
TEM_3λ/4	909.6	920.5
TE010a	1166.0	1125.4
TE010b	1166.1	1197.3

These resonances should never be excited, since their frequencies are far away from the fundamental mode frequency, 500 MHz, and from the HOM frequencies [2]. This is true for the full range of the plunger, between the two extreme positions considered in the table.

2.2 Thermal Behaviour

The attenuation of the electomagnetic field which penetrates in the plunger housing corresponds to a reduced thermal load of the structure. To evaluate this reduction we have performed thermal simulations of the structure, with input data the electromagnetic power density distribution obtained from the previous MAFIA simulations. Table 3 compares temperature values for the old (r_i = 40.5 mm) and the new (r_i = 12.5 mm) design.

Table 3: Temperature values, old and new design

r_i [mm]	position [mm]	P_{HFS} [W]	T_{max} [°C]	T_{flange} [°C]
40.5	0	150	120	93
	40	1100	300	240
12.5	0	97	51	42
	40	900	34	28

In the new design temperatures are higher for the “fully out” position than for the “fully in” position. In fact in the “fully out” position, for which the temperature distribution is shown in figure 3, the lower field attenuation results in a slightly higher power dissipation, even if the absolute value of the field is lower than when the plunger is inside the cavity. The maximum temperature is around 50 °C for the new design, that is about 6 times lower than in the old one. The flange temperature is shown since this is the reference value.

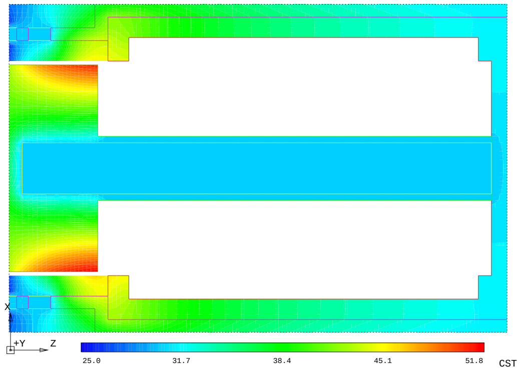

Figure 3: New HOMFS design, temperature distribution

3 NEW PLUNGER TESTS

3.1 Power Tests

The new plunger can be installed in the same housing of the old plunger. Figure 4 shows the drawing of the prototype. Power tests have been performed up to 60 kW at the ELETTRA RF laboratory test stand.

The results of the power test are shown in table 4. The cavity with the new plunger installed could operate at 60 kW, at a pressure level in the low 10^{-9} mbar range, while the flange temperature, which has been our reference for all the tests, showed a maximum of 35 °C in the "fully out" position.

Table 4: Pressure and temperature vs. plunger position

Position [mm]	P_d [kW]	Pressure [mbar]	T_{flange} [°C]
0.0	60.0	$5.4\ 10^{-9}$	35.0
10.0	60.0	3.310^{-9}	23.3
30.0	60.0	3.910^{-9}	21.8
40.0	60.0	3.610^{-9}	23.0

With the plunger inside the cavity there is almost no heating of the plunger housing, with the temperature close to 20 °C, the cooling water temperature.

Table 5: Measured vs. MAFIA values

		Temperature		Power	
Position [mm]	P_d [kW]	Measure [°C]	Mafia [°C]	Measure [W]	Mafia [W]
0	60.0	36.1	42.0	70	97
40	60.0	23.6	25.0	700	900

A good agreement between MAFIA simulations and experiment is also confirmed in table 5. The measured temperature at the flange location and the power dissipated in the plunger are shown. The last one is a calorimetric measurement, with a water cooling flux of 300 litre/hour.

3.2 *Low power tests*

The HOM shifting behaviour of the HOMFS with the modified plunger is similar to that of the original design. The frequency variation as a function of the plunger position is shown in figure 5. The biggest change is on the fundamental mode, whose range is reduced to 1000 kHz, compared to the original range of 1200 kHz [1]. However the actual range in the old design is limited to 34 mm, instead of 40 mm, due to some multipacting effects observed when the plunger with RF contacts penetrates too far into the cavity. The shifting range remains thus unchanged, since with the new design no multipacting is observed and the full range can be used.

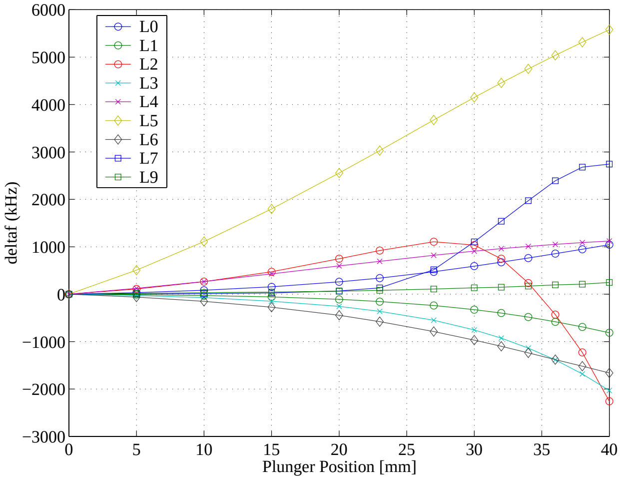

Figure 5: HOM frequency shifts vs. plunger position

4 CONCLUSIONS

An improved, RF contact free, design of the HOMFS plunger has been presented. Any overheating of the plunger housing is avoided by a proper shaping of the plunger, which results in a strong attenuation of the TE_{11} coaxial mode. Resonances in the plunger housing are at harmless frequencies. Proper cooling has been provided to remove the RF power dissipated on the plunger. The design has been checked with high power tests of a prototype, showing good agreement between MAFIA results and experimental data. The HOM shifting properties of the plunger are not affected, on the contrary, since the new plunger can penetrate further into the cavity the frequency shifting range is improved.

REFERENCES

[1] M.Svandrlik et al., "Improvements in curing CBI by mode shifting…", PAC 97, Vancouver, pp.1735-1737.

[2] M.Svandrlik et al., "Simulations and measurements of HOMs of the ELETTRA RF cavities…", EPAC 96, Sitges, pp.2053-2055.

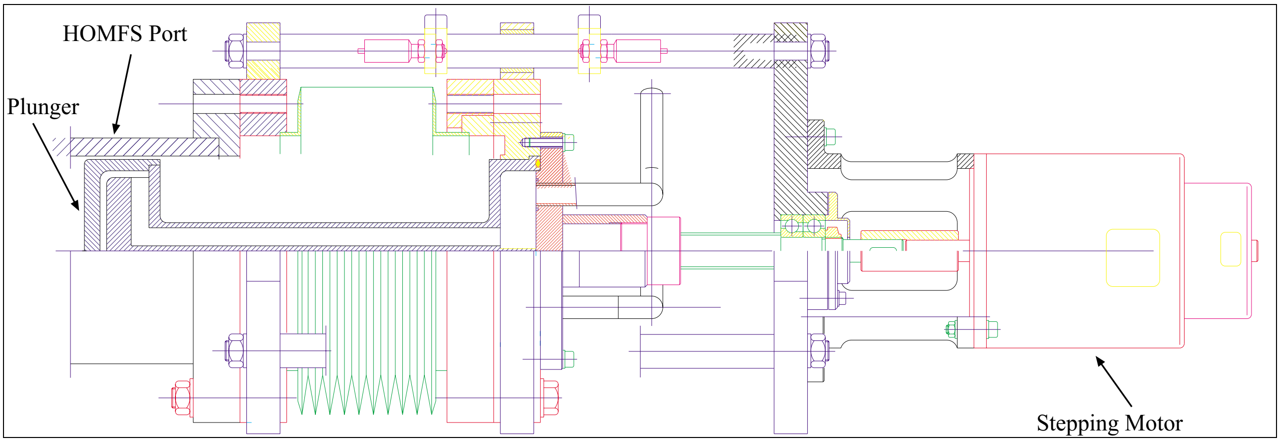

Figure 4: HOMFS with the prototype of the new plunger