IMPEDANCE OF DAΦNE SHIELDED BELLOWS

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Abstract

In order to avoid sliding contacts in the DAΦNE bellows design, the bellows screen is made of thin strips oriented in the vertical plane and separated by small gaps. The strips are produced by a hot forming method and have a waved shape, allowing both the longitudinal expansion and the horizontal shift.

The results of numerical simulations and impedance measurements for the shielded bellows are presented. The methods to eliminate and damp the residual Higher Order Modes (HOM) in such a complicated structure are discussed. The possible power losses and the impact of the bellows impedance on the beam dynamics are estimated.

1 INTRODUCTION

The bellows placed between the DAΦNE [1] arcs and straight sections must allow 35 mm longitudinal expansion and 10 mm horizontal offset. It was decided to avoid any sliding contacts in the bellows which can be burned out due to the high current flowing on the bellows screen. Moreover, if, for any reason, there is no contact between the sliding surfaces the capacitance between the sliding contacts can create a resonant circuit with the rest of the bellows. This can affect the multibunch beam stability and is a source of possible high power loss. Another potential danger is creation of dust particles between the sliding surfaces.

The bellows design originally proposed for DAΦNE [2] is shown in Fig. 1.

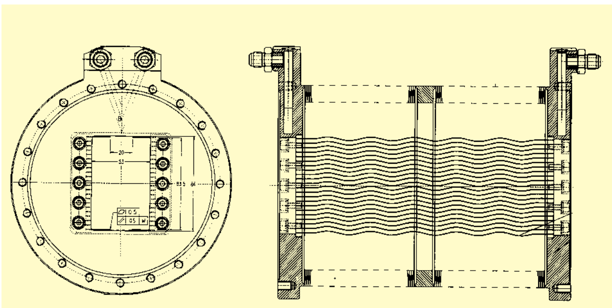

Figure 1 - Initially proposed DAΦNE bellows design.

The bellows screen is made of thin waved strips oriented in the vertical plane and separated by 4 mm gaps. The width of a strip is 5 mm, i. e. wider than the gap between the strips in order to attenuate radiation outside the screen.

In this paper we discuss the results of bellows impedance measurements and numerical simulations and describe methods to damp residual High Order Modes (HOMs) in such a complicated structure.

2 PROTOTYPE MEASUREMENTS

In order to check the effectiveness of the screen and to measure the bellows impedance a prototype has been built. The bellows itself was substituted by a pill-box cavity having approximately the same sizes as bellows.

Figure 2 shows the results of the impedance measurements with a standard wire method [2]. Dotted lines correspond to HOMs trapped in the pill-box volume without the screen, while solid ones show the shunt impedance of the HOMs remaining in the structure with the inserted screen.

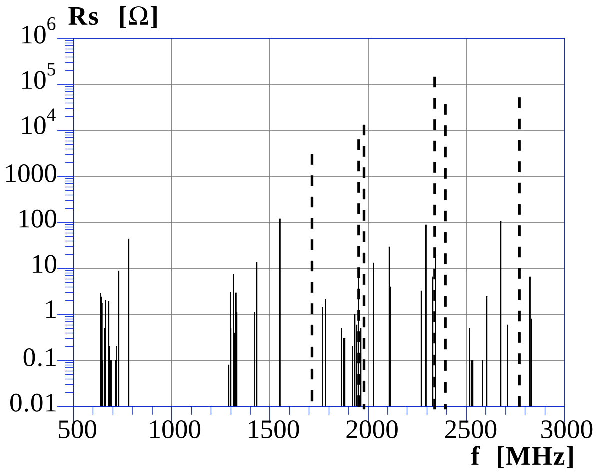

Figure 2 - Measured prototype HOM shunt impedances.

Some observations can be done by analyzing the results presented in Fig. 2. First, the HOMs of the cavity itself having the shunt impedances up to 10^5 Ω are successfully eliminated by the screen. On the other hand, the screen introduces new HOMs. Some of them are at very low frequencies.

The frequencies of the new modes appear to cluster around frequencies f = nc/2l, where n = 1,2,3,.. and l is the strip length. Even though the shunt impedances of these mode are very low the rise time of the multibunch instabilities due to the modes is at a manageable limit of the DAΦNE longitudinal feedback system. Moreover, the number of the modes is high and the frequency distribution is rather dense.

This means that probability of the coupling of the beam power spectrum lines to the HOMs is not negligible. The power loss in case of the full coupling can be of the order of some thousand watts.

This gives rise to the problem of how to dissipate such a power. If the HOM fields were mostly trapped between the strips, the problem would get unsolvable: it is practically impossible to dissipate the power under vacuum without strong heating and breaking the strips.

So numerical simulations were undertaken in order to understand why these new modes appear, what is the field configuration of the modes and how to damp them to a harmless level.

3 NUMERICAL SIMULATIONS

Numerical simulations for a 1/4 of the structure have been performed with MAFIA [4]. Due to the memory and CPU time limitations we have simulated the structure with the straight strips. Table 1 shows the first found HOMs.

Table 1. Parameters of HOMs found by MAFIA

mode	f [MHz]	Rs [Ω]	Q
1	807.631	0.109	8830
2	823.323	0.387	6651
3	828.950	0.059	5322
4	830.912	0.193	4671
5	831.744	0.018	4319
6	832.165	0.004	4131
7	832.316	0.327	4042
8	833.016	**7.062**	13880
9	1608.646	0.529	12440
10	1644.461	0.247	9400
11	1655.915	2.479	7517
12	1659.926	0.032	6572
13	1661.939	0.231	6027
14	1662.651	1.389	5746
15	1663.741	1.234	19370
16	1969.460	0.043	19820
17	2392.983	1.072	15120

Again we can observe the clusters of modes with wavelengths close to $\lambda = 2l/n$. The strongest mode in each cluster is the mode of TEM kind (see Fig. 3)) concentrated between the pill-box surface and the screen structure playing the role of the inner conductor for such a coaxial. The other modes are trapped between the strips (see Fig. 4 as an example) having relatively low shunt impedances.

The shunt impedances in the simulations are lower than in the measurements. This is because the strips were straight in the simulations while in the measurements the strips had the waved shape.

The simulations of the prototype with the waved strip screen have been performed with HFSS code [5] modeling the measurement by the wire method. It has been found that the mode pattern still has the same clustered structure but the shunt impedances are substantially increased. In particular, the TEM mode in the first cluster reaches the shunt impedance values of 56 Ω, in the second cluster the coaxial mode has the shunt impedance of 206 Ω.

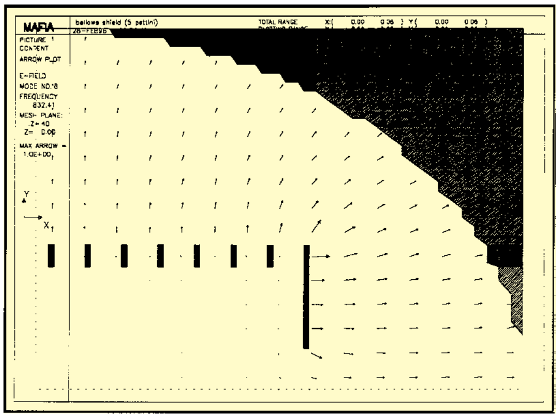

Figure 3 - Example of coaxial HOM (mode 8 in Table 1).

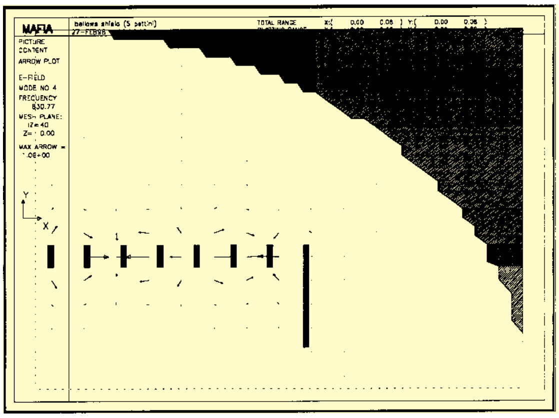

Figure 4 - Example of a HOM trapped between strips.

This agrees reasonably well with measurements on the prototype, where these mode have the shunt impedance of 43 Ω and 121 Ω, respectively. The same increase is observed also for the other modes in the waved strip screen.

4 MEASURES TO DAMP HOMS

In order to push frequencies of the HOMs beyond the bunch spectrum, i. e. to avoid dangerous power losses, it was proposed to put transverse connections between nodes of the waved strips. In this way we reduce the length of the slots created between each neighbouring strips. It means that TM wave guide modes with wavelength $\lambda > 2l$, where l is the reduced slot length, can not penetrate outside the screen and excite resonant HOMs. As far as the connections are placed between the nodes the flexibility of the screen does not change much.

However, due to the fact that the bellows are placed between arcs and straight section there are two lateral slots along the screen which are foreseen for the synchrotron radiation exit. It is clear *a priori* that some modes are left in the structure. At most we can close one lateral slot on the side where the synchrotron radiation does not go.

In order to damp further the remaining modes we propose in addition to the connections to use transverse plates as shown in Fig. 5. To fit the bellows shape the plates have been chosen to have the "half of the moon" shape.

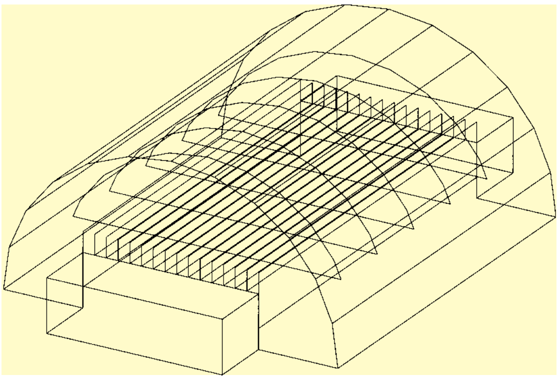

Figure 5 - Sketch of the screen with transverse plates.

In our understanding these plates push the electric fields of the coaxial type modes further away from the beam axis thus reducing the coupling of these modes to the beam. The second advantage is that the plates prevent penetration of the TE modes into the outer volume. The third, the plates can be considered as an radiator which helps to dissipated lost power.

The measurements were performed on a new prototype with thinner strips (0.2 mm) allowing to measure the shunt impedance of the modes as a function of the bellows expansion.

Table 2 shows the measured HOM parameters and the estimated longitudinal multibunch instability rise times for 217 mm bellows length (Maximum expansion is 230 mm).

Table 2. Parameters of measured HOMs.

mode	f [MHz]	Rs [Ω]	τ [ms]
1	667.0	0.8	258.9
2	954.1	1.3	132.5
3	974.8	2.2	77.8
4	1511.8	0.9	191.2
5	1528.5	----	
6	1750.2	0.8	233.5
7	2415.9	6.5	40.7
8	2482.4	----	
9	2645.8	1.9	159.0

As it can be seen, the rise time is higher than the radiation damping time which is equal to 17.8 ms for DAΦNE. Remembering that there are 8 bellows in the ring one could expect a proportional reduction of the rise time. However, we believe that all the bellows will be differently expanded, i.e. it is hardly possible that all the frequencies of the HOMs having similar field configuration in different bellows coincide exactly. Nevertheless, if this happens the multibunch instability rise time will be still longer than the damping time provided by the feedback system.

In order to estimate the losses in the worst case let us consider the full coupling (hardly possible) of the mode at 974.8 MHz with a bunch power spectrum line for 120 equally spaced bunches. It gives 85 W. This is a quite acceptable value. We should also stress here that not all the power is dissipated under the vacuum. Due to the coaxial nature of the remaining modes a part of the power is dissipated on the bellows surface on air.

One of our concerns was the transverse instability. We have no a set for the measurements of the transverse modes yet and have to rely on MAFIA simulations in this case. Fortunately, the rise times due to the transverse modes calculated by MAFIA are very much higher (order of seconds) than the damping time which is 36 ms for horizontal plane and 37 ms for the vertical one. Certainly, the transverse plates ("half of the moon") help much in damping of the modes.

CONCLUSIONS

A bellows design without sliding contacts has been proposed. Complete set of measurements on the prototype and numerical simulations confirmed that there are no HOMs dangerous for the beam dynamics both in the expanded and squeezed state of the bellows. The remaining modes can drive neither transverse nor longitudinal multibunch instability. Even in the most unfavourable situation the power loss due to these modes is acceptable.

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