DESIGN AND ELECTROMAGNETIC ANALYSIS OF THE NEW DAFNE INTERACTION REGION

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Abstract

A new interaction region (IR) vacuum chamber has been designed for the DAFNE upgrade aimed at testing of the crabbed waist collision scheme.

Compared to the existing IR vacuum chamber, the new one has a simplified design and consists essentially of the confluence of straight tubes, having a double Y shape.

Sharp discontinuities have been avoided to limit the beam impedance of the structure. However, the study of the electromagnetic interaction with the beam is necessary in order to avoid excessive power loss due to possible higher order modes (HOM) trapped in the Y-shape chamber. The first design of the chamber has been analyzed with HFSS and HOMs have been found and characterized. On the basis of these results some modifications in the geometry of the IR chamber have been introduced to eliminate or attenuate these trapped resonances. The results of these simulations are presented.

New electromagnetic shielding for the bellows inserted in the IR chambers, have been developed as well. The design criteria and the simulation results for these shielded bellows are also reported.

INTRODUCTION

The Φ-Factory DAFNE has been delivering luminosity to the KLOE, DEAR and FINUDA experiments since year 2000. FINUDA has concluded its run just this month. A significant upgrade of DAFNE, with the aim to increase the machine luminosity, is now in progress and will be completed before starting the run dedicated to the SIDDHARTA experiment. One of the most important operations foreseen for this upgrade is the installation of a new IR, suitably designed to exploit the "large crossing angle" and "crabbed waist" concepts according to the scheme presented at the 2nd Frascati Workshop on SuperB-Factory, March 2006 [1]. This scheme does not need very short bunches in the rings, that is the standard (but very expensive and difficult) way to increase the luminosity.

Operating with long bunches, the problems related to the beam coupling impedance of the vacuum chamber are relaxed, because the beam power spectrum is limited to a lower frequency region and possible high frequency impedance contributions are less dangerous. Nevertheless, great care has been taken to minimize the impedance of every new component and device designed for this upgrade.

Concerning the IR, at a first sight [2], owing to its simplified design, the new chamber layout should have smaller impedance with respect to that has been operating till now. A drawing of the vacuum chambers of one half of the IR is reported in Fig. 1. The beam pipe appears composed essentially by straight tubes without sharp discontinuities, except for the Y-shape section, where the common IR chamber is split in the two separate rings. HOMs could be trapped in the Y-section and, if the beam interacts with them, problems related to power losses may arise. This effect has been experienced at SLAC in the PEP-II collider, where power losses in the Y-shaped chamber of the order of several kW have been measured [3]. To evaluate parameters of the potentially dangerous HOMs, a frequency domain analysis of the structure has been carried out with the HFSS [4] code.

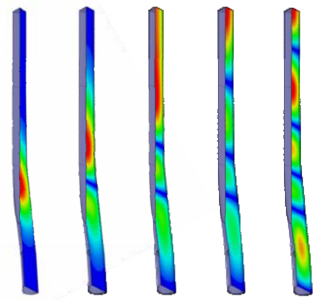
Figure 1: The new IR vacuum chamber layout (half).

Eight bellows will be installed on the IR (blue coloured in Fig.1) to compensate misalignments between pieces of chamber. Eight other bellows are on the chambers diametrically opposite to the IR. These bellows must be provided with a RF shield to avoid looking like cavities for the beam. Two different new shield designs have been developed starting from the experience gained in the shields of the existing DAFNE bellows [5] [6]. Also in this case, the design has been aided by checking the shielding properties of the proposed solutions by HFSS.

IR VACUUM CHAMBER

Even if all the possible discontinuities have been avoided in the design of the IR chambers, the points where the two rings join together in a single pipe are sources of beam produced e.m. fields. HFSS simulations have pointed out that these fields are able to give rise to trapped HOMs. The results of the eigenmode simulations are summarized in terms of mode frequencies, Q values and field configurations in Fig. 2. Only the modes having TE_{11} transverse configuration, which are the lower frequency modes, have been considered applying the proper boundary conditions on the symmetry planes. Despite the HOM electric field is directed horizontally it still contributes to the power losses since the beam trajectory is not symmetric with respect to the vacuum chamber axis. The pipes diameter is 55mm in all the three branches of the Y and the TE_{11} cut off is 3.2373GHz. In each of the two tables of Fig. 2, the 5^{th} mode propagates out of the pipe as pointed out by a driven mode solution with matched ports at the structure ends. In a first design the diameter of the common pipe was larger (61mm) and afterwards it has been reduced to increase the frequency of the first trapped resonance and then to reduce the total number of HOMs.

TE11 modes Even IP symmetry	f [GHz]	Q
Mode 1	3.0517	14783
Mode 2	3.1484	15924
Mode 3	3.1873	11441
Mode 4	3.2019	12414
Mode 5	3.2314	



TE11 modes Odd IP symmetry	f [GHz]	Q
Mode 1	3.0499	15430
Mode 2	3.1461	13750
Mode 3	3.1863	10667
Mode 4	3.2113	10923
Mode 5	3.2404	

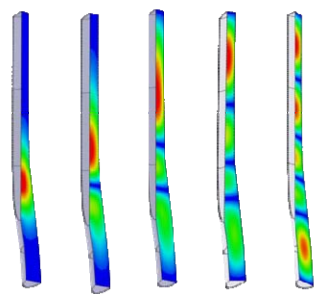


Figure 2: List of the first 10 TE_{11}-like modes found by HFSS eigenvalue solution with even and odd symmetry conditions with respect to the IP. The 5th mode frequency is above the cut off of the pipe.

The coupling impedance of each HOM depends on the component of the electric field which is parallel to the beam trajectory (reported in Fig. 3 for the 2nd odd, to give an example), on the power dissipated on the aluminium chamber walls and on the mode frequency.

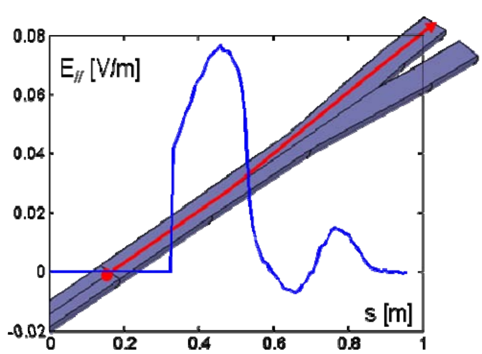


Figure 3: Electric field component tangential to the beam trajectory for the mode2 odd (from HFSS simulations).

Since the field is not concentrated in a relatively short gap, like in a cavity, but it interacts with the beam for a long distance, impedance is very sensitive to frequency variations through the transit time factor. The HFSS model used in simulations leaves out a number of small mechanical details and possible imperfections that could yield shifts of the actual HOM frequencies with respect to the calculated values. For this reason each mode impedance has been evaluated as a function of the mode resonant frequency around the nominal value obtained by simulations. The results are shown in Fig. 4.

The beam power spectrum (BPS) lines at the 8th and 9th RF frequency harmonics (FH) are the closest to the frequency of these HOMs.

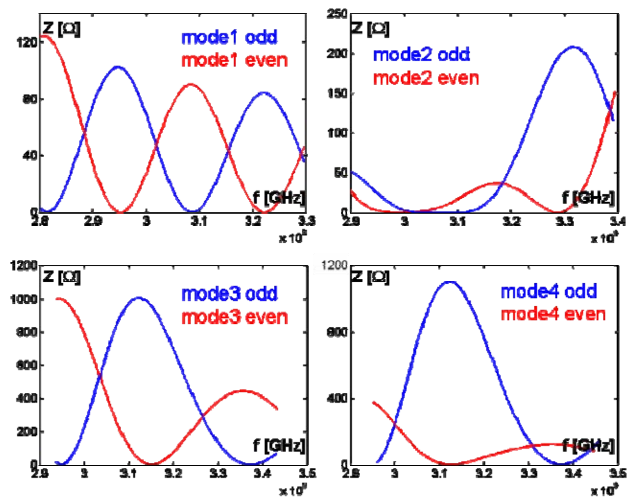


Figure 4: Coupling impedance of the 8 TE_{11}–like trapped modes as a function of their frequency.

But the 9th FH (3.314GHz) is above the frequency cut-off of the beam tube and the 8th FH (2.946GHz) is about 200MHz below the lowest frequency HOM. Therefore, if the HFSS evaluated frequencies are exact, no coupling between the BPS lines and the HOMs is possible and no beam power is dissipated on the chamber walls. The worst possible scenario should happen when the HOM with the highest impedance at the 8th FH (mode3 even) has a frequency shifted by more than 240MHz and it full couples to the 8th FH. In this case, considering a 2A beam stored current and a 2cm bunch length, the power losses would be about 1.7kW, dissipated on a 2m long pipe. The only mode having the field concentrated in a relatively short region is the mode 1 and, if full coupling occurs, the power losses would be less than 200W. Despite such a power seems to be manageable, two cooling channels have been placed at each Y-chamber junction.

BELLOWS SHIELDINGS

Four bellows are placed in each sector drawn in Fig. 1. They connect pipes having circular cross section with 88mm diameter. The inner radius of bellows convolutions is about 65mm, the outer one 80mm and the length about 50mm. Then a RF shield is necessary to hidden the chamber discontinuity to the beam.

The previously adopted shields [6] are made with a number of mini-bellows lined up very close to each other in order to reproduce the pipe section. This solution had the problem that the mini-bellows are tending to lose their elasticity and, when compressed, they could bend degrading the uniformity of the shield contour.

The new bellows shield has been designed as described in Fig. 5. Two cylindrical shells made of aluminium are fixed at the bellows ends and assure continuity to the beam pipes except for the gap between them. But even this gap is shielded by a number of adjacent Be-Cu strips placed all around the Al shells. The shape of the strips is preformed as two waves that give elasticity to the system and a central flat region that shields the shell gap.

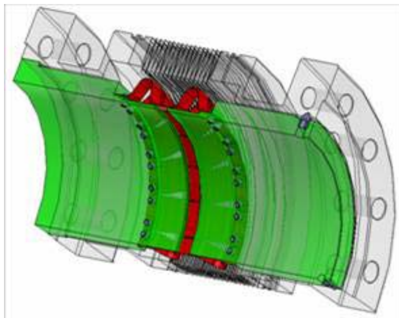


Figure 5: The new IR shielded bellows (a quarter section).

Fig. 6 shows the fields generated in the structure by the beam. The beam is represented by a current flowing along a coaxial conducting wire. The field coming out of the shield is completely negligible in the left plot where the strips are in contact with the two half shells. The unshielded field increases if this contact is lacking. The plot on the right of Fig. 6 shows the situation in presence of 0.3mm separation. Nevertheless, in both cases, to appreciate the presence of a field in the volume outside the shield without saturation inside, a logarithmic intensity scale has been used. The contact between strips and cylindrical shells will be ensured by a spring wrapped around the flat part of the strips [7].

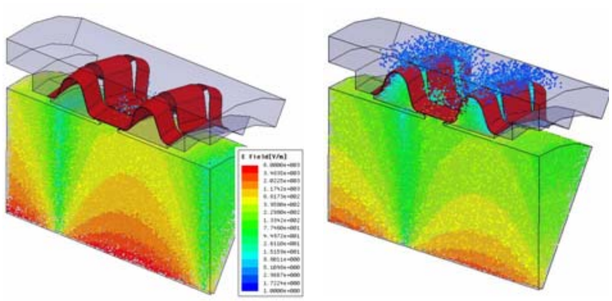


Figure 6: Beam generated fields in the shielded bellows at 3 GHz (HFSS simulations). Left: strips in contact with the cylindrical shells. Right: 0.3mm gap between them.

The coupling impedance of the structure has been evaluated in a frequency range from DC to 5 GHz and the result, reported in the plot of Fig. 7, is a confirmation of very low impedance values.

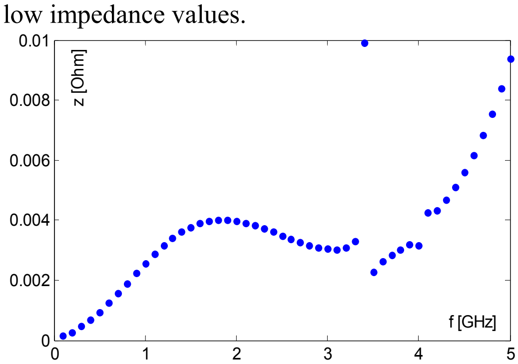


Figure 7: Shielded bellows coupling impedance.

The above described shielding has been preferred, because it is simpler to realize and cheaper with respect to a different solution previously designed and shown in the drawing of Fig. 8 (left). It consists of a grid of preformed Be-Cu strips. The number of the strips and their dimensions along the radial coordinate have been determined by several HFSS simulations. The plot on the right of Fig. 8 shows that, up to 5 GHz at least, the field remains sufficiently confined by the shield when the spacing is 10 degrees and the strip height is 20mm.

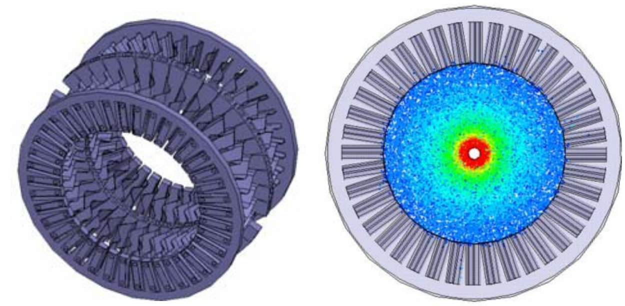


Figure 8: Study of an alternative bellows shielding.

CONCLUSIONS

The design of the new IR vacuum chamber for the DAFNE upgrade has been carried out with the goal to reduce the number of trapped HOMs and limit their effects in terms of interaction with the beam. The simulation results ensure a comfortable situation since the probability of HOM coupling with the power beam spectrum lines is very weak and, even if it occurs, the power losses can be easily managed.

The contribution to the impedance given by the new shieldings developed for the bellows of the IR is completely negligible.

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