SIMULATION OF HOM LEAKAGE IN THE PEP-II BELLOWS

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Abstract

An important factor that limits the PEP-II from operating at high currents is higher-order-mode (HOM) heating of the bellows. One source of HOM heating is the formation of trapped modes at the bellows as a result of geometry variation in the vacuum chamber, for example, the masking near the central vertex chamber. Another source comes from HOMs generated upstream that leak through the gaps between the bellows fingers. Modeling the fine details of the bellows and the surrounding geometry requires the resolution and accuracy only possible with a large number of mesh points on an unstructured grid. We use the parallel finite element eigensolver Omega3P for trapped mode calculations and the S-matrix solver S3P for transmission analysis. The damping of the HOMs by the use of absorbers inside the bellows will be investigated.

INTRODUCTION

The PEP-II interaction region (IR) has a complex geometry that allows for two beam lines entering and leaving the central vertex chamber via a crotch region. There is complicated masking in the vacuum chamber connecting the crotch and the vertex chamber. One of the factors that prevent the PEP-II from operating at high currents is HOM heating of the bellows in the IR region. Excessive temperature rise has been observed at the forward vertex bellows. HOMs can manifest themselves in the bellows as trapped modes, or as fields due to propagating modes generated from upstream at the crotches or masks and leaking into the bellows [1]. This paper is to simulate these parasitic fields that contribute to the bellows heating.

In previous simulations of HOM heating of the PEP-II IR [2], the bellows were approximated by simplified models or left out completely. As a result, HOM heating of the bellows was never fully addressed. In particular, the issue of power leakage into the bellows from HOMs generated upstream was not considered simply because it requires a model of the bellows with fine details such as the bellows fingers. These fine features are difficult to model accurately without using such a huge number of mesh points that the simulation is quickly beyond the reach of standard computational resources.

In the upgrade under consideration for the vertex bellows, there are plans to mount ceramic tiles on the walls of the bellows convolution to absorb HOMs and reduce heating. It is of great interest to be able to evaluate the effectiveness of this damping scheme. The present simulation is the first ever effort to model the bellows fingers realistically so that HOM leakage into the bellows and HOM damping by the ceramic absorbers can be estimated. This is made possible by the use of the parallel finite element field solvers Omaega3P and S3P. [3].

THE BELLOWS MODEL

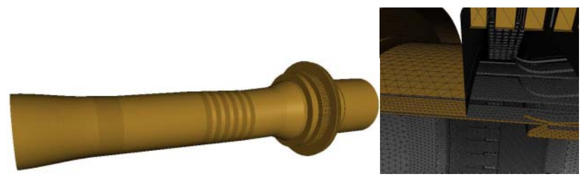

Figure 1: The model of the bellows and its surrounding (Left); the surface mesh of the bellows (Right).

The geometrical model used for the simulation is shown in Figure 1 (left). It consists of the IR forward vertex bellows and the forward masks. Because of symmetry, only one half of the model is simulated. A CAD model of the structure is read as input into the mesh generation program CUBIT [4] to generate a tetrahedral mesh. In order to resolve the fine details of the bellows which include the contact and spring fingers, the finger gaps, the ceramic tiles and the convolution, very small elements are used to provide an accurate representation of the geometry in these regions. Also, in order to resolve the skin depth of the ceramic tiles for damping calculations, even smaller elements are used in this region. As a result, the entire mesh consists of approximately 2.6 million tetrahedral elements. The average edge length is about 0.5 mm and the minimum edge length about 0.05 mm, an order of magnitude smaller. Using Omega3P on the IBM SP3 at NERSC, a run with the direct complex solver takes about 5 minutes on 128 processors to calculate one eigenmode when linear elements are used for this mesh.

SIMULATION APPROACH

Two types of calculations are presented in this paper, namely, determination of localized modes in the bellows, and the investigation of the effectiveness of absorbers in damping HOM's. The underlying approach of these calculations is briefly described as follows.

(a) Determination of Localized Modes

We use the real eigensolver Omega3P to calculate the modes in the structure. In order to determine if a mode is localized or not, we alter the boundary condition imposed at the two open ends of the vacuum chamber that the beam travels through. We first apply the electric boundary condition and then the magnetic boundary condition. Those modes that remain unchanged with the change in boundary condition are determined to be localized or trapped modes.

(b) Effect of lossy materials

The treatment of lossy materials in RF structures requires the use of complex solvers. For trapped modes, Omega3P has a complex solver that calculates the complex eigenfrequency in the presence of lossy materials. From the imaginary part of the eigenfrequency, the quality factor due to power loss in the lossy materials can be determined. This allows the effect of ceramic tiles that line the walls of the bellows to be evaluated.

In the case of HOM fields leaking into the bellows through the gaps between the bellows contact fingers, we use the complex solver in S3P, a parallel S-matrix code. to study the effect of the ceramic absorbers on the leakage fields. The S-matrix calculations are carried out by loading waveguide modes at the ports which are defined at the two open ends of the structure. The reflection and transmission coefficients are obtained at the ports for different waveguide modes. In the absence of absorbers, each row of the S-matrix satisfies the unitary condition, which is equivalent to the conservation of energy. This is no longer true when the ceramics tiles are included and the deviation from unitarity provides the amount of power that is absorbed.

HOM CALCULATIONS IN BELLOWS

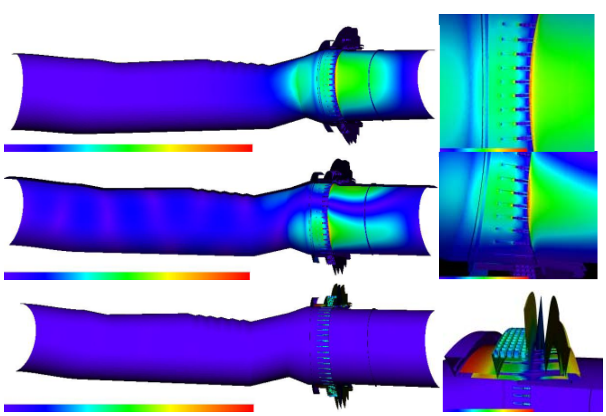

Figure 2: Magnetic field of vacuum chamber mode at 3.716 GHz (Top); vacuum chamber mode at 5.947 GHz (Middle); bellows mode at 6.368 GHz (Bottom). Note the field leakage of the vacuum chamber modes into bellows.

Using Omega3P's real solver, we calculated 20 modes in the bellows structure shown in Figure 1 and they cover the frequency range from 3.5 to 6.5 GHz.. The majority of these modes have fields occupying the whole region of the structure and therefore can be considered not trapped. The few remaining ones are considered as localized modes and they can be divided into two groups: vacuum chamber modes with fields mainly in the vacuum chamber, and bellows modes with fields mainly inside the bellows.

Figure 2 (top, middle) shows the magnetic field contours of two localized vacuum chamber modes at 3.716 GHz and 5.947 GHz respectively. They are TE11-like and TE21-like modes, with their frequencies slightly above the corresponding beampipe mode cutoff frequencies. They are well trapped upstream by the masks, but could possibly extend further downstream toward the central vertex chamber if more of the downstream geometry had been included. In this sense, these vacuum chamber modes are not fully trapped as the variation of the geometry downstream has been ignored. But the important feature of these modes is that the fields can penetrate through the finger gaps into the bellows convolution to provide a source of heating inside the bellows. A fully trapped mode at 6.368 GHz is shown in Figure 2 (bottom) and has fields only inside the bellows, and hence it will not be excited by the beam. Since the frequencies of the vacuum chamber and bellows modes are quite far apart, it is unlikely that changing the bellows length under any operating conditions will lead to any resonant coupling between them.

HOM DAMPING WITH ABSORBERS

For reasons of limited space and avoiding the generation of additional heating from image currents, it is desirable to place HOM absorbers inside the bellows to damp possible localized modes and to absorb any HOM power that leaked into the bellows. Figure 3 shows the placement of the ceramic tiles inside the bellows. They are water-cooled absorbers mounted on the bellows convolution and close to the contact fingers so as to better damp the leakage fields from the HOMs modes in the vacuum chamber. The ceramic tiles used in the simulation have a dielectric constant of 30 and a loss tangent of 0.11.

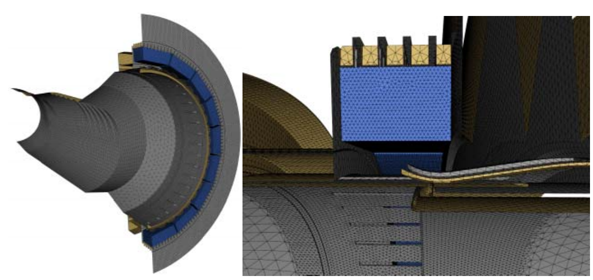

Figure 3: Location of ceramic tiles inside the bellows (Left); the surface mesh of the tiles and bellows (Right).

We use the complex eigensolver in Omega3P to determine the complex eigenfrequency of the modes due to the damping by the ceramic tiles. Figure 4 shows the quality factor Q, defined by 0.5*Re(f)/Im(f), as a function of the mode frequency f. The Q values can be roughly divided into a group of modes with Q greater than 10,000 and another group with Q smaller than 100. The first group consists of essentially vacuum chamber modes while the second group are bellows modes. The results show that there are more bellows modes when compared with the lossless case, and their Q values are in the range of 20-50. One of the damped bellows mode at 6.290 GHz

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is shown in Figure 5 where it can be seen that the mode has high field in the tiles and does not leak through the small finger gaps into the vacuum chamber.

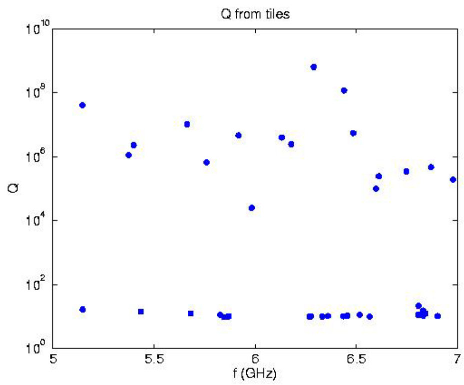

Figure 4: The quality factor of HOM's in the bellows due to absorption by ceramic tiles.

For the group with Q greater than 10,000, most of the modes are not localized, and therefore the absorbers have little effect on reducing their Q. The most highly damped mode is the TE21-like mode at 5.847 GHz, with field leakage through the finger gaps as described in the last section. However, the Q is about 25,000, an order of magnitude greater than the wall loss Q which is about 2000 for a stainless steel vacuum chamber, so the damping by the ceramic tiles is insignificant.

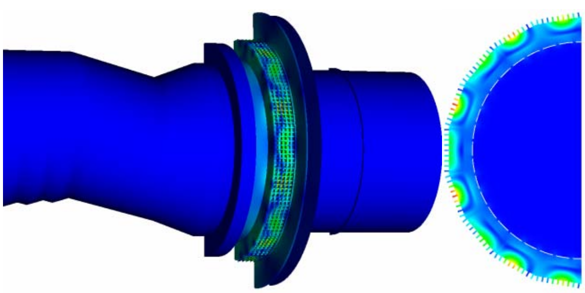

Figure 5: Magnetic field contours of the bellows mode at 6.290 GHz in the presence of absorbers.

ABSORPTION OF LEAKED HOM POWER

As we previously pointed out, HOM power generated elsewhere in the vacuum chamber can propagate pass the vertex bellows and couple into it via leakage through the finger gaps. It is of interest to determine how effective the ceramic tiles are in damping these leakage fields. To achieve this, we use the S-matrix solver S3P to calculate the power loss when transmitting a given amount of input power from one end of the structure to the other end. By subtracting the transmitted and reflected power from the input power, one can determine the amount of power that is absorbed by the ceramic tiles in the bellows.

Since only TE modes can penetrate through the finger gaps, we limit the excitations to TE modes in the vacuum chamber. Within the main beam spectrum up to 7 GHz, TE11 and TE21 are the only propagating modes. Simulations were performed using the complex solver in S3P with TE11 and TE21 modes as input modes at the upstream and then the downstream ports. For each mode, the power absorbed was obtained as the difference between the input power and the power that went to transmission and reflection summed over all propagating modes. Figure 6 shows the power absorption for the TE11 and TE21 modes driven from the upstream end (left) and the downstream end (right). Power transmitted from upstream (originating in the crotch region) shows as much of it is reflected at the masks before reaching the bellows. On the other hand, power transmitted from downstream (originating in the vertex chamber) is absorbed at about 0.1% level for frequencies higher than the TE21 cutoff frequency. This can be attributed to the higher excitation of the TE21 fields near the bellows with better coupling through the finger gaps into the bellows.

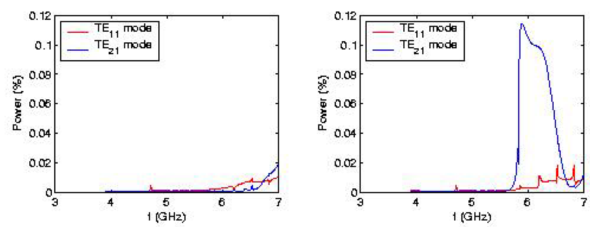

Figure 6: Power absorption for modes propagating from upstream (Left); and from downstream (Right) as a function of frequency.

CONCLUSIONS

We have used the parallel finite element frequency domain solvers Omeg3P and S3P to investigate HOM heating in the PEP-II vertex bellows. We have observed HOM power leakage through the gaps between the bellows fingers. We have found that the placement of ceramic tiles inside the bellows can absorb the leakage fields from traveling wave power propagating in the vacuum chamber.

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