RF MODES IN THE PEP-II SHIELDED VERTEX BELLOWS*

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Abstract

Experimental and simulation study of RF modes were carried out for the complicated geometry of the shielded vertex bellows near the IP region of the PEP-II B-factory. A beam position monitor button electrode located 50 cm from the bellows provides a signal for spectrum measurement. Calculations indicate monopole, dipole and quadrupole modes can exist in the bellows structure near the experimentally observed frequency region of 5 GHz. The observed modes are correlated to the bellows heating. The beam-generated fields are scattered by the masks, taper and axial offsets and heat the bellows by coupling through the RF shield fingers.

INTRODUCTION

The PEP-II B-Factory collides 1.7 A of 3 GeV positrons with 1.0 A of 10 GeV electrons, in trains of several hundred bunches. The bunch length is 1.3 cm. Within the BaBar detector near the IP, where the two beams share a common vacuum chamber, anomalous heating is observed at thermocouples situated on a shielded bellows structure at the juncture of a beryllium beam pipe with a copper vacuum chamber. The heating is determined to be due to higher order modes [1]. A signal from a nearby BPM was used to measure the spectrum of the fields excited by the beams. These observations reveal several high Q modes correlated with the bellows temperature. Computer calculations have found eigenmodes which can exist in the bellows structure near the observed frequencies. Further calculations are performed modelling the vacuum chamber and bellows together in 3D as coupled cavities from which coupling parameters are obtained for the dipole and quadrupole modes. This study complements and extends the pioneering work carried out by Stan Ecklund et al. [1] during the last physics run.

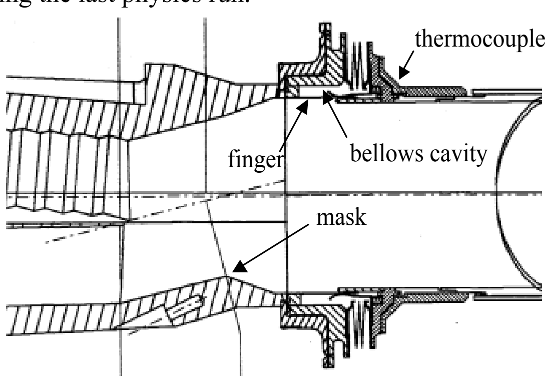

Figure 1: Bellows structure and vacuum chamber showing synchrotron masks and site of thermocouple with high temperature readings.

THE BELLOWS STRUCTURE

Figure 1 gives an overview of the bellows area. Positrons are incident from the left, electrons from the right. The IP is located roughly 20 cm to the right of the bellows. The bellows are shielded from the beam chamber by a series of 16 metal fingers azimuthally separated by gaps or slots. The variations in the beam pipe vertical cross section couple the beam field and high order transverse modes. It is the transverse modes which are expected to couple into the bellows through slots between the fingers. The slots are made to vary in length from 10 to 13 mm in response to thermal expansion and contraction of surrounding structures. During a recent maintenance period the vertex chamber was extracted from the BaBar detector and the slots were found to be fully extended at 13 mm.

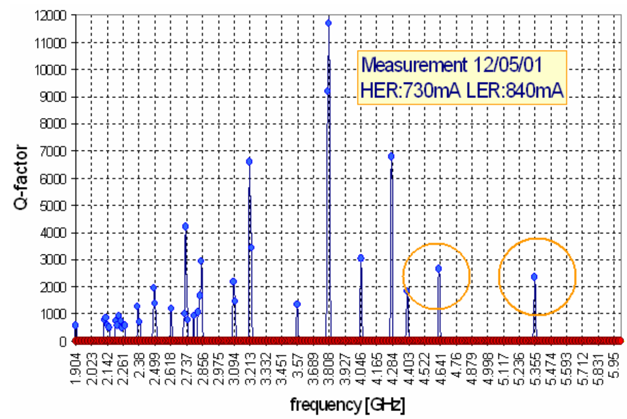

Figure 2: FFT of a gated oscilloscope BPM button signal in the gap between trains. The circled peaks show amplitude correlation with the thermocouple temperature.

SPECTRUM MEASUREMENTS

The colliding bunch trains have an intervening gap of about 350 ns required for the ramp-up of an abort kicker and the clearing of ions for the electron ring. A beam position monitor button electrode located 50 cm from the bellows provides a signal to a HP54120 high frequency oscilloscope and a R&S gated spectrum analyzer. The signal is gated in time to coincide with the gap where no beam is present. An FFT of the oscilloscope signals is shown in figure 2. To calculate the equivalent Q-factor the amplitudes are measured in small time windows at the beginning and the end of the gap.

The same spectrum was also observed with the gated spectrum analyzer. Within a forest of peaks in the 5 GHz region several modes are identified as having amplitudes correlated with the bellows temperature. The amount of

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thermal power dissipated in the bellow vs. time was calculated from the temperature data. In figure 3 this calculation is compared with the amplitude of one of the peaks.

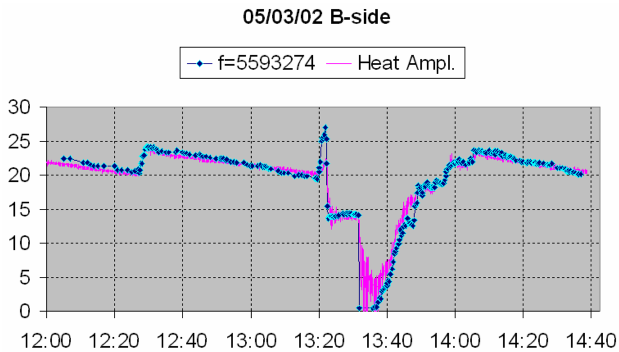

Figure 3: Estimated thermal power (pink) from thermocouple data and measured peak amplitude (blue) of a 5.6 GHz mode vs. time.

The figure includes data from a beam abort in which one of the beams was lost followed by a subsequent loss of the remaining beam. The slow rise after the beam loss reflects filling the rings back to nominal currents. The data indicate contributions from both beams to the heating and mode power.

MAIN MODES

Two dimensional eigenmode calculations are performed for the bellows cavity. The fingers and beam chamber are not modelled in this calculation. We found several modes in frequency range of 5-6 GHz. They are: monopole, dipole and quadrupole modes. Frequencies of first modes are given in table 1.

Monopole	4.75 GHz	7.22 GHz	8.05 GHz
Dipole	5.46 GHz	8.37 GHz	9.44 GHz
Quadrupole	6.19 GHz	8.82 GHz	9.78 GHz

Table 1: Eigenmode frequencies.

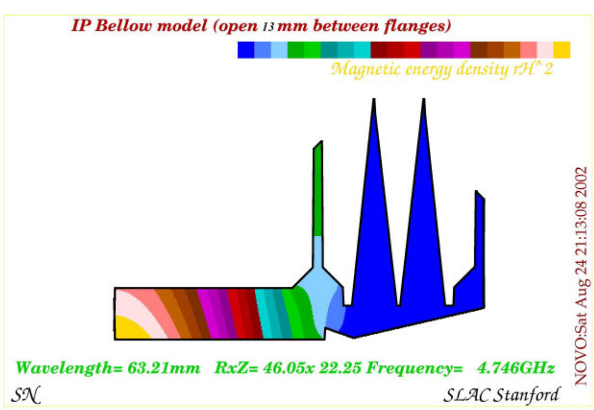

Figure 4: Monopole 4.75 GHz. Magnetic energy density.

The monopole mode is computed using a proprietary code NOVO [2]. The magnetic field energy density for the monopole mode integrated over the azimuthal angle is shown in figures 4.

Dipole and quadrupole modes are obtained with MAFIA [3]. The magnetic field energy density for dipole and quadrupole modes are shown in figures 5-6. There is high energy density at the bottom of the bellows convolutions for the dipole and quadrupole case. This magnetic energy density corresponds to large longitudinal magnetic flux.

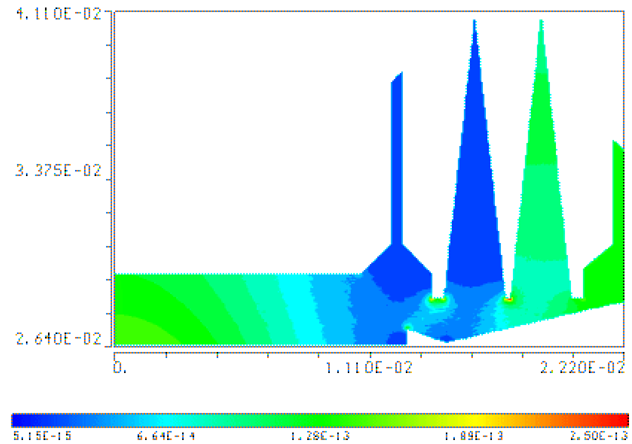

Figure 5: Dipole 5.46 GHz. Magnetic energy density.

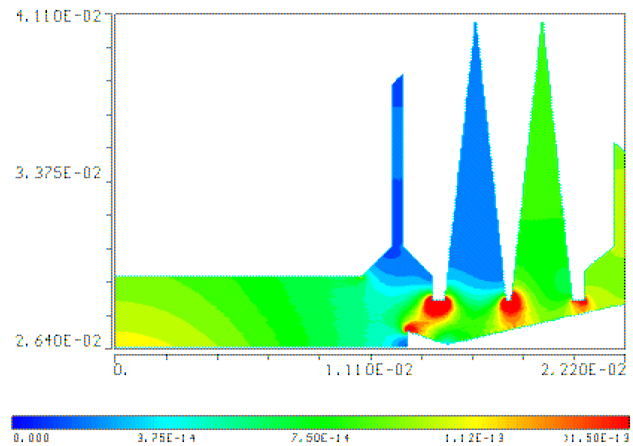

Figure 6: Quadrupole 6.19 GHz magnetic energy density. The scale is truncated at the high end to enhance the density pattern in the hot spots.

COUPLING STUDIES

So far we have determined the existence of modes in the bellows cavity which are likely responsible for the observed heating. To examine a possible excitation mechanism we now construct an inner beam cavity with slots in its outer walls linking the outer bellows cavity in its simple coaxial configuration. The evolution of a particular mode in each cavity is observed as the longitudinal dimension of the beam cavity is varied. The bellows cavity dimensions are held fixed in these studies. Furthermore, the slots are kept at the center of the longitudinal dimension of the beam cavity, to minimize the effect of the cavity walls. Within the regime where no coupling is present, the bellows cavity frequency remains constant while the beam cavity frequency changes with the change in length. If there is no coupling, the change in the beam cavity frequency will have no effect on the fixed frequency of the bellows cavity. If there is coupling, one expects a shift in the bellows cavity frequency as the beam cavity frequency approaches the bellows cavity frequency. The closest approach of the two frequencies yields the degree of coupling. The larger the closest approach, the larger the coupling. We give the coupling as the minimum frequency separation over the average frequency. Monopole mode coupling is not considered since the magnetic field lines are purely azimuthal, however, if the beam axis and the cavity axis are not parallel, a longitudinal coupling component will be introduced. The result for the dipole case is shown in figure 7. For a given slot size, frequencies of the dipole mode for both cavities and their difference are plotted as a function of beam cavity length The minimum frequency separation is 75 MHz yielding a 1% coupling.

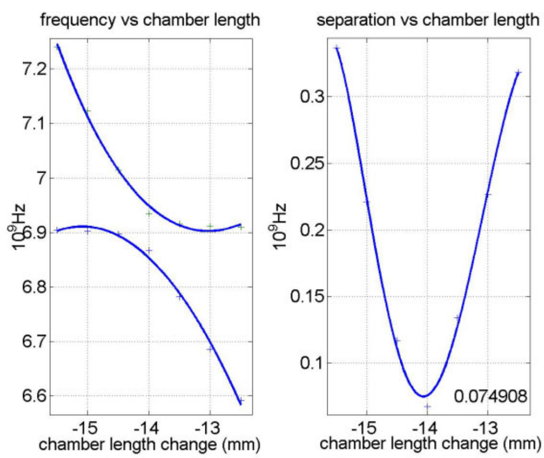

Figure 7: Dipole mode frequency for the beam and bellows cavities and their difference as a function of beam cavity length for a slot width.

Typical plot for the dipole modes in the beam chamber and bellows cavity is shown in figure 8.

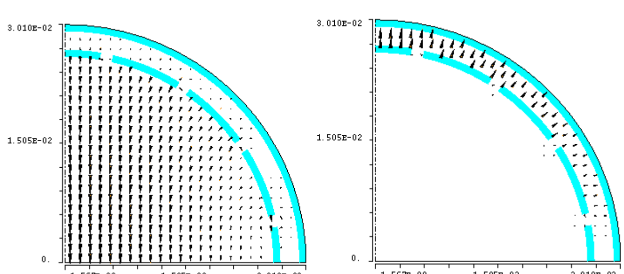

Figure 8: Dipole electric field in the beam cavity (left) and bellows cavity (right).

As shown in figure 9 for the quadrupole case, a minimum difference in frequency of 229 MHz indicates a higher degree of coupling of roughly 2%.

To extrapolate, we investigate coupling for different slot widths. The minimum frequency separation as a function of slot size for the quadrupole modes is shown in figure 10, where the horizontal axis is the fractional width of the real slot width of 0.81 mm.

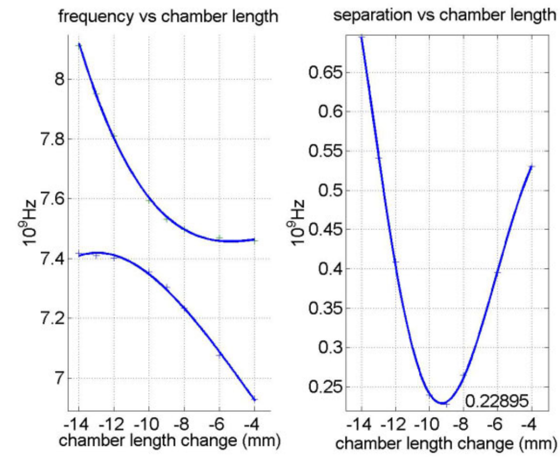

Figure 9: Quadrupole mode frequency for the beam and bellows cavities and their difference as a function of beam cavity length.

The data is fitted with an analytic expression derived from electric and magnetic polarizabilities of small apertures [4] which is given in terms of slot width w and length l and inversely proportional to $\ln(4l/w)-1$. Both the data and fit are fairly linear and flat in the region of interest. Practically speaking, reduction of coupling for the quadrupole modes by narrowing the slots is not feasible.

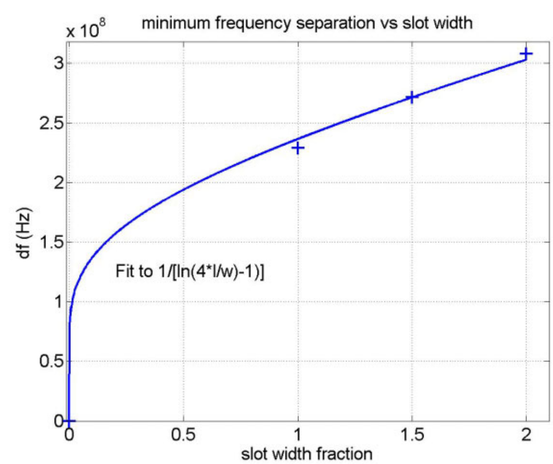

Figure 10: Coupling (+) and analytic expression (solid line) vs. fractional slot width.

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