

# TRAPPED MODES IN CESR SLIDING JOINTS

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## Abstract

Trapped modes in the sliding joints in CESR were investigated as a possible source of instabilities. To detect these modes, experiments were performed where pairs of bunches of positrons were run through at various spacings. It was hoped that constructive and destructive interference of wake fields would produce varying amounts of heating. Data taking was time consuming, and insufficient numbers of data points could be taken to fit to the wake fields. To help solve this, the frequency of the mode was measured on the bench. A single trapped mode and its profile were observed. The trapped mode has a frequency of 3.59 GHz, just below the TM cutoff of the beampipe. Measurements of the mode were used to predict a shunt impedance of 4.9 ohms. The corresponding loss factor is slightly higher than the total loss factor found in previous time domain measurements[6]. The program ZAP[8] was used to predict an instability threshold of about 2.1 A.

## 1 INTRODUCTION

A section of waveguide, like a beampipe, has a cutoff frequency below which modes cannot propagate down the guide. If there is an enlargement in part of the guide, a mode can exist there that is unable to propagate in either direction down the waveguide. This "trapped" mode will have a frequency just below the cutoff frequency of the guide if the perturbation is small. The frequencies of trapped modes have been estimated analytically[1, 2]. In this paper, the clear observation of a trapped mode in a CESR sliding joint is described and the consequences to the machine investigated.

## 2 TWO BUNCH TESTS

In order to search for trapped modes in the sliding joints, a single beam, two-bunch test was undertaken[3]. The first bunch would excite any trapped modes. The second would pass through the fields six to twenty-eight nanoseconds later. This would create varying amounts of heating depending on the phase of the trapped mode when the second bunch passed. Because the time constant for the heating of the sliding joints was around ten minutes, waiting for the temperature to stabilize was time consuming, and only a limited number of data points could be taken.

Because the bunch measurements were made in terms of temperature, a calibration was made to relate the energy lost in the sliding joints to the temperature differences observed. A resistor was lowered into an unused cooling pipe hole on the sliding joint and surrounded by thermally con-

ductive grease. With no current in the accelerator, known currents could be passed through the resistor at a known voltage.

The data from the two bunch tests did not appear to represent a single mode in the joints, but there was insufficient data to fit two modes to the small number of data points. In order to fit this data, an attempt was made to measure the frequency of any trapped modes by making bench tests.

## 3 BENCH TESTS

In previous experiments[4], two apparently trapped  $TM_{01}$  type modes were observed. A Slater perturbation method[5] was used to determine the field profiles of the modes. The results suggested that these peaks were actually the first and second order cavity modes produced by end plates used to terminate the ends of the sliding joint.

The problem of differentiating cavity and trapped modes was then addressed. It was important to be able to separate out the cavity modes, while also terminating the ends of the cavity to clean up the measurement. Sliding electrical shorts were constructed that could be moved freely along the inside of the beampipe. Indium was used between the sliding joint and the beampipe sections in order to improve the conduction at the joints.

The length of the cavity could now be quickly and easily changed. Changing the length caused the cavity modes to move, but any trapped mode would maintain the same frequency. By using this method, an unshifting peak was spotted at 3.5977 GHz, just below the TM cut-off frequency. In order to establish if this was a trapped mode, the profile was measured using a Slater perturbation method[5] identical to the one used above. The profile observed, shown in Fig. 2, had the characteristic shape of a trapped mode located near the center of the sliding joint. The Q value for the measure mode was at least 1800, and rose close to 2000 when the contact between the beampipe sections was particularly good. Because the actual extensions of the sliding joints in the accelerator varies appreciably, the frequency of the mode was measured as a function of the separation of the bellows plates. The original data was taken with a separation between the bellows plates of 0.83 inches. It can be seen in Fig. 3 that the frequency changes over an approximately 50 MHz range. Notice that the full width at half maximum of an individual peak is about 1.8 MHz, so the separations must be fairly close for the modes in the different sliding joints to interact.

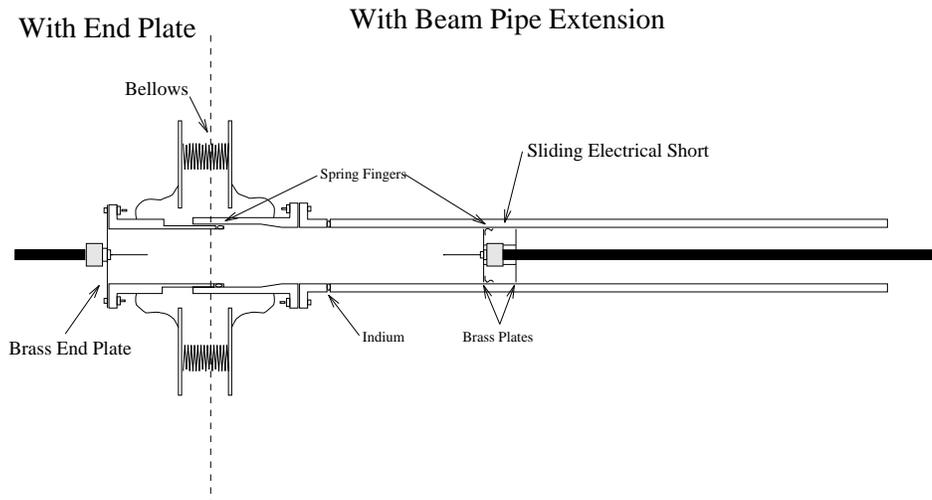


Figure 1: The diagram above shows the brass end plate used in the early bench measurements along with the beampipe section and sliding short used in the later measurements. They are shown together for space and comparison reasons: the sliding short was never used with the brass end plate.

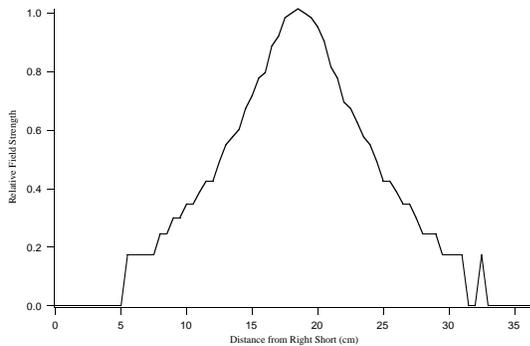


Figure 2: The plot above shows the relative electric field strength of the mode as a function of position.

#### 4 CALCULATION AND COMPARISON

Attempts were made to use the frequency measured above and make a fit to the two bunch test data. The calibration done above had already indicated that the temperature variations expected would be on the order of a degree. Attempts to fit to individual joints seemed dominated by noise, so an average was taken over all of the joints in the machine. There seemed to be a consistent change in temperature between data points. Unfortunately, the fits clearly indicated a very non-physical result for the heating. When the fits were extrapolated to zero bunch spacing, the heating was not a maximum, in fact, it appeared to be near a minimum, which is clearly nonsensical. It seemed clear from the pattern of the points, and the non-physical nature of the fits that could be made, that current variation probably dominated any temperature effect that could be measured.

Knowledge of the relative field profile and the frequency of the mode allowed the calculation of the transit time factor for the mode. The value for this factor was 0.787.

Previous bench measurements[6] had determined an ap-

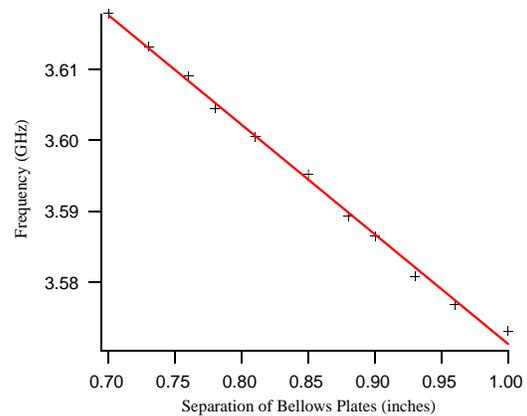


Figure 3: The frequency of the trapped mode changed as a function of the extension of the sliding joint. This is important since the extension of the joints vary greatly around the accelerator.

proximate total loss factor for the sliding joint of  $3.9 \times 10^{-3}$  ( $V/pC$ ) at a bunch length of 1.8 cm. The loss factor due to the trapped mode should depend on bunch length in a Gaussian fashion as shown in Fig. 4. Information about the trapped mode was used to determine its contribution to the total loss factor of the sliding joint. The field configuration in the sliding joint was estimated by using the transverse dependence of the calculated fields of the lowest order TM mode[7] and the longitudinal profile measured above. This field configuration was used to calculate the stored energy in the mode and, thus, the shunt impedance of the mode. This calculation gave a shunt impedance ( $R/Q$ ) of 4.9 ohms. This impedance relates to a loss factor of  $4.2 \times 10^{-3}$  ( $V/pC$ ) for the trapped mode in the sliding joint at a bunch length of 1.8 cm. Note that this value is higher than the measured value for the total loss factor,

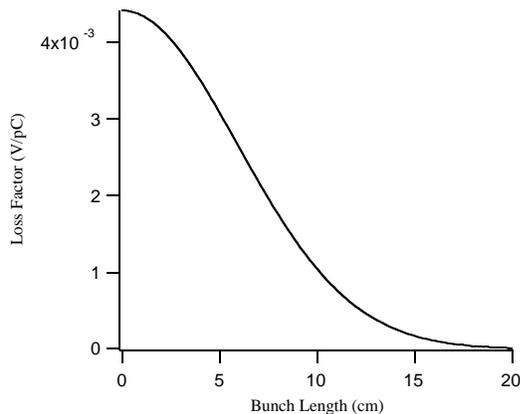


Figure 4: The loss factor due to the trapped mode should depend on bunch length in a Gaussian fashion, as shown above.

which includes all of the modes in the joint. In any case, the high value of the loss factor for the mode suggests that the trapped mode is the dominant source of impedance in the sliding joint.

Analytical estimates of the trapped mode[10] predicted that the mode would be found 21 MHz below the cutoff frequency compared to an experimentally measured difference of about 80 MHz. The predicted shunt impedance was lower, only about 2.1 ohms.

Under normal operating conditions, the loss factor above relates to about 80 eV lost per sliding joint per electron. Because there are one hundred sliding joints in the ring, the total energy loss would be 8 keV per revolution.

The program ZAP[8] was now used to estimate the effects of the trapped mode on beam stability. The program could not deal with the large number of actual sliding joints in CESR. First, as a very rough measure, a simulation was done with a single mode with one hundred times the predicted impedance. This rough test came up with all stable modes under normal operating currents, and an instability did not occur until a current of 2.13 A was used. Next, twenty sliding joints were used, with each having five times the impedance of a single joint. In this test, there were some Landau damped modes over the entire reasonable current range. Unstable modes appeared at currents of 2.17 A, a value well above current operating conditions.

For tests where more than one mode was used, the frequencies of the sliding joint modes were not assumed to be the same. The distribution of sliding joint extensions in the ring had been sampled previously[9]. Of the hundred sliding joints in the accelerator, the extensions of 31 had been measured. To determine the extension of a random joint, a measured value was selected at random. The extensions were measured to the nearest thirty-second of an inch, but were only measured at one point around the rim of the bellows plates, so significant error was possible. To simulate this uncertainty, a Gaussian deviate of one thirty-second of an inch was added to the randomly selected measured

value. Using the measurement discussed above, the extension was translated into a frequency for the trapped mode.

## 5 CONCLUSION

Trapped modes in the sliding joints were studied to see if they might eventually place a limit on the beam current. Machine studies generated interesting data, but data collection was too time consuming for the number of unknowns involved. Attempts to measure the frequencies using a network analyzer shed doubt on earlier measurements of the mode frequencies, but indicated a trapped mode in the sliding joint at about 3.60 GHz with a Q factor of about 2000. The mode observed predicted a loss factor of  $4.2 \times 10^{-3}$  (V/pC) due to the trapped mode. The loss factor is slightly higher than expected from earlier measurements, but indicates the importance of the trapped mode in the overall impedance of the structure.

## 6 ACKNOWLEDGMENTS

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