ANALYSIS OF RF MODES IN THE ANL APS VACUUM CHAMBER USING COMPUTER SIMULATION, ELECTRON BEAM EXCITATION, AND PERTURBATION TECHNIQUES*

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I. Introduction

The APS vacuum chamber consists of a nearly elliptical beam chamber coupled to an antechamber through a 1-cm-high, 10-cm-long pumping slot over most of the 1104 m of storage ring circumference.[1] A cross section in a plane perpendicular to the beam direction is shown in Fig. 1. Nonevaporable getter (NeG) strips in the antechamber are the pumping element. The 1-cm-high slot has two functions: to provide good conductance for vacuum pumping and for transmission of the photons into the beam ports.

This configuration with a pumping slot is not unique. Similar arrangements are planned for the Advanced Light Source (ALS)[2] and the storage rings at the ESRF[3] and STA-SR[4] projects.

We thought that coupling of the beam to the antechamber might occur through the slot. Since the beam fields are transverse magnetic to the beam (TM_z), no coupling occurs below the TM cutoff of the slot (15 GHz for 1 cm) because no wall currents are interrupted. Also, the frequency spectrum of a rigid bunch is well below 15 GHz.

Both computer calculations and measurements were done to verify that no coupling occurs. Computer calculations in the frequency domain and two-arm wire measurements with picosecond pulses were previously reported.[5] Figure 2 shows the dominant TM_z mode in the beam chamber is not perturbed by the slot. The wire measurements confirmed that little coupling occurs between the two chambers.

In addition to those earlier studies, a real-time MAFIA-T3[6] study in 3D was done, and a measurement of modes excited by a 38-ps, 20-MeV electron beam has been completed. These results are the primary topic of this paper. Some measurements made with a network analyzer and bead perturbation equipment will also be discussed.

II. Real-Time Computer Calculations

A 1-m-long section of vacuum chamber was used for the e-beam measurements. The input geometry

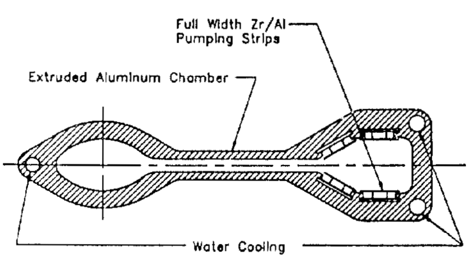

Fig. 1. Cross section of APS vacuum chamber showing beam chamber, pumping slot, and antechamber.

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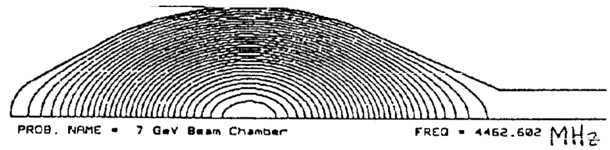

Fig. 2. H-field plot of the dominant TM_z mode in the beam chamber with longitudinal slot.

for the MAFIA-T3 computer code modeled a 1-m-long vacuum chamber section with flat conducting plates with one inch beam holes on each end. E- and H-fields were calculated at the top of the beam chamber, the middle of the slot, and the top of the antechamber, due to a beam with a σ_z of 2 cm. The boundary conditions used assure that only TM_z modes will be generated. Figure 3 shows the E-field at the top of the beam chamber. The dominant component of the E-field is normal to the conducting boundary, as expected, and is 10^{13} V/m. Both x and y components are about two orders of magnitude less. The frequency of the excited mode is about 5.5 GHz, consistent with excitation of the first TM_z mode.

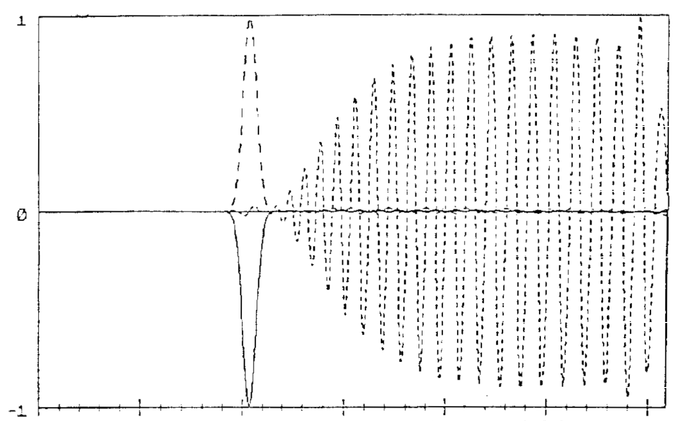

Fig. 3. E-field at the top of the beam chamber.

Figure 4, the E-field in the middle of the slot, is five orders of magnitude lower than the field in the beam chamber. Figure 5, the E-field at the top of the antechamber, is ten orders of magnitude lower. These calculations support the conclusions reached from the frequency domain calculations and the two-arm wire measurements.

Calculations made with the beam horizontally and vertically displaced by ± 1 cm from the center of the chamber show that coupling was still negligible.

III. Electron Beam Measurements

A 1-m-long section of the APS vacuum chamber was fitted with flat end plates with 1-inch beam tubes centered on the beam chamber. Electron bunches (38 ps FWHM) are directed through the chamber on center or horizontally or vertically displaced by ± 1 cm. A 6-GHz oscilloscope records the E-fields excited by the passage of 2×10^{10} electrons. The plan was to measure the E- and H-fields, but the H-field probes

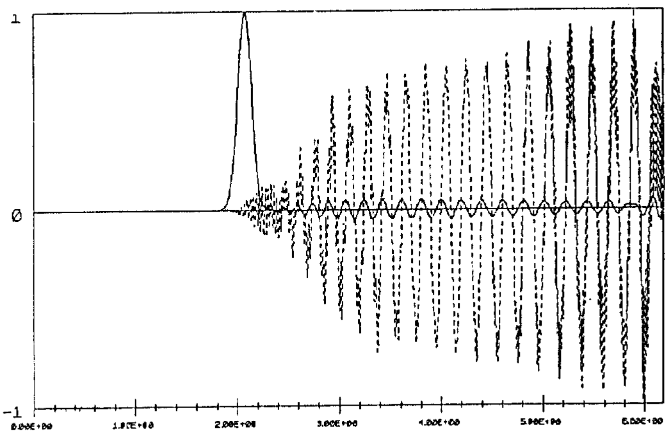

Fig. 4. E-field at the top of slot. The relative amplitude is 10^7 V/m.

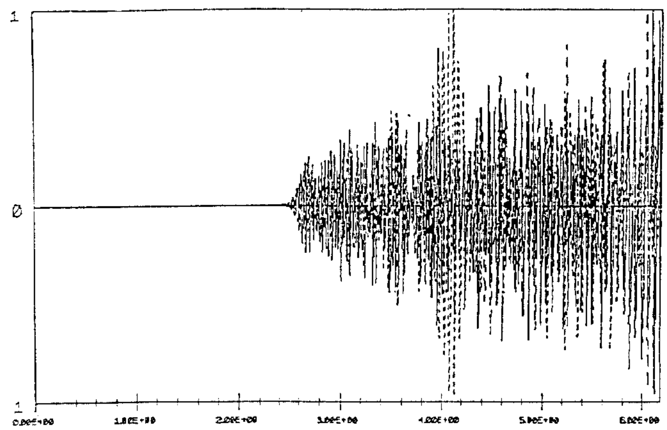

Fig. 5. E-field at the top of the antechamber. The relative amplitude is 10^2 V/m.

are too sensitive to the E-field. The E-field probes have 50 db of H-field rejection, and so only E-field measurements were made.

A full-length, full-height, 1.5-cm-deep rf shorting bar could be fitted into the slot at the face of the beam chamber so that the chamber is elliptical. This permits relative field measurements with and without a pumping slot, avoiding the difficulties of making absolute measurements.

An FFT was made of the data. Log plots of the FFTs are shown in Figs. 6 through 9. A cross-section of the vacuum chamber with the probe locations is also shown. The FFT amplitude measured at each probe is plotted directly below that probe's location.

Excited modes were found at frequencies in the range of 5.5 to 6.0 GHz. The fields for these modes are in the beam chamber with virtually no penetration into the slot. Figure 6 shows the relative FFT amplitudes of the E-field at 5.5 GHz with and without the shorting bar. The measured field strengths are the same. Figure 7 shows the relative FFT amplitudes of the E-field at 6.5 GHz with the beam on the center and displaced ± 1 cm horizontally and vertically. Again, the E-field amplitudes fall off rapidly in the slot and antechamber (not sensitive to beam position).

One anomalous mode, at a frequency of about 4 GHz, does occur and is not yet explained. The E-field is concentrated in the slot but is gone with the shorting bar and is not affected by beam displace-

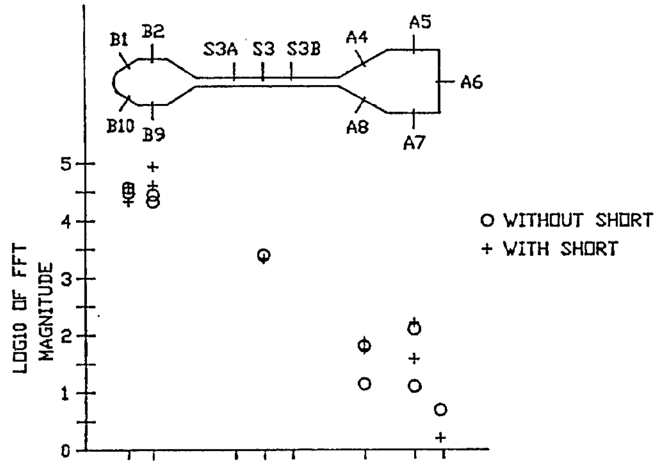

Fig. 6. E-field measurements at 5.5 GHz with and without slot shorted.

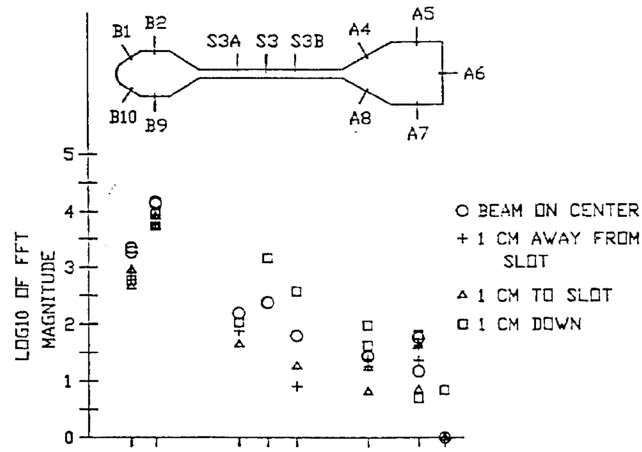

Fig. 7. E-field measurement at 6.5 GHz with beam on chamber centerline, ± 1 cm horiz. displacement, and 1-cm vertical displacement.

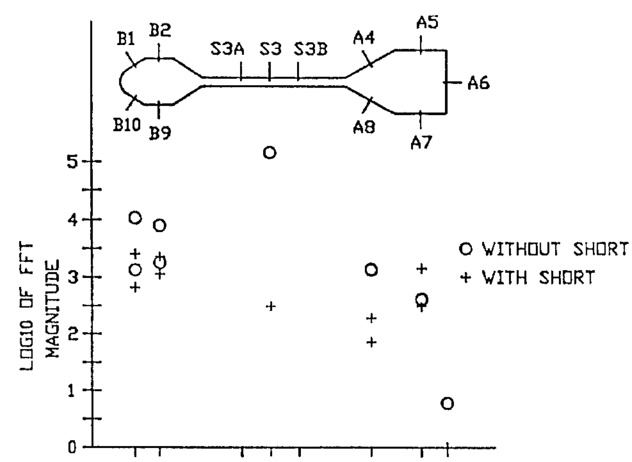

Fig. 8. E-field measurements at 4 GHz with and without slot shorted.

ments. Figure 8 shows the FFT amplitudes of the E-fields at 4 GHz with and without the shorting bar; the field strength is reduced by four orders of magnitude with the shorting bar. Figure 9 shows the FFT amplitudes of the E-fields at 4.0 GHz with the electron beam displaced horizontally and vertically by ± 1 cm. Clearly, the field distribution is not affected by beam position. Since 4.0 GHz is below the cutoff of the first TM_z mode in the beam chamber (4.46 GHz), it is either a TE_z or a hybrid mode. We are still doing studies to find the source of this mode.

IV. Bead-Pull Perturbation Measurement Studies

The chamber can be excited in the 4-GHz frequency range and the mode with the same E- and H-fields found. Then a standard technique of pulling metal and dielectric beads along the beam axis is used to determine the E- and H-fields along the axis.[7] If several degenerate modes exist, then it is difficult, if not impossible, to separate them.

The bead-pulling apparatus is described in another paper at this conference.[8] The transmission matrix element was measured from the beam chamber probe to a probe in the slot (Fig. 10). A number of excited modes are evident and have the same E-field distribution as the mode excited by the e-beam. The difference between the modes is the number of standing waves along the beam axis. Figure 11 shows the result of a bead perturbation measurement of one of the excited modes.

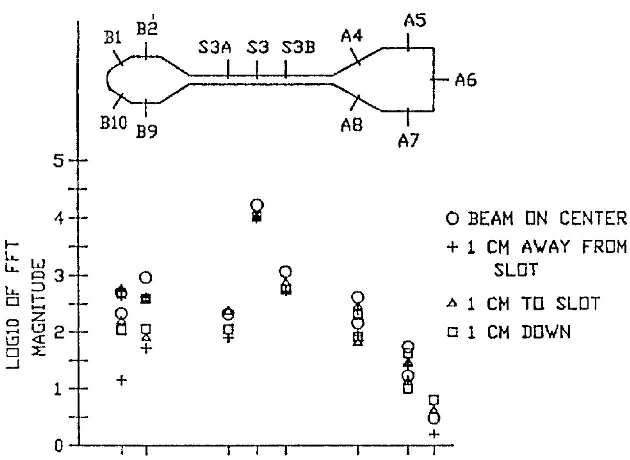

Fig. 9. E-field measurement at 4 GHz with beam on chamber centerline ± 1-cm horizontal displacement, and 1-cm vertical displacement.

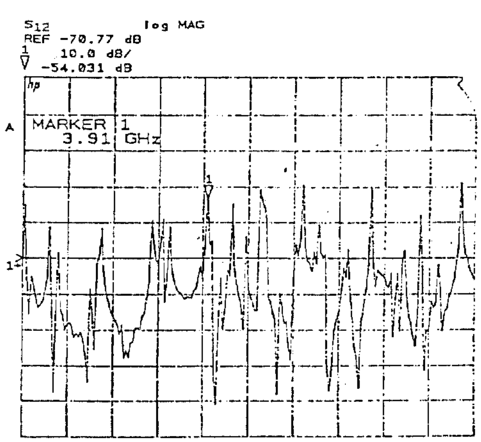

Fig. 10. Value of transmission matrix element between a beam chamber probe and slot probe over the frequency range of 3.5 to 4.5 GHz.

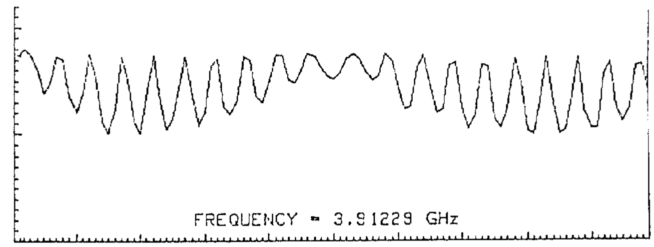

Fig. 11. Value of transmission matrix element between a beam chamber probe and slot probe as a conducting bead is pulled along the z-axis (10 cm per major division).

V. Summary

We conclude that any TMz modes excited in the beam chamber will be confined there. We are continuing investigation of the anomalous 4-GHz mode; the first procedure is to make measurements with a good H-probe. A new type has been developed and has been tested with E-field rejection of over 20 db. The H-field is coupled with two loops oppositely oriented. A broadband quadrature hybrid doubles the H-induced voltages and cancels any E-induced voltages. Next, we will compare results obtained with the flat end plates with tapered transitions for the electron beam. Also, a chamber that is 2 1/2 times larger in transverse dimension will be tested. This chamber has lower cutoff frequencies, making measurements with the available test equipment easier.

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