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RF IMPEDANCE STUDIES OF A BEAM CHAMBER AND LONGITUDINALLY SLOT-COUPLED VACUUM PUMPING ANTECHAMBER*

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The storage ring vacuum chamber of the proposed 7-GeV synchrotron light source at Argonne National Laboratory is planned to have a semi-elliptical beam chamber, with a longitudinal slot coupled to an antechamber containing NEG pumping strips. Concern over the RF impedance of this complex chamber has stimulated the need to understand the limitations it will have on the beam intensity, the RF acceleration system and on the beam lifetime. Calculations using numerical EM field programs have estimated the waveguide modes of this chamber and the impedance and loss parameter for the expected 1-2 cm beam bunch length. The loss parameter is shown to differ little from an elliptical beam chamber without the slot and antechamber. An experimental program has begun to verify the estimates of the impedance for these complex vacuum chamber components using laboratory methods. Preliminary results are presented for the measured loss parameter for a short length of beam vacuum chamber and for other components. These results are compared with their calculated values.

I. Introduction

The vacuum chamber for the Advanced Photon Source (APS) is planned to have a beam chamber (elliptical in shape of about 6-cm wide by 4-cm high) connected by a 1 cm. high longitudinal slot to a larger (approximately 8 by 6 cm) antechamber [1,2,3]. The antechamber will contain several non-evaporable getter (NEG) pumping strips, which provide the vacuum required for adequate beam lifetime.

As a Gaussian beam bunch with charge q and rms bunch length σ_ℓ passes through a cavity, the energy lost is related to the loss parameter $k(\sigma_\ell)$ by the relation

$$U_o = k(\sigma_\ell)\, q^2 \quad .$$

The loss parameter is the integral of the longitudinal impedance of the cavity weighted by the spectral components in the beam bunch. For a cavity with many modes of frequency f_n, $k(\sigma_\ell)$ is given by

$$k(\sigma_\ell) = \sum_n k_n(0)\, \exp[-(\omega_n\, \sigma_\ell/c)^2]$$

where $k_n(0) = \omega_n\, R_n/(4\, Q_n)$, R_n = the shunt impedance, Q_n = the quality factor and $\omega_n = 2\pi\, f_n$. With the σ_ℓ = 1-2 cm bunch length expected, the contribution for modes near 15 GHz will be down by a factor of 10^{-5} relative to the modes near 1 GHz. Therefore, it is expected that the loss parameter for the APS beam will have little dependence on the modes above 15 GHz.

The RF impedance seen by the circulating beam is of concern for the beam stability, as well as for the requirements it places on the RF system due to parasitic mode energy loss. Since the TM mode cutoff frequency for the 1-cm coupling slot is about 15 GHz, modes in the antechamber below this frequency should not contribute to the longitudinal impedance seen by the expected 1-2 cm beam bunch. The effect of modes greater than the cutoff frequency should be small, as shown above.

II. Analytical Results

To verify these qualitative expectations, the EM modes for the vacuum chamber and other components have been modeled using programs SUPERFISH [4] and URMEL [5]. SUPERFISH can be used to calculate the cutoff frequencies of waveguides with a general cross-section in the xy-plane. The TM modes were calculated for the vacuum chamber geometry with and without the connection to the antechamber. Fig. 1(a) shows the H-field lines at the cutoff frequency of the first TM mode. The EM fields are confined to the beam chamber and the cutoff frequencies are essentially the same, 4.15 GHz, for both geometries.

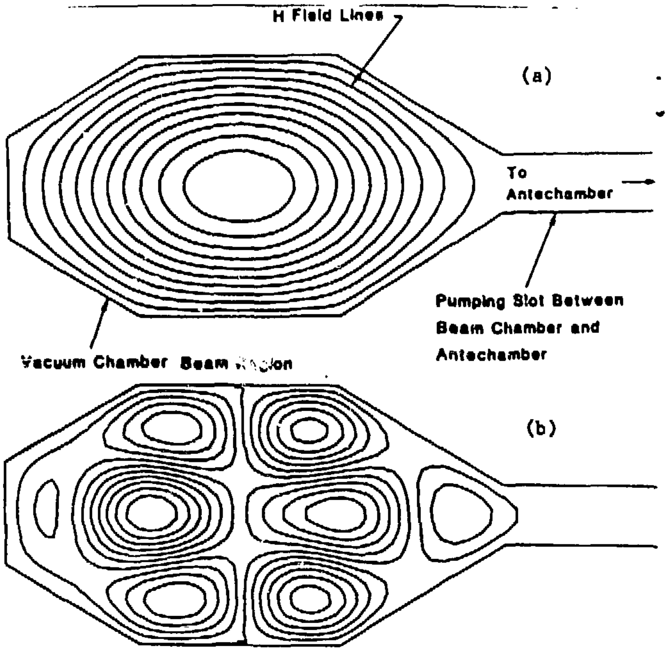

Fig. 1. (a) SUPERFISH calculation of the H-field lines for the first TM mode, 4.15 GHz, of the beam chamber region for the proposed APS vacuum chamber. (Antechamber is not shown). (b) H-field lines for the 11.97-GHz TM mode of the vacuum chamber.

Figure 1(b) shows the H-field lines for a TM mode with a cutoff frequency at 11.97 GHz. The fields are starting to penetrate into the pumping slot and some distortion is apparent compared to a simple beam chamber. Deep penetration does not occur for frequencies below about 14 GHz. These observations support the contention that the loss parameter for the vacuum chamber should not differ significantly from an elliptical beam chamber.

III. Measurement Techniques and Analysis

The first stage of an impedance measurement program for the APS is to develop a laboratory system to measure the loss parameter using the wire and pulse technique proposed by Sands and Rees [6]. This method

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DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED estimates the energy loss of the beam bunch by passing a Gaussian current pulse $I_0(t)$ on a thin wire through the center of the chamber. The transmitted current pulse $I_m(t)$ has undergone a similar energy loss in the chamber under test, to that of a beam bunch with the same rms bunch length, σ_ℓ. The loss parameter $k(\sigma_\ell)$ is then given by the relation [6]

$$k(\sigma_\ell) = \frac{2Z_0\int I_0(t)\,I_d(t)\,dt}{[\int I_0(t)\,dt]^2}$$

where $I_d(t) = I_0(t) - I_m(t)$ and Z_0 is the characteristic impedance of the input and output connections to the chamber under test. In order to verify the estimate that the actual vacuum chamber has a value k similar to that of an elliptical chamber without the antechamber, in time to effect design changes, an existing digital time domain analysis system was modified. This system was used to measure the beam coupling impedance for high-frequency beam pickup [7]. The modified system is shown in Fig. 2. A fast pulse (≈150 picoseconds FWHM) was split into two arms with one signal passing through a reference chamber and the second passing through the chamber to be measured. The output of each chamber was measured by a sampling scope and the output of each channel was digitized and recorded for computer analysis. This system allowed simultaneous measurements of $I_0(t)$ and $I_m(t)$. The signals were carefully calibrated for offsets and gains by running identical chambers in both arms and by switching the chambers. After smoothing the data and adjusting for timing drifts between the two arms, the value $k(\sigma_\ell)$ was calculated using numerical integration of the digitized data. Comparing a sequence of measurements of identical 50-Ω coaxial transmission lines yielded a k value consistent with zero within a standard deviation of ±0.005.

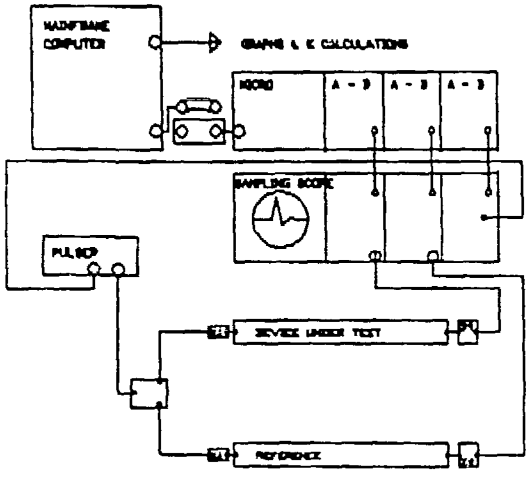

Fig. 2. Schematic diagram of the time domain measurement system used to determine the loss parameter for vacuum components.

By placing a component to be tested in one arm and a matched 50-Ω reference chamber in the other arm, the difference in the k parameters can be measured. Fig. 3 shows measurements of $I_0(t)$ and $I_m(t)$ for the proposed vacuum chamber and a matched 50-Ω elliptical beam chamber. Fig. 4 shows the difference signal $I_d(t)$ for the same components in Fig. 3. For small differences our present method (similar to that of Weaver et al. [8]) will be limited by the measurement resolution of the signals $I_0(t)$ and $I_m(t)$. Future improvements will incorporate the analog difference method [9,10]. However, in the latter case the relative timing of the device under test and the reference must be carefully adjusted before measuring $I_d(t)$. With the present system, the relative timing is adjusted numerically by alignment of the zero of the second derivative on the leading edge of $I_0(t)$ and $I_m(t)$. In addition, the measurement resolution is presently dominated by the slewing of the trigger discriminator rather than by the digitizer accuracy or the noise level of the input to the sampling scope. This will be improved by eventually using a fast real-time oscilloscope.

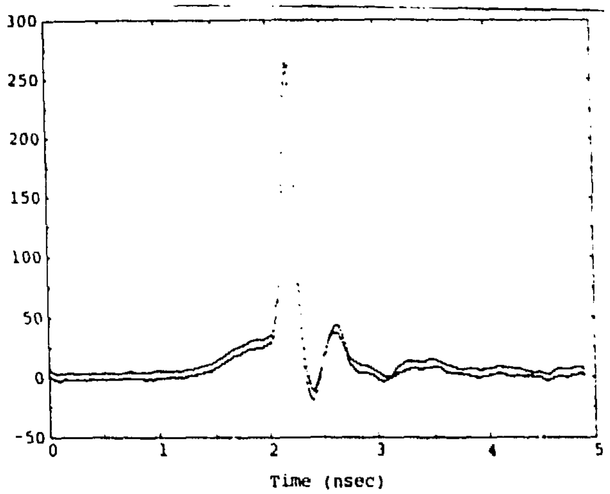

Fig. 3. Measurement data for the reference signal $I_0(t)$ and the transmitted signal $I_m(t)$ for a one-meter section of vacuum chamber with abrupt transitions.

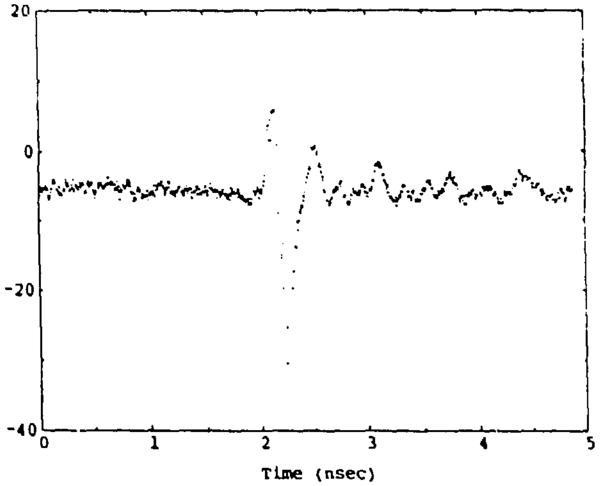

Fig. 4. Difference current $I_d(t)$ not smoothed, for the vacuum chamber measured in Fig. 3.

Future plans also include comparing the measured loss parameter using wire techniques with measurements of relativistic beam coupling impedance to certain dominant modes in the expression for k. This technique will be a continuation of the studies performed on beam pickup impedance [7]. This method will also be helpful in understanding the transverse impedance for these complex vacuum chambers.

IV. Results

Two test vacuum chambers, each one meter long, were made in order to measure the loss parameter. Each chamber had a cross-section as shown in Fig. 1 but with a different transition from the elliptical beam chamber to the slot-coupled antechamber. One chamber had an abrupt (90°) transition, while the other had a tapered (~ 30°) transition. A third chamber consisting of just the elliptical beam chamber without the slot coupled antechamber was built to compare with the more complex geometry. All three chambers had the same electrical length and identical transition to 50-Ω connectors. The reference signal was measured using a 7/8" coaxial transmission line with the same electrical length as the chambers.

The measured loss parameter for all three chambers was small (k=0.005 to 0.008 V/pC) and was dominated by the systematic resolution of our measuring system. To within the measurement uncertainty all antechambers had a loss parameter comparable to the loss parameter of the elliptical chamber without the antechamber. Although preliminary, these results confirm the modal analysis described above. Measured k for the vacuum chambers compares closely with the assumed value of k=0.006 V/pC/m, which was scaled from measurements of existing storage ring and includes the influence of transitions and bellows. This value has been used in all design calculations for beam stability and RF parameters.

Future improvements in our measurement method have been mentioned previously and should yield significant improvement in our measurement resolution for such small values of k. However, the wire method is strictly valid only for short discontinuities and thin wires. Future studies to measure beam excitation of the dominant modes of the loss parameter are planned to better understand the limitations of the wire method on the k value for long chambers.

As a further check of our systematics, we have measured a short pill-box cavity (15.24-cm diameter by 2-cm long). Fig. 5 shows the reference and transmitted signal for this cavity. The result for three measurements of this cavity was k=0.244 ± 0.008 V/pC. The expected value of k for this cavity was k=0.22 V/pC and was estimated by using the first four TM modes calculated by URMEL [5]. The difference in these values is easily attributed to the uncertainty in the actual spectral components in the signal pulse. Future improvements in this system will include a Fourier analysis of the reference pulse to be used in the calculation of k, rather than assuming a Gaussian pulse shape.

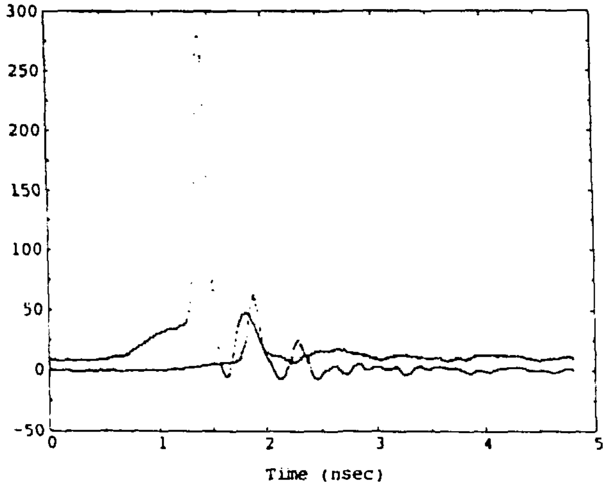

Fig. 5. Measured data for the reference signal $I_0(t)$ and the transmitted signal $I_m(t)$ for the pill-box cavity described in the text. The transmitted data $I_m(t)$ has not been corrected for the time delay.

Acknowledgements

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References

[1] Yang Lai Cho, "Status and Overview of the Synchrotron X-ray Source at Argonne", this conference.

[2] R. Nielsen et al., "Vacuum Chamber Development for the Synchrotron X-ray source at Argonne", this conference.

[3] R. Wehrle, et al., "Vacuum System for the Synchrotron X-ray Source at Argonne", this conference.

[4] K. Halbach and R. F. Holsinger, "SUPERFISH - A Computer Program for Evaluation of RF Cavities with Cylindrical Symmetry", Particle Accelerators, Vol. 7, (1976).

[5] C. Palm, U. van Rienen and T. Weiland, "URMEL and URMEL-T User Guide", DESY M-85-11, (December 1985).

[6] M. Sands and J. Rees, "A Bench Measurement of the Energy Loss of a Stored Beam to a Cavity", PEP-95, Stanford Linear Accelerator Center, Palo Alto, California, (August 8, 1974).

[7] S. L. Kramer et al, "Relativistic Beam Pickup Facility", Proceedings of the 12th International Conference on High Energy Accelerators, FNAL, 258, (1983).

[8] J. N. Weaver et al, "Bench Measurements of Loss Impedance for PEP Beam Line Components", IEEE NS-26, 397, (1979).

[9] M. J. Billings, et al., "Simulation Measurement of Bunch Excited Fields and Energy Loss in Vacuum Chamber Components and Cavities", IEEE NS-26, 3583, (1979).

[10] J. Peters, "Bench Measurements of Energy Loss of a Stored Beam to Vacuum Components", IEEE NS-24, 1446, (1977).