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AUTHOR(S) Y. Iwashita, AT-1
S. O. Schriber, AT-D0
J. M. Potter, AT-2
D. A. Swenson, Texas Accelerator Center

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

BEAM-CAVITY INTERACTION MEASUREMENTS IN A DAW STRUCTURE*

Y. Iwashita,** S. O. Schriber, MS HB11, J. M. Potter, MS HB18
D. A. Swenson,† and G. S. Mavrogenes,††

Los Alamos National Laboratory, Los Alamos, NM 87545 USA

**Visiting Scientist from Institute for Chemical Research, Kyoto University, Kyoto, Japan

†Texas Accelerator Center, The Woodlands, TX 77380 USA

††Argonne National Laboratory, Argonne, IL 60439 USA

Summary

Mode excitations induced by relativistic electron beams have been measured in a disk-and-washer (DAW) structure. The structure had three washers, each with four radial support stems, and half-disk end terminations. The design DAW operating frequency was 1300 MHz, the same as that used to accelerate the electron beam. Both short-pulse (35-ps, 800-Hz, 17-nC/pulse) and long-pulse (10- μ s, 2-A average) conditions were used in the beam-excitation experiments. Mode spectra were measured and identified using low-power techniques employed after the high-power beam measurements. Mode frequency calculations for the complete three-washer geometry were performed using URMEL for up to $m = 7$. Calculated results are compared with data determined from low-power and beam driven excitation of the DAW structure.

Introduction

A DAW structure geometry has several advantages compared to conventional structure geometries. Besides a coaxial geometry, which permits simple brazing and assembly techniques, advantages include high shunt impedance, high coupling constant, and good vacuum conductance. Because of higher order passbands (in particular the TM₁₁-like passband) overlapping the region of the operating-mode frequency, DAW structures have not been accepted for many projects, in contrast to an earlier enthusiasm based on structure attributes. Although there are solutions to the mode-overlapping situation, many passbands still exist in the neighborhood of the operating mode frequency. Mode excitations in these passbands might have harmful properties for normal-structure operation.

To address the issue of passband interference and excitation, a DAW cavity geometry was selected, with overlapping passbands, for experiments in which a high current electron beam would be transmitted through a several-cavity structure. Excitation effects and deleterious effects would be investigated using beam sensors and spectrum analyzers. The DAW geometry was not designed to avoid overlapping passband effects, nor to compensate for the stem perturbation on the operating mode. The structure was fabricated from copper-plated iron and consisted of three washers (each with four radial supports) and half-disk end terminations. The design operating frequency was 1300 MHz, the same as that of the linac used to accelerate the electron beam.

Experimental Setup

The Argonne linac^{1,2} was used to produce the injected electron beam. The linac had unique feature that could produce ~35-ps single-bunch short pulses at 800 Hz repetition rate. Short pulses were achieved by a combination of a coaxial triode gun (50-A peak current, 5-ns rise and fall time) and a subharmonic prebuncher employing the sixth subharmonic. Characteristics of the output beam from the linac were

21-MeV, 800-Hz, 13- μ A average current, 16.5 nC per pulse, and ~400-A peak current for short-pulse operation. The other operating long-pulse mode of the linac was also employed to investigate build-up effects—a long pulse with 2-A average, 10- μ s, 0.3- μ s rise and fall time.

The DAW structure³ was mounted in a large vacuum chamber that encompassed the whole structure, including diagnostics. Sixteen rf magnetic and electric sampling probes were connected to the DAW. Four probes were on each end plate (at about the washer radius with 90° separation). The other eight probes were on the outer wall, four each at the washer position and at the disk position. Each set of four probes consisted of two electric probes and two magnetic probes, one of which was perpendicular to the structure radius with the other parallel to the radius. The electric probe on the front end plate was used for obtaining the data shown in Table I. This probe was less sensitive to the structure operating mode and, therefore, provided more protection for the sensitive rf measuring apparatus. Signals were coupled from the DAW structure in the vault to the measuring apparatus by 1.27-cm-diam, 24-m-long Andrews cables with #44 AW connectors.

During the course of the experiments, measurements on build-up effects were attempted, using the long-pulse mode of the Argonne linac. In the long-pulse mode, the energy was concentrated at frequencies close to the harmonics of the beam, with sidebands spaced at intervals equal to the reciprocal of the pulse width, and with very little energy at other frequencies. Thus, the only modes that could be excited substantially were those that were near the beam frequency or its harmonics. We saw no evidence for any such modes other than the normal accelerating mode. Only a few other strongly coupled modes (belonging to the operating-mode passband) could be clearly identified in the long-pulse data.

Calibration

The raw data were recorded as power levels in dBm from a spectrum analyzer used to evaluate the interaction. Data were recorded for each mode with the beam on-axis, and again with the beam approximately 1 cm off-axis—both horizontally and vertically. The off-axis data were useful in establishing the presence of position-dependent modes, which are also potential beam blow-up modes. To relate the signal measured at a pickup probe to the actual stored energy in the structure it was necessary to measure the coupling of the probes to each mode. The procedure employed during low-power measurements was as follows. With the structure driven at the resonant frequency of a mode, net rf power into the structure was determined by subtracting reflected power from incident power. (Net power usually was about 1% of incident power because the drive loop was weakly coupled to the structure.) For convenience, incident power was determined by detuning the cavity with a large metallic probe so that all the power was reflected. This procedure was valid because the generator had a leveled rf output that provided the same forward power, independent of load. The advantage of this technique was that the loop resistive losses automatically were taken into

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account and the power meter could be left connected to the reflected power port of the directional coupler. The calibration factor used was the attenuation from the drive to the pickup probe $\alpha = P_0/P_1$, where P_0 is the output power measured at the pickup probe and P_1 is the input power to the cavity.

TABLE I
MEASUREMENT OF EFFECTIVE SHUNT IMPEDANCE
FOR MODES <2600 MHZ

f (beam) MHz	On ¹ dBm	Off ² dBm	diff	f (cold) MHz	Q	ZT ² Kohm	comment
436	-39	-40	-1	437.1	4000	140	STEM P1/3
660	-29	-28	1	662.5	20000	400	TM01 ZERO
704	-63	-65	-2	705.6	7000	.4	TE11 P1/3
808	-39	-39	0	807.7	9000	40	TE11 2P1/3
816	-25	-24	1	815.0	14000	70	TM01 P1/3
849	-56	-45	11	848.7	11000	60	TE11 P1
1063	-22	-22	0	1069.0	17000	3000	TM01 2P1/3
1107	-51	-40	11	1113.5	30000	9	*TM11 ZERO
1137	-53	-41	12	1142.7	20000	3	*TM11 P1/3
1236	-64	-68	-4	1239.2	11000	<.1	TE21 2P1/3
1238	-50	-37	13	1241.4	20000	14	*TM11 2P1/3
1286	-61	-64	-3	1290.4	10000	<.1	TE21 P1
1343	-23	-34	-11	1346.7	20000	12000	ACC. MODE
1457	-63	-65	-2	1448.8	16000	.4	TM21 P1/3 B ₁
1465	-42	-41	1	1469.6	14000	200	TM02 2P1/3
1465	-42	-41	1	1469.6	11000	2	TM21 2P1/3 B ₁
1472	-45	-44	1	1476.2	30000	2	TE31 2P1/3
1477	-57	-58	-1	1481.7	15000	1.4	TE31 2P1/3
1484	-34	-34	0	1488.9	20000	200	TM02 ZERO
1489	-45	-45	0	1493.7	15000	30	TM02 P1/3
1498	-62	-62	0	1502.3	20000	.4	TM21 2P1/3 B
1569	-55	-65	-10	1566.4	13000	10	TE12 2P1/3
1638	-67	-62	5	1637.6	13000	.9	TM31 2P1/3 ?
1689	-64	-64	0	1689.6	8000	1.4	TE41 2P1/3 E or H=0
1728	-58	-55	3	1727.9	10000	.2	TM31 2P1/3 or H=1
1730	-40	-58	-18	1728.5	20000	.4	H=1
1733	-55	-58	-3	1732.1	9000	.5	H=1 or 3
1735	-51	-16	35	1734.4	10000	4	H=1
1736	-53	-50	3	1735.5	11000	4	H=1
1738	-52	-52	0	1737.8	3000	1.4	H=0
1778	-60	-61	-1	1777.0	8000	<.1	H=3
1798	-63	-63	0	1802.1	7000	<.1	TM2xx
1822	-59	-59	0	1823.2	30000	<.1	H>0
1841	-45	-45	0	1840.3	11000	14	H=0
1840	-82	-33	49	1840.3	18000	14	*TM12 2P1/3
1887	-82	-47	35	1885.9	11000	.5	*H odd
1905	-26	-26	0	1905.2	12000	300	H=0
1933	-37	-37	0	1932.9	12000	200	H=0
1963	-55	-55	0	1962.1	30000	4	H=1
1968	-54	-42	12	1967.9	18000	4	H=1
1972	-61	-61	0	1971.4	13000	.6	H=1
2000	-47	-33	14	2000.6	12000	500	*TM12 ZERO
2010	-17	-17	0	2011.9	20000	900	H=0
2109	-66	-60	6	2113.2	18000	.9	H=1
2111	-59	-53	6	2115.1	20000	<.1	H=1
2136	-17	-17	0	2139.7	20000	400	H=0
2203	-29	-29	0	2207.8	20000	60	H=1
2281	-47	-38	9	2286.4	20000	9	H=1
2284	-52	-61	-9	2289.9	20000	<.1	H=1
2331	-58	-49	9	2335.1	17000	<.1	H=1
2392	-63	-51	12	2395.5	20000	5	H=1
2400	-64	-57	7	2403.6	20000	5	H=1
2408	-67	-54	13	2412.6	30000	7	H=1
2412	-60	-53	7	2416.4	17000	7	H=1
2455	-58	-37	21	2459.4	30000	11	H=1
2461	-63	-55	8	2465.5	30000	<.1	H=1
2469	-66	-58	8	2474.3	20000	.5	H=1
2480	-60	-52	8	2485.1	19000	1.4	H=1
2492	-29	-28	1	2494.9	30000	140	TM0
2511	-58	-44	14	2515.4	20000	6	H=1
2523	-49	-55	-6	2529.0	20000	.9	H=1
2545	-47	-42	5	2550.4	20000	20	H=0
2564	-58	-46	12	2567.2	30000	1.4	H=1
2567	-56	-51	5	2572.0	30000	<.1	H=1
2578	-64	-62	2	2582.2	18000	<.1	H=1
2583	-55	-41	14	2587.2	30000	9	H=1
2587	-67	-42	25	2591.2	80000	9	H=1
2590	-27	-26	1	2594.6	20000	14	H=1

* Off-axis shunt impedance in Kohm/cm²

¹ Probe power for beam on-axis
² Probe power for beam 1 cm off-axis

Data Analysis

Data were analyzed by using the measured cavity power to determine the effective shunt impedance ZT^2 . For short enough beam pulses, it was adequate to consider the beam as a delta-function impulse of current with net charge q . The correction for pulse width was less than 15% at the highest frequency of interest (2600 MHz) and was ignored. The effective shunt impedance was calculated from the expression for the

energy delivered to a cavity by a single pulse

$$E = \frac{\omega}{2} \frac{ZT^2}{Q} q^2, \text{ where } \omega \text{ is the angular frequency of the}$$

mode, Z is the shunt impedance, T is the transit-time factor, and Q is the mode quality factor of the structure. The energy was determined from the measured

power at the pickup probe by $E = \frac{P_0 \cdot Q}{\alpha \cdot \omega}$, where P_0 is the maximum power measured at the pickup probe after the beam pulse passes through the cavity. These two equations can be solved for the effective shunt impedance

$$ZT^2 = 2 \frac{P_0 Q^2}{\alpha \omega^2 q}$$

For normal beam-deflecting modes, the shunt impedance as measured on-axis should be zero. Because of the finite diameter of the beam, there is some on-axis signal for all modes observed. A more useful measure of the coupling of the beam to deflecting modes is the shunt impedance at some distance off-axis. The off-axis shunt impedance was determined by subtracting the power measured with the beam on-axis from the power measured with the beam displaced 1 cm in the direction of maximum excitation. Table I lists the data and the calculated effective shunt impedances for all modes observed below 2600 MHz. Modes that showed an increase in excitation of 3 dB or more when the beam was moved off-axis were considered deflecting modes, and the effective shunt impedance at 1 cm off-axis was calculated. These modes are marked with an asterisk in Table I.

The data actually yielded a value that was 25% of the calculated shunt impedance for the accelerating mode, taking into account the measured Q . This low value could be explained by an unaccounted 6 dB of attenuation in the measurement cable plus padding. Assuming that this was the case, Table I data were corrected accordingly, which is equivalent to scaling the data to the known shunt impedance for the accelerating mode.

The effective shunt impedance is a measure of the combined effects of several of the cavity properties. For a perfect TE mode, there should be no net interaction with the beam. Presumably, the observed coupling is due to the presence of TM components arising from distortion of the fields by the disk, washer, and washer supports. The results also depend on the phase velocity of the wave in the cavity system and on the finite length of the structure. Therefore, the results presented here are useful for understanding the interaction of a beam with a DAW accelerator, however, some care must be exercised in extrapolating the data to other structure configurations or lengths.

Although the shunt impedance of the lowest order TM₁₁-type modes is relatively low, there is a TM₁₂ deflecting mode at 2000 MHz with a surprisingly large shunt impedance (40 times lower than the operating mode for an off-axis beam).

Mode Measurement

Cold-cavity measurements were performed with the structure after the high-current, beam-cavity-interaction measurements. Because of stem perturbations, higher order modes above 1.6 GHz were difficult to assign (for example, a TE₃₁ mode can be mixed with the TM₁₁ modes). Bead-pull measurements on-axis and off-axis were completed with metallic and dielectric beads for mode identification. Space restrictions do not permit a presentation of this data here. Figure 1 shows the measured spectra that were identified to azimuthal mode number $m = 4$.

Mode Frequency Calculation

Mode frequency calculations for the complete three-washer geometry were performed using URMEL⁴ and PISCES⁵ for up to azimuthal mode number $m = 7$. The calculated mode spectra up to about twice the operating frequency for $m = 0$ to 7 are shown in Figure 2. The version of URMEL available could not be used to calculate the TE0 modes as can be done with SUPERFISH if the boundary condition is properly modified. SUPERFISH is not suitable for this application because it calculates only one mode at a time and could miss some modes.

A generalized version ($m \geq 0$) of PISCES is still under development by one of the authors (Y.I.); the axisymmetric version was used to calculate TE0 modes.

Fig. 1. Measured mode spectra for the DAW structure consisting of three washers and terminated in half-cavities.

Conclusions

The results show that the impulse excitation of an accelerator structure by a movable beam is an effective way to identify deflecting modes that may be involved in beam blow-up at high currents. The shunt impedances can be determined by careful correlation with cold measurements on the structure and pickup probes. These shunt impedances can be a useful guide to the significance of modes in beam blow-up processes. This method measures the steady-state properties of the modes, hence, one must be careful in interpreting the data because the signals are not seen until after the energy from each cavity has combined and spread throughout the structure.

References

1. G. Mavrogenes, W. Rambler, W. Wesolowski, K. Johnson, and G. Clifft, "Subnanosecond High-Intensity Beam Pulse," *IEEE Trans. Nucl. Sci.* **20** (3) (1973), 919.
2. W. Gallagher, K. Johnson, G. Mavrogenes, W. Rambler, "A High Current Electron Linac," *IEEE Trans. Nucl. Sci.*, **18** (3) (1971), 584.
3. G. Mavrogenes, "Investigation of the Disc-and-Washer Structure," *IEEE Trans. Nucl. Sci.* **28** (3) (1981), 2853.
4. T. Weiland, "TBC1 and URMEL - New Computer Codes for Wakefield and Cavity Mode Calculations," *IEEE Trans. Nucl. Sci.* **30** (4) (1983), 2489.
5. Y. Iwashita, "Calculation of rf Fields in Axisymmetric Cavities," submitted to the 5th COMPUMAG Conference on the Computation of Electrical and Magnetic Fields, June 3, 1985, Colorado State University, Fort Collins, Colorado.

Fig. 2. Calculated mode spectra for the DAW structure consisting of three washers and terminated in half-cavities.