EXPERIMENTAL STUDY OF APLE TM_{110}-LIKE HIGHER ORDER MODES AND DAMPING TECHNIQUE*

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Abstract

The APLE accelerator structure is a CW, RF-driven standing wave electron accelerator structure which will be moderately beam-loaded ($\geq$ 250 mA). The following work details the design of the damping scheme for the TM_{110}-like band of modes to prevent the onset of the beam break-up instability due to this band.

Introduction

The APLE accelerator is a 5-cell magnetically coupled standing wave structure, which is detailed elsewhere in these proceedings[1]. It operates in the pi-mode at 433.333 MHz. The RF power is magnetically coupled to the structure through WR-1800 waveguide. Just as the accelerator mode is one of a band (TM_{01}) of five modes, the TM_{110}-like band has five modes. Elsewhere in these proceedings[2] are established requirements for the quality factor for each of the five modes in the band as a function of average beam current, in order to insure we do not start oscillation of these modes. This gave us a requirement that the loaded Q of these modes must all be less than 10^4. We set about to damp this classical beam break-up mode, while minimally damping the accelerator mode. This was critical since APLE is a CW accelerator and we did not want to have to cool the damping probe, due to joulean heating from currents driven in the probe from the accelerator mode. Furthermore, the elaborate cooling system design virtually determined that any damping probes would need to be put in the end walls of the end cells. We chose a 4 slot per web configuration to allow a dipole mode of arbitrary orientation to propagate throughout the structure, so that damping in the end cells can be performed.

Experimental Apparatus

The following studies were performed at 13/24 scale (accelerator mode at 800 MHz) with RF fed into the structure through WR-975 waveguide. The structure is a clamped aluminum (6061-T6) mock-up. A computerized bead-pull apparatus is used to map field strengths for both the accelerator and dipole modes. A matched set of five weakly magnetically coupled sample probes in each cell was used for relative phase measurements between cells. Each of the five cells is equipped with a slug tuner for frequency adjustment. With the structure in an operational state (flat accelerator mode) the dipole band is first characterized and a damping scheme developed. Below in figure 1 is shown a longitudinal view of the cells looking down the beamline.

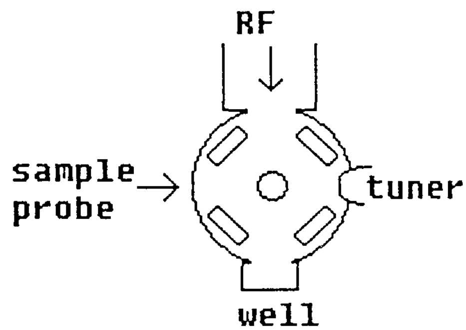

Figure 1
Longitudinal View of Accelerator Structure

Some of the more relevant details of the structure[1] are listed below:

1) the 4 slots in the web are 30 degrees long, resulting in a 1.9 % and 2.9% relative bandwidth in the accelerator and dipole modes, respectively.

2) the input coupler, symmetrization well, tuners and sample probes are positioned between slots.

3) 1.280" diameter holes for the damping probe are in both of the end walls of the end cells. Their centers are at the same distance from the beam as the center of the slots.

The damping probe is a magnetically coupled loop which is made of wire 1/16th inch in diameter. The end of the loop is a 1/2 inch full radius. The loop is oriented to couple to radial magnetic field. In this way excellent rejection of the accelerator mode is inherent in the design, easing the requirements on the external filter network. Damping measurements are made as a function of this insertion length into the cavity. Integral to this probe, a filter network of some sort will be necessary to stop some of the

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accelerator mode that may still be present.

Procedure

Since the accelerator mode will see a very large impedance presented to the HOM damping probes (due to the aforementioned filter network) the pi-mode accelerating field is flattened by bead pull techniques with the type-N coaxial connectors on the HOM probe open. This means the accelerator is tuned as in operation. We then examine the 5 normal modes of the TM_{110}-like band and compare their structure with what one would find in a structure tuned for a flat pi-mode in the dipole band. The scheme for spoiling the Q's of these modes is developed as we make de-Qing measurements.

Results

Survey

It is found that for the dipole band that there are two distinct polarizations for each of the five modes. They are arbitrarily named 1 and 2 as defined below in conjunction with Figure 1:

polarization #1: Transverse B field across beam pipe is horizontal.
polarization #2: Transverse B field across beam pipe is vertical.

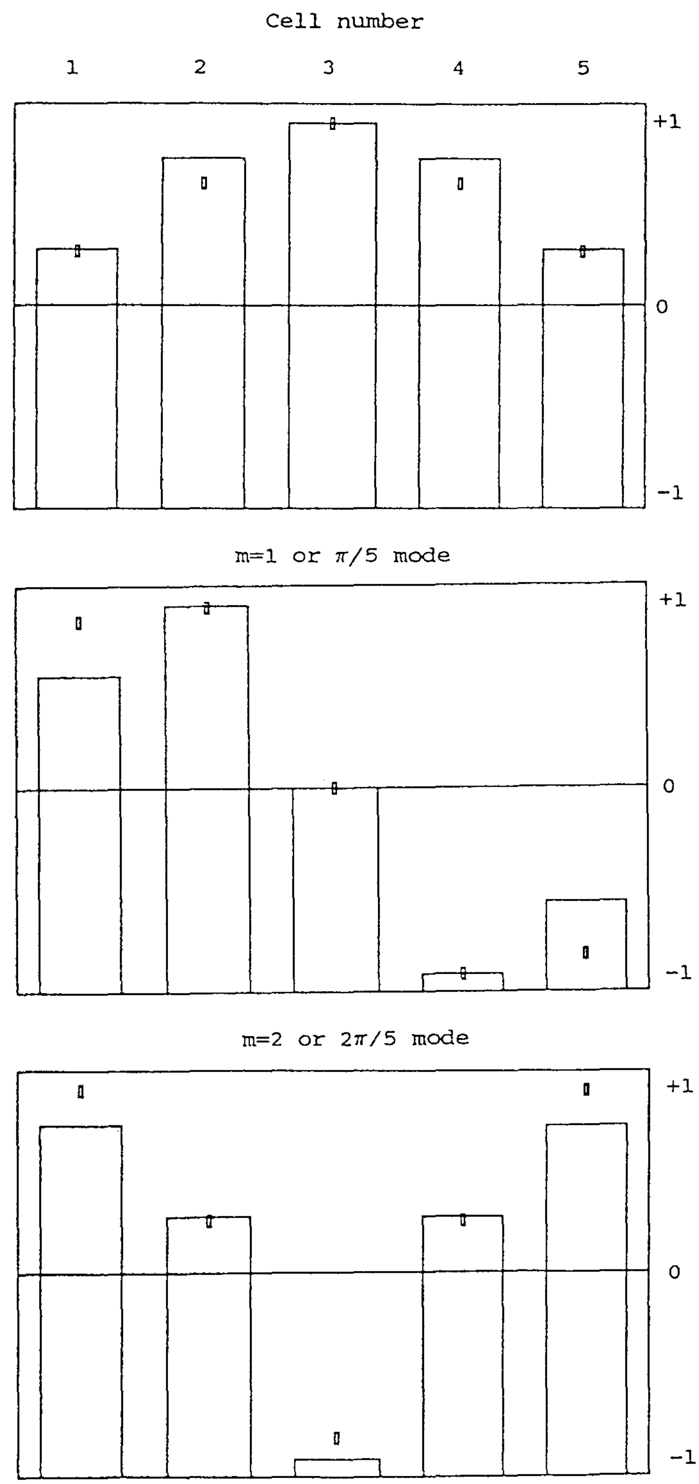
The orientation of these basis modes is determined by the symmetry reducing items such as the coupling slot, tuners, well, etc. Rotating the slots 45 degrees does not change the orientation of the two polarizations. In fact, the relative bandwidth remains about the same. We chose to have the four slots where they are, because rotating them 45 degrees had some undesirable effects on the operation of the accelerator mode.

The de-Qing requirements for the 5 modes in the band assumed the modes had amplitudes in the various cells based on the ideal model, where the HOM pi-mode is flat. We proceeded to measure the real modes in order to assess the impact of these corrections to the starting currents required for oscillation. These 5 modes, m=1, 2, 3, 4, 5 correspond to (m/5) x 180^0 phase shift per cell on the Brillioun diagram. For example, for polarization 2, in figures 2a through 2e we show the comparison between this idealized case and the actual mode structure. The idealized amplitudes are shown as histograms, the actual values as rectangles.

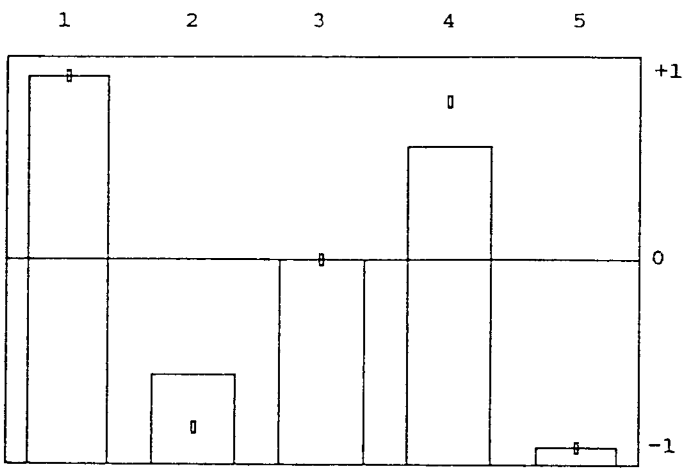
The values of the eigenvectors are normalized arbitrarily to the largest amplitude of the bunch. The +/- signs show a 180^0 phase shift between cells. Expressing these APLE modes in terms of a linear combination of the ideal modes, we find the APLE modes contain at least 96 % of their stored energy in the ideal mode. These differences were found to insignificantly affect the damping requirements.

Figure 2

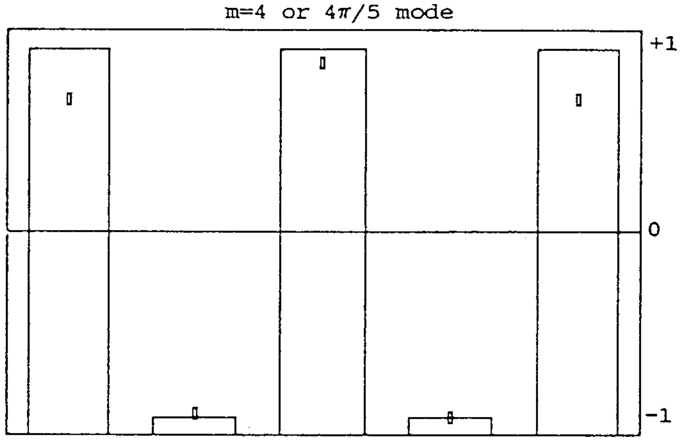
Comparison of Idealized Dipole Mode Field Distribution to Actual Values in the APLE Structure



m=3 or 3π/5 mode



m=4 or 4π/5 mode



m=5 or π mode

damping results

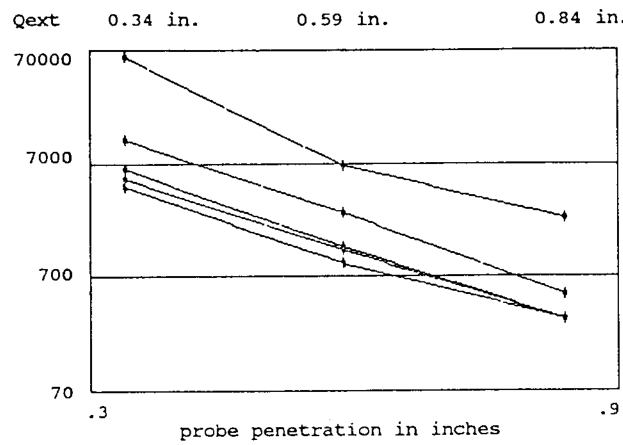
The damping probe locations in the end plates are each 45 degrees from the input coupler, but 90 degrees from each other. The requirement we have is that the Q's for all 5 modes (both polarizations) must be below 10^4. This turned out to be most difficult for the m=1 mode, polarization #2. Three of the 5 modes (m=odd) have substantial amounts of stored energy in the coupler cell. For polarization #1 these three modes are additionally damped by the input coupler. The external Q provided by the input coupler for these are as follows (assuming a perfect load, looking back toward the klystron):

Table 2
Damping of Polarization #1 Due to Coupler

mode	Q_E (total)
m=1	3,250
m=3	3,130
m=5	850

We took data for B_r coupling orientation with the following probe penetrations; 0.343, 0.593, and 0.843 inch. We oriented the two HOM damping probes 90 degrees from each other, on opposite ends of the accelerator structure. We measured the following outcoupled power for the indicated modes. We first flattened the accelerator fields with infinite impedance on the HOM probes. Then we made our measurements for the HOM modes.

Figure 3
Total Damping of Both Polarizations Due to Both of the Higher Order Mode Damping Probes



It should be noted that the coupling to the accelerator mode is most likely due to probe imperfections and can perhaps be minimized in production by rotation. Also, the rotation of the probes 45 degrees to couple only one polarization per end of the structure, achieves nothing different. The total loading on the modes is the same. Both polarizations are equally loaded by each of these probes.

Conclusions

The 0.59" penetration satisfies our requirements for the damping of these modes (For a Q_e= 6800 and a Q_0 = 40,000, Q_L = 5800). Greater damping would increase the risk of heating the probe with the accelerator mode, as well as broadening the modes to the point were although the Q's are very low they would interact with harmonics of the electron pulse train, making far more current available to begin oscillation.

References

[1] T.L. Buller, T.D. Hayward, D.R. Smith, V.S. Starkovich, A.M. Vetter "Design of the APLE Accelerator Cavity" Proceedings of this conference

[2] A. Vetter and T. Buller "Regenerative BBU Starting Currents in Standing Wave Cavities" Proceedings of this conference