AN 805 MHZ DISK AND WASHER STRUCTURE FOR THE FERMILAB LINAC UPGRADE

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Abstract

The Linac Upgrade program, a portion of the Tevatron Upgrade, calls for increasing the energy of the existing 200 MeV, 201.25 MHz linac to 400 MeV in order to reduce beam emittance degradation in the Booster. This is to be accomplished by replacing the last four Alvarez linac tanks with more efficient, higher gradient 805 MHz linac structure. One of the linac structures currently under study in a collaboration between Fermilab and SAIC is the Disk-and-Washer accelerating structure with bi-periodic tee supports, four per washer pair. This structure has a stop-band for the TM_{11} mode (a problem in other designs) centered near the π TM_{02} accelerating mode frequency. A novel heat shrinking technique is used in the construction of a ten-cell one-meter long vacuum prototype structure. Description of the structure, testing techniques and test results are presented.

Introduction

The Disk-and-Washer (DAW) rf accelerating structure is a viable candidate for consideration in the acceleration of ions to higher energies where the efficiency of the Alvarez drift-tube structure falls due to the increasing power losses on the drift tubes. The DAW structure has the advantage of high efficiency (effective shunt impedance), large coupling between cells, and good vacuum conductance. It suffers from the problem of a multiplicity of other modes in the vicinity of the accelerating mode and the mechanical problem of supporting and cooling the central washer in a way which does not degrade the rf properties of the structure. The DAW structure has been extensively studied in the USSR[1] and has been used in the accelerator at the Institute of Nuclear Research, USSR Academy of Sciences, Moscow.[2] This structure was proposed for the PIGMI Project at LANL, and was evaluated for use on the NBS Racetrack Microtron.[3] An acceleration cavity for TRISTAN has been constructed at KEK, Japan.[4]

The DAW structure has been studied at Fermilab as a possible structure to extend the energy of the 200-MeV proton linac to 400 MeV. The Linac Upgrade project consists of replacing the last four drift-tube accelerating tanks, from 116 to 200 MeV, by new accelerating structure operating at a higher frequency and higher gradient to extend the energy to 400 MeV. A duty factor of 0.2% is required. In the DAW structure, this low duty factor simplifies the cooling of the central washers. This allows the use of smaller, biperiodic, tee supports for the washer supports. The four-tee configuration can introduce a stopband in TM_{11}-like modes which overlap the region of the operating mode frequency. The tees can be designed to present a small perturbation to the accelerating mode by placing and shaping them so as to closely match the null in the accelerating mode field configuration, though necessarily presenting a much greater perturbation to the structure coupling mode. Thus, it appears that some of the disadvantages of the DAW structure can be overcome in the Fermilab application by developing a design based on washer tee supports following the ideas of Swenson and Iwashita.[5,6]

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Description of Models

The programs SUPERFISH and MAFIA[7] have been used to design a 200-MeV prototype DAW. The parameters for the design are shown in Table I. MAFIA was used to calculate the added losses due to the tees, about 5%. This power loss on the tees reduces the shunt impedance (ZTT) by 5% from the ideal value calculated from SUPERFISH. MAFIA was also used to calculate the full dispersion curve for the structure up to 1.4 GHz, Fig. 1. The biperiodic tee supports produces a stopband in the TM_{11} mode centered near the operating frequency of the accelerating TM_{02} π mode. The biperiodic tees have produced stopbands in most of the modes with the one exception being the TM_{02} mode because of the placement of the tee supports in the null of this mode.

Table I - Nominal DAW Cavity Parameters

Frequency (MHz)	805
Cell length (β = 0.5662) cm	10.544
Cavity radius (cm)	27.220
Disk radius (cm)	20.119
Half disk thickness (cm)	2.672
Tee-support tubing O.D. (cm)	0.5
Washer radius (cm)	17.604
Half washer thickness (cm)	0.63
Nose angle	30°
Nose radius (cm)	0.5
Bore radius (cm)	1.5
Gap length (cm)	4.23
ZTT (single cell) MΩ/m	45.9

To study the DAW structure we have built a number of assemblies which can be configured in different ways, as shown in Fig. 2. The parts consist of two one-meter, ten-cell cavities, one with power capability and one demountable, a coaxial bridge coupler with a tuner and wave guide rf port,[8,9] a set of end plates for terminating either the coupling or the accelerating modes, and demountable disks for extra tuning capability. For example, the use of a pair of removable disks and a pair of coupling mode terminators on the one meter DAW sections allows an investigation of the coupling mode. The use of the pair of accelerating mode terminations allows study of the accelerating mode and all other modes which may be present. In a similar manner the bridge coupler can be studied by itself or configured with the other structures.

The one-meter section and coaxial bridge coupler were constructed so that power tests, under vacuum, could be performed with water cooling adequate for a 0.2% duty factor and a maximum surface field up to 35 MV/m. The washers were machined from OFE class II copper plate. A cooling channel was machined in the plate and covered with a copper ring with flared stainless-steel adapters for connecting the tee supports. The nose cone was machined out of OFE copper cylinders. These parts constituting the washer assembly were then brazed together. The disks were made of aluminum and plated with 0.005 cm of copper. The tees are copper plated stainless steel tubing. Bimetallic aluminum-stainless steel struts are press-fitted into the disks and used to connect the tee supports for the washers. The disk-and-washer assembly is shrunk fit into the copper-plated aluminum tanks. An aluminum weld from the tank outside makes a water tight, vacuum tight joint between the outside cylinder and the struts. Water cooling is provided through channels on the outer tank wall to each washer with two tees carrying the water in and two tees carrying the water out. Vacuum/rf flanges are welded on the ends of the tanks to accept the end plates terminators or the bridge coupler for rf power testing. The bridge coupler contains the rf input wave guide port, rf tuner and the vacuum pumpout port.

Tuning Procedure

The structure must be tuned so that the accelerating mode and the coupling mode occur at the same frequency at the confluence of the TM_{01} and TM_{02} passbands. The construction procedure requires that the dimensions of the individual washers and disks be adjusted before assembly. It is a characteristic of the DAW structure that the frequency of the accelerating mode (TM_{02}) is most sensitive to the accelerating gap, or dimension of the washer nose-cones, which has only a small effect on the coupling mode (TM_{01}) while the radius of the disk effects the frequency of the coupling mode with only a small effect on the accelerating mode. Configurations of one, two, and three cells, Fig. 3, were setup so that the frequencies would be measured of the accelerating and coupling modes. The dimensions of the washers and disks were then determined using as a guide sensitivity coefficients determined from SUPERFISH.

The procedure for tuning was done in the following sequence.

a. In the two-cell configuration with accelerating mode terminators, the frequency of the accelerating mode was determined and adjusted by reducing the length of the nose cone.

b. In the one cell configuration with proper nose-cone dimensions, the frequency of the coupling mode was measured and adjusted by increasing the radius of the removable disk. This cell does not include the perturbation caused by the tee supports.

c. The frequency of the three-cell configuration was measured. This configuration represents one cell with the tee perturbation and two cells without tees.

d. Using a linear combination of these measured frequencies, the geometrical dimensions of the disks and washers could be determined so that the frequency of the accelerating mode and the coupling mode in the ten-cell configuration would be equal with π phase shift per accelerating cell.

This procedure was successful and resulted in a measured frequency for the ten-cell cavity when fully assembled which was about 100 kHz below the desired value. This frequency was well within the tuning range of the end-cell tuners.

Preliminary Results

The dispersion curve, Fig. 1, has been calculated using the MAFIA code. There is good agreement between the calculated dispersion curve and the measurements in the ten-cell cavity over the passband of the TM_{01} and TM_{02} modes. The largest error of about +7% occurred at the lower frequency cut-off of the TM_{01} mode. A preliminary check of the other modes also showed good agreement. However, two satellite resonances were found near the π accelerating mode frequency. These satellite resonances near the π mode had the symmetry of the TE_{31} mode; one with a field null on the vertical tees, the other on the horizontal tees. Studies are continuing with the MAFIA code with errors in the location of the tees, washers and gap spaces to understand the sensitivity of these resonances to errors.

The end cells of the 10-cell cavity can be tuned by adding a small electric field perturbation. This tuning moves the π-mode resonance away from the TE_{31} resonances where its Q can be measured without interference effects. The measured Q of the cavity after this tuning is 28,000 which is 16% below the prediction of SUPERFISH after a correction of 5% for power loss on the tee supports. This agrees with our expectation. The effective shunt impedance is 38.6 MΩ/m. The field pattern measured by pulling a metallic bead on axis at a fixed frequency and measuring the phase change is shown in Fig. 4. In this figure the ordinate is proportional to the square root of the electric field in the accelerating gap. The field is very flat. The structure was found to be extremely stable with a coupling constant of about 30% showing very little tilt. The cell-to-cell field variations are less than 1.5% and due mainly to cell-to-cell geometry changes of ±0.050 cms.

Further Measurements

After the measurements on the ten-cell cavity have been completed, the coaxial bridge coupler will be added to the assembly and fine tuned. When the low power tests have been completed, water and vacuum will be connected and high power measurements will start. A 1.2 MW, 805 MHz test stand will be used to test the structure at full power. These tests will enable a definitive comparison to be made between the DAW structure and the more conventional side coupled structure for the Fermilab Linac Upgrade.

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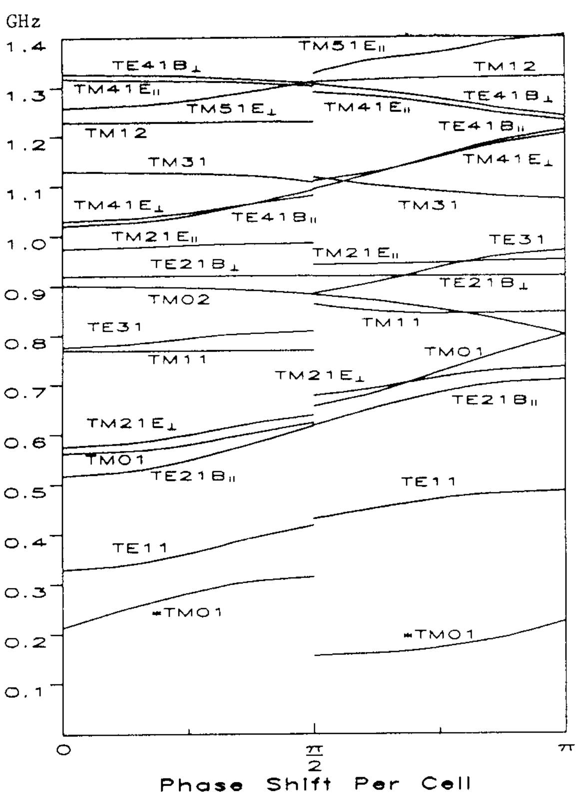

Fig. 1 Dispersion curve calculated with the MAFIA code

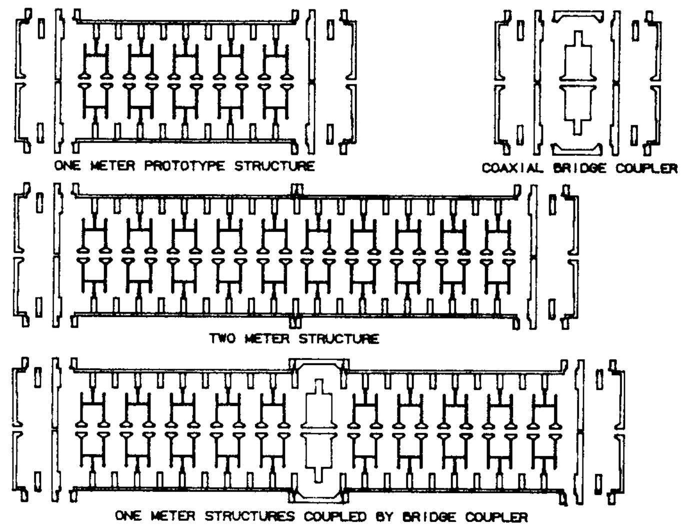

Fig. 2 Disk and Washer Linac configurations

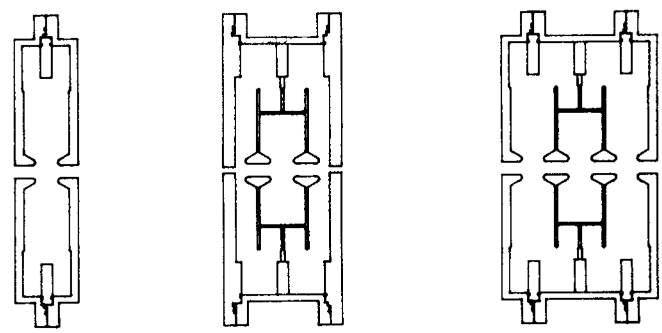

Fig. 3 One, two and three cell frequency test configurations

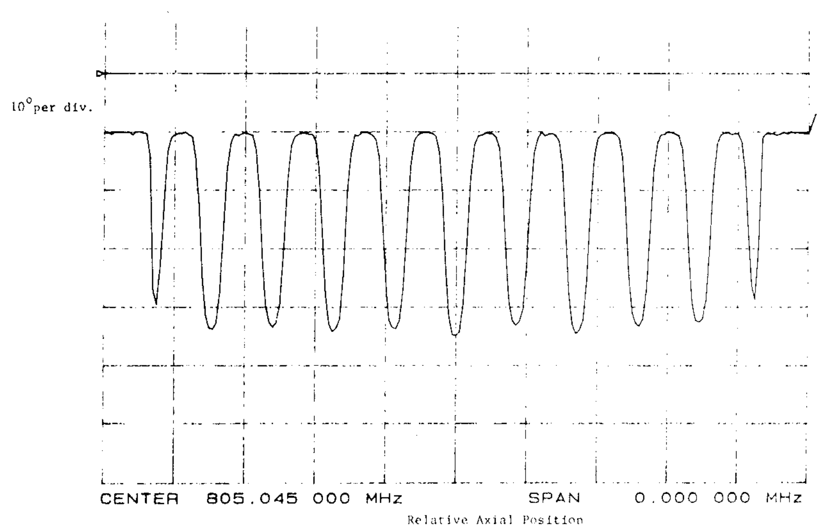

Fig. 4 Ten-cell DAW field distribution