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TEST OF A 1 m LONG DISK-AND-WASHER ACCELERATING TUBE

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Summary

A 1 m long accelerating tube of $\beta = 1$ and 2856 MHz disk-and-washer (DAW) structure[1] has been fabricated[2]. The washer is supported by two radial stems at 90° each other. Beam accelerating experiments have been performed. The overlapping of an accelerating mode frequency with the TM_{11}-like mode passband is avoided. Both unloaded quality factor, Q_0, of the accelerating mode and the effective shunt impedance, ZT^2, deduced from beam accelerating experiments are found to be about 3/4 of the calculated values of the infinite periodic structure.

Introduction

The DAW accelerating structure is expected to have many advantages[3] as compared with the other structures. Two of it's most attractive properties are the high degree of coupling between adjacent rf cavities and the high effective shunt impedance. The high degree of coupling is important for reducing structure sensitivity to tuning and assembling errors, beam loading and transient effects. The high effective shunt impedance is important for reducing rf power or achieving higher accelerating gradient for the same rf power.

In spite of these attractive advantages the DAW accelerating structure has not been used in actual accelerators as far as published. The following difficulties have been made clear.

1) Since the accelerating mode is not in the lowest order passband, possibility for mode overlap problems occurs[4,5,6,7]. Then, in the worst case, the driving rf power itself excites the TM_{11}-like deflecting mode.
2) Since the support stems introduce a strong rotational asymmetry[4,8,9], dipole and/or quadrupole modes should be mixed in the accelerating mode.

The former problems can be eliminated by separating the TM_{11}-like mode passband from the accelerating mode. The difficulty of the mode mixing problem is reduced at the same time.

In order to realize the attractive features mentioned in the beginning, we have been studying the DAW cavities. Though more promissible support is considered we adopted radial stems because of it's simplicity[9,11]. As the results of a systematic study[8], two radial stems per washer were mounted at 90° to each other and their orientation were changed by 180° between adjacent washers. Measured rf characteristics and the results of beam accelerating experiments are presented below.

Beam deflecting mode

A short accelerating tube as a prototype of the 1 m long accelerating tube for the rf power test was constructed. It consisted of five cavities, full cavity terminators and a coaxial coupler which was seated in the end of the tube. We observed in the short accelerating tube that the frequency of the accelerating mode overlapped with the passband of the TM_{11}-like deflecting mode which is shown in fig. 1. Mixing of the accelerating mode and TM_{11}-like deflecting mode was observed at the time when the accelerating frequency was changed by tuners. In general, the closer in frequency two mode are the stronger they are mixed by perturbation. Then the deflecting mode should be separated from the accelerating mode as far as possible. In the prototype tube, radius of the cylinder was optimized to be 68.5 mm by using the computer code[10] SUPERFISH. In order to separate these modes from each other, we have decided to reduce the radius of the cylinder. Test cavities were made to confirm that the two modes were separated enough. Dispersion curves measured in test cavities are also shown in fig. 1. In this figure, it is shown that the frequency of the TM_{11}-like mode passband ranges in higher than 2900 MHz. However, the calculated values of ZT^2 and Q_0 decrease from 95 MΩ/m and 31200 to 87 MΩ/m and 27300, respectively. The values of ZT^2 of the prototype tube was measured to be about 43 MΩ/m by using the bead-pull method. On the other hand, ZT^2 of the 1 m long tube is about 65 MΩ/m as mentioned later. It is considered that the improvement of the ZT^2 in the 1 m tube is due to solving the mode overlapping problem and decrease of the end effect.

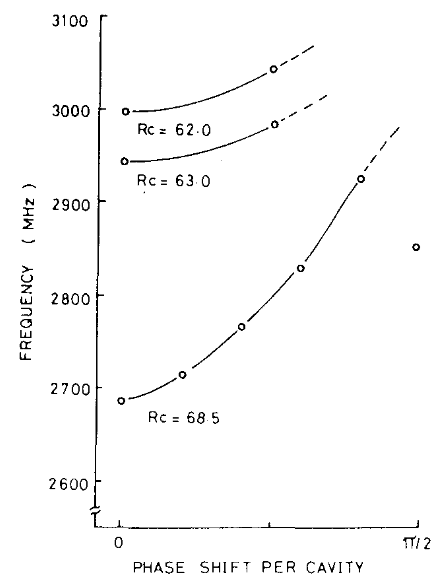

Fig. 1. Dispersion curves of the TM_{11}-like mode. R_c : Radius of the cylinder.

Description of the accelerating structure

The 1 m long DAW accelerating tube of   = 1 and 2856 MHz is assembled from reguler sections, full cavity terminators and a coaxial coupler. The reguler segment consists of a disk and cylinder machined from a single piece of copper and a washer supported by two radial stems. The coupler is placed at the center of the tube as shown in fig. 2, in which a central electrode is supported by two pairs of radial stems. These are made by bright copper except stems made of copper-plated stainless steel. Washers and a central electrode in the coupler are cooled by water which flow through the stems. The dimensions of the cavity are shown in fig. 3. An outer diameter of the stem is 9.5 mm. Two frequency tuners which can be manipulated from outside of the cavity are installed on the cylinder wall at the opposite position to the stems in every reguler segment and at the center in the coupler. The tuner in the reguler segment shifts the accelerating mode frequency downward and the coupling mode frequency upward. The tuner in the coupler dose not change the accelerating mode frequency and shifts the coupling mode frequency downward. The accelerating and the coupling mode frequencies have been tuned to 2856 MHz and 2870 MHz, respectively. The latter frequency is a lower tuning limit on this accelerating tube. The rf coupling constant between the wave guide and the accelerating tube made through an iris is adjusted to 1.33 of over-coupling.

By measuring admittance, the Q_0 is deduced to be about 20000. The ZT^2 deduced from the bead-pull method is about 60 MΩ/m.

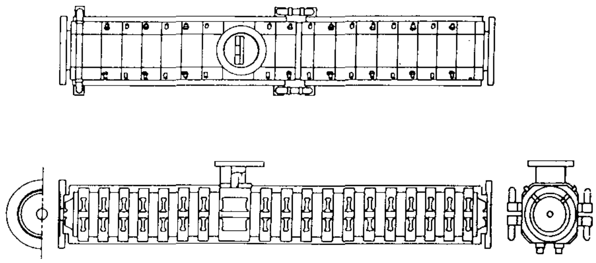

Fig. 2. The DAW accelerating tube of 1 m long.

	(mm)
t_D	12.52
t_W	4
t_R	7.22
R_H	7.5
R_N	1.2
R_R	2.2
R_C	63
R_D	52.19
R_W	42.62
θ	30°
g	15.04
L	26.24

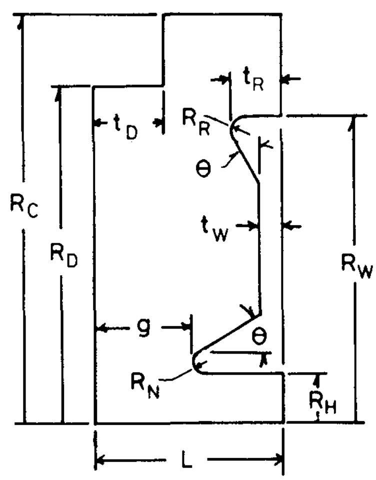

Fig. 3. Parameters of the DAW accelerating structure.

Beam accelerating experiment

The experimental setup for the DAW accelerating tube is illustrated schematically in fig. 4.

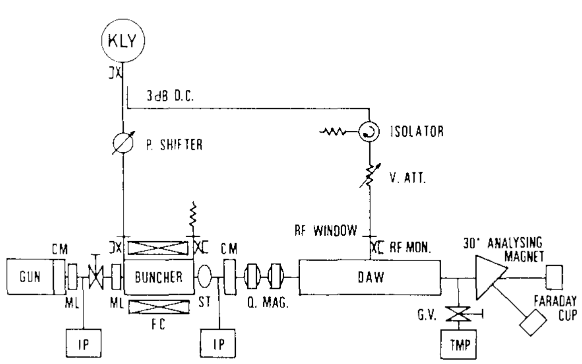

Fig. 4. Experimental setup for the beam test of the accelerating tube.

A klystron is used to generate a rf pulse of 8 μsec width and 6 MW of the maximum peak power. The power from the klystron is devided between a traveling wave type buncher and the DAW accelerating tube by using a high power 3 dB coupler. One is fed to the buncher through a phase shifter. The other is fed to the DAW tube through an isolator and a variable attenuator. The 100 keV electron beam from an electron gun is bunched and accelerated to 1 to 2 MeV by buncher.

The electron beam energy is analyzed by means of a 30°bending magnet followed by a slit of 2 % momentum width and a ferrite core monitor.

Energy spectra of an accelerated electron beam of pulse width of 1 μsec are shown in fig. 5. They are observed every 100 nsec by measuring the current which pass through the magnet and the slit. Accelerating current in this case is about 80 mA.

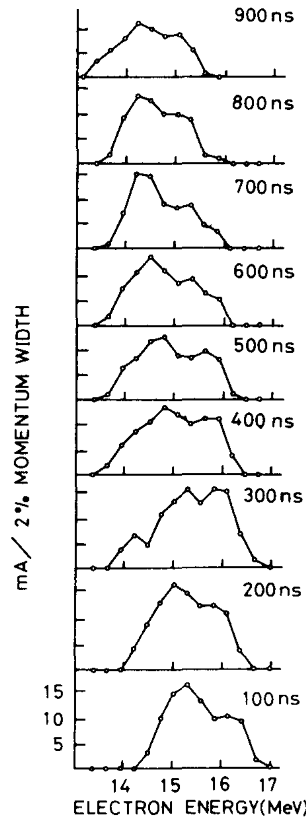

Fig. 5 Energy spectra of an accelerated beam observed every 100 nsec.

A transient energy gain, V(t), is expressed as follows.

$$V(t) = \frac{2\sqrt{\beta ZT^2 L P_0}}{1+\beta}\,\xi(t) - \frac{iZT^2 L}{1+\beta}\,\eta(t),$$

$$\xi(t) = 1 - e^{-\omega(1+\beta)(t_0+t)/2Q_0},$$

$$\eta(t) = 1 - e^{-\omega(1+\beta)t/2Q_0},$$

where L is the structure length, ω is the operating angular frequency, t_0 is the delay time of beam pulse relative to rf pulse, t is the elapsed time after the injection of the beam is started, P_0 is the driving power and i is the beam current. If t_0 is long enough compared with the build up time, the first term of the right hand side of the equation is regarded as constant. Then the ZT^2 is obtained from the slope of the V as the function of η.

From fig. 5, it is clear that the peaks of the spectrum shift to lower energy direction as the passage of time. Because of debunching in drift space after the buncher and phase slip during acceleration, each spectrum has two peaks.

Peak energy versus η is plotted in fig. 6. Measured points (open circles) are roughly on a straight line (solid line). The ZT^2 deduced from the slope of this line using the relation mentioned above is about 65 MΩ/m. This value is about 75 % of the calculated one of infinite periodic structure without any stem.

Any evidence of beam breakup (BBU) phenomena is not experienced up to 2 A of accelerated beam current.

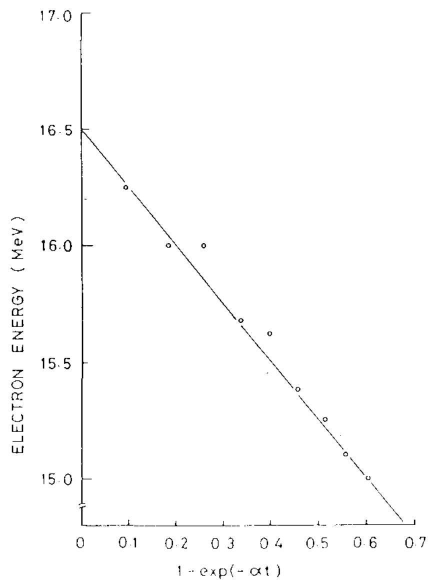

Fig. 6 Time to electron energy relation.
α: $\omega(1+\beta)/2Q_0$.

Discussion

In table I, results of the experiments are summarized together with those of other type of accelerating tube, inwhich characteristics of the side-coupled structure of LAMPF[12] and on-axis coupled structure of Univ. of Mainz[13] are scaled to 2856 MHz. The value of the DAW is lower than those of the side-coupled and the on-axis coupled structures. If the radius of beam bore hole of the DAW,which is the most sensitive parameter for ZT^2, is reduced to the same size as ones of the other coupled structures, ZT^2 valuse of these all strctures will be nearly equal. On the other hand, the coupling constant and the Q values are much larger than those of the other coupled structures. Therefore, a large beam current will possibly be accelerated by the DAW and accelerating efficiency will be increased, though a behavior of BBU in the case of a long linac system is stil unclear.

Present results show that the TM_{11}-like deflecting mode passband is removed from the accelerating frequency by reducing the cylinder radius from one optimized. The difficulty of the mode mixing is reduced by the mode separation. Furthermore excelent features of the DAW accelerating tube is realized by adopting the coufiguration of two stems at 90°.

Table I. Comparison of the characteristics of accelerating structure.

	DAW	LAMPF[12] (Scaled)	MAINZ[13] (Scaled)	SLAC[14]
Op. mode	$\pi/2$	$\pi/2$	$\pi/2$	$2\pi/3$
Q_0	20000	15300	16208	13200
ZT^2 (M /m)	65	77	79	38.4
Groupe velocity	0.5	0.05	0.026	0.0122
Cavity radius (cm)	6.3	3.94	-	4.13
Bore radius (cm)	0.75	0.54	0.6	1.13

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