BACKWARD TRAVELING WAVE ELECTRON LINAC*

Chen Huaibi, Huang Yuanzhong, Lin Yuzheng, Tong Dechun, Ding Xiaodong
Department of Engineering physics, Tsinghua University, Beijing 100084

Abstract

Future electron linacs will require high gradient acceleration. This paper studies the high shunt impedance backward traveling wave electron linac accelerating structure (BTW). Experiments were performed to prove the feasibility of the BTW structure.

INTRODUCTION

Wide use of electron linacs requires improved accelerating units. The direct approach of improving structure shunt impedance has been made these decades for SW structures. But similar progress has not occurred with the forward E-coupled TW structure. New proposals were recently made using the H-coupled backward TW geometry in the $3\pi/4$ mode and in the $7\pi/8$ mode [1]. The idea is to dissociate the RF coupling region from the beam-field interaction region as is the case in SW, to allow optimization. All modes between $2\pi/3$ and π can be chosen but a compromise must be found between high Q values and sufficient coupling for moderate slot apertures [2]. In addition, it is difficult to adjust the frequency of each cell. Therefore, the lower $3\pi/4$ mode was chosen to be.

Backward traveling wave properties

The BTW accelerator structure combines the advantages of traveling waves and standing waves. The forward TW electrically coupled on-axis structure (the classical "disk-loaded waveguide") is remarkable for its good adaptation and short filling time. The SW magnetically coupled off-axis is remarkable for its high shunt impedance. The BTW advantages are: (i) with reference to the forward TW, the presence of noses insures good shunt impedance, (ii) with reference to SW, BTW has no complicated coupling cells. However, since the RF input is near the beam exit and the buncher is near the RF exit, the field level depends on the line attenuation and for long pulses on the beam loading [3].

The Tsinghua university accelerate laboratory has developed a set of BTW accelerating tube. Initial experiments have demonstrated that the BTW accelerating structure is a promising accelerating structure.

$3\pi/4$ BACKWARD TW STRUCTURE DESIGN

General design

Figure 1 shows the structure which consists of 32 cells plus input and output couplers. These couplers are magnetically coupled to the structure and to the external RF wave guides. The working frequency is 2856 Mhz. The total length is 1.16 meter. The input coupler should be located at the beam exit for the backward TW structure.

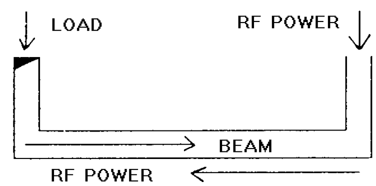

Fig.1 BTW structure

Cell design

Figure 2 shows the cell geometry with a beam aperture diameter of 7 mm and coupling slots corresponding to vg/c=1% for a bandwidth of 27 Mhz. The cells are all identical and are rotated by 90 degrees relative to each other to avoid having coupling slots face to face. The distance between noses, optimized using the SUPERFISH code for a half-cell geometry, is 21.4 mm for the optimum effective shunt impedance.

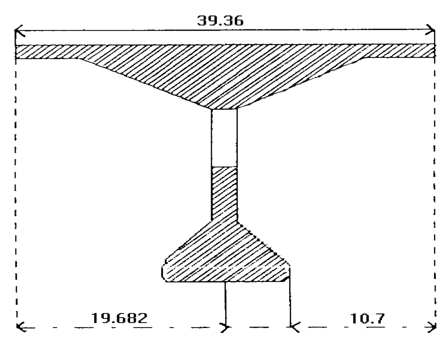

Fig.2 BTW cell geometry

Physical design

Figure 3 gives the phase oscillations curves, The radial beam envelope is shown in figure 4.

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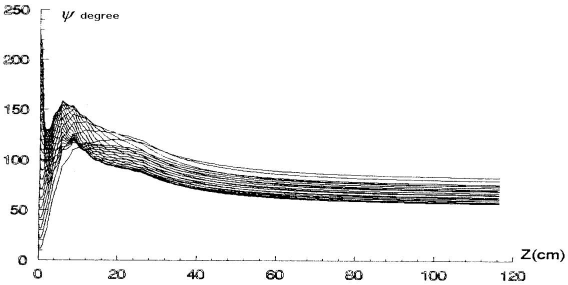

Fig.3 BTW acc. tube phase oscillation

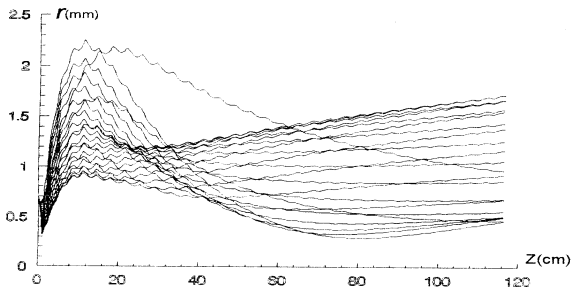

Fig.4 BTW acc. tube radial beam envelope

MATCHING AND TUNING

The tuning process is intended to adjust the phase shift in every cavity to the design value. The uniform cavity chain was tuned by tuning each cavity in the $\pi/2$ mode at a frequency of 2866 Mhz. The cavities will then operate at a frequency of 2856 Mhz in the $3\pi/4$ mode.

Matching is done by adjusting the dimensions of the coupler cavities so as to insure a low standing-wave ratio at the input and output of the structure. The accelerating traveling wave structure is obtained by adjusting the coupler so that the RF power arriving through a rectangular waveguide is coupled to the structure without reflection from the input aperture of the first cavity, the coupler cavity. The problem is how to carefully determine the dimensions of the coupling aperture. The basic ideas are based on Kyhl's method presented in a SLAC note [4], and Chanudet's method which was used at LAL [5].

COLD MEASUREMENTS OF THE STRUCTURE

ρ ~ f curve

It is well known that ρ ~ f curve in a TW accelerating tube is much flatter than that in a SW accelerating tube, especially in the near region of f_0, where ρ is nearly constant. The frequency range of VSWR below 1.2 should be 1~4 Mhz, with a minimum VSWR approximately equal to 1.0. For our BTW accelerating tube, the measured minimum VSWR is 1.02, and the frequency range of VSWR below 1.1 is 2 Mhz. (Figure 5)

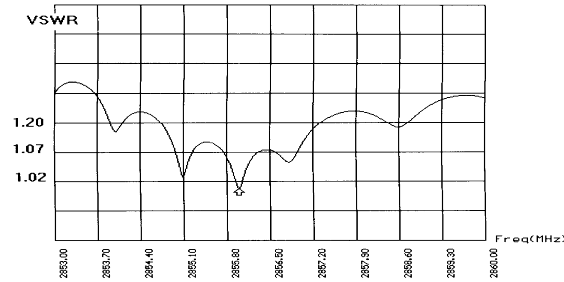

Fig.5 ρ ~ f curve of the BTW acc. tube

TW field Distribution

Figure 6 shows the measured result of the electrical field distribution on-axis. Including the input and output couplers, the measured attenuation coefficient is A=0.24 Np.

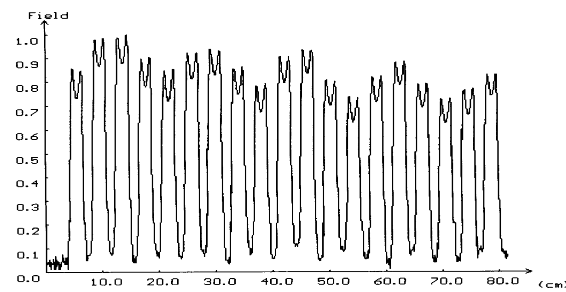

Fig.6 BTW structure electrical field distribution

Other microwave parameters

RF parameters of H-coupled cells must be measured to know their shunt impedance. The Q and R/Q factors of the cavity chain were measured with a coupling slots angle of 30 degrees in the $3\pi/4$ mode for the SW. The dispersion curve is shown in figure 7.

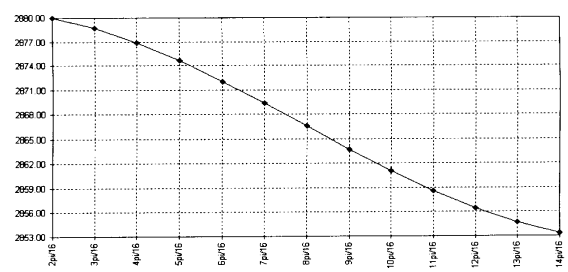

Fig.7 BTW structure dispersion curve

The effective TW shunt impedance can be obtained from these measurements using the classical relation: Zeff(TW)=2Zeff(SW). and the following cell RF parameters, Q=13000, R/Q=7056 ohm/m, and Zeff=85.7 Mohm/m. Table 1 gives a comparison of the measurement data with the design values.

Table1 Comparison of measured data with design values.

	calculated values	experimental results
shunt impedance	103.2 $M\Omega/m$	85.7 $M\Omega/m$
group velocity	0.82% C	0.81% C
Q value	13000	13000
coupling coefficient	1%	1.01%
attenuation coefficient	0.286 $/m$	0.329 $/m$

COMPARISON OF THE BTW STRUCTURE WITH THE DISK-LOADED ACCELERATING TUBE

Table 2 gives a comparison of the design parameter for a 9 MeV 3π/4 H-coupled (BTW) accelerating tube and the 2π/3 E-coupled (disk-loaded waveguide, i.e. FTW) used as a radiation source for inspecting large containers at customs.

A 40 kev electron beam with a converging will be to be injected into the BTW accelerating tube. The design values of the electron beam focal spot size are less than 3 mm diameter and a pulsed beam current of 170 mA with 3.5 MW input RF power.

CONCLUSION

The design presented in this paper adopts a backward traveling wave structure to bunch and accelerate electrons proving the feasibility of developing the BTW accelerating tube. The BTW structure has several advantages. The BTW structure shunt impedance is higher than that of a disk loaded waveguide. In addition, the BTW is a backward wave structure, which is beneficial for efficiently using the microwave power, especially in the bunching section which has varying phase velocity.

The cold measurements data are now available for the design and the RF adjusting of a 3π/4 H-coupled backward TW structure. Results of this research suggests that the backward traveling wave accelerating structure is preferable, because BTW has a higher effective shunt impedance, a shorter filling time and is more stable to operate.

Table 2 : Comparison between 2π/3 FTW and 3π/4 BTW

	BTW accelerating tube	FTW accelerating tube
coupling pattern	magnetic coupling	electric coupling
operating mode	traveling wave	traveling wave
operating frequency	2856 Mhz	2856 Mhz
operating mode	$3\pi/4$	$2\pi/3$
shunt impedance	85.7 $M\Omega/m$	62 $M\Omega/m$
coupling coefficient	1%	2%
Q factor	13000	14200
group velocity	0.82% C	1.6% C
attenuation factor	0.3 $/m$	3 db
total length	1.16 m	2.21 m
buncher length	20.8 cm	42.6 cm
buncher number	9	17
capture factor	60%	80%
peak field	15.7 MV/m	6.7 MV/m
average field	10 MV/m	5 MV/m
external focusing (coil)	without	4

A 9 MeV BTW accelerating tube operating in the 3π/4 mode has been designed with a 1.16 m single section and a buncher as radiation source for inspecting large containers at customs.

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