THE INTERDIGITAL H-TYPE STRUCTURE DEVELOPED AT INS

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Abstract

The electrical properties of a ridged IH resonator have been studied systimatically. In the constant velocity model measurements, it is shown that the ridges play very important role to improve the gap voltage distribution along a beam axis. For a model linac with increasing cell length, much better voltage distribution is obtained by introducing a pair of "Wing Tuners" into a ridged resonator. The quality factor and the shunt impedance of the linac cavity are nealy same as those without the tuner. A small proton model linac has been constructed to demonstrate the operational capabilities of the tuner. The experimental results of the prototype agree well with the design characteristics.

1. Introduction

The rf characteristics of an IH type accelerating structure have been extensively studied by Russian[1],[2] and French[3],[4] authors. According to their results, an IH linac has the substantial advantages of small transverse dimensions and high shunt impedances at a low velocity region. A simple mechanical structure of the cavity is also one of the most attractive points of the IH linac. This structure, therefore, is suitable for a heavy ion accelerator. In spite of these advantages, serious disadvantages still exist; complicated lengthy model measurements, and undesirable distribution of the acceleration voltage. In the case of a linac, where the cell length varies appreciably, gap voltage distribution has a strong peak near the entrance because the capacitive load concentrates on the low velocity side of the linac. Such a voltage distribution tends to disturb the stable beam acceleration. Other unwanted effects of the voltage concentration are concerned with the localized power losses and low value of acceleration efficiency.

The gap voltage distribution, however, can be adjusted by matching cutoff frequencies of the individual unit cells, and by adding certain impedances at the ends of the linac. The most simple way may be to tune the capacitance distribution along the beam axis by adding a capacitance plate close to the acceleration electrodes. The shunt impedance of the linac, however, is neccesarily reduced since the added capacitances cause the excess power loss. Therefore, another type of tuning method should be developed for an IH linac to maintain an important merit of high shunt impedances.

2. Cold Model Measurements

The IH structure developed at Saclay[4] has two opposite ridges in the resonator as shown in Fig.1. The drift tubes are mounted alternately on each ridge with short stems. Both of upper and lower ridges separate the IH resonator into the left and right half cavities, and the strong magnetic coupling between these cavities is achieved through the end spaces between the ridges and the tank end walls. In the proposed linac, additional capacitance plates are installed against the ridges in order to match the cutoff frequencies of the individual unit cells. The separation of these functions is very effective to shorten the time required for the model measurements, although the shunt impedance of the structure is necessarily reduced by the added capacitive elements. The Munich group[5] adopted this structure as a postaccelerator of the 14 MV MP Tandem Van de Graaf. The success at Munich has stimulated the linac people to further efforts in developement and construction work of the IH structure.[6]-[9]

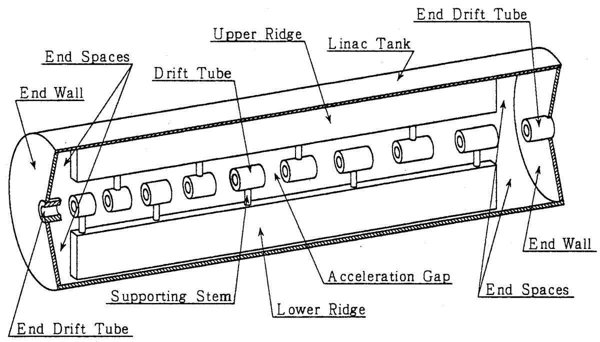

Fig. 1. A general view of a symmetrically ridged Saclay type IH structure.

Ridges and End Spaces

At INS, basic rf characteristics of the ridged IH structure have been studied with a constant velocity model.[6] The resonator is made of brass and has the inner diameter and the length of 40 cm and 96 cm, respectively. A general view of the model resonator is essentially same as Fig.1 except that the unit cell length is kept constant through the linac. As mentioned above, the open spaces at the both ridge ends are filled with inductive energy due to the magnetic flux with which the left and right half cavities are coupled to each other. With the magnetic energy, the end spaces act as the inductive termination impedances of the ridged waveguide, and the gap voltage around the ridge ends is increased very much whereas the resonant frequency is lowered appreciably. An example of such effects is shown in Fig. 2, where the gap voltage

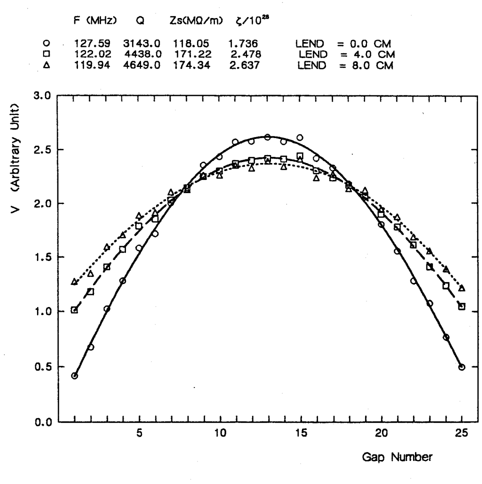

Fig. 2. An example of the gap voltage distribution of a constant velocity model for various end space volumes.

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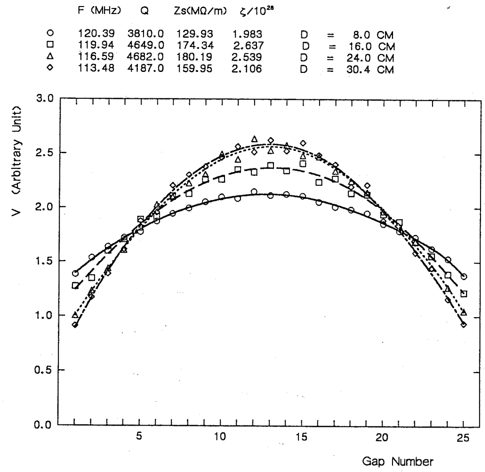

Fig. 3. An example of the gap voltage distribution of a constant velocity model for various inter-ridge distance, d.

distribution is given for various end space volumes. The measured shunt impedance is improved from 118 to 174 MΩ/m by an amount of 47 %, although the length of the resonator is 20 % increased by the end termination.

The rf properties of the resonator is also affected strongly by the ridge profile in a diametric and axial plane, especially by the inter-ridge distance, d. An example of the effects is shown in Fig.3, where the variation of the gap voltage distribution is given for different ridge geometries. As indicated in the figure, there exists an optimum value for d to obtain a high shunt impedance. Qualitative explanation may be as follows. At large d, the power loss in the supporting stems is large and reduces shunt impedance, whereas the stray capacitances between drift tubes and opposite ridges etc. cause excess power loss at small d.

Other interesting effects of the ridge profile (ERT) is discussed later.

Wing Tuners

In order to tune the lower cutoff frequencies of the individual unit cells, a pair of Wing Tuners are introduced as inductive elements. A schematic drawing of the Wing Tuner is given in Fig.4. An asymmetrically ridged resonator is adopted because of its simple structure in arranging the tuners, and because of the convenience of installing the focusing elements into "earth side" drift tubes. The Wing Tuner, the lower ridge and the tank wall form a fan-shaped single turn coil into which the magnetic flux cannot penetrate. The shielding effects effectively reduce the local cross sectional area of the resonator tank, and the peak of the voltage distribution is shifted toward the high velocity side as shown in Fig.5. In this example, the model linac is designed to have a velocity increase of factor of two, and has a drift tube structure of $\pi/3\pi$ mode. The Wing Tuners are 26.5 cm long and cover about 1/3 of the ridge length. The measured shunt impedance slightly decreases from 84.5 to 78.0 MΩ/m, depending on an angle between the ridge and the Wing Tuner. The decrease may be due to rather large increase in the resonant frequencies.

Another type of the inductive tuner, End Ridge Tuner (ERT), is also checked experimentally. The ERT is essentially same as the end cut of the long comb proposed by P. M. Zeidlits and V. A. Yamnitskii.(1) As can be seen in Fig.4, the main role of the ERT is to shorten the path of the axial magnetic flux. The effects of the tuner are strongly dependent on the magnetic flux density in the vicinity of the tuner. The ERT is, therefore, effective when it is used auxialiarily with the Wing Tuners.

3. Proton Model

Based on the successful results of cold model measurements, a prototype linac is constructed to demonstrate the operational capabilities of the tuners. The main parameters of the linac are summarized in the Table. An asymmetrically ridged resonator is adopted because of the same reasons described above.

Design and Construction

In order to determine the geometrical dimensions of the linac, a series of the low level rf measurements is performed with the model resonator described in Sec.2. At first, the optimum values are searched for the angle and the length of the Wing Tuners, and at the optimum geometry of the Wing Tuners, further improvements of the voltage distribution is tried with the End Ridge Tuner. After the geometries of these tuners are fixed, the inner diameter of the linac tank is estimated with the aid of the experimental results of these measurements.

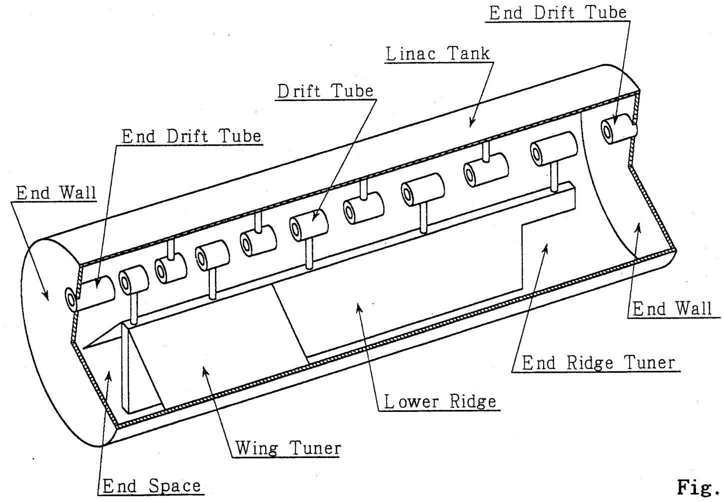

Fig. 4. A schematic drawing of the Wing Tuner and the End Ridge Tuner in an asymmetrically ridged IH resonator.

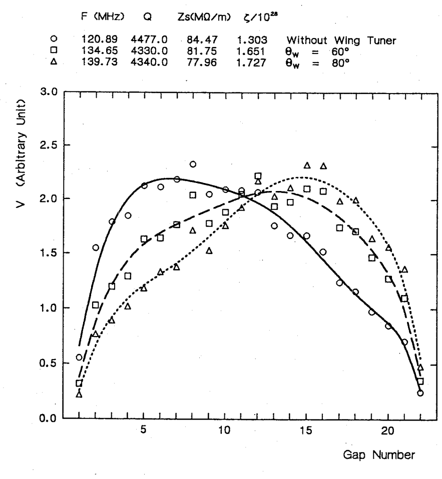

Fig. 5. An example of typical shift of the voltage peak by the Wing Tuner. In this example, unit cell length is increased from 1.5 to 3.0 cm by a factor of two. The length of the Wing Tuner is 26.5 cm and amounts to about 1/3 of the ridge lngth.

The resonator tank is made of mild steel, and copper plated with a thickness of more than 30 μm, whereas the skin depth is calculated to be 6.7 μm at 100 MHz. The surfaces of the plated copper are treated with chromic acid. The bases of the ridges and two ledges for the Wing Tuners are welded to the inside wall of the tank. The drift tubes of the linac are made of solid copper, and an ESQ lens is installed in each 3π mode drift tube. The resonator is equipped with a capacitive trimmer to adjust the resonant frequency.

Experimental Results

The resonant frequency and quality factor of the prototype linac are measured to be 101.6 MHz and 6300, respectively. These values are expected at 100.3 MHz and 5700 with the model measurements. The major reason for the difference in Q-values may be an ambiguous value of the electric conductivity of brass. The gap voltage distribution is measured with the perturbing ball method and reproduces the expected distribution very well. The shunt impedance of the linac is estimated at 123.9 MΩ/m and satisfactorily high.

A test stand including a duoplasmatron ion source and two bending magnets has been constructed for the beam acceleration tests. The rf power is fed to the linac with a loop coupler. The required rf power for the beam acceleration is as low as 300 Watts, and confirms the expected high effective shunt impedance. The momentum spectrum of the accelerated protons is analysed by a magnet. An example of the measured momentum spectra is shown in Fig.6. The measured spread in the momentum spectrum is mainly due to the definite resolution of the measuring system.

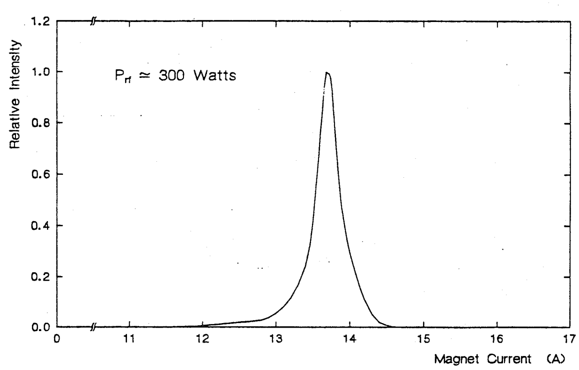

Fig. 6. An example of the momentum spectrum of the accelerated protons.

4. Conclusion

A ridged IH linac is confirmed to work excellently especially when it is equipped with the inductive tuning elements of the Wing Tuner and ERT. The gap voltage distribution of an IH linac is perfectly controlled by a pair of Wing Tuners without an appreciable decrease of a shunt impedance. The End Ridge Tuner also works very well as an auxialiary tuner. These tuners have an important advantage of the simple and firm structure.

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Table
The IH prototype linac parameters.

Frequency	100 MHz
Input energy	15 keV (β = 0.57 %)
Output energy	161 keV (β = 1.86 %)
Tank	
Inner diameter	48 cm
Length	92 cm
Drift tube diameter	4 cm (3π), 2.6 cm (π)
Gap to cell length ratio	1/3
Stem diameter	1.2 cm
Ridges	
Width	2.4 cm
Length	80 cm
Height	24 cm (lower), 8 cm (upper)
Wing tuners	
Length	17 cm
Angle	90 deg.
End ridge tuner	10 cm
Focusing	
Elements	ESQ
Maximum voltage	± 2.5 kV
Q-factor	6300
Shunt impedance	123.9 MΩ/m