ACCELERATOR STRUCTURE FOR LOW-ENERGY ELECTRON BEAM

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Abstract

A special high quality bunching cell for low-energy electron beam pre-acceleration is described. This cell was tested in an X-band standing wave accelerator. 25-keV electrons were injected into this bunching cell, connected to a linac structure, and more than 50% of them accelerated to the nominal energy.

I. INTRODUCTION

The problem of low-energy electron injection into an accelerator structure is of interest from a practical point of view, particularly for industrial and medical portable linacs [1], [2], and [3]. But this problem is difficult to solve easily. It is well known that commonly used accelerator structures such as disc loaded wave guide (DLWG), and on-axis coupled or side-coupled resonant structures are not effective in the normalized particle velocity interval under 0.4 - 0.5 because of high attenuation parameters and accordingly low quality factor and shunt impedance values.

On one hand, this undesirable range can be avoided by using the high injection voltage - not less than 50 kV and sometimes up to 185 kV, as in the Tokyo University accelerator [4]. This is not desirable.

On the other hand, if the acceleration field is high enough we can "cut out" a short phase range of injected particles without care about the capture rate. This is also not desirable. In addition, the above methods are much more complicated at X- and Q-band.

The offered standing wave structure [5], [6] has a higher quality factor and shunt impedance in low energy ranges and allows bunching and preaccelerating of more than 50% of injected particles without an external focusing field. This structure can be easily integrated with others.

II. GENERAL REMARKS

As indicated above, the lower the particle velocity the less efficient the structure when using the main field space harmonic for acceleration.

Next we consider higher number space harmonics for acceleration [7]. The phase speed we can write as

$$v_p = 2\pi f D/(\theta + 2\pi m) \qquad (1)$$

f - frequency;
D - structure cell length;
θ - phase shift per cell;
m - Fourier series harmonic number.

For example, using m = +/- 1 harmonics

$$v_{p_0} = 3v_{p_{-1}}$$

and (2)

$$v_{p_0} = 5v_{p_{+1}}$$

we can make the cell three or five times longer and reduce the attenuation parameter. Table 1 presents the DLWG travelling wave shunt impedance values in MOhm/m for three different space harmonics and variable iris hole radius in synchronized particle velocities interval.

Table 1 Space Harmonics Shunt Impedance, MOh/m

particle velocity	0.2 x c			0.4 x c		
a/λ	0.1	0.12	0.14	0.1	0.12	0.14
m = +1	0.3	0.11	0.02	1.7	1.6	0.96
m = -1	0.8	0.24	0.06	10.2	6.7	4.1
m = 0	0.9	0.05	0.02	11.8	7.5	4.7

There are a number of advantages and disadvantages in using different space harmonics, but the essential result is that their efficiency is comparatively low in this velocity interval.

Actually, we can consider the process of acceleration using different space harmonics numbers as having different transit time effects. Using the relationship between accelerating gap transit time (tt) and microwave field oscillation period (T) we obtain

$$tt = 1.5 \times T,\ m = -1 \qquad (3)$$

In the second case, when m = -1, a particle sequentially sees the accelerating, the decelerating and then the accelerating field during the gap transition time, so the integral effect is positive. But the deceleration field seen by a particle is in the gap middle area and has a maximum efficiency.

The main idea of the offered structure is to place a drift tube in the middle of the gap, where a particle normally sees the decelerating field, as it is done in the Alvarez structure. This keeps the field phase locked on the opposite sides of the drift tube as shown in Fig. 1.

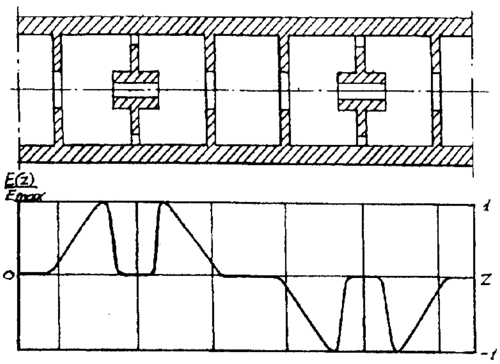

Fig. 1 Cross-section of the Structure

The dependence of the offered structure shunt impedance on the synchro-particle normalized velocity compared to those of the usual structures is shown in Fig. 2.

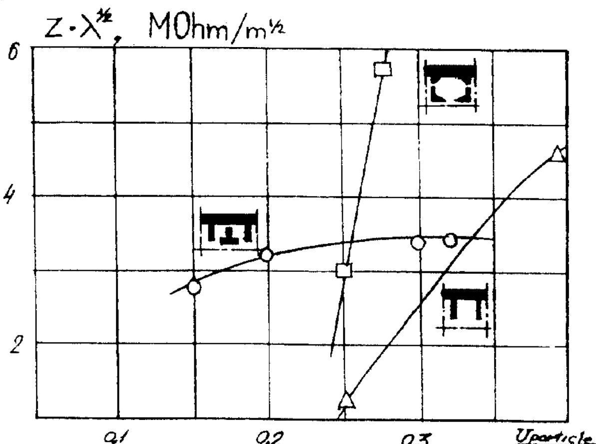

Fig. 2 Shunt Impedance versus Particle Velocity

At very low values close to β_{min} as considered in this case the Ω - cell structure impedance is close to that of the DLWG with the same iris thickness and is even smaller than shown in Fig. 2. The zero shunt impedance is referred to the case when the length between neighbor irises becomes zero because of the iris thickness t so that D = t.

$$\beta_{min} = 2\pi/\theta \times t/\lambda_0, \qquad (4)$$

λ_0 - free space wavelength.

The smaller the wavelength (for example in X- and Q-band), the higher β_{min}.

Using Fourier analysis and considering the center of the drift tube as a starting coordinate we determine that the number of the acceleration field harmonic is m = 5 for the field shown in Fig. 1.

III. EXPERIMENTAL VERIFICATION

The single dual-cell resonator for the offered structure is shown in Fig. 3. Two types of investigated parameters are shown in Table 2.

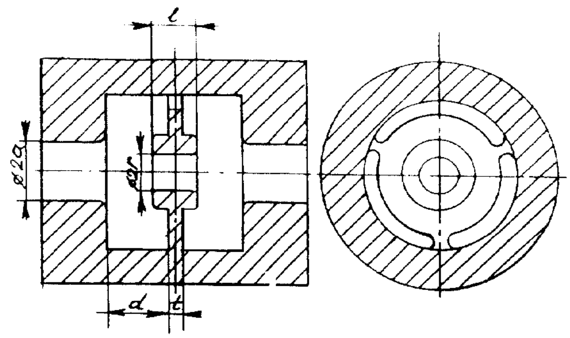

Fig. 3 Experimental Resonator Formed by a Pair of Cells

Table 2
Parameters of X-Band Resonators

N^0	d	2r	2a	Qo	$Emax/(PQ)^{1/2}$
	mm	mm	mm	--	$kV/MW^{1/2}/m$
1	12.56	5.00	7.68	4000	1336
2	6.08	5.00	7.68	4000	1336

For both types the parameter (2d+t)/l that is responsible for the quality and field values is about 3. The two pair of cells were joined together over the coupling cell and formed a segment of a structure shown in Fig. 1. The unloaded Q-value became 5800 and the field parameter - about 1158 $kV/MW^{1/2}/m$.

The frequency field distribution along the central axis obtained by perturbation technique is presented in Fig. 4. Particle dynamics modelling using this field distribution indicated that with 40 kW dissipated in this resonator, the fields accelerate about 56% of the injected particles to the energy 150 - 180 keV without any external focusing field.

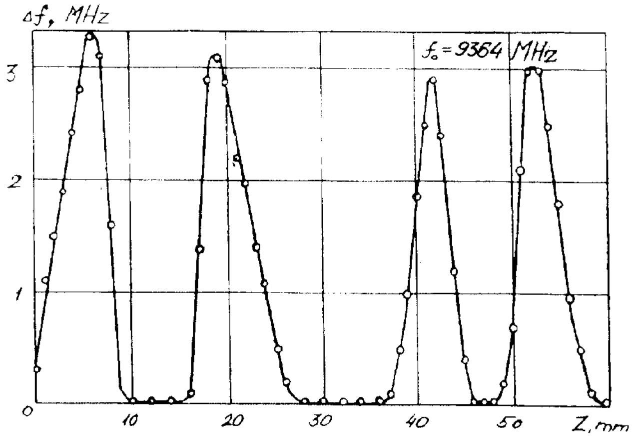

Fig. 4 Experimental Frequency Deviation Distribution Along the Axis Obtained by Perturbation Technique

The pair of cells N^{0}1 was used as the first cell of the experimental X-band structure shown in Fig. 5. The total length of the structure is 11.6 cm and the loaded quality factor is 2000. The accelerator is shown in Fig. 6 under high power test. The structure used no external focusing coils.

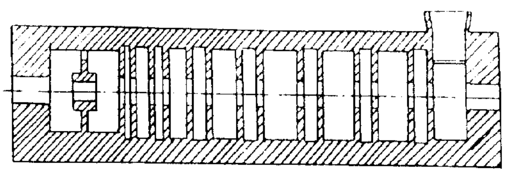

Fig. 5 X-Band Standing Wave Biperiodic Structure with Bunching Cell.

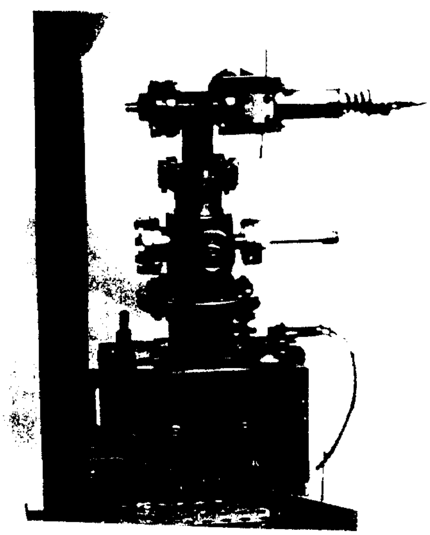

Fig. 6 Experimental Accelerator Device with Vacuum Pump

The linac parameters are as follows:

Microwave pulse power........................500 kW

Initial energy..............................25 keV

Final loaded energy..........................0.7 MeV

Pulse current...............................30 mA

Accelerated beam spot diameter...............~ 1 mm

IV. CONCLUSIONS

This structure was useful for field modelling and gentle beam forming at the bunching stage. It was recommended for use in the portable linac project [8].

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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