CHARACTERISTICS OF THE PARALLEL COUPLED ACCELERATING STRUCTURE

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Abstract

The prototype of parallel coupled accelerating structure is developed. It consists of five accelerating cavities, common exciting cavity and RF power waveguide feeder. The exciting cavity is a segment of rectangular waveguide loaded by resonance cupper pins. Its operate mode is TE_{105}. Connection between exciting cavity and accelerating cavities is performed by magnetic field.

The theoretical model of the parallel coupled accelerating structure is developed. According to model basic parameters of parallel coupled accelerating structure are studied.

The frequency tuning of all cavities is carried out. Structure is tested under high input power.

INTRODUCTION

A linear electron accelerator for radiation chemistry researches is being developed by Institute of Nuclear Physics, Institute of Chemical Kinetics and Institute of Catalysis of SB RAS. The energy of accelerator is 3-5 MeV. The gun with RF control for a beam π-chopper is used. Injection energy is 50 keV, pulse current is up to 1 A. The 100% particles capture is achieved by use this injector and 10 mm aperture. The basis of accelerator is parallel coupled accelerating structure [1].

The parallel coupled accelerating structure is shown in Fig. 1 and Fig. 2. RF power from a klystron feeds the exciting cavity (1) through inductive coupling window (7). The exciting cavity excites the accelerating cavities (2). The connection of the exciting cavity with the accelerating cavities is provided by magnetic field through coupling slots (5). The focusing alternative magnetic field is created along the beam axis by permanent magnets (3) with radial magnetization inserted in the iron yoke (4). This kind of focusing provides large enough magnetic gradient while keeping the weight of the focusing system considerably small. The cupper pins (6) are used to tune the cavity resonance frequency.

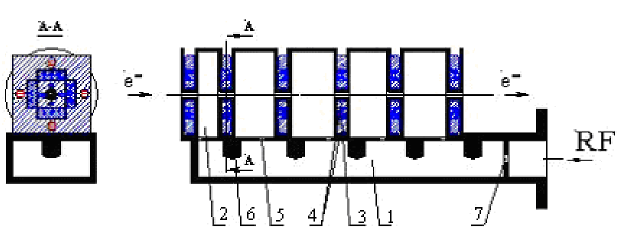

Figure 1: Scheme of the parallel coupled accelerating structure.

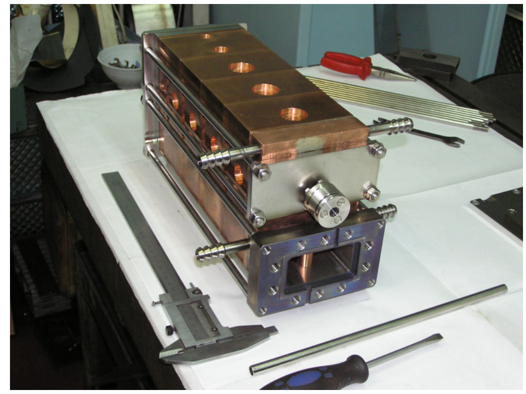

Figure 2: Parallel coupled accelerating structure.

Parallel coupled accelerating structure has some advantages versus structures with sequential power feeding. RF power is supplied to the accelerating cavities by parallel way from the exciting cavity. In result there is no need to have a high power in the first accelerating cavity. So the overvoltage and breakdown problems, thermal surface damage near the coupling slots are absent. The design of parallel coupled accelerating structure allows us to create compact beam focusing system based on the permanent magnets with radial magnetization. The accelerating cavities are not connected with each other by electric field therefore aperture of the drift tubes between cavities is limited only by the beam focusing. By changing the coupling factor between exciting and accelerating cavities it is possible to make a random power distribution along the structure. The accelerating structure can be used as for high average current with high average power as for short nano- and picoseconds duration current pulses with high amplitudes.

TWO COUPLED CAVITIES

For parallel coupled accelerating structure calculation the amplitude-frequency and phase-frequency characteristics of two coupled cavities (see Fig. 3) are obtained [2].

$$G_1 = -1 + \frac{2\Omega_{L2}\beta_1}{(1+\beta_1)\Omega_{L1}\Omega_{L2} + \beta_c}, \quad (1)$$

$$V_1 = a_1\sqrt{4\beta_1(1+\beta_1)\frac{Q_{L1}}{\omega_{01}}}\frac{-j\Omega_{L2}}{(1+\beta_1)\Omega_{L1}\Omega_{L12} + \beta_c}, \quad (2)$$

$$V_2 = a_1\sqrt{4\beta_1(1+\beta_1)\frac{Q_{L1}}{\omega_{01}}}\frac{Q_{L2}k_c}{(1+\beta_1)\Omega_{L1}\Omega_{L12} + \beta_c}, \quad (3)$$

$$\beta_c = k_c^{\,2}Q_{01}Q_{L2} = \left(1 + 4Q_{L2}^{\,2}\delta\omega_2^{\,2}\right)\frac{P_2}{P_1}, \quad (4)$$

where G_1 is the reflection factor from two coupled cavities; $V_{1,2}$ and $W_{1,2} = \left|V_{1,2}\right|^2/2$ are the normalized amplitudes and the storage energies in the first and second cavity correspondingly; $\Omega_{L1,2} = 1 + 2jQ_{L1,2}\delta\omega_{1,2}$; $\delta\omega_{1,2} = (\omega - \omega_{01,02})/\omega_{01,02}$; β_c is the coupling factor of cavities; $Q_{L1} = Q_{01}/(1+\beta_1)$, $Q_{L2} = Q_{02}/(1+\beta_2)$. $Q_{L1,L2}$, $Q_{01,02}$, $\omega_{01,02}$ are the loaded quality factors, unloaded quality factors and the resonance frequencies of the first and second cavity correspondingly; $k_c \approx |f_\pi - f_0|/f_{\pi/2}$ is the intercavity coupling constant [3], f_π, f_0 and $f_{\pi/2}$ are the frequencies of π-mode, 0-mode and $\pi/2$-mode in the cavities; $\beta_{1,2}$ are the coupling factors between the first and second cavity and external waveguides 1 and 2 (see figure 3) without intercavity connection. $P_{1,2}$ are the loss powers in the first and second cavities.

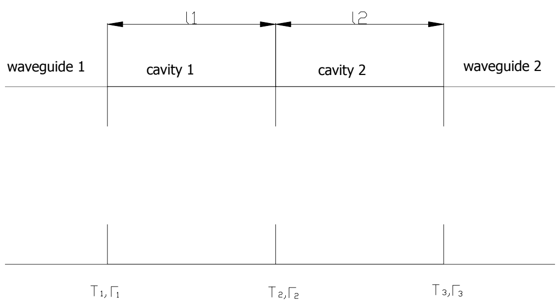

Figure 3: Two coupled cavities.

On the basis of above expressions the method of coupling factor measurement is suggested [4]:

$$\beta_c = k_c^2 Q_{01} Q_{L2} = \frac{\beta_1 - \beta_{1+2}}{\beta_{1+2}}, \tag{5}$$

where β_{1+2} is the coupling factor with feeding waveguide under connection between cavities.

If two coupled cavities have different frequencies f_{01} and f_{02} correspondingly the matching with feeding waveguide will be under relative frequency detuning $\delta_0 = (f_{01} - f_{02})/f_{01}$ in the point of $\delta\omega_0 = (f - f_{01})/f_{01}$:

$$\begin{cases} \delta\omega_0 = \dfrac{\pm 1}{2Q_{01}} \cdot \sqrt{(\beta_1 - 1)\cdot(\beta_c - \beta_1 + 1)} \\ \delta_0 = \left(\dfrac{Q_{01}}{Q_{n2}(\beta_1 - 1)} - 1\right)\cdot \delta\omega_0 \end{cases} \tag{6}$$

For the parallel coupled accelerating structure single exciting cavity is connected with five accelerating cavities. In this case accelerating cavities can be presented as one cavity with equivalent unloaded quality factor $Q_{0e} = \dfrac{\sum k_{ci}^2 Q_{0i}^2}{\sum k_{ci}^2 Q_{0i}}$ and equivalent coupling factor $k_{ce}^2 = \dfrac{\left(\sum k_{ci}^2 Q_{0i}\right)^2}{\sum k_{ci}^2 Q_{0i}^2}$, where Q_{0i} and k_{ci} are the unloaded quality factors and the coupling factors for i-th accelerating cavity.

INTERCAVITY COUPLING CONATANT CALCULATION

In paper [5] expression of k_c for two connected cavities with coupling by magnetic field was obtained:

$$k_c = \frac{2}{3}\mu_0 a^3 \frac{H_1 H_2}{\sqrt{W_1 W_2}} e^{-\alpha\cdot d}, \tag{7}$$

where μ_0 is the magnetic conductivity, a is the radius of circular coupling slot, d is the thickness of coupling diaphragm, $H_{1,2}$ are the magnetic field amplitudes in the unperturbed cavities, $W_{1,2}$ are the storage energies in the first and second cavities correspondingly, $\alpha = 2\pi\dfrac{\lambda}{\lambda_c}\sqrt{1-\left(\dfrac{\lambda_c}{\lambda}\right)^2}$ is the wave attenuating factor in the cylindrical waveguide with TE_{11} oscillation mode, $\lambda_c = 3.41a$, λ is the wave length in the cavities.

In case of parallel coupled accelerating structure the approximating intercavity coupling constant can be obtained with help of (7):

$$k_c \approx \frac{16}{3}\frac{a^3 e^{-\alpha\cdot d}}{\sqrt{Vol_{ex} Vol_i \delta}}, \tag{8}$$

where Vol_{ex} is the volume of exciting cavity and Vol_i is the volume of i-th accelerating cavity, δ is the relation between storage energy in the exciting cavity with pins (6) and without pins for TE_{105} oscillation mode (see Fig. 1).

PARALLEL COUPLED ACCELERATING STRUCTURE CALCULATION

Calculated unloaded quality factors on the HFSS code are following: $Q_{exc0} = 10000$ is the exciting cavity, $Q_{10} = 4000$, $Q_{20} = 14000$, $Q_{30} = 16000$, $Q_{40} = 16000$, $Q_{50} = 16000$ (accelerating cavities numbering corresponds beam travel) are the accelerating cavities.

From beam dynamics calculation with energy 5 MeV the coupling factors were chosen: $\beta_{c1} = 1.3$, $\beta_{c2} = 1.3$, $\beta_{c3} = 1.3$, $\beta_{c4} = 1.3$, $\beta_{c5} = 1.3$. From (1)-(3) and β_{ci} the coupling factor between exciting cavity and feeding waveguide was obtained and equaled to $\beta_1 = 7.5$. In result the exciting cavity loss power is about 15% and accelerating cavities loss power is about 85% from generator power.

From (4) and (8) for coupling diaphragm between exciting cavity and accelerating cavities with cross section 10×10 mm^2 and thickness 6 mm the coupling factors were calculated: $\beta_{c1} = 0.39$, $\beta_{c2} = 0.77$, $\beta_{c4} = 0.72$,

$\beta_{c3} = 0.72$, $\beta_{c5} = 0.72$. Thus cross section 10×10 mm^2 and thickness 6 mm for coupling slots were chosen as initial sizes.

MEASUREMENT AND TUNING OF PARALLEL COUPLED ACCELERATING STRUCTURE

After structure manufacturing the frequency of exciting cavity was found more than frequency of accelerating cavities on 700 MHz and coupling factor with feeding waveguide equaled to $\beta_1 = 3.8$. To save a vacuum tightness of structure the exciting cavity was tuned only to match structure with feeding waveguide. The necessary frequencies were calculated with help of (6). The resulting cavities parameters are presented in table 1.

Table 1: Cavities Parameters

Cavity	frequency, MHz	Unloaded quality factor	Coupling factors
Exciting cavity	2454.975	5500	β_1=3.85
Accelerating cavity №1	2454.597	2700	β_{c1}=0.19
Accelerating cavity №2	2454.621	12500	β_{c2}=0.77
Accelerating cavity №3	2454.621	14500	β_{c3}=1.35
Accelerating cavity №4	2454.627	14500	β_{c4}=1.35
Accelerating cavity №5	2454.618	14500	β_{c5}=1.35

Coupling factor between structure and feeding waveguide in the point of frequency $f_0 = 2454.558$ MHz is equaled $\beta_0 = 1.05$.

Parallel coupled accelerating structure was tested under high input power. The measured transient processes are shown in Fig. 5-7.

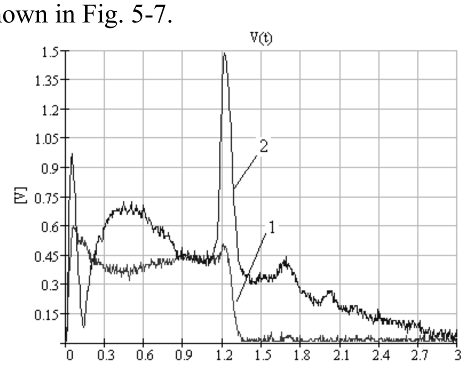

Figure 5: Transient processes in the structure with input power 1.5 MW (1-input signal, 2 – reflected signal).

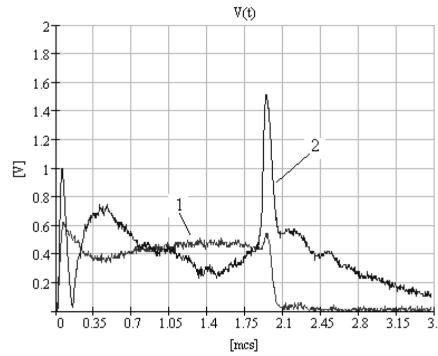

Figure 6: Transient processes in the structure with input power 2 MW (1-input signal, 2 – reflected signal).

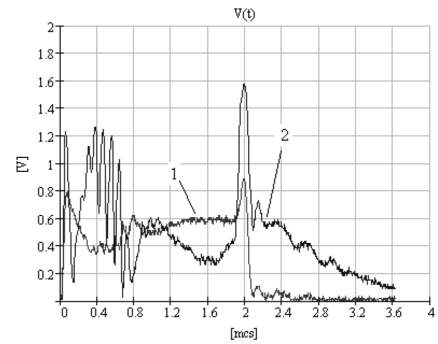

Figure 7: Transient processes in the structure with input power 3 MW (1-input signal, 2 – reflected signal).

CONCLUSION

Parallel coupled accelerating structure is made, tested, and measured. Working vacuum is obtained. RF stand with klystron KIU-111, modulator, waveguide tract, vacuum system and accelerating structure is launched. Parallel coupled accelerating structure is tested under high power. It can work with input power more than 3 MW.

REFERENCES

[1] O.N. Brezhnev, P. V. Logatchev, V. M. Pavlov, O. V. Pirogov, S. V. Shiyankov, Ju. D. Chernousov, V. I. Ivannikov, I. V. Shebolaev. PARALLEL-COUPLED ACCELERATING STRUCTURES. Proceedings of LINAC 2002, p.213 .

[2] Ju. D. Chernousov, V. I. Ivannikov, I. V. Shebolaev, V. M. Pavlov, A.E. Levichev. Bandpass characteristics of coupled cavities. Radio engineering and electronics, vol. 55, 2010. In printing. (in Russian)

[3] T. Wangler. RF Linear Accelerators., Wiley & sons ed, 1998

[4] Ju. D. Chernousov, V. I. Ivannikov, I. V. Shebolaev, V. M. Pavlov, A.E. Levichev. Method determining intercavity coupling constant for two coupled cavities. Patent RU №2368986 C1, 2009.

[5] J. Gao, "Analytical formula for the resonant frequency changes due to opening apertures on cavity walls", Nuclear Instruments and Methods in Physics Research A311 (1992) 437-443