# PROTOTYPE OF 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 excitation cavity and RF power waveguide feeder. The excitation cavity is a segment of rectangular waveguide loaded by resonance cupper pins. The excitation cavity operate mode is $TE_{105}$. Connection between excitation cavity and accelerating cavities is performed by magnetic field.

The expressions for intercavity coupling factor excitation cavity to accelerating cavities and coefficient of efficiency for RF power transmission from generator to accelerating cavities are obtained using coupled cavities theory.

The parallel coupled accelerating structure electrodynamic characteristics are measured.

## 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, pulse current is up to 1 A. The parallel coupled accelerating structure [1] is used as accelerating structure.

The parallel coupled accelerating structure is shown in Fig. 1.

RF power from a klystron feeds the excitation cavity (1) through inductive coupling window (7). The excitation cavity excites the accelerating cavities (2). The connection of the excitation 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.

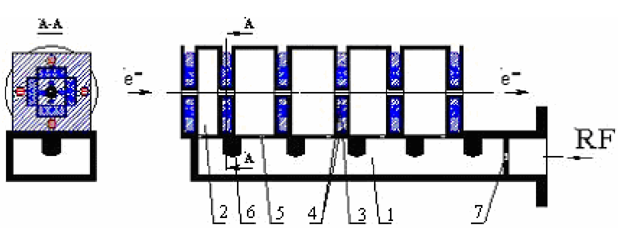


Figure 1: Parallel coupled accelerating structure.

## BEAM DYNAMICS

The prior calculation shown that electric field in the first accelerating cavity (downstream the beam travel) has to be smaller in comparison with other cavities to decrease the radial electric fields influence on the beam dynamics. The difference of the first cavity electric field amplitude in comparison with other cavities in 4 times allows us to obtain acceptable beam dynamics in the accelerator. The fields in the remained fourth cavities can be equal.

The calculated beam dynamics in the accelerating cavities system is shown in the Fig. 2. The gun with RF control for a beam $\pi$-chopper is used. Injection energy is 50 keV. The 100% particles capture is achieved by use 10 mm aperture and up to 1 A beam pulse current. Before accelerating in the accelerator cavities the beam is grouped by additional RF buncher and focused by solenoidal magnetic lens with the field value is about 0.5 kGs. The maximum magnitude of the focusing magnetic field in the accelerating structure is 0.8 kGs. After accelerating the beam energy is about 5 MeV and total feeding power is 2.5 MW (pulse duration of the beam is about 0.2 ns). Particles energy spread is about 1%.

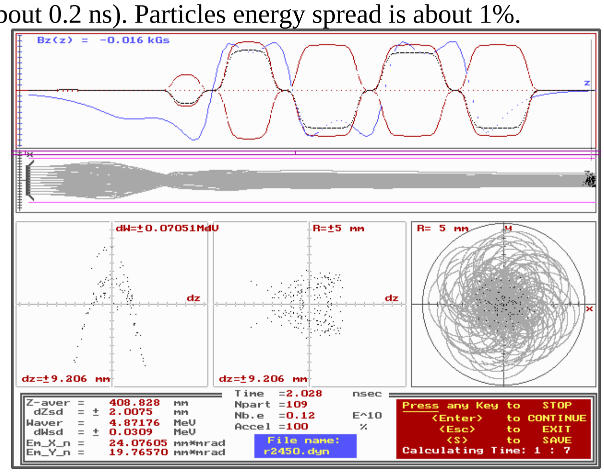


Figure 2: Particles dynamics in the parallel coupled accelerating structure.

## INTERCAVITY COUPLING FACTOR

As was shown above, the optimum electric field relations in the accelerating cavities are: $\frac{E_2}{E_1} = 4$, $E_2 \approx E_3 \approx E_4 \approx E_5$. Moreover it is desirable that coefficient of efficiency for transmitted RF power $P_{tr.acc}$ to accelerating cavities is amounted $\eta = \frac{P_{tr.acc}}{P_g} = 90\%$, where $P_g$ is power of a generator.

The intercavity coupling factor $k_c$ is defined in the two coupled cavities theory. It determines the ratio of storage energy in the first cavity $W_1$ (cavities are counted in the RF power feed) to storage energy in the second cavity $W_2$ [2]:

$$k_c{}^2 = \frac{1}{Q_{02}{}^2}\frac{W_2}{W_1} = \frac{1}{Q_{02}Q_{01}}\frac{P_2}{P_1}\,, \qquad (1)$$

where $Q_{01,02}$ - unloaded quality factor and $P_{1,2}$ - loss power of the first and the second cavity correspond.

By analogy with (1) the intercavity coupling factor between excitation cavity and *i*-th accelerating cavity for the parallel coupled accelerating structure can be defined as:

$$(k_c{}^2)_i = \frac{1}{Q_{0i}Q_{0exc}}\frac{P_i}{P_{exc}}\,, \qquad (2)$$

where $Q_{0exc}$ - unloaded quality factor of the excitation cavity, $Q_{0i}$ - - unloaded quality factor of the *i*-th accelerating cavity, $P_{exc}$ - loss power of the excitation cavity, $P_i$ - loss power of the *i*-th accelerating cavity.

Let's determine parameter

$$\gamma_i = \frac{P_i}{P_1}\,, \qquad (3)$$

then $\frac{P_i}{P_{exc}} = \gamma_i \frac{P_1}{P_{exc}}$.

The transmitted power to accelerating cavities is lost in the cavity walls. Taking into account coefficient of power efficiency $\eta = \frac{P_{tr.acc}}{P_g} = \frac{\sum P_i}{P_g}$ the relation is obtained:

$$\frac{\sum P_i}{P_{exc}} = \frac{\eta}{1-\eta}\,. \qquad (4)$$

Using (3) and (4), expression (3) can be rewritten:

$$(k_c{}^2)_i = \frac{\eta}{1-\eta}\cdot\frac{\gamma_i}{\sum\gamma_i}\cdot\frac{1}{Q_{0i}Q_{0exc}}\,. \qquad (5)$$

Parameter $\gamma_i$ is defined by unloaded quality and accelerating cavities electric field relations:

$$\gamma_i = \frac{P_i}{P_1} = \frac{Q_{01}}{Q_{0i}}\cdot\frac{W_i}{W_1} \approx \frac{Q_{01}}{Q_{0i}}\cdot\frac{E_i{}^2 L_i}{E_1{}^2 L_1}\,, \qquad (6)$$

$L_i$ - is the length of *i*-th cavity.

To estimate unloaded quality the computing calculation was carried out by 3D electromagnetic code HFSS [3]. All cavities are copper except the first cavity that has one of the walls performed from stainless steel to decrease $Q_{01}$. The calculations were shown: accelerating cavities unloaded quality factors are $Q_{01} = 4000$, $Q_{02} = 14000$, $Q_{03} = Q_{04} = Q_{05} = 16000$; excitation cavity unloaded quality factor - $Q_{0exc} = 7000$.

To achieve required distribution electric field along accelerating cavities and 90% coefficient of power efficiency the intercavity coupling factors between excitation cavity and *i*-th accelerating cavity were calculated according to (5) and (6): $(k_c)_1 = 0.94\times10^{-4}$, $(k_c)_2 = 1.39\times10^{-4}$, $(k_c)_3 = (k_c)_4 = (k_c)_5 = 1.4\times10^{-4}$.

To measure $(k_c)_i$ once can use (1) expressed storage energy relation by measured coupled factors between accelerating structure and feeding waveguide:

$$(k_c)_i = \frac{1}{\sqrt{Q_{0i}Q_{0exc}}}\sqrt{\frac{\beta_0-(\beta_1)_i}{(\beta_1)_i}}\,, \qquad (7)$$

where $\beta_0 = \frac{P_{ex}}{P_{exc}}$ - coupling factors between accelerating structure and feeding waveguide without connection with accelerating cavities, $(\beta_1)_i = \frac{P_{ex}}{P_{exc}+P_i}$ - coupling factors between accelerating structure and feeding waveguide under connection with *i*-th accelerating cavity, $P_{ex}$ - external power from the structure with $P_g = 0$.

Coefficient of power efficiency $\eta = \frac{P_{tr.acc}}{P_g}$ can be defined also by measured values $\beta_0$ and $\beta_1 = \frac{P_{ex}}{P_{exc}+\sum P_i}$:

$$\eta = \frac{P_{tr.acc}}{P_g} = \frac{4\beta_1}{(\beta_1+1)^2}\cdot\frac{\beta_0-\beta_1}{\beta_0}\,. \qquad (8)$$

## PARALLEL COUPLED ACCELERATING STRUCTURE MEASURED CHARACTERISTICS

One of the important parallel coupled accelerating structure parameters are the size of the coupling slots between excitation cavity and accelerating cavities (indicated as (5) in the Fig. 1). At first these slots were approximated from calculated above smaller intercavity coupling factor and then tuned by hand.

As the connection slot between excitation cavity and accelerating cavity is placed in the maximum of magnetic field then accelerating cavity can be replaced by rectangular cavity with $\frac{\Lambda}{2}$ length ($\Lambda$ - is the wave length in a waveguide). If excitation cavity is the same rectangular cavity the intercavity coupling factor for such new system can be easy calculated by expression [2]

$$k_c = \frac{T}{\pi}\left(\frac{\lambda_0}{\Lambda}\right)^2, \qquad (9)$$

here $T$ - is transmission factor for the inductive widow into infinity waveguide with sizes like intercavity slot, $\lambda_0$ - is wave length in the free space. For operate frequency 2450 MHz and $(k_c)_1 = 0.94\times10^{-4}$ the transmission factor according to (9) is about $T \approx 1\times10^{-3}$. It can be used as initial approximation for the transmission factor of the intercavity slot.

The sizes of the coupling slot with this $T$ are 10×10 mm$^2$ cross section and 6 mm thickness (under HFSS code simulation).

The manufactured prototype of parallel coupled accelerating structure is shown in the Fig. 3.

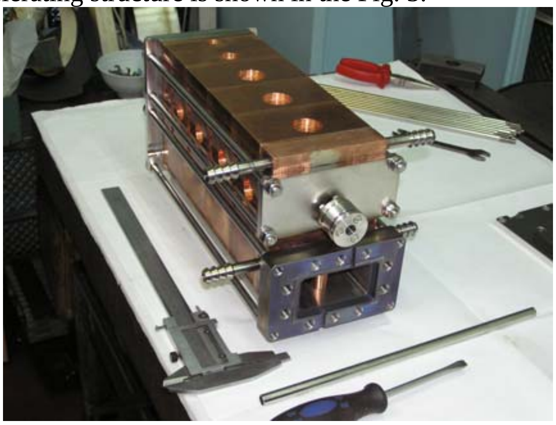

Figure 3: The parallel coupled accelerating structure.

To match the frequency characteristics of the excitation cavity following dependences were measured:

$$f[MHz] = 3467.4 - 66.5H ,$$

$$f[MHz] = 2477.8 - 0.68L ,$$

$$\beta_0 = -16.5 + 0.52L ,$$

where $H$ - high of the resonance pins in mm, $L$ - is the width of the inductive coupling window (indicated as (7) in the Fig. 1) in mm, $\beta_0$ - waveguide to excitation cavity coupling factor without connection with accelerating cavities.

Measured unloaded quality factors of the accelerating cavities are $Q_{01} = 2800$, $Q_{02} = 10200$, $Q_{03} = 11000$, $Q_{04} = 11000$, $Q_{05} = 11400$ and excitation cavity is $Q_{0exc} = 6000$.

Coupling factors between accelerating structure and feeding waveguide without connection with accelerating cavities is about $\beta_0 \approx 7$ and under connection with all accelerating cavities is about $\beta_1 \approx 1$. Therefore coefficient of power efficiency according to (8) is $\eta \approx 86\%$.

The intercavity coupling factors between excitation cavity and *i*-th accelerating cavity were obtained: $(k_c)_1 = 1.1 \times 10^{-4}$, $(k_c)_2 = 1.2 \times 10^{-4}$, $(k_c)_3 = 1.5 \times 10^{-4}$, $(k_c)_4 = 1.5 \times 10^{-4}$, $(k_c)_5 = 1.5 \times 10^{-4}$.

## CONCLUSION

The parallel coupled accelerating structure was designed. Its prototype was manufactured as well.

The matching of main excitation cavity frequency and waveguide to excitation cavity coupling factor were carried out.

The initial approximation of the coupling slots sizes between excitation cavity and accelerating cavities were estimated due to obtained expression for the intercavity coupling factor.

The matching of accelerating cavities was performed because of achieved expression for the coefficient of power efficiency. The 85% power efficiency was realized. Also the intercavity coupling factors between excitation cavities and accelerating cavities were measured. On the bases of measurement it can be conclude that electric field distribution along the axis of accelerating cavities is expressed by following relations: $\frac{E_2}{E_1} = 3.0$, $\frac{E_3}{E_1} = 3.6$, $\frac{E_4}{E_1} = 3.6$, $\frac{E_5}{E_1} = 3.7$. These are required beam dynamics with 100% particles capture.

At present the parallel coupled accelerating structure is prepared to testing with beam current.

## REFERENCES


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