ACCELERATING STRUCTURE FOR HIGH-GRADIENT ACCELERATOR

O.N. Brezhnev, V.M. Pavlov, O.V. Pirogov, Ju.D. Chernousov[1]
Budker Institute of Nuclear Physics,
Siberian Branch of Academy of Science, 630090 Novosibirsk, Russia, Lavrentiev Ave., 11,
e-mail: Pavlov@inp.nsk.su

[1]*Institute of Chemical Kinetic and Combustion,*
Siberian Branch of Academy of Science, 630090 Novosibirsk, Russia, Institutskaya Str., 3,
e-mail: Chern@catalysis.nsk.su

The conventional TW-mode accelerating structures are usually used for high gradient linacs. But these structures grow old quickly during running. It is very serious problem for creation next linear colliders [1].
In this article brief review of defects TW-mode accelerators is presented, and circuit of an accelerator on the basis of a parallel coupled cavity structure, in which accelerating resonators fed parallel from a few waveguides, is offered.
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1 INTRODUCTION

We are seen a few inconveniences of TW-mode accelerating structures:

1. Breakdown development from RF point of view:

The place of RF breakdown advances to a generator for standard TW-mode operated structure. Each breakdown leads allocation of all accumulated energy form power input up to a place of initial point RF breakdown. Whole structure damaged up to a place of initial point, and the upstream part of the structure has more damages then downstream cells.

One way for overcoming this is to transit onto the SW-operate mode.

2. Breakdown consequences:

2.1. The surface damages occur more often on the nose cone, where the structure has the maximum electric field. When the damage nose cone is happened and the pits and volcano-like mountains are appeared, the change resonant frequency of the E_{010}-mode cavity is proportional to

$$\frac{\Delta f_0}{f_0} \sim \frac{\Delta V_{\text{pit(mountain)}}}{V_{\text{cavity}}}.$$

But the main frequency of cell is changed a little, because the number and size of pits and mountains into one cavity are approximately equal, and general $\Delta V_{\text{pit(mountain)}}$ is approximately equal to zero.

But the coupled coefficient between cells in case of the small iris aperture $2a$ and thickness of diaphragm d is proportional to [3] $k \sim a^3 \cdot e^{-\alpha_e d}$. Average changes of "$a$" will result in shift of phase between cells θ , affecting the detuning characteristics.

One way for overcoming this is the transition on outside coupling slots like biperiodic structure.

2.2. Products of destroy surface (which spoils vacuum condition in structure) in standard TW-structures are removed out through the whole channel of an accelerator (diameter of an aperture approximately of 9-10 mm at a length of accelerating structure of order 1 m by operate frequency 11÷ 14 GHz).

All of enumerated possible decisions are included in the parallel-coupled cavity structures.

2 PARALLEL COUPLED CAVITY ACCELERATING STUCTURES

Parallel-coupled accelerating structures have been used earlier [2]. But inasmuch as standard rectangular waveguides have the phase velocity more then c the coaxial feeder was used. Unfortunately, the coaxial line can not be used for feeding the high gradient colliders with a high input RF power.

If we do not take into account the coaxial feed line, such kind of a structure has a lot of advantages:

The RF breakdown takes place only into a single cavity and does not provoke a breakdown in the other cavities. Only $1/N$ fraction of full RF stored energy is involved in the process of damage (N is the number of cavities).

The coupling cavity slot is placed on the flank edge of cavity. It is not a place with a strong electric field. But the damage of an aperture is not so catastrophic.

In the parallel coupled cavity structure the products of destroied surface are removing out quickly from the cavities into a waveguide feeder, which has a large cross size (when waveguide feeder has a standard rectangular form).

There is a very simple HOM problem solution: it is possible to make the damping HOM slot with a higher mode load along waveguide feeder or at the end of the waveguide.

The parallel coupled accelerating structure with rectangular waveguide feeder are shown on Fig. 1.

The Fig. 1(a) shows single-waveguide-feeder accelerator like that of [4]. It has 3-cell π -operate accelerating mode cavities.

The Fig. 1(b, c, d) shows multiwaveguide structures [5] in which as a resonant elements E_{010} cylindrical cavities are used.

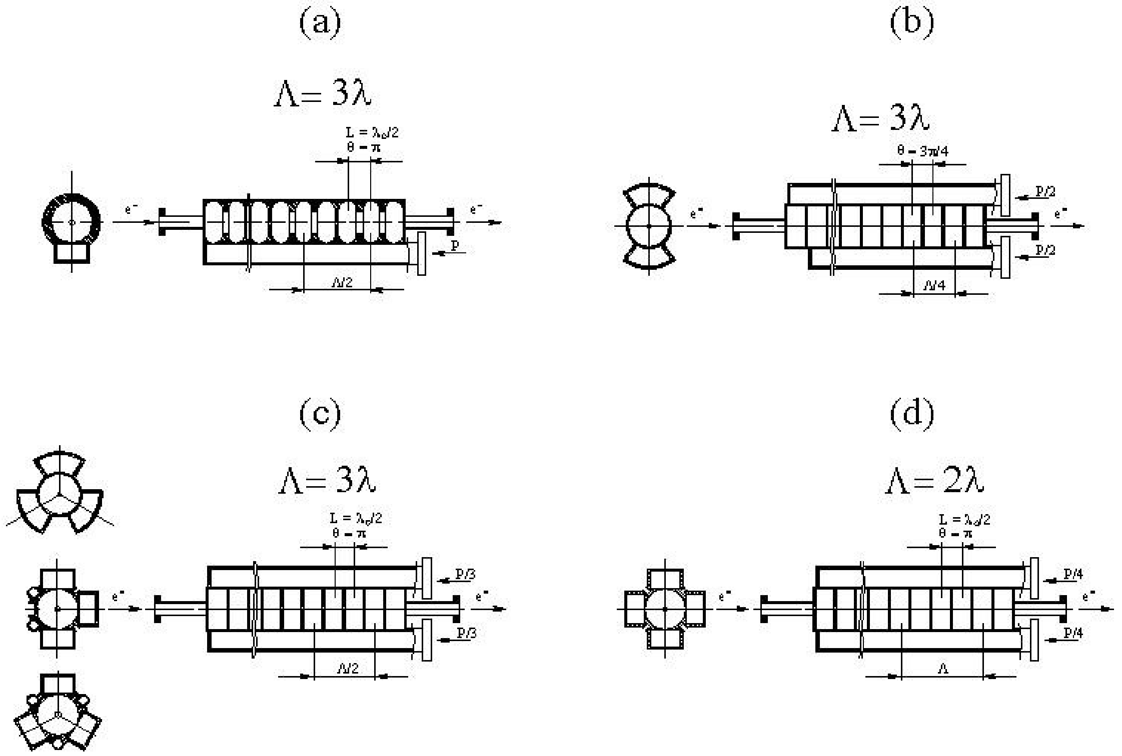

Fig. 1. Parallel coupled cavity accelerating structures with rectangular feeding waveguides.

In case of two feed waveguiges (Fig. 1 (b)) one can use the travelling wave regime in feed waveguides. The equality of accelerating particles velocity and phase velocity is valid in case of opposing motion accelerating particles and power in waveguide. The operating mode in this case may be $\pi/2 < \theta < \pi$ and the wavelength of a waveguide is equal to $\Lambda = \frac{\beta\lambda}{(\pi/\theta)-1}$. In Fig. 1(b) shown is the case when $\theta = 3\pi/4$ ($\beta = 1$) and the distance between cavities equals to $2p = \Lambda/4$ ($\Lambda = 3\lambda$). This corresponds to minimum waveguide reflection. But this structure is very difficult to tuning.

Fig. 1(c) shows a three-waveguide-feed of cavities. For $\beta = 1$ the operating mode is $\theta = \pi$ and $\Lambda = 3\lambda$.

All variants (a), (b) and (c) have the rectangular waveguide with the wavelength $\Lambda = 3\lambda$. Such waveguide has large wave resistance (threefold for conservation of waveguide high resistance) and small group velocity $0.33\cdot c$

The most attractive is the case (d): four feed waveguides. For the operating mode $\theta = \pi$ waveguides with $\Lambda = 2\lambda$ must be used. They have not a so-large wave resistance and the group velocity equals to $0.5\cdot c$. Such accelerator can be fed by two RF klystron with a double RF output.

Fig. 2 shows the rectangular waveguide coupled in common wide wall with cavity (a), its full equivalent circuit (b) and equivalent circuit of one period (c). In Fig. 2(b, c) shown are: Y_0 - the wave admittance, the ideal transformer coefficients m_W, m_S and susceptances jB_W and jB_g - are determined by sizes of the waveguide, cavity and coupling aperture.

$$Z = \frac{m_W^2}{jB_W + jB_g + m_S^2 Y_C}, \quad Y_C = \frac{Q_0}{Z_0\cdot(1+2jQ_0\cdot\delta k)},$$

$k = \omega/c$, $\delta k \approx (k-k_0)/k_0$, $Z_0 = 120\pi$ Ω, Q_0 is the quality factor. The cavity exciting current is equal to

$$I_0 = -j\cdot\frac{j_0\cdot Q_0}{\sqrt{k_0}(1+2jQ_0\cdot\delta k)}\cdot\frac{m_S}{m_W} = -j\cdot\frac{j_0 Z_0 m_S Y_C}{m_W\sqrt{k_0}},$$

$$j_0 = \int_V (j_c\cdot\vec{\varepsilon})\,dV = 2I_C\cdot\int_z \varepsilon_z(z)\cdot\cos(\omega t+\varphi)\,dz = 2I_C\cdot Int_C\cdot\cos(\varphi)$$

ε is normalized cavity distribution function of the electric field ($\int_V(\vec{\varepsilon}\cdot\vec{\varepsilon})\,dV = 1$), I_C is the average beam current, φ is the angle between accelerating current and cavity oscillations.

For $\theta_\Lambda = \pi$ at the resonance frequency the reflected power is equal to

$$P_{ref} = \left\{\frac{2\beta N-1}{2\beta N+1}\cdot\sqrt{P_{Inp}} - \frac{N\sqrt{2\beta Z_e l}\cdot I_C\cdot\cos(\varphi)}{2\beta N+1}\right\}^2,$$

where:

N - number of single cavities per one waveguide,
β - single cavity coupling coefficient,
P_{Inp} - input power,
Z_e - effective cavity shunt impedance per length unit,
l - length of a single cavity.

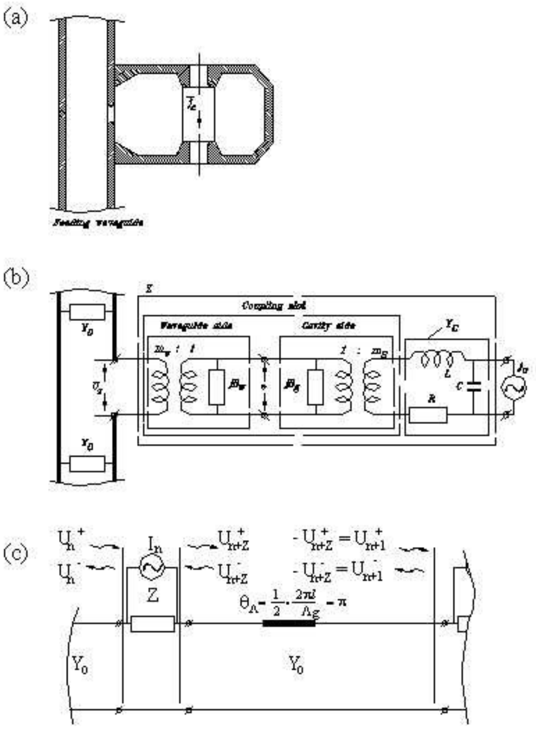

Fig. 2. (a) waveguide-cavity aperture coupling, (b) its equivalent circuit, (c) equivalent circuit of one period.

Distribution of n-th cavity electric field is $E_n = u_n \cdot \varepsilon$, where u_n is the amplitude that equals to

$$u_n = (-1)^{n-1} \cdot \left\{ \frac{\sqrt{4(2\beta)P_{Inp}}}{(2\beta)N+1} \cdot \sqrt{\frac{2Q_0}{\varepsilon_0\omega_0}} - \frac{I_C\cos(\varphi)}{(2\beta)N+1} \cdot \frac{2Q_0 Int_C}{\varepsilon_0\omega_0} \right\}$$

Energy gain per single cavity is equal to

$$U_n = \frac{\sqrt{4(2\beta)P_{Inp}Z_e l}}{(2\beta)N+1} \cdot \cos(\varphi) - \frac{I_C Z_e l}{(2\beta)N+1} \cdot \cos^2(\varphi),$$

but the total energy gain is equal to

$$U = N \cdot U_n = N \cdot \frac{\sqrt{4(2\beta)P_{Inp}Z_e l}}{(2\beta)N+1} \cdot \cos(\varphi) - \frac{N \cdot I_C Z_e l}{(2\beta)N+1} \cdot \cos^2(\varphi)$$

The charm of such kind cavities powering and operating on π -mode is the equal increment of accelerating particle energy in all cavities (constant gradient accelerating regime) with equal sizes of all cavities and coupling slots.

For a matched regime (reflected power is equal to zero) without current load $P_{ref} = 0 \Rightarrow 2\beta = 1/N$ and then

$$u_n = (-1)^{n-1} \cdot \left\{ \sqrt{P_{Inp}/N} \cdot \sqrt{\frac{2Z_0Q_0}{k_0}} - \frac{I_C\cos(\varphi)}{2} \cdot \frac{2Z_0Q_0Int_C}{k_0} \right\}$$

$$U_n = \sqrt{(P_{Inp}/N)Z_e l} \cdot \cos(\varphi) - \frac{I_C Z_e l}{2} \cdot \cos^2(\varphi),$$

$$U = N \cdot U_n = \sqrt{N} \cdot \sqrt{P_{Inp}Z_e l} \cdot \cos(\varphi) - \frac{N \cdot I_C Z_e l}{2} \cdot \cos^2(\varphi).$$

The simple case is $I_C = 0$ and $\varphi = 0$:

the amplitude of electric field in the n-th cavity is equal to

$$u_n = (-1)^{n-1}\sqrt{P_{Inp}/N} \cdot \sqrt{\frac{2Z_0Q_0}{k_0}} = (-1)^{n-1} \cdot \sqrt{\frac{2P_{Inp}Q_0}{N\varepsilon_0\omega_0}} = u_{n0},$$

the energy gain per one cavity is equal to

$$U_n = \sqrt{\frac{P_{Inp}Z_e l}{N}} = U_{n0},$$

and the total energy gain is equal to

$$U = N \cdot U_n = \sqrt{N} \cdot \sqrt{P_{Inp}Z_e l} = U_0.$$

If m of N cavities are shorted (size of coupling slot is equal to zero) for example in case of breakdown, then we must to replace N by N-m. In this case the reflected power is increased up to

$$P_{ref} = \frac{m^2}{(2N-m)^2} \cdot P_{Inp}, \quad m = 0,1,\ldots,N,$$

$$u_n = \frac{2N}{2N-m} \cdot u_{n0}, \qquad n = 1,\ldots,(N-m),$$

$$U_n = \frac{2N}{2N-m} \cdot U_{n0}, \; U = (N-m) \cdot U_n = \frac{2(N-m)}{2N-m} \cdot U_0.$$

All the above is related only to a single waveguide feeder. One can see that unlike the travelling wave mode accelerator, the increase of the amplitude of electric field in a parallel coupled cavity accelerator is small, when one cavity is breakdown.

Example:

Operating frequency	11424 MHz ,
Input power	$P_{Inp} = 2 \times 75$ MW = 150 MW ,
Nb. of waveguides	4 ,
Nb. of cavities per single feeding waveguide	45,
Effective shunt impedance	$Z_e = 90$ MΩ /m ,
Energy gain	$E_{acc} = 75$ MV/m ,
Input power for single cavity	$P_1 \cong 0.83$ MW ,
Total length of accelerating section	$L \cong 2.37$ m ,
Energy gain per section	$U \cong 178$ MeV .

If only 1 from 45 cavities of single feeding waveguide is shorted in case of breakdown, the amplitude of electric field in the other cavities concerned to this waveguide is increased only up to

$$u_n = \frac{2N}{2N-m} \cdot u_{n0} = \frac{90}{89} \cdot u_{n0} = 1.011 \cdot u_{n0}.$$

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