PARALLEL-COUPLED ACCELERATING STRUCTURES

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Abstract

The well-known parallel-coupled cavity structures working on SW regime have some advantages in comparison with conventional TW-mode accelerating structures that usually used for high gradient linacs. In this article brief review of TW-mode accelerators defects is presented. Some accelerators based on a parallel-coupled cavity structure in which accelerating cavities fed parallel from a few rectangular waveguides are discussed.

In addition the low energy accelerator for intensive electron beam based on parallel-coupled cavity structure and permanent magnets is presented.

1 PARALLEL-COUPLED ACCELERATING STRUCTURES FOR HIGH GRADIENT ACCELERATOR

One can find a few inconveniences of TW-mode accelerating structures:

1. Breakdown development from RF point of view:

1.1. The place of RF breakdown advances to a generator for standard TW-structures. Each breakdown leads to the accumulated energy dissipation from the initial point of RF breakdown up to the structure input. So the upstream cells of the structure have more damages then downstream ones.

The possible way to overcome this problem is to transit on SW-operation 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 pits with volcanolike mountains are appeared. The change of resonant cell frequency is proportional to the cell volume change due to pits and mountains appearance. Since the number and volume of pits and mountains into one cavity are approximately equal, the main frequency of cell keeps practically unchanged.

But the coupling coefficient between cells in case of small iris aperture 2*a* and thickness of diaphragm *d* is proportional to [1] $k \sim a^3 \cdot e^{-\alpha_e d}$. Average changes of "*a*" will result in shift of phase between cells θ, affecting the detuning characteristics.

This problem can be solved by the side-coupled structure approach.

2.2 Products of surface explosion (due to RF breakdown) in standard TW-structures are pumped out through many cells (the aperture is approximately 7-9 mm at the length of accelerating structure about 1 m for operating frequency of 11÷ 14 GHz).

All mentioned above problems can be solved within the parallel-coupled cavities structure approach.

Parallel-coupled accelerating structure with coaxial feeder was used earlier [2]. Unfortunately, the coaxial line can not be used as feeder for the high gradient colliders with high input RF power.

If we change the coaxial feeding line to rectangular waveguide, this kind of structure will have a lot of advantages:

The RF breakdown takes place only into the single cavity and does not provoke a breakdown in other cavities. Only 1/*N* fraction of full stored RF energy is involved in process of surface 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 strong electric field, and the damage of accelerating channel aperture has not so catastrophic consequences.

In the parallel-coupled cavity structure products of the surface damage are removed out quickly through the waveguide feeder, which has larger cross-section.

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

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

The Fig. 1(a) shows one-waveguide-feeder accelerator [3]. This accelerator consists of few modules. Each module is a 3-cells SW π -mode structure.

The Fig. 1(b,c,d) shows multy-waveguide structures [4] in which as a resonant elements E_{010} cylindrical cavities are used.

In case of two feeding waveguides (Fig. 1 (b)) one can use the travelling wave regime in waveguides. The accelerated particle velocity can be equal to the phase velocity for the opposite motion of accelerated particle and RF power in waveguide. The operating mode in this case may be $\pi/2 < \theta < \pi$ and wavelength of waveguide is equal to $\Lambda = \dfrac{\beta\lambda}{(\pi/\theta)-1}$. But this structure is very complicated in tuning.

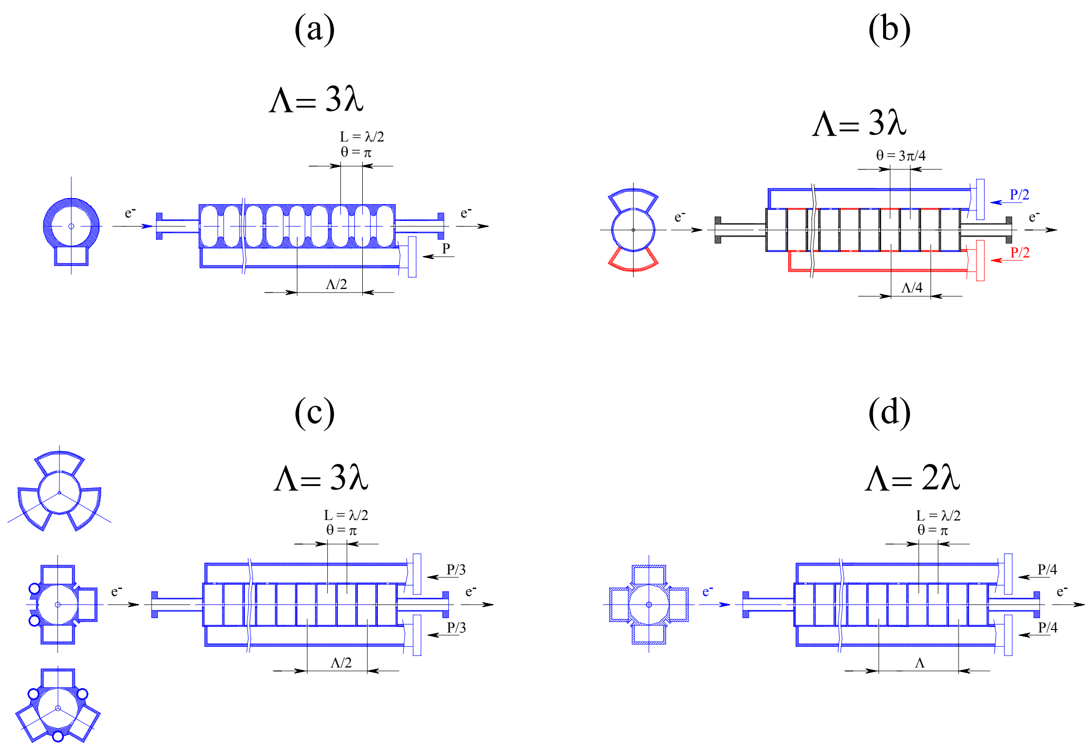

Figure 1: Parallel-coupled cavities accelerating structures with rectangular feeding waveguides.

Fig. 1(c) shows three-waveguide-feed structure. For $\beta = 1$ operate mode is $\theta = \pi$ and $\Lambda = 3\lambda$.

The most attractive is the case (d): four waveguides. For operating mode $\theta = \pi$ waveguide with $\Lambda = 2\lambda$ must be used. In this case waveguides have not so large wave resistance and group velocity equals to 0.5·*c*. This accelerator can be fed by two klystrons with double RF output.

The distribution of electric field in the n-th cavity connected to the same waveguide at $\theta = \pi$ and resonant frequency can be written as $\vec{E}_n = u_n \cdot \vec{\varepsilon}$, where $\vec{\varepsilon}$ is normalized cavity distribution function of electric field ($\int_V (\vec{\varepsilon} \cdot \vec{\varepsilon}) dV = 1$) and u_n is amplitude that equals to

$$u_n = \frac{\sqrt{4(2\beta)P_{Inp}}}{(2\beta)N+1} \cdot \sqrt{\frac{2Q_0}{\varepsilon_0 \omega_0}} \cdot \cos\varphi_{Inp} - \frac{I_C}{(2\beta)N+1} \cdot \frac{2Q_0 Int_C}{\varepsilon_0 \omega_0}, \quad (1)$$

where

N - number of the single cavities per one waveguide,

β - single cavity coupling coefficient,

P_{Inp} and φ_{Inp} - power and phase of generator,

Q_0 - cavity quality factor,

I_C - average beam current, $Int_C = \int_z \varepsilon_z(z) \cdot \cos(\omega t) dz$.

The charm of this kind of structure feeding consists in the equivalence of all the cavities (equal dimensions of all cavities and coupling slots). Nevertheless this structure operates in Constant Gradient accelerating regime.

For the simple case of the matched regime $P_{ref} = 0$ ($2\beta = 1/N$), $I_C = 0$ and $\varphi_{Inp} = 0$. One can find the amplitude of electric field in *n*-th cavity:

$$u_n = \sqrt{\frac{P_{Inp}}{N}} \cdot \sqrt{\frac{2Q_0}{\varepsilon_0 \omega_0}} \equiv u_{n0}.$$

If *m* of *N* cavities are shorted (size of coupling slot equal zero) for example in the case of breakdown, then we have to replace *N* by *N-m* in (1):

$$u_n = \frac{2N}{2N - m} \cdot u_{n0}, \quad n = 1,\dots,(N - m), \quad m = 0,1,\dots,N - 1$$

One can see that as distinct from TW accelerator the increasing of electric field amplitude in parallel-coupled cavity accelerator is small in the case of RF breakdown. As an example the overvoltage coefficient for the accelerating structure with 45 cavities per single feeding waveguide will be less then 1.02 in the case of breakdown in one cell.

2 PARALLEL COUPLED CAVITY STRUCTURE WITH PERMANENT MAGNETS FOCUSING SYSTEM

The development of an electron accelerator on low energies (less then 10 MeV) with average current per pulse more than 0.1 A represents some difficulties due to influence of the space charge on beam dynamics. To retain a beam the solenoidal magnetic field of the order 0.05 - 0.2 T is necessary. The weight of focusing solenoid is significant, the DC power sources and cooling system are necessary. It essentially increases the weight and cost of the accelerator.

The beam focusing by a sign-alternating magnetic field formed by permanent magnets allows the accelerator weight and cost reduction [5]. Permanent magnets with a large remanence are attractive for producing strong magnetic fields. In parallel-coupled structure [6] the creation of an alternating magnetic field on the axis of a beam with the help of radially magnetized magnets is possible. In such a structure the accelerating cavities are located sequentially one after another and are excited from a wave-guide through a common wall. If for excitation of cavities a rectangular wave-guide with the phase velocity $v_\varphi > c$ is used, the cavities should be installed at the distance $L = \lambda_0 / \left(c/v + \lambda_0 / \Lambda_g \right)$ apart, where λ_0, Λ_g - wavelengths of the accelerating field in free space and in the wave-guide respectively. The direction of particle motion in the structure must be opposite to the direction of the wave-guide phase velocity. Under these conditions the synchronous acceleration of particles with variable velocity v is possible. The intervals between accelerating cavities are free and can be used for installation of focusing magnets.

The scheme of such a structure with built-in magnets is shown in Fig.2. One can see there the distributions of focusing magnetic field and relative amplitude of accelerating RF field in the cavities.

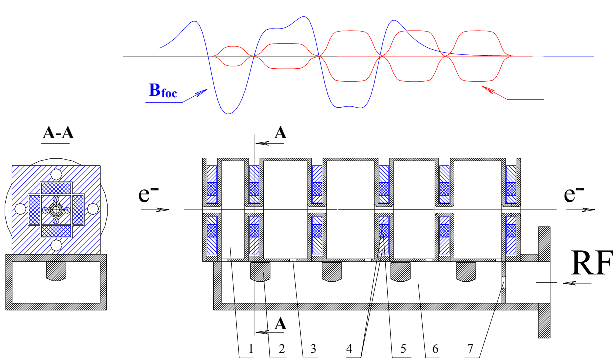

Figure 2. Scheme of the accelerating structure.
1 – accelerating cavity, 2 – capacity protuberance, 3 – coupling slot, 4 – symmetrized magnetic circuit, 5 – magnets, 6 – transmission-type cavity, 7 – input coupling hole.

The accelerating cavities (1) are excited from the transmission-type cavity (6) through coupling slots (3) in the common wall. Excitation of the whole system is carried out through a coupling hole (7). The transmission-type cavity (6) represents a cut of the rectangular wave-guide, operated on H_{104} -mode. The wave-guide is loaded by capacity protuberances (2) to reduce the wavelength. The distance between the neighboring coupling holes (3) is $\lambda_0 / 2$. Therefore accelerating cavities are exited by the transversal component of the magnetic field of cavity (6) with a phase shift π. To create radially magnetized system four rectangular Nd-Fe-B magnets (5) are used. The aperture magnetic field is symmetrized by Fe- bushes (4) with a round hole. Magnets (5) are located inside the intervals between cavities (1). The magnets are magnetized alternately - from axis and to axis of structure. This produces an alternating longitudinal magnetic field on beam axis. The adjusting accessories of magnets are demountable, that allows to repair them.

As an example one of the variants of beam dynamics calculation is presented:

Basic data:

Operating frequency 2856 MHz,
Injection energy 50 kV (input energy spread 2%),
Average beam current 1.95 A ,
Pulse duration of input current - π injection,
Diameter of input beam 4 mm,
Diameter of aperture is equal to10 mm,
Cavity diameter 80 mm,
Length of cavities: 18, 22, 32, 36 and 36 mm,
Phase shift between cavities equal to π,
Input RF powers (without current load) 0.025, 0.15, 0.25, 0.35 and 0.45 MW respectively.

The results of calculation:

Average output energy 3.6 MeV,
root-mean-square deviation of energy ±0.7 %,
Electrons capture 100 %.

Calculated normalized emittance of accelerating particles is less than 33 π·mm·mrad for both x and y directions.

At present time the prototype of accelerator on parallel-coupled cavity is in production.

3 REFERENCES

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