DEVELOPMENT OF RF ACCELERATOR ON PARALLEL-COUPLED STRUCTURE – TREND IN ACCELERATOR TECHNIQUE

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Abstract

Development of parallel-coupled accelerating structure (PCS), creation of RF linier accelerator based on PCS is new and rapidly developing field of accelerator technology. Compared with conventional accelerating structures with serial communication - the standard traveling and standing waves structures, the PCS has a lot of features and advantages. There are many problems in the development of RF linear accelerators: breakdowns at high power levels, the destruction of the structure due to overheating, the excitation of higher-order mode, the decline of field strength along the structure, transients, beam loading, beam focusing, multipactor, radiation accelerator cleanliness, etc. PCS - the best accelerating structure for solving these problems.

INTRODUCTION

To construct RF accelerators, accelerating structures of traveling and standing waves [1] have been used and improved for a significant amount of time. By method of excitation, these are the structures with serial communication, where the microwave power is linked up with one of the structure's cavities and then it is subsequently circulated from one cavity to another. Both the accelerating structures with serial communication and the electron linear accelerators in these structures are characterized by a significant number of scientific and technical problems. Some of the problems and the challenges set accordingly are listed below:

- Cavity RF breakdown, and reduction of breakdown influence on the structure and the accelerating beam.
- Local pulsed overheating, input elements destruction, and heat reduction.
- Excitation of higher order modes, and "decimation" of the mode spectrum.
- Decline in strength of the accelerating field along the structure's axis, and challenge on developing the specified field.
- Accelerated particles focusing at considerable beam currents, and challenge on developing the effective system of beam focusing.
- Problems of injection current control, and challenge on developing the effective control systems.
- Transient processes in the structure, and stabilization of the microwave field amplitude.
- Load of the structure by the beam current, and stabilization of accelerating voltage.
- Radiation background, and provision with a high beam capture close to 100%.
- Excitation of secondary-emission resonant discharge, and its suppression.
- Forming the electron beams of considerable average power (at least 10-100 kW) at energy over 5 MeV.

The main solutions of these problems for standard accelerating structures intended for low-energy accelerators as well as for high-energy physics seemed to be found. For example, for structures with high accelerating gradient, these are an increase in the accelerating field frequency, reduction in the pulse duration, optimization of the cavity shape, selection of the work surface materials, preparation and training of accelerating structures [2]. For the standard structures, limit operations are defined, the optimal values are found.

Recently, an interest in parallel-coupled accelerating structures has been deepened. These structures are characterized not by the consistent, but by the parallel method to supply the microwave power to the accelerating cavities. Such a circuit design makes it possible to expect for higher limit values in comparison with the standard structures with serial communication - traveling and standing waves.

PARALLEL-COUPLED STRUCTURE FOR RF ACCELERATOR

Key Idea Development

An idea of the "Parallel Coupled Structure" (PCS) in the accelerator technology occurred upon the paper [3] published which describes the structure containing the accelerating cavities powered in parallel from the lead-in coaxial waveguide. The phase velocity of the wave in the coaxial line is equal to the light speed, thereby the wave and accelerated electrons synchronization is ensured. Currently, a new focus area in the accelerator technology is being developed, various schemes of accelerating structures are being offered, features and advantages of the PCS are being investigated [3-13].

A circuit scheme disadvantage [3] was a low level of microwave power supplied to the accelerating cavities through a coaxial line. Easy replacement of the coaxial line with the hollow waveguide is impossible, since the wave phase velocity in the waveguide is bigger than the light speed, the wave "runs away" from the accelerated particles, synchronism is impossible. While developing [3], we proposed a scheme with a counter-movement of waves and particles. The a concept of reverse power input is applied, the particles and accelerating field synchronization in the PCS can be achieved under usage of the rectangular waveguide as an exciting element operating in the traveling wave regime [4]. A structure schematic diagram is shown in Figure 1.

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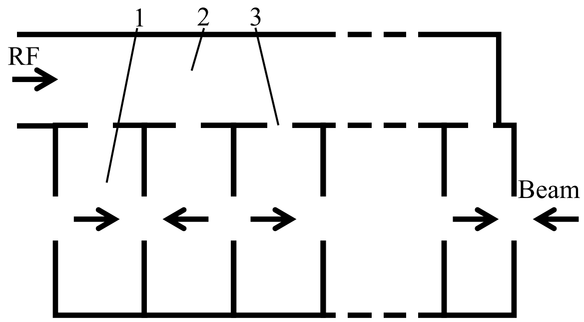

Figure1: The PCS scheme with rectangular exciting waveguide and reverse power input.

Accelerating cavities 1 are excited by the RF wave traveling along the rectangular waveguide 2 through the coupling slots 3. Microwave power and electron inputs are performed at the opposite ends of the accelerating structure. If the structure geometry is the case, the following condition is fulfilled:

$$L=\lambda_g\lambda_0(V/C)/[\lambda_g+\lambda_0(V/C)],$$
$$\Delta\varphi=2\pi\lambda_0(V/C)/[\lambda_g+\lambda_0(V/C)]. \qquad (1)$$

where L - the space in between the near-by cavities' centers, $\Delta\varphi$ - the oscillation phase shift in the near-by cavities. The bunch moving towards the wave from one cavity to another one gets into the same phase of accelerating field oscillations. Under this condition, synchronism is provided, and the particles are accelerated. Here λ_g, λ_0, V, C are respectively the wave length in the waveguide, in free space, the electron velocity and the light speed. According to the accelerating cavities excitation method, such a structure is a structure with parallel connection with variable distance L between the cavities defined by the normalized particle speed V/C. For example, when $V = 0.4C$ (the electron velocity under injection of 50 kV), in the 10-centimeter wave length range, under $\lambda_0 = 10$ cm, $\lambda_g = 15$ cm, it is found that $L\approx3$ cm, the oscillation phase shift in the near-by cavities $\Delta\varphi = 2\pi/5$; at $V = C$, we obtain: $L = 6$cm, $\Delta\varphi = 4\pi/5$. This example shows that such an accelerating structure is suitable for accelerating the electron in a wide energy range. With increase in beam energy, the phase shift and the distance between the cavities (structure step) have to grow respectively (1). The structure step is suitable for the construction of its optimized cavities. For relativistic electrons at $V = C$, the structure step is $L = 6$ cm. Such a step size is close to half the wave length ($\lambda_0/2 = 5$ cm). By installing into the size L the cavity of optimized form, a structure with shunt impedance, close to the maximum value can be achieved. For non-relativistic electrons, the structure step is smaller that is also useful for installing the cavities with smaller longitudinal dimensions. In addition, magnetic field focusing elements can be installed into the free spaces among the cavities.

New Ideas at SLAC

Close to the focus area, SLAC is currently doing researches. The accelerating structures comprising of a traveling wave waveguide for supplying the microwave power to the accelerating cavities or their groups connected to the waveguide in parallel are offered. The concept is being developed rapidly [6,9,10]. These suggestions seem a repetition of our path in this area [4], including the new challenges. Thus, each cavity included into the side wall of the waveguide [4,6,9,10] reflects, so it disturbs a traveling wave mode in the waveguide, and standing wave occurs. As a result, the ratio of oscillation amplitudes in the cavities is changed. In addition, the wave amplitude falls along the excitation waveguide due to running wave mode therein and sequential power take-off. The excitation conditions for accelerating cavities are different. This makes it necessary to select an individual coupling factor for each cavity that complicates the structure construction and setting. For these reasons, serious problems may occur while implementing the conceptual circuit schemes [6,9,10] experimentally.

Conceptual RF Schematic Diagram of the New Type PCS

We proposed and are currently investigating the new type accelerating PCS comprising of the subsequently situated accelerating cavities with microwave power carried out from a common passage exciting cavity through individual coupling slots [7,8] (Fig.2).

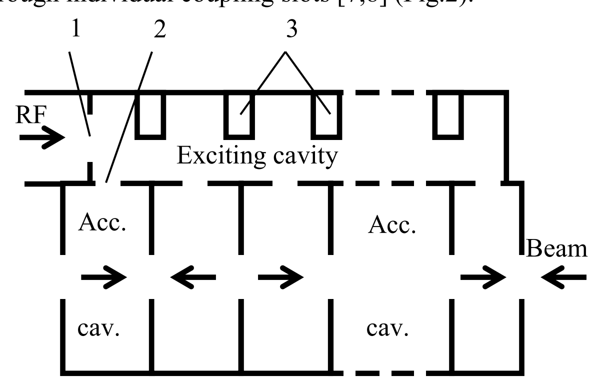

Figure 2: New conceptual PCS scheme [7,8].

Accelerating cavities of the structure are excited individually, working in a standing wave mode, communication via electromagnetic field among them is hardly seen. Microwave power from the generator is supplied to the PCS via the input inductive diaphragm 1. In the transmission-type exciting cavity constructed from the rectangular waveguide section, a standing wave is set, H_{10N-1} mode, where N - number of accelerating cavities. To reduce the wave length, the cavity is loaded by pins 3. Excitation of accelerating cavities is carried out at the standing wave maxima through the slots 2 due to magnetic-field coupling. The near-by cavities are excited in the antiphase, the structure operates on π-mode oscillations in accordance with the terminology. Due to matching pins 3, the cavity wave length is equal to a wave

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length in free space λ_0. The distance between the near-by coupling holes 2 is equal to $\lambda_0/2$, the distance between the first near-by cavities is equal to $\lambda_0 V/2C$, where V - the electron speed, synchronous acceleration of electron bunches from relatively low speed to the light speed C is provided.

PCS VS STANDART STRUCTURES

The papers presented at this conference [12,13] contrast the solutions of two major problems among the given above, i.e., the breakdown problem and the problem of beam capture in the acceleration mode, the standard structure, and in the new type PCS [7,8].

Breakdown

Under the breakdown in the PCS, only one cavity is excluded from the acceleration mode, breakdowns in cavities occur independently, each breakdown is of probabilistic nature. If $\beta_{||}$ - a breakdown probability during the pulse in one specific cavity, then for the PCS consisting of N cavities, $\alpha_{||}$ breakdown probability during the same pulse in n cavities is determined by:

$$\alpha_{||} = N\beta_{||}^n, \quad (2)$$

If one breakdown in the PCS is assumed to be possible and a pulse is considered to be lost under simultaneous breakdowns in two cavities, then from (2) with n = 2, N = 100, $\alpha_{||} = 10^{-2}$ one finds $\beta_{||} = 10^{-2}$. The breakdown probability requirements in one specific cavity for PCS are significantly reduced; it is several orders of magnitude smaller in comparison with standard structures [12].

Capture

In electron accelerators based on the standard accelerating structures consisting of a series of subsequently excited accelerated cavities – the "series-connected structures" [1], using the diode guns for beam injection, the capture usually doesn’t exceed 30-40%. In the developed microwave accelerator, one received a high capture rate close to 100% in the acceleration mode [13] due to the property of the PCS - the microwave beam focusing in the accelerating cavities, installed into PCS the magnetic system, and the use of an electron gun with injection current RF control.

CONCLUSIONS

RF accelerators tend to be characterized by a significant number of problems. The main solutions of these problems for standard accelerating structures intended for low-energy accelerators as well as for high-energy physics seemed to be found. Estimated and direct experimental comparisons show the features and advantages of the PCS versus the standard structures for low and high energy. The breakdown requirements to the cavities are significantly reduced. This makes it possible to raise the accelerating gradient [12]. It is possible to install a magnetic periodic focusing system into the microwave PCS accelerator. Along with the microwave focusing and using the electron gun with injection current microwave control, it ensures the beam capture close to 100% in the acceleration mode [13].

Development of the idea of microwave power parallel supply to the accelerating cavity, construction and investigation of RF accelerators based on the parallel-coupled accelerating structure, identification of features and benefits are a long-term trend in the accelerator technology [3-13].

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