CHARACTERISTICS OF THE MODEL OF LINEAR ACCELERATOR BASED ON PARALLEL COUPLED ACCELERATING STRUCTURE WITH BEAM LOADING

Yu. Chernousov, V. Ivannikov, I. Shebolaev, ICKC, Novosibirsk, Russia
A. Barnyakov, A. Levichev, V. Pavlov, BINP, Novosibirsk, Russia

September 24 - 28, 2012, St.Petersburg, Russia
Outline

- Motivation
- RF feeding schemes
- Parallel Coupled Accelerating Structure (PCAS)
- Beam characteristics
- Beam Loading: Equations and Results
- Breakdowns
- Advantages of PCAS
- Conclusions

September 24 - 28, 2012, St.Petersburg, Russia
Motivation

• Development robust low energy accelerator
• Detection advantages of parallel feeding
• Demonstration advantages of parallel feeding
• Parallel Coupled Accelerating Structure – the best decision for low energy accelerator and high-gradient high energy accelerator?
RF feeding schemes: serial feeding, parallel feeding

Sequential (serial) feeding scheme

Parallel feeding scheme

September 24 - 28, 2012, St.Petersburg, Russia
Parallel coupled RF feeding schemes

Rectangular Waveguide

RF Power

Beam

Accelerating Cavities

Directional Coupler

Source

Load

Accelerator Cavity

Nth Accelerator Cavity

S. Tantawi, V. Dolgachev. 2006. SLAC


October 24 - 28, 2012, St.Petersburg, Russia
Parallel coupled accelerating structure – conceptual RF scheme

- RF source
  - Input Diaphragm
  - Input Slots
  - Tuning Pins
  - Exciting Cavity
  - Beam

Accelerating Cavities

September 24 - 28, 2012, St.Petersburg, Russia
Parallel coupled accelerating structure – design scheme

RF power from a klystron feeds the excitation cavity (6) through inductive coupling iris diaphragm (7). The excitation cavity (6) excites the accelerating cavities (1). The connection of the excitation cavity with the accelerating cavities is provided by RF magnetic field through coupling slots (3). The focusing alternative magnetic field is created along the beam axis by permanent magnets (4,5) with radial magnetization inserted in the iron yoke (4). The copper pins (2) are used to tune the resonance frequency of exiting cavity (6).
Parallel coupled accelerating structure – working model

September 24 - 28, 2012, St.Petersburg, Russia
Beam Loading: Equations

Complex amplitude $U$ of equivalent acceleration voltage on the cavity

$$\tau \frac{dU}{dt} + U = U_G - U_{B0}$$

Energy gain of the beam:

$$U_A = (U_{G0} \cos \theta - U_{BO})[1 - \exp(-t / \tau)]$$

$$U_A = (U_{G0} \cos \theta - U_{BO}) + [U_{G0} \cos \theta \exp(-t_B / \tau) - U_{BO}] \times \exp(-(t - t_B) / \tau)),$$

where $t \geq t_B$

Dependence on time disappears if:

$$U_{G0} \cos \theta \exp(-t_B / \tau) - U_{BO} = 0 \quad t_{BO} = \tau \ln \frac{2(kZLP_G)^{1/2} \cos \theta}{IZL}$$

and as a result

$$U_A = (U_{G0} \cos \theta - U_{BO}) = \text{CONST}$$

$$\tau = \frac{2Q_0}{\omega_0 (1 + k)} \quad U_G = U_{G0} \exp(i \theta) \quad U_{B0} = \frac{IZL}{(1 + k)} \quad U_{G0} = \frac{2(kZLP_G)^{1/2}}{(1 + k)}$$
Beam Loading: Experimental Results

The experimental observations of beam loading effect are performed by the following way. Pulsed electron beam of rectangular form with pulse duration of 1 μs (test pulse, red) with constant magnitude of injection current (0.1A) and variable delay time in reference to the klystron pulse (yellow) was injected into the accelerator. A Faraday cap with metal plates in front of them was installed at the exit of the accelerator. Electrons with high energy overcome the metal plates, and those with low energy get stuck in it. Part of accelerated beam overcoming the metal plate of any thickness and electrons passed through the plate fall into the Faraday cap and pulsed current is recorded by oscilloscope.

The dependence of beam energy on time becomes the dependence on time of magnitude of a current from Faraday cap recorded by oscilloscope.

September 24 - 28, 2012, St.Petersburg, Russia
Beam pulse characteristics

- Beam current oscilloscope picture (current amplitude is about 300 mA, pulse duration 5 ns)
- Cross section of the beam at the exit of accelerator
- Dependence of output beam current on klystron power (as a percentage to the input current)
  - In the RF control regime, the beam capture is about 100%
RF pulse of the klystron. 1.6 MW, 5 μs.

Reflected signal from the accelerating structure.

Stored RF energy in the 5-th accelerating cavity.
Breakdowns

Reflected signal.

Breakdown in the 5-th accelerating cavity.
The stored energy is dissipated during less then 100ns.
Breakdowns

- Breakdown in the 5-th accelerating cavity
- Breakdown in the other accelerating cavity

The 5-th cavity
Almost doesn't See
Breakdowns: more detail in the poster MOPPA 018

September 24 - 28, 2012, St. Petersburg, Russia
Advantages of PCAS: all due to parallel feeding of the accelerating sells

- Maximizes RF power distribution efficiency
- Minimizes RF power flows via coupling slots
- Localization the RF breakdown in each cell
- Enhanced vacuum pumping conductance
- Built-in PPMFS – Periodic Permanent Magnetic Focusing System
- PCAS + RF-control Gun ⇒ 100% capture

- Parallel Coupled Accelerating Structure – the best decision for low-energy accelerator.
- Parallel Coupled Accelerating Structure – the best decision for high-energy accelerator?
Conclusions

The work of PCAS with electron beam in different regimes is demonstrated. Short pulses mode: electron energy – 4 MeV, pulse current – 0.3A, pulse duration -2.5 ns – 5 ns; long pulses mode: electron energy – 2.5 MeV, pulse current – 0.1A, pulse duration - 0.1-4μs. When the electron gun worked in RF-control regime the capture about 100 % was achieved.

Beam loading effect in PCAS takes place. Method of compensation of energy spread of accelerated electrons by delaying the moment of injection in the PCAS gives encouraging results.

The equations in the simplified form describing transients allow interpreting the experimental pulse dependences obtained by a method of retarding metallic plates in pulse regime.

Breakdowns: PSAC almost doesn't "notice" the breakdown in the separate cavity.

Method of feeding of accelerating cells in parallel from a rectangular waveguide helped to create the robust low-energy accelerator.

Certainly the method of feeding of accelerating cells in parallel from a rectangular waveguide will help to create the robust high gradient accelerating structures.