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

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Outline

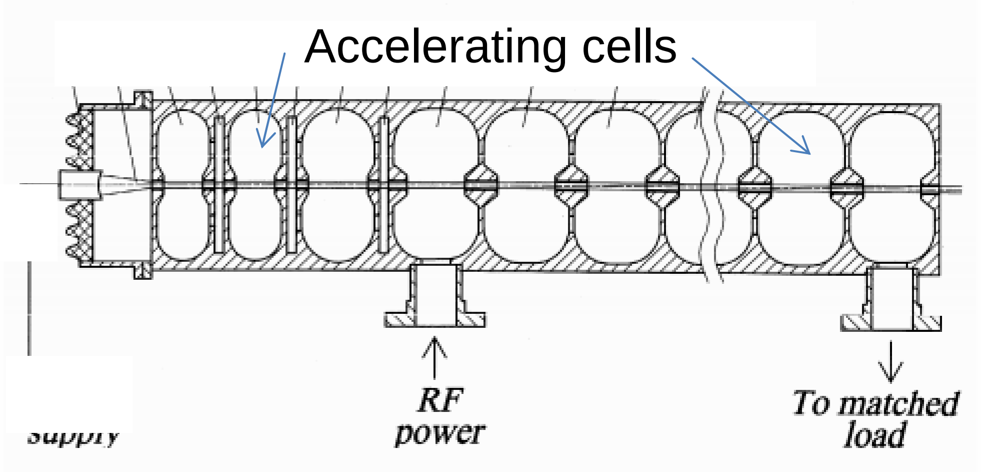
- Motivation
- RF feeding schemes
- Parallel Coupled Accelerating Structure (PCAS)
- Beam characteristics
- Beam Loading: Equations and Results
- Breakdowns
- Advantages of PCAS
- Conclusions

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?

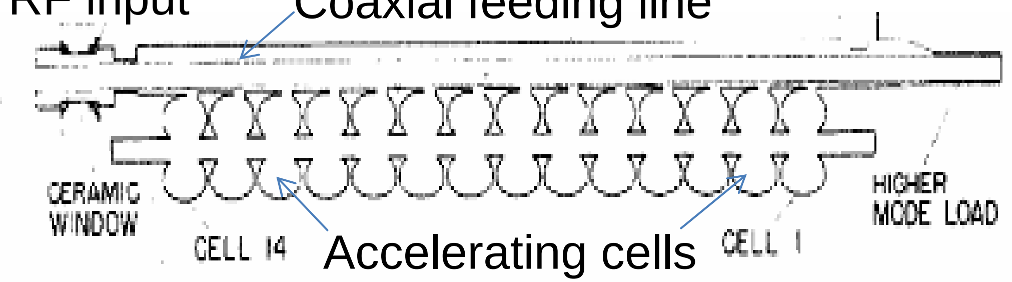
RF feeding schemes: serial feeding, parallel feeding

Sequential (serial) feeding scheme



Vitaly M. Pirozhenko_ EFFICIENT TRAVELING-WAVE ACCELERATING STRUCTURE. Proceedings of EPAC08, p.2746.

Parallel feeding scheme



R.M. Sundelin, J.L.Kirchgessner, and M.Tiger. Parallel Coupled Structure. IEEE Trans.on Nucl.Sci., Vol. NS-24, No.3, 1977, p.1686).

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Parallel coupled RF feeding schemes

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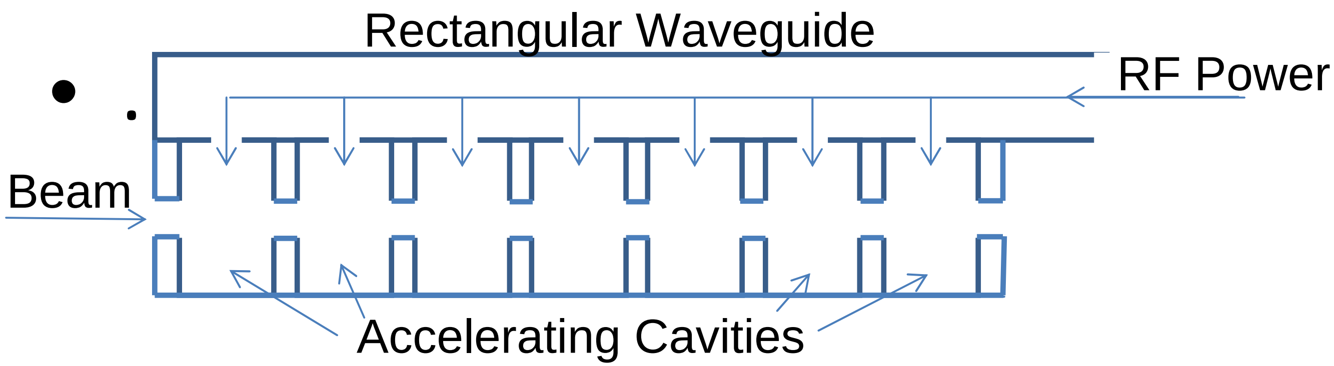
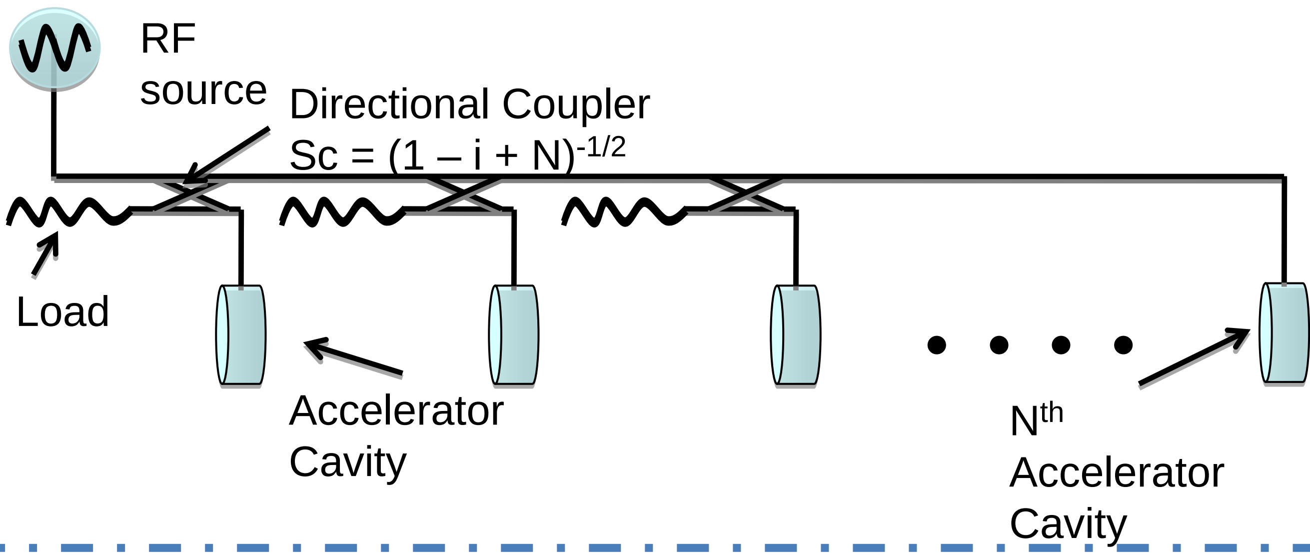


Yu. Chernousov,
V.Ivannikov,
I. Shebolaev.
1986.
Novosibirsk



S. Tantawi,
V. Dolgachev.
2006.
SLAC

Parallel coupled accelerating structure – conceptual RF scheme

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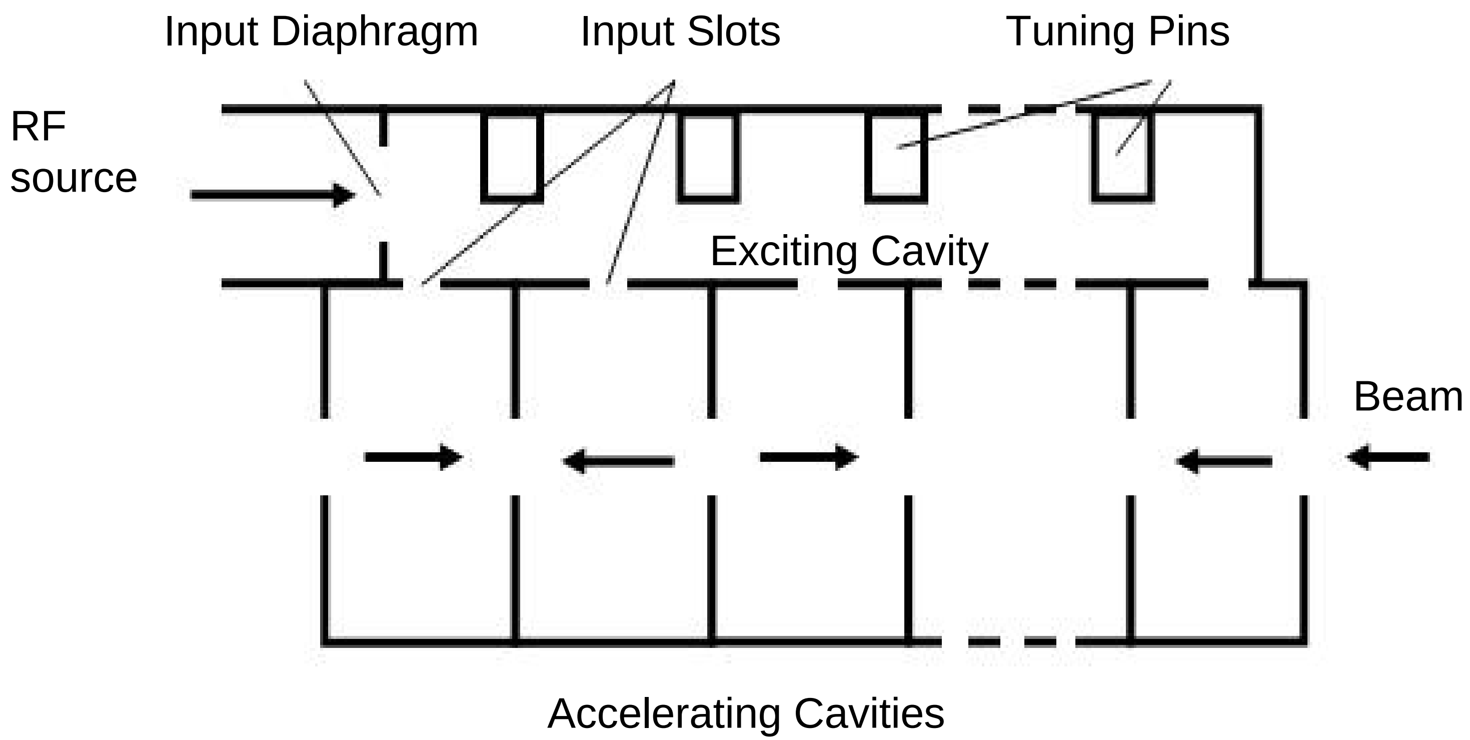
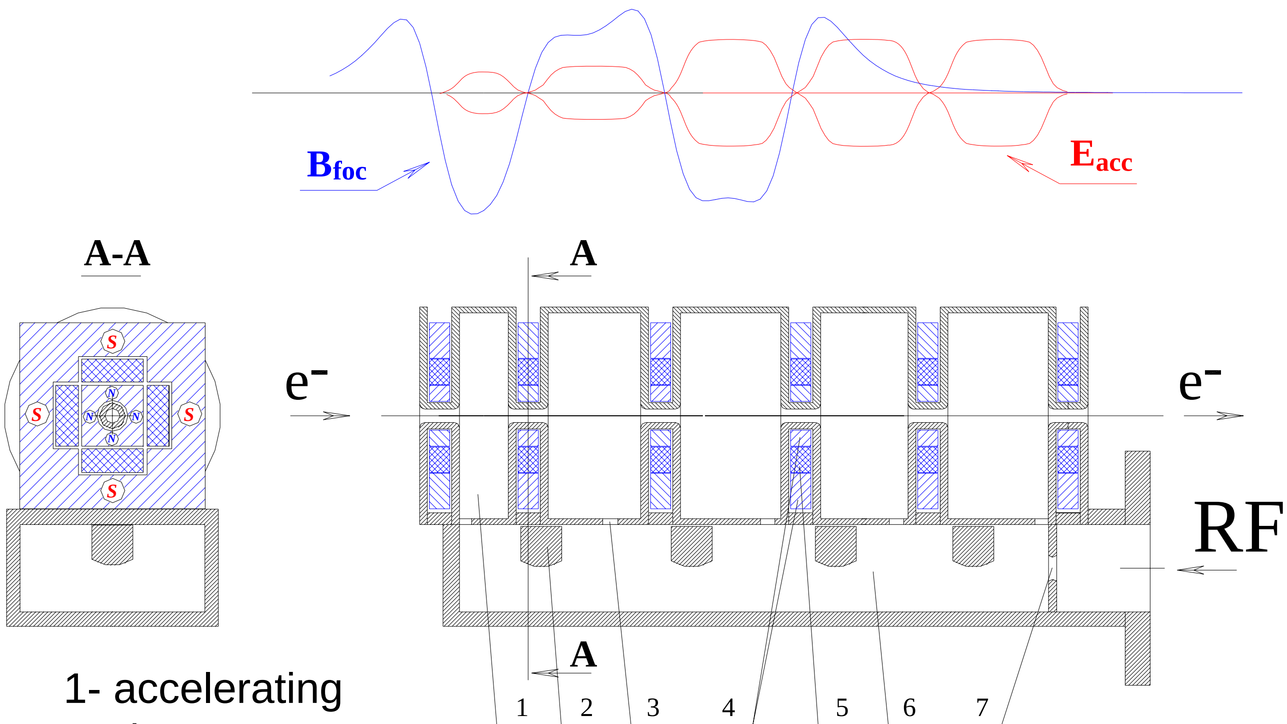


Parallel coupled accelerating structure –design scheme



1- accelerating cavity

2- tuning pins

3- input slots

4,5 - PPMFS

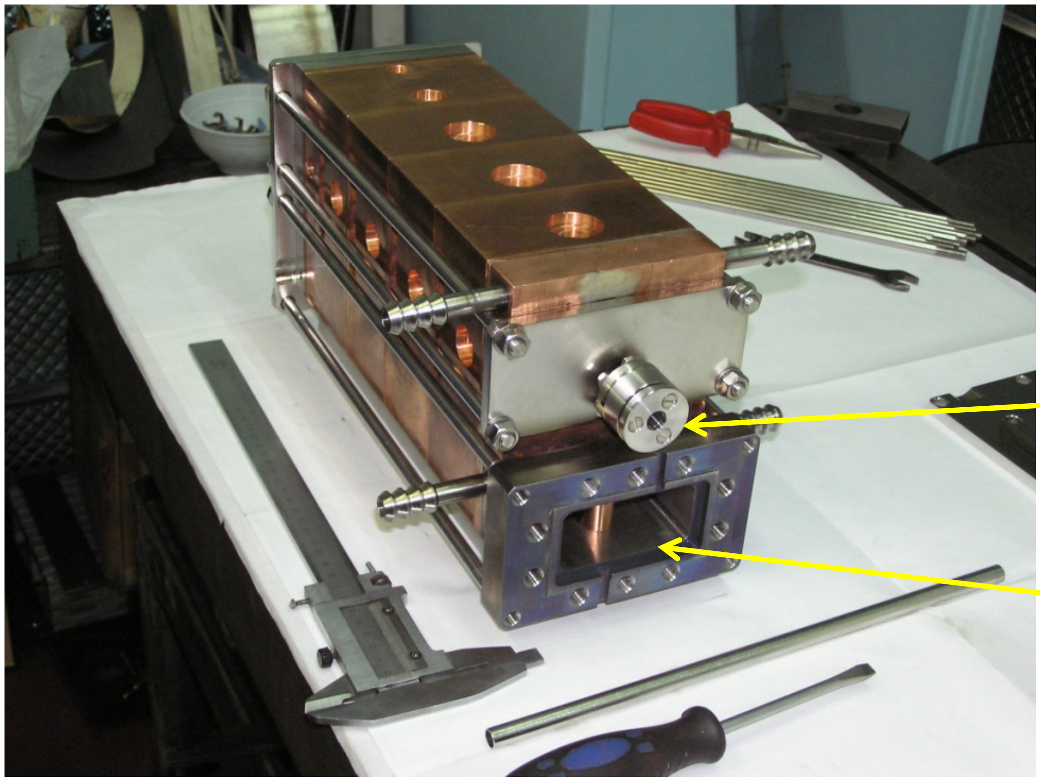
6- exciting cavity

7- input diaphragm

PPMFS – Periodic Permanent Magnet Focusing System

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



Beam Loading: Equations

Complex amplitude U of equivalent acceleration voltage on the cavity $\Rightarrow$ $$\tau \frac{dU}{dt} + U = U_G - U_{B0}$$

Energy gain of the beam: $U_A = (U_{G0} \cos\theta - U_{B0})[1 - \exp(-t/\tau)]$

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

$$t \geq t_B$$

Dependence on time disappears if:

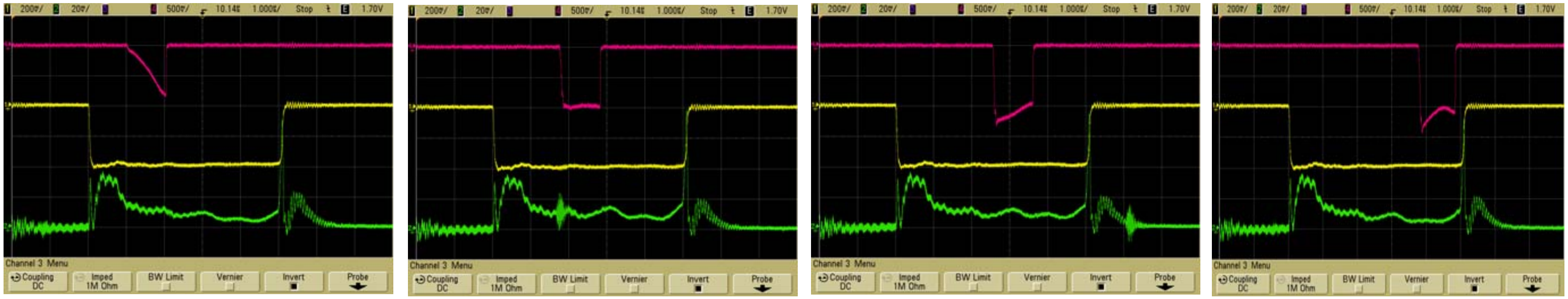
$$U_{G0} \cos\theta \exp(-t_B/\tau) - U_{BO} = 0 \qquad t_{B0} = \tau \ln \frac{2(kZLP_G)^{1/2} \cos\theta}{IZL}$$

and as a result

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

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

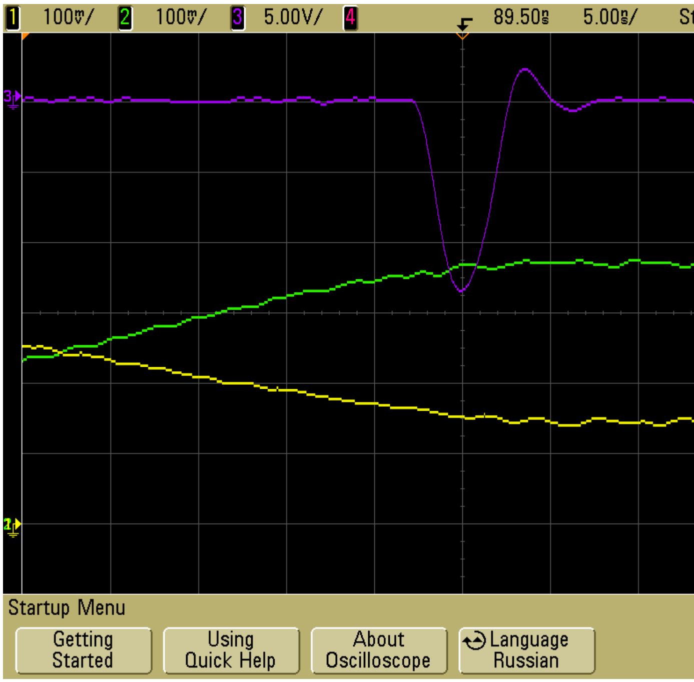
Beam Loading: Experimental Results



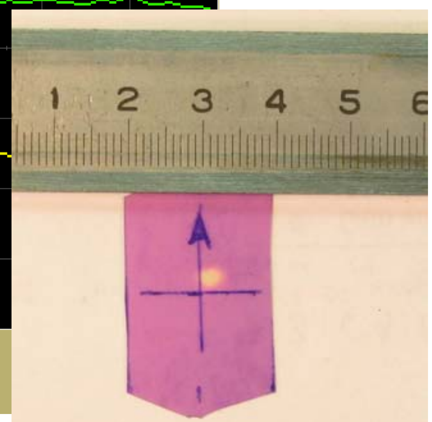
The experimental observations of beam loading effect are performed by the following way. Pulsed electron beam of rectangular form with pulse duration of 1 μs (test pulse, red) with constant magnitude of injection current (0.1A) and variable delay time in reference to the klystron pulse (yellow) was injected 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.

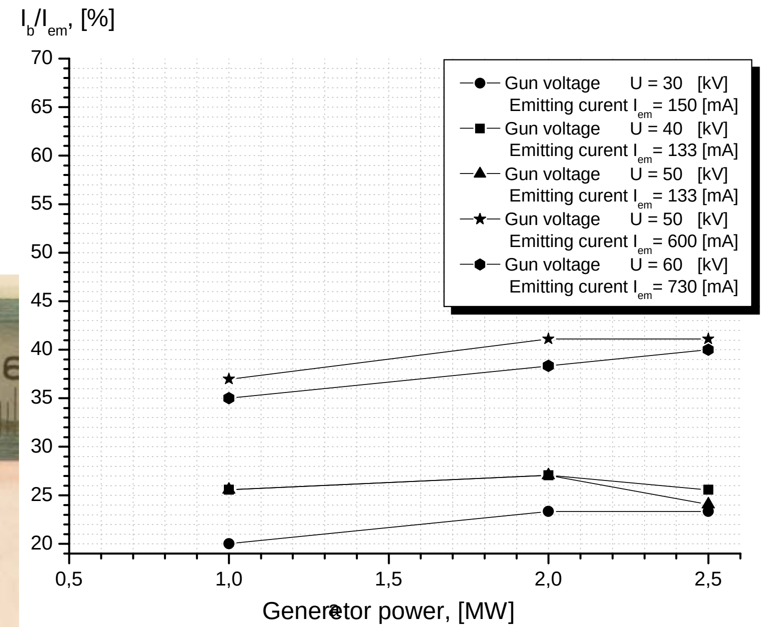
Beam pulse characteristics



Beam current oscilloscope picture (current amplitude is about 300 mA, pulse duration 5 ns)

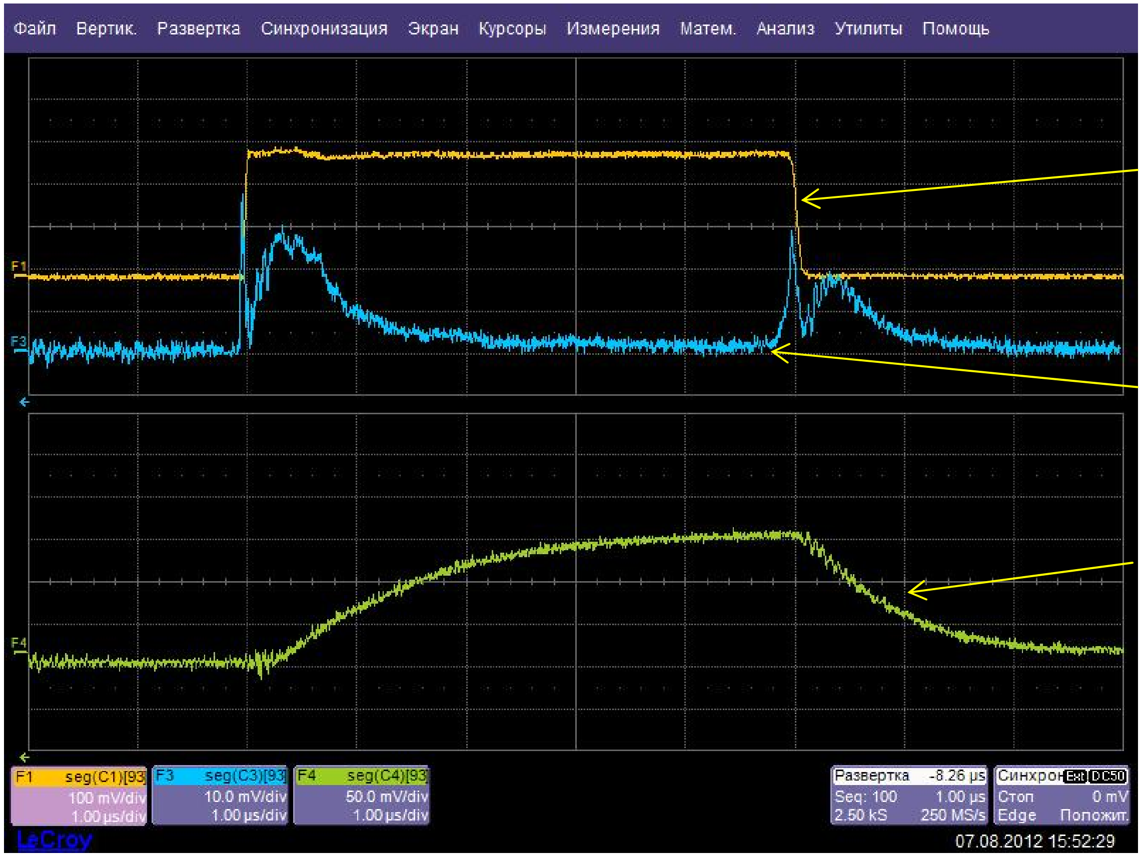


Cross section of the beam at the exit of accelerator



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 %

Breakdowns

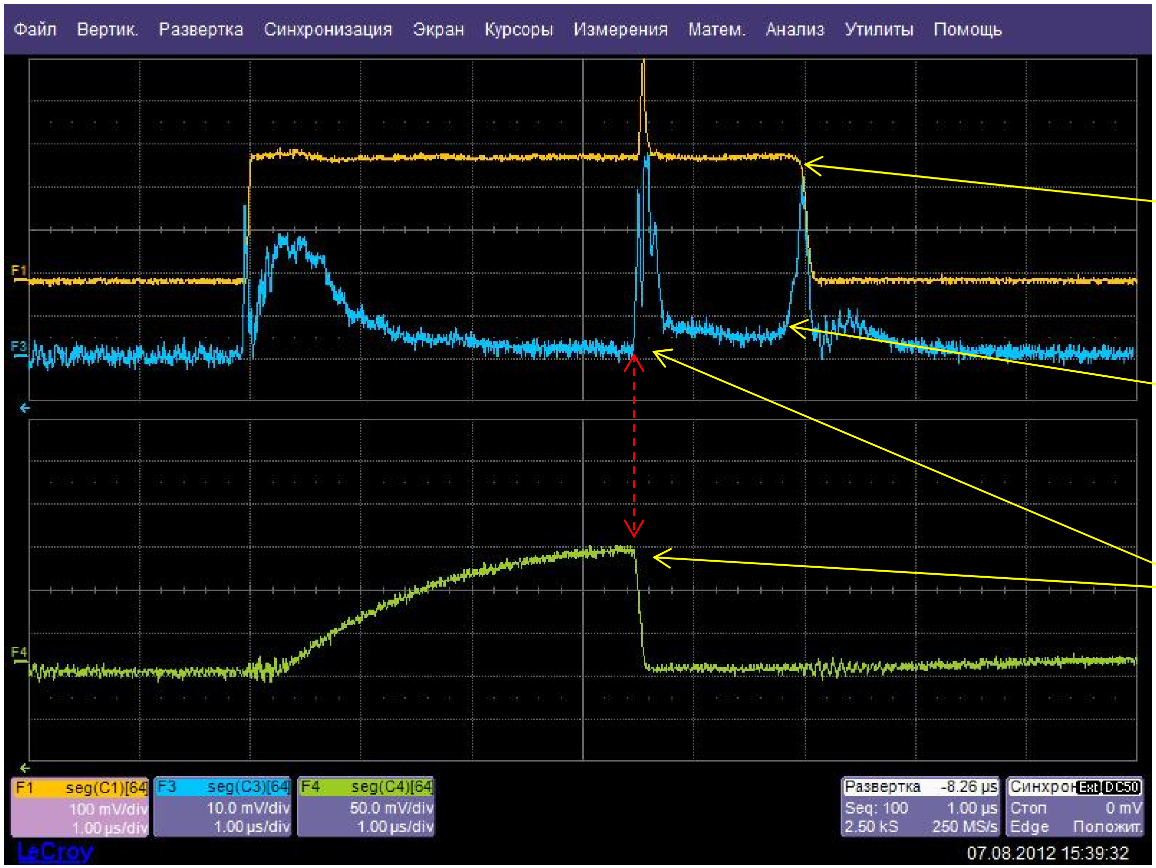


RF pulse of the klystron.
1.6 MW, 5 µs.

Reflected signal from
the accelerating structure .

Stored RF energy in the
5-th accelerating cavity.

Breakdowns

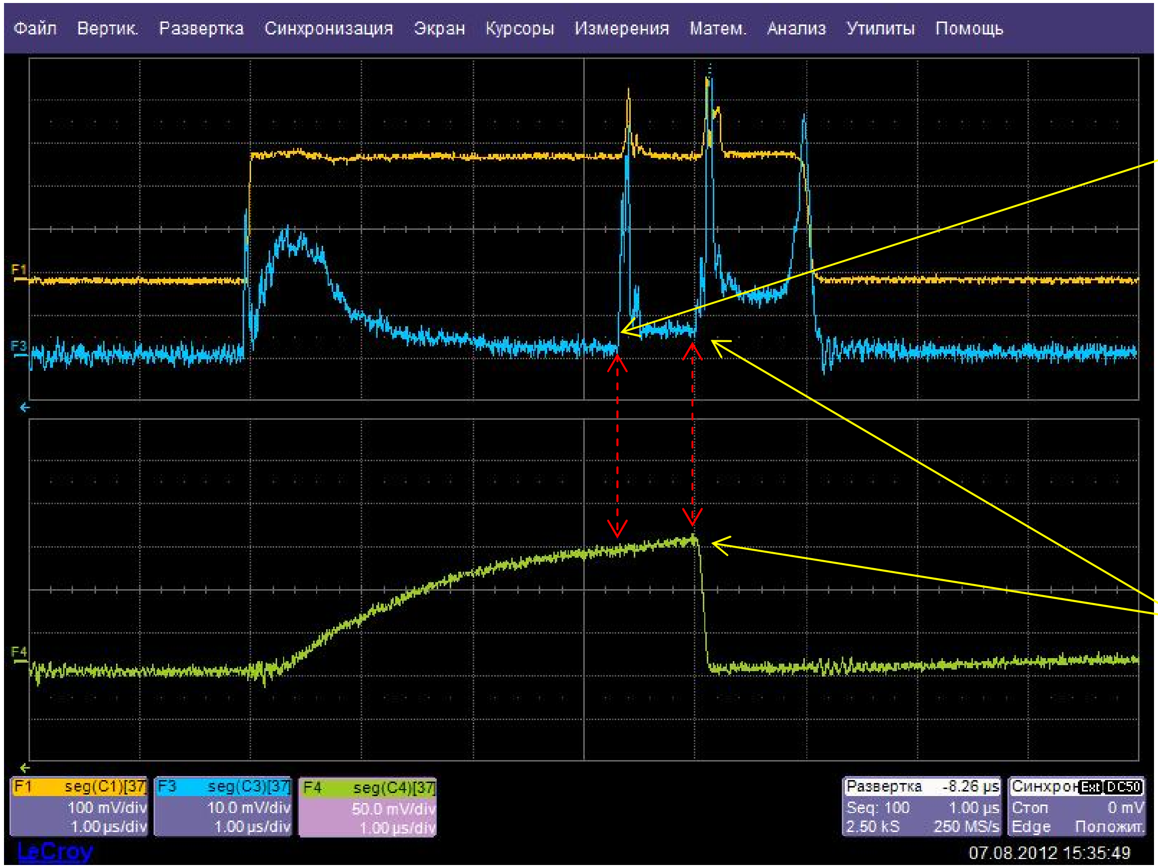


RF pulse of the klystron.

Reflected signal.

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

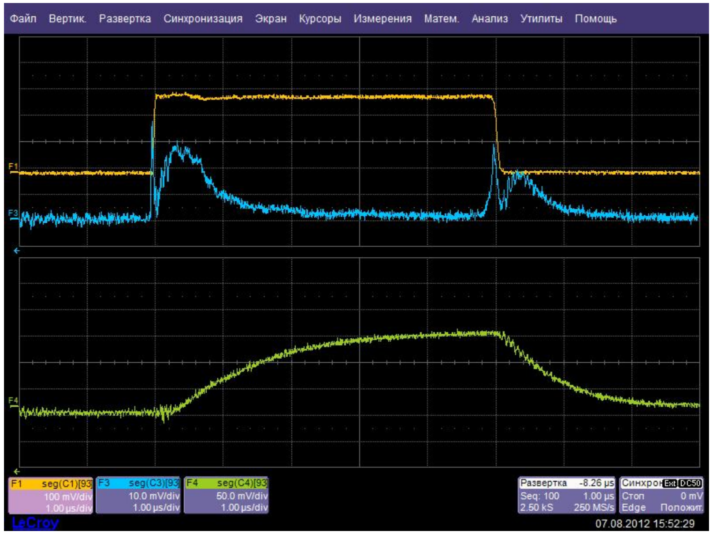
Breakdowns

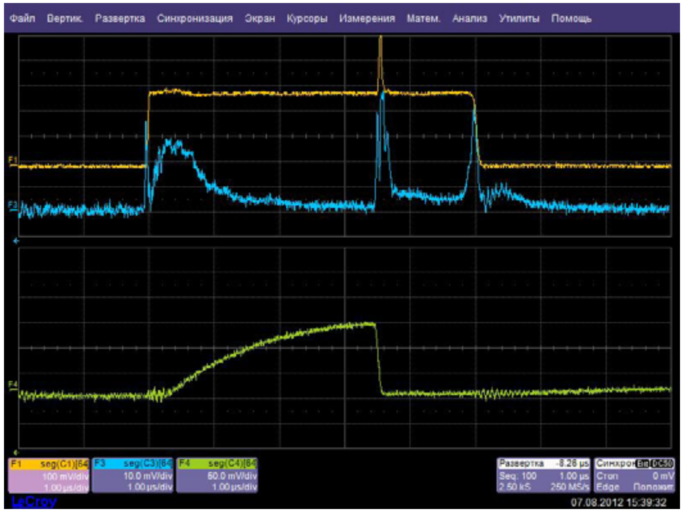


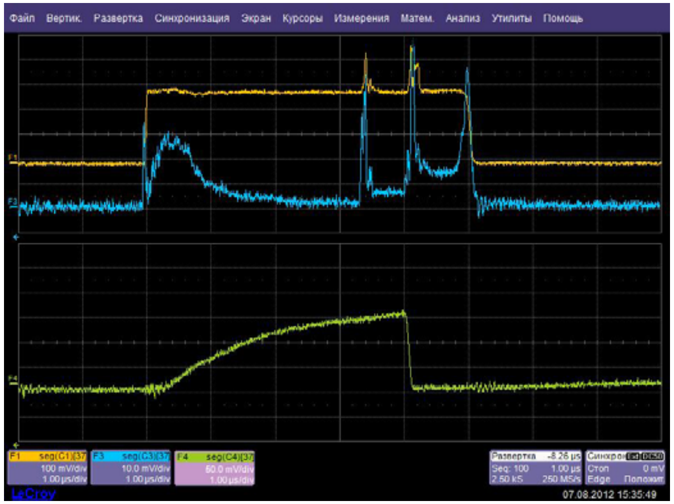
Breakdown
in the other
accelerating cavity

Breakdown
in the 5-th
accelerating cavity
The 5-th cavity
Almost doesn't
See

Breakdowns: more detail in the poster MOPPA 018







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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 $\Rightarrow$ 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 sells in parallel from a rectangular waveguide helped to create the robust low-energy accelerator.

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