RF-POWER UPGRADE SYSTEM WITH RESONANT LOADING

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The RF-power upgrade systems with RF-field energy compression are intended for accelerating wave power increase in order to increase an accelerated beam energy or decrease the feeding RF-generators power. At present a number of energy compression system (ECS) types and designs with various properties are known [1]. Among these a system with a resonant load presents the certain interest for practical use. The main difference of such ECS from the other types is that here a resonant load is an essential part of the system that influence significantly on its parameters. They can be named as systems with connected resonators also.

I. THEORY

A. The main principles of work and a system characteristics

The main principle of the system with resonant loading operation is based on the following: for certain parameters of a system formed by two connected resonators all energy primarily stored in one resonator passes by terns from one resonator to another. For the first approximation it may by considered that a maximum value of equivalent RF-power in each resonator is determined by expression:

$$P_1 / P_2 = Q_2 / Q_1 \qquad (1)$$

where P_1 and P_2 - equivalent RF-wave power in the first and second resonators; Q_1 and Q_2 - the first and second resonator quality factors. From expression (1) it follows that the higher resonators q-factor relation the more equivalent power increase can be achieved. The resonators can be with standing or travelling waves. In case of resonators with travelling waves (TWR) the equivalent power is the quite certain power of RF-wave circulating in resonator ring.

The variant of ECS with a resonant load is submitted on fig.1 [2]. Here accelerating structure 4 is a part of a TWR. The switched coupler 2 transfers the system operation mode from storing energy to its use. During the energy storing period (state A) the coupler 2 connects generator 1 output to storing resonators 3 and the acceleration structure 4 output - to an absorbing load 5. To use the stored energy (state B) the coupler 2 is switched in such way that the acceleration structure output becomes connected to storing resonators, forming TWR.

The system works as following. In state (À), an energy storing in resonators 3 occurs. The wave, reflected from storing resonators (SR), passes through a TWR and arrives in a load 5. When the energy storing process ends the coupler

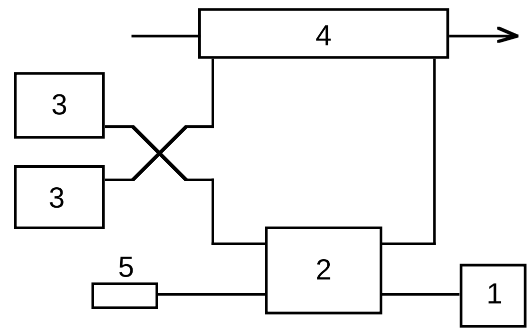

Fig. 1. An RF-energy compression system with a resonant load (1 - RF-generator; 2 - switched coupler; 3 - storing resonators; 4 - accelerating structure; 5 - absorbing load).

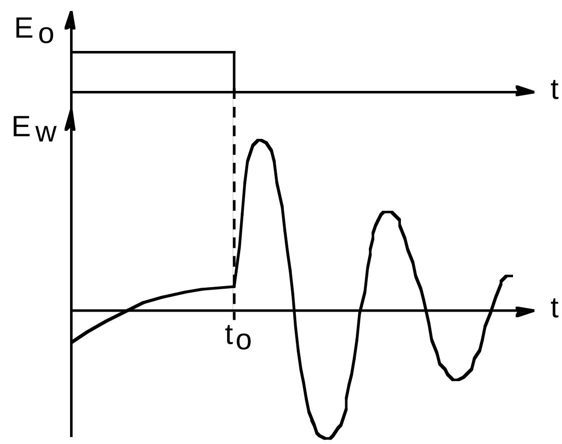

Fig. 2. The RF-wave average amplitude variations in a system with a resonant load (E_o - generator wave amplitude; E_W - wave in TWR ring).

transformed in state B. So the wave coming to SR is a wave leaving from accelerating structure. A wave phase shift in a TWR is chosen so that the wave coming on SR has the same phase as the wave irradiated from them. Then after each turn-over the amplitude of a wave circulating in TWR ring will grow so long as all accumulated in SR energy will not pass completely in TWR. And after this the return swapping of energy from TWR to SR will begin. The qualitative graph of the circulating in TWR wave average amplitude variations are shown on fig.2. If the energy losses in TWR are insignificant, the factor of wave power increase Kp in such system can be evaluated on following expression:

$$Kp = P_W / P_o = W_S/(T \cdot P_o) \qquad (2)$$

where P_W and P_o - the power of RF-waves in TWR and on a generator output, accordingly; W_S - energy stored in resonators; T - time (duration) of one turn-over of a wave in a TWR. Practically the achievable values of factor Kp in such system can make 150 ...200 (for SR with self q-factor $Q_o = 10^5$ and more (for superconductor resonators). The time of the high power wave existence in TWR appears to be about an order higher, than for the case when RF-pulse is formed on active load.

B. Field calculation equations

Let's consider a system shown in fig.1. After a generator switching-off and TWR forming the wave, emitted from the SR is added to a wave circling in the TWR. In this case the amplitude of a summarised wave at the acceleration structure entrance during the energy use period is described by a following expression:

$$E_W(t) = \begin{cases} \left(-\frac{2\beta}{1-\beta}(1-e^{-t/\tau})+1\right)\cdot E_0\ , & for \quad 0 \le t < t_0 \\ \sum_{n=0}^{N} E_{wn}(t)\ , & for \quad t \ge t_0 \end{cases} \qquad (3)$$

where :

$$E_{wn}(t) = -\frac{2\beta}{1+\beta}\cdot E_0(1-e^{-\frac{t_0}{\tau}})\cdot e^{-n\alpha}\cdot e^{-\frac{t-t_0-T}{\tau}}\cdot F(-n,1,A)$$

$$F(-n,\ 1,\ A)\ = \sum_{k=0}^{n}\frac{C_n^k}{k!}(-1)^n\ A^n$$

$$A = \frac{2\beta}{1+\beta}\cdot\frac{t-t_0-nT}{\tau}$$

N = $[(t-t_o)/T]$ - number of wave revolutions in TWR.

C. Calculation results

The graph of dependence of wave amplitude at an accelerating structure entrance on time t for $t > t_o$ is indicated in fig.3. Calculations were made for a system with following parameters: $Q_o = 100.10^3$; $\beta = 5$; t_o = 2,5 μs; T = 40 ns; α = 0,01. One can see, that the wave amplitude changes are executed by inherent steps, the duration of which is equal for a wave turn-over time in a TWR (it is supposed, that changing of the system operation mode is executed instantly).

On fig.4 the graphs of a maximum normalized wave amplitude at an acceleration section entrance averaged for a time of one turn-over in a ring dependence on a duration of turn-over period T for various values of attenuation in a ring are given for the same system parameters.

The results presented show, that the attenuation in a TWR appreciably influences on the wave amplitude E_W (and, hence, and on Kp value) only for small magnitudes of the turn-over time (T < 50 ns). Also researches have shown, that the optimum value of a coupling factor β (for a maximum

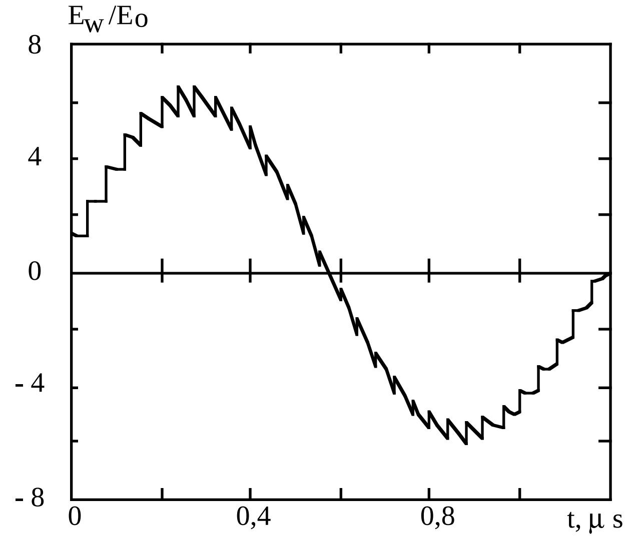

Fig.3. Changes of normalized amplitude of a wave at an accelerating structure entrance E_W/E_o from the time t for $t > t_o$.

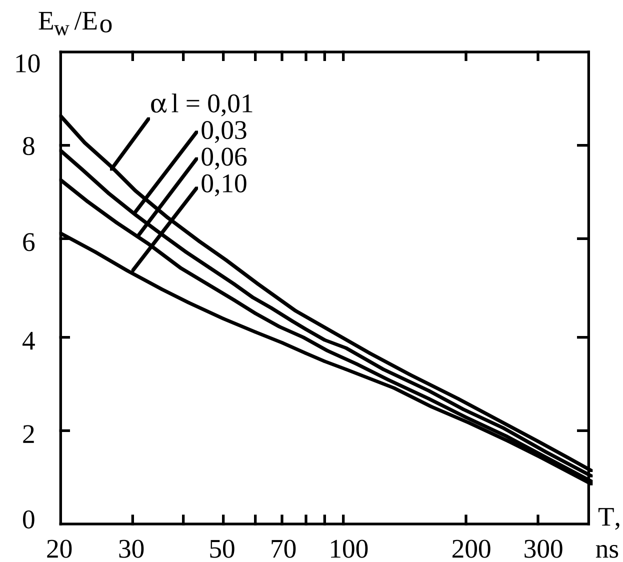

Fig.4. Dependence of maximum averaged for a one turn-over time wave amplitude at an accelerating structure entrance E_W/E_o on a duration of one turn-over period T.

wave amplitude E_W) is determined only by a duration of an energy storing period t_o .

Theoretical researches of an accelerated beam energy changes within a stored energy using period have shown, that in difference from time dependence of wave amplitude in TWR (see fig.2) the time dependence of beam energy is smooth and has no any steps.

II. EXPERIMENTAL RESULTS

The experimental researches of a ECS with resonant load were conducted at RF-generator pulsed power up to 100 kW in S-band. For energy storing there were used a copper cylindrical cavities with H_{015} mode. This cavities had an unloaded q-factor Q_o = 90.10^3 and coupling factor β=6. For changing the system operation mode a waveguide discharge switches were used. The experiments were conducted at two values of a wave turn-over duration in a ring: 40 ns and 24 ns. The summary energy losses in a ring in both cases were about 0,05.

The typical RF-wave normalized power variations in a TWR within the energy using period is shown in fig.5.

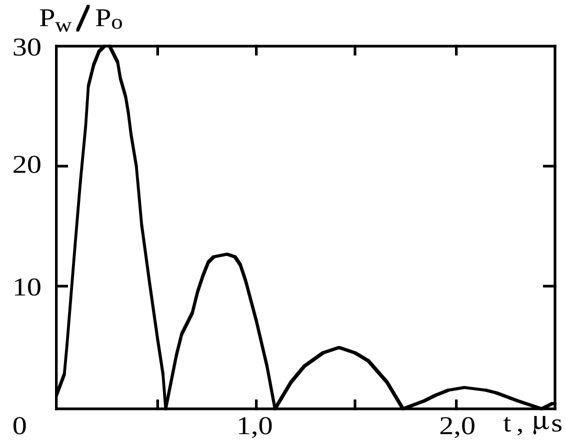

Fig. 5. The RF-wave normalized power variations in a TWR within the energy using period P_w /P_o.

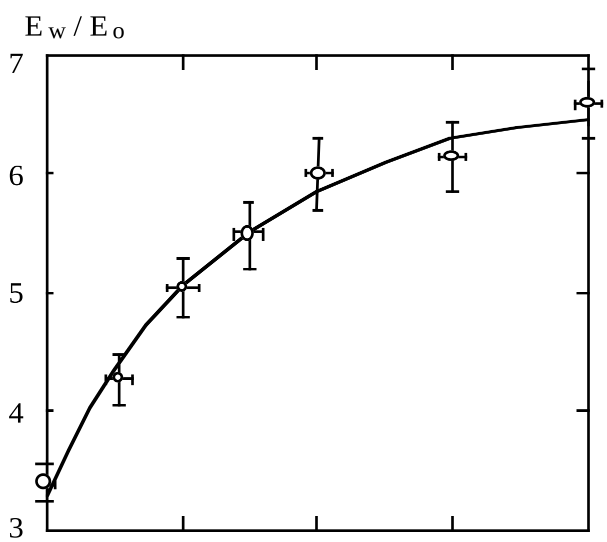

Fig. 6. A maximum normalized wave amplitude in TWR E_w /E_o dependence on an energy storing period duration t_o.

The results of measurements and calculations (on expression (3)) of a maximum wave amplitude E_{wm} in TWR dependence for considered parameters of a system on an energy storing period duration are shown in fig.6. The measurements and accounts were made for a ring with a one turn-over duration T = 40 ns and RF-generator output pulsed power up to 10 kW. A measured values of a maximum power increasing factor K_p for t_o = 2,5 μs are the following: for a ring with T = 40 ns Kp = 15,0±0,5 dB (~ 32 times); for a ring with T = 24 ns Kp = 17,0±0,5 dB (~ 50 times). The calculated values are 14,9 dB and 16,8 dB, accordingly. A number of experiments on a system work research was also conducted at an RF-generator power up to 100 kW in a pulse. In these experiments the high-voltage switch modulator was used only for initialization of discharge, and the formation of a plasma in a switch was executed at the expense of a dropping RF-wave power. In this case a system was capable to work also. As it was expected, there occur a little decrease of a power increasing factor Kp (at the expense of losses in the switches while plasma formation). At source power about 100 kW the measured value of Kp was about 14±0,5 dB (~25 times). Further increase of source power resulted in appearing of RF-discharges in a TWR waveguides, since the path was under atmospheric pressure, and the maximum wave power in a waveguide for this conditions is about the permissible one (corresponded to electrical strength for used waveguide: 72x34 mm^2), i.e. about 2 - 2,5 MW.

As far as in a given system a mode transfer switching is executed at a high power level there is a necessity to use the discharge switches, that limits to some extend an opportunities of such systems application. However, as a positive fact it should be noted, that here the switches in an opened state (i.e. in absence of discharge) operates only at a feeding generator power level. In the other type systems with storing resonators (for example, the system with variable resonator parameters [1]) a switch in opened state should maintain the power levels equal to those of an output RF-wave. This permits a considerable simplifying of constructions of a switch and a managing high-voltage modulator, and in a number of cases (at not so large power levels) to use for switching a solid-state devices.

III. REFERENCES

[1] Shalnov A., Bogdanovich B., Ignatyev A., Senyukov V. RF-power Upgrade Systems with Energy Compression for Electron Linacs. (1995 Particle Accelerator Conference). 1995.

[2] Ignatyev A.P., Senyukov V.A. Sistema vysokochastotnogo pitaniya uskoritelya zaryajennich chasticz. Pat. 1832406, Russia, 5 H05 H7 / 02, Priority from 25.12.1990.