RF-POWER UPGRADE SYSTEMS WITH ENERGY COMPRESSION FOR ELECTRON LINACS

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Application of the RF-energy compression systems as an RF-source for linear charged particles accelerators is represented to be rather perspective, as far as they permit to increase pulsed power of accelerating wave without application of any additional or more powerful RF-generators and, hence, to increase an output beam energy of an accelerator. More over, application of such systems enables an essential expand of a beam energy adjustment range, that in some cases permits to use only one unit instead of a number.

The systems can be used for existing units modernization, as well as for development the new ones. The theoretical questions of the energy compression systems using as an RF-power source for linacs were already considered in details a long time ago [1, 2]. But this considerations deals only with a possibility of use of a unique energy compression system with an RF-energy storage in a high-quality-factor cavity with a variable connection factor. Practically, however, for particle acceleration such systems was not used.

The only type of the RF-energy compression systems, that was practically used for particle acceleration, is the SLED system, which was offered in 1974 at SLAC for 20 GeV accelerator energy increase [3]. In a consequence the similar systems were realized on acting accelerators in China (1986) [4] and USSR (MEPhI, 1987) [5]. In 1985 P.Wilson offered an RF-energy compression system with the time delay lines (DL) used for an energy storage [6]. Actually, a modernized variant of a SLED system, offered by V.Balakin in 1990 as an RF-source for a linear collider VLEPP [7], also may be considered as a DL application for RF-energy storage.

The new types of energy compression systems recently suggested delivered a question on necessity of these systems classification and researching the questions on perspectivity and expediency of their use as the RF-feed sources for electron linacs (and, in general case, not only for electron).

The present report is devoted to classification of the RF-energy compression systems (ECS), that may be used as the RF-feed sources for electron linacs.

The classification scheme of ECS is shown on fig. 1. As far as the working principle of each particular system is basically determined by an energy storage element used, from this point if view all systems can be divided into three groups: a) the systems with energy storage in cavities; b) the systems with energy storage in DL; c) the systems with energy storage in combined storing elements.

The first group concern ECS, in which the RF-field energy is accumulated in a high-quality-factor cavity and the output pulse is formed at the expense of a wave, emitted from a cavity. In systems of the second group the RF-energy is accumulated in DL, and the output pulse is formed by the initial RF-pulse separate parts detained in time with the subsequent addition in a load. The third group concerned with systems that used for energy storage cavities and DL both.

The first group systems can be divided with respect to load used: a) with an active load; b) with a resonant load (in these systems the reflected wave affected essentially on a system operation). The systems with an active load can be divided in conformity on a way of a system operation mode (energy storage or use) transfer into following types: a) systems with variable cavity parameters (any of cavity parameters is changed for stored energy using); b) system with constant cavity parameters (operation mode changes only by a generator wave phase and/or amplitude modulation).

The systems with an energy storing in DL can be divided by a principle of DL use: a) with DL use for time detained of RF-pulses; a) with DL use as a resonator elements (such resonators using enables to form the flat top output pulses). The first group of ECS can be divided for switching elements used: a) high power switching; b) low power switching; c) without any switching elements (such systems can be related to ECS conditionally). This division matters for practical application of ECS.

Certainly, a further division on the various attributes can be carried out, however at present it seems to be inexpedient, since will cause an unjustified complication of the classification scheme. It is necessary also to note, that the indicated scheme is conditional up to a certain degree, as far as some systems can be simultaneously referred to different types.

The systems with constant parameters of storage cavities (SC) can be divided on the output pulse top form (system with variable SC parameters practically always form pulses with exponentially dropping top, and system with DL - the flat top pulses): a) systems without pulse top correction; b) systems with pulse top correction. Such division is connected to the possible areas of system practical use.

The ECS are characterized by the following main parameters:

- factor of a wave power increase - Kp - relation of a system output wave pulsed power to a feeding generator power;
- energy transfer efficiency η_e , which is defined as a relation of energy, transferred by system into a load, to energy "received" by system from generator;
- duration of an output RF-pulse - t_p. Parameter is important for ECS practical use. The real values of the various types ECS main characteristics are listed in table .

System type		Output pulse top form	Power increase factor, Kp	Efficiency, η_e	Output pulse duration, t_p
with storage cavities	variable parameters	dropping	30 - 50 (dB)	0,4 - 0,6	1 -100 ns
	constant parameters	arbitrary, dropping	6 - 7	0,6 - 0,7	0,1 - 1 µs
	with resonant loading	bell waveform	10 - 30 (dB)	0,6 - 0,7	0,1 - 1 µs
with time delay lines	high power switching	flat	2 - 8	0,8 - 1,0	10 - 100 ns
	low power switching	flat	2 - 8	0,8 - 1,0	
	without switching	flat	2 - 5	0,8 - 1,0	
	DL - elements of resonators	flat, dropping	2 - 10	0,6 - 0,7	

The main work principle of the ECS with SC variable parameters based on a fact that at a sharp increase of the SC connection factor after the energy storage process completed results in stored energy fast outcome thus forming a high-power RF-pulse. The running or standing waves resonators can be used here for energy storage. Such systems were well enough investigated theoretically and experimentally. The maximum efficiency of energy transforming for such systems does not exceed 0,815, that is due to features of energy storing processes in cavities (though there are the methods of an energy transfer efficiency increase practically up to 1,0 [8]). The main disadvantages of ECS with SC variable parameters are: a) necessity of high-power RF-switches use (at the power levels of hundreds megawatts such switch represents rather complicated and power-intensive device), and b) significant output power variations within RF-pulse.

Typical representative of ECS with SC constant parameters is the system SLED. Such systems are largely free from defects, inherent to systems with variable SC parameters. They don't need to use high-power switches, and the output pulse top has less abrupt recession (besides, there exist some ways to change the top form). However, the maximum value of factor Kp for such systems is not more then 9 (real value do not exceed 6...7, due to the finite value of a SC connection factor). This is their main disadvantage (though, there are ways for the Kp value increase to some extend).

In the ECS with combined methods of operation mode transfer (storing or using energy) a SC parameters variation and a generator wave modulations are used both.

The main difference of the ECS with a resonant loading from the other types is that here the load is an essential element, that appreciably influence on a system characteristics. Also they can be named as systems with connected resonators. The principle of these systems work is based on following: at certain parameters of a stored in one of them completely passes serially from one resonator into another. The relation of maximum equivalent RF-power in these resonators is reverse proportional to the relation of their unloaded quality factors. For resonators with running waves the equivalent power represents quite certain RF-power, circulating in a resonator ring. The practically achievable values of Kp in such systems are about 150 ...200 (for SC with Qo = 10^5) and more (for superconducting resonators). The wave with such power "existence" time in a ring is about an order higher, than for case with pulse outcoming into an active load.

The DL application as an energy storing elements in ECS, used for linacs feed, has a number of advantages in comparison with SC. The main advantages of such systems are the following: 1) they always formed a flat top output pulse, and 2) the energy transfer factor can come nearer to 1.0 when using a small loss DL, because the basic energy losses inherent to systems with SC are here away.

The main work principle of the ECS in which DL are used for RF-pulse separate parts time delay consists in dividing the initial pulse by a switching device in a number of equal duration parts, which with the help of DL are displaced in time so, that to a target summing device (to a load) they would come simultaneously. Thus the power of a wave in this summing device will increase in so much time, in how many parts an initial pulse was divided. Such pulse division can be executed with the help of amplitude (switching at a high power level) or phase (switching at a low level) modulation.

When using DL as a storing elements a creation of ECS without any switching elements is possible. In this case the useful load - accelerating structure - is an integral part of a system. The accelerating structure actually appears included in a resonator with running waves. The application of DL permits to reduce the transient process time in such a resonator up to a minimum. The systems with DL as elements of resonators unite the properties of systems with SC and DL. The positive properties of such systems are the flat top output pulse forming and a relatively simplicity of construction. On the other hand, they have relatively low efficiency as the systems with SC.

The considered classification scheme of the energy compression systems that can be used as RF-sources for linacs feed permits to evaluate the main properties of such systems and also an expediency of its use for achieving of required parameters of accelerated beam. Besides this it enables to determine the main ways of developing of the energy compression systems with required characteristics.

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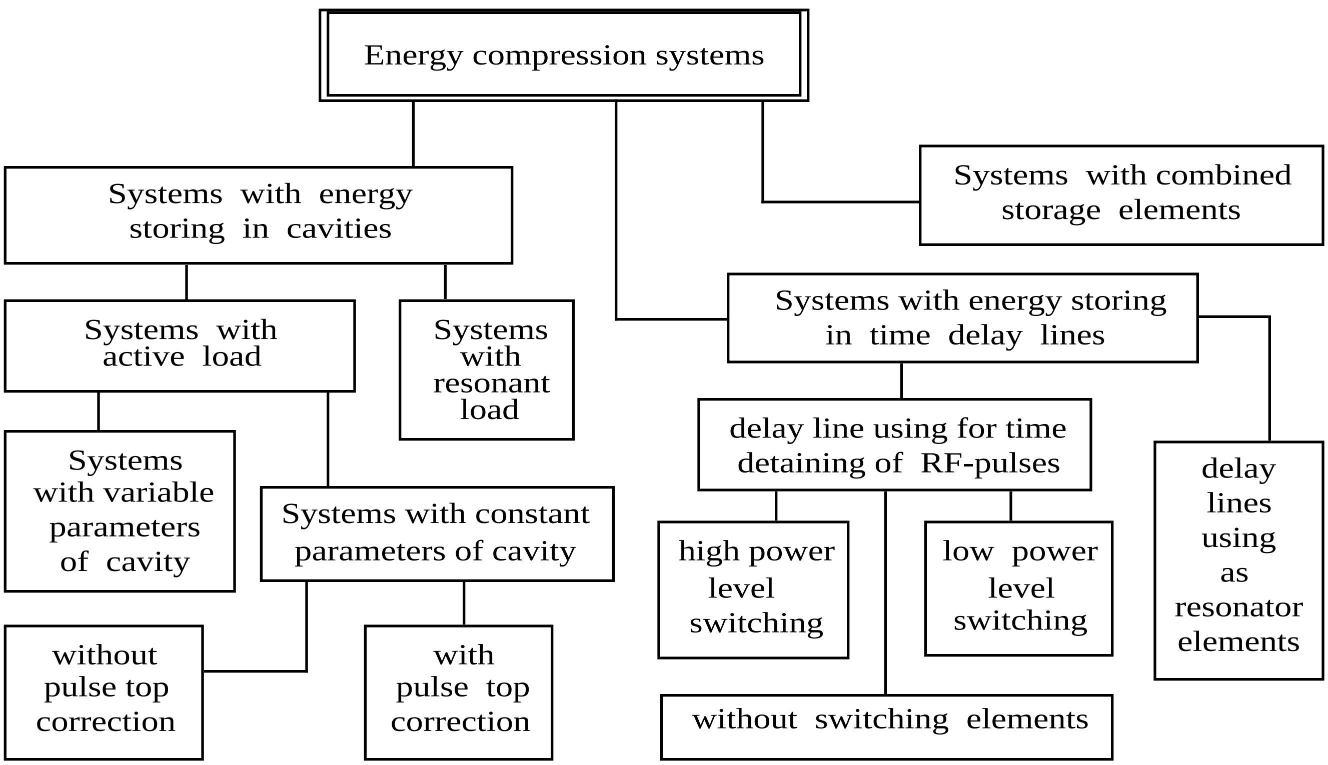

Fig. 1. Energy compression systems (ECS) classification scheme.