RF Pulses with Flat Output Waveform Generator in RF Power Upgrade System

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Abstract

The paper contains theoretical and experimental research results of electron linac with RF power upgrade system as an RF source. Application of this systems gives a possibility to increase the accelerated beam energy without RF source (generator or amplifire) power increasing. Cavities are used for RF energy storage in this system as well as in SLED one. In difference with this system usage of amplitude-phase modulation of generator wave allows to form a flat topped RF pulse of accelerated wave. In this case a beam energy increasing can be achieved without beam energy spread widen.

INTRODUCTION

A serios problem of accelerated beam energy spread widen arises when designing an electron linac with RF power upgrade system as a power source.

Some evident advantages are inherent to RF power upgrade systems with cavities as an energy storage elements. But its have an essential fault aslo. When using such a system for electron linac feeding a considerable changing of RF wave amplitude at accelerating structure input results in accelerated beam energy spread widing. This changing is conditioned by a cavity emitted wave damping at a stored energy use period. One possible way to overcome this fault is discussed in work [1]. Here in order tocompensate an energy spread widing one should accomplish a beam current modulation within a beam pulse duration. However this method have a limited usage, in particular, it can not be used for negligible current loading cases.

Another way of this problem solving is suggested in this paper. A flat output waveform RF pulses are formed by this linac RF power feeding system with RF energy compression. Such a pulses at accelerating structure input are formed by means of amplitude-phase modulation of the RF power generator (or amplifire) wave. Here it must be pointed out that such a way of RF power pulses shaping is available only for energy upgrade systems in which an output wave is formed by a generator wave and emitted from a storage cavity one combining [1-4].

THEORY

It is an exponential law the emitted from a storage cavity wave amplitude during an output RF pulse is decreasing according to. So the generator wave amplitude should increase in time during RF pulse in order to compensate the emitted wave decreasing. The resulted output wave amplitude will be constant within some time interval if the generator wave amplitude increasing law is choosed in a proper way. Time interval duration, where output wave amplitude is constant, depends on different system parameters and, in particular, on the wave amplitude value at the accelerated structure input which is needed. The pulse flat top end moment corresponds to that one when a generator output RF power comes to its maximum value because this value is limited and the output RF wave amplitude couldn't increase more.

Electron linac with such a system as an RF source is shown in fig.1. The main elements of this linac are as following: an initial RF generator 1 (here and after number of element corresponds to its position in fig.1); output RF power amplifire (klystron) 2; highspeed phaseshifter 3; two storage cavities 4 connected to the accelerating structure by a 3-dB coupler 5; cavities coupling change elements 6; auxiliary RF amplifire 7; shaped pulse generator 8 and accelerating structure 9.

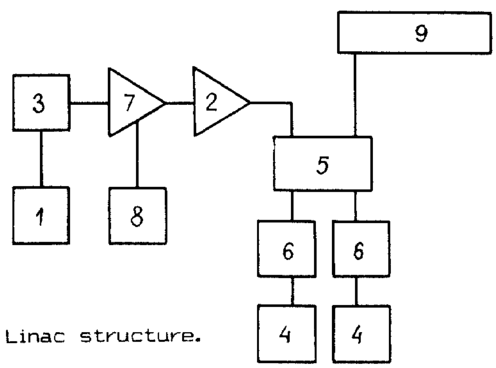

Fig.1. Linac structure.

The linac RF system work can be illustrated with the help of time diograms shown in fig.2. RF energy accumulation at cavities 4 takes place during the first and the best part of a generator RF pulse duration (time interval from 0 to t_o). In this period in order to store a maximum possible amount of field energy the cavities coupling is established to proper value by means of elements 6. By the way it can be pointed out that this elements presence is not necessary. Cavities coupling value increasing (by means of elements 6) and generator wave phase inverse are accomplished at the same moment t_o . This results in stored energy discharge from the

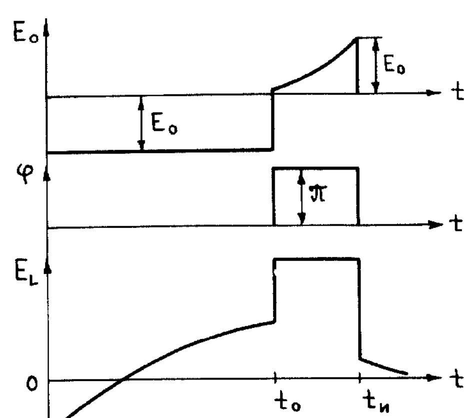

Fig.2. Linac operating time diograms.

cavities. The discharging period duration equals to the rest part of generator RF pulse one (time interval from t_o to t_u). Amplitude modulation of the amplifire 2 output wave takes place within this period. It's accomplished by the amplifire exited wave modulation as well as it is for the phase modulation. Auxiliary amplifier 7 with shaped pulse generator 8 and a highspeed phaseshifter 3 are used for this combined amplitude-phase modulation. As a result a flat top output waveform RF pulse is formed at an accelerating structure input. In order the pulse top to be a really flat the amplifire 2 output wave amplitude must be changing in accodance with a cirtain law.

To define this law one could consider an equation for cavity emitted wave amplitude E_e [2] :

$$T_c \frac{dE_e}{dt} + E_e = -\alpha E_o \qquad (1)$$

where E_o-amplifire output wave amplitude; $\alpha = 2\beta/(1+\beta)$; ; $T_c = Q_o/\pi f_o(1+\beta)$- cavity time constant; β - cavity coupling factor; Q_o and f_o - cavity unloaded Q - factor and frequency, respectively.

Considering the amplifire wave E_o to be constant within time interval (0, t_o) and output wave $E_L = E_o(t) + E_e(t)$ to be constant within time interval (t_o, t_u) the solution of equation (1) could be represented as following:

$$E_o(t) = \begin{cases} -E_o \,, & 0 \leq t < t_o \\ -\left\{ \frac{1}{\alpha_2 - 1} E_L + \left[\frac{2\sqrt{\beta_1\beta_2}}{1+\beta_1} E_o \left(1 - e^{-t_o/T_{c1}}\right) - \frac{\alpha_2}{\alpha_2 - 1} E_L \right] e^{\frac{\alpha_2 - 1}{T_{c2}}(t - t_o)} \right\} , & t_o \leq t \leq t_u \end{cases} \qquad (2)$$

where $\alpha_2 = 2\beta_2/(1+\beta_2)$; $T_{c1} = Q_o/\pi f_o(1+\beta_1)$; $T_{c2} = Q_o/\pi f_o(1+\beta_2)$; β_1 and β_2 - cavity coupling factor within energy storage time period (0, t_o) and stored energy using period (t_o , t_u), respectively.

This case an output wave amplitude E_L for corresponding time intervals is:

$$E_L(t) = \begin{cases} -\alpha_1 E_o e^{-t/T_{c1}} + (\alpha_1 - 1)E_o \,, & 0 < t < t_o \\ E_L \,, & t_o \leq t \leq t_u \\ (E_L - E_o) e^{-(t - t_o)/T_{c2}} \,, & t > t_u \end{cases}$$

where $\alpha_1 = 2\beta_1/(1+\beta_1)$.

The analisis of equation (2) shows that a power upgrade factor $K_p = (E_L/E_o)^2$ for certain output RF pulse duration $\Delta t = t_u - t_o$ reaches its maximum value for quite concrete cavity coupling factors β_1 and β_2. Curves of power upgrade factor dependens against cavity coupling factors values are shown in fig.3. The curves are given for alternating coupling ($\beta_1 \neq \beta_2$) and constant coupling ($\beta_1 = \beta_2 = \beta$) systems bouth. Coupling factors β_1 and β_2 are equal to its optium values.

EXPERIMENTS

A 30 MeV electron linac was used for experimental investigations of this RF energy compression system. The main parameters of this linac are the following: accelerated beam energy 10-30 MeV; beam current 0-300 mA; amplifire output power 20 MW; RF pulse duration 2.5 μS ; accelerated structure length 4.4 m; loading factor a/λ = 0.14.

A cylindrical cavities with quality factor $Q_o = 90\cdot10^3$ and coupling factor $\beta = 10$ are used as an energy storage elements in experimental unit. It

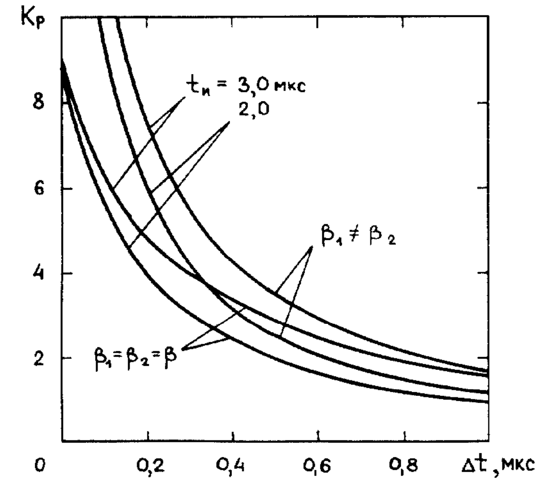

Fig.3. Curves of upgrade factor K_p v.s. pulse duration Δt for optimum value of coupling factors β_1 , β_2 and β .

is a constant coupling system. Complicated amplitude-phase modulation was carried out with the help of highspeed phaseshifter based on semiconducter elements (phase modulation) and an auxiliary amplifire based on a traveling wave tube controlled by a shaped pulse generator (amplitude modulation).

Experimentally measured values of power upgrade factor K_p v.s. output pulse duration Δt are given at fig.4. The same dependens but calculated for the same values of Q_o and β are shown here also.

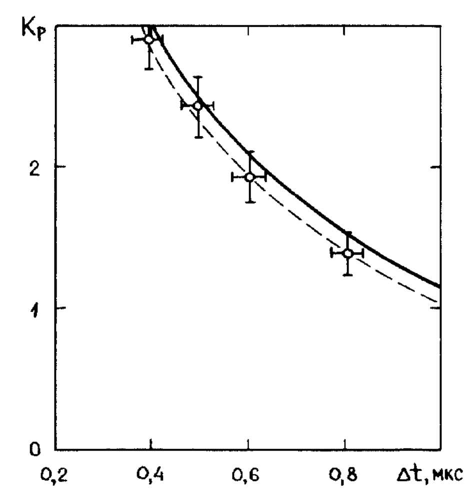

Fig.4. Measured (– – –) and calculatid (———) values of K_p for cavity with $Q_o = 90\cdot10^3$ and β = 10.

Experiments accomplished to investigate a linac beam energy spread behaviour when using an amplitude-phase modulation of an RF generator wave show that a beam energy spread (at a half-height level) for output puls duration from 0.4 to 1.0 μS in this case is about 4-5 times narrow that it is for SLED system (i.e. without amplitude modulation) [3] . Here it makes 2-3 % . A typical beam energy spectra obtained by a magnetic analyser are given in fig.5. For the same operating parameters of the linac a beam energy spectra for SLED system use are given also.

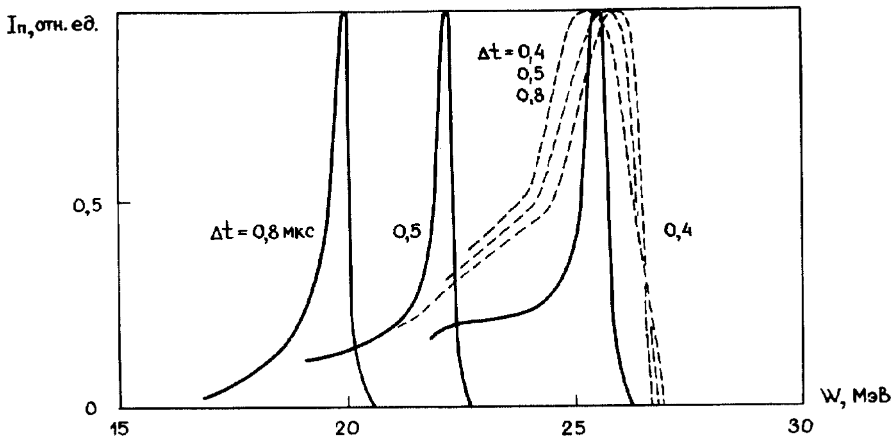

Fig.5. Accelerated beam energy spectra for RF energy compression system with (———) and without (— — —) amplitude-phase modulation.

As a result one may point out that a linac accelerated beam increase without energy spread widen can be achieved by using an RF energy compression system with cavities as an energy storage elements and amplitude-phase modulation of a generator wave for linac RF feeding. A beam energy spread in this case would be at least not wider then it's for initial linac configuration (without any compression system). It allows to make an energy compression system with storage cavities application field much wider.

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