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AN INVESTIGATION INTO THE EFFECTS OF CURRENT PULSE SHORTENING IN MULTISECTION LINEAR ACCELERATORS

A. I. Zykov, I. A. Grishayev, V. A. Vishnyakov
N. I. Mocheshnikov, and G. D. Kramskoy*

In the course of work with a 2 Gev accelerator it was established that it is quite difficult to produce the average accelerated current of the order of 1 microampere at the output. It was also established that the increase above a certain limit of the current (drawn from an injector 800 mm long, with an energy of 6 Mev) injected in the accelerator, does not

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Translated by
Leo Kanner Associates
Redwood City, Calif.
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increase the current at the output of the entire accelerator, because here we observe a noticeable shortening of the current pulse. Formerly it was considered that the maximum current of a linear accelerator is determined at a prescribed duty ratio, only by the load characteristics of the accelerating structure and the value of the high-frequency power introduced into the accelerator. However, from 1961 on, works [1,2,3] appear in the literature in which phenomena are investigated, which were termed "current pulse shortening", "beam destruction", etc.

It was shown that with a certain value of the pulse current introduced in the accelerator, determined in each specific instance by a whole series of factors -- length of the accelerator, geometry of the accelerating wave-guide, the working oscillation type, the amplitude of the accelerating field, etc., in the accelerator a parasitic wave is excited, which results in a deflection of the beam and its falling on the walls of the wave-guide, which is the cause of shortening of the current pulse. We must emphasize that in the works [1,2,3] mentioned accelerators were investigated which consisted as a rule, of an injector and a single section, i. e. accelerators with energies of 10-30 Mev. Moreover, it was mentioned that the critical current value below which the "shortening" is not observed, is usually not less than 200 mA and/or much higher, depending on the type of the accelerating structure.

Thus, the "shortening" phenomenon applied to the multisection accelerator was not reflected in the literature.

Actually it was vaguely assumed that the critical current at the output of a multisection accelerator consisting of identical sections, will be at least of the same order as the critical current for one accelerating section of which it consists.

We have performed certain measurements in the study of the current pulse shortening phenomenon in energies of 300 Mev and 2 Gev [4,5]. The character of the destruction of the beam was observed; the amplitude and frequency of oscillations generated by the beam were measured; the change of the amplitude of the hybrid wave upon the displacement of the axis of the accelerating system was measured; the dependence of the maximum value of the current at which the beam destruction effect is observed, on the length of the accelerator was found.

The current pulse shortening begins from the rear front, inasmuch as the last electrons are in the strongest transverse deflecting field. In Fig. 1a we show the characteristic process of current pulse shortening in one of the sections of the accelerator upon an increase of the current pulse value. In Fig. 1b we show oscillograms of high frequency oscillation envelope excited by the wave beam, with the basic accelerator operating frequency of 2797 megacycles, and various pulse current values, and in Fig. 1c we show the oscillograms of oscillations excited by the parasitic wave beam. The measured frequency of parasitic oscillations, identical for all accelerating sections, proved to be 3922 ± 4 megacycles, which coincides well with the frequency predicted by high-frequency measurements. In Fig. 2 we show the dispersion characteristic of the first hybrid wave EH_{11}. On the horizontal axis we measure off the phase shift on the wave-guide cell, on the vertical -- the frequency in megacycles. The straight line corresponds to the condition that $V_{\phi} = c$. Its point of intersection with the curve takes place when the frequency is 3922 megacycles and the phase shift is 125.6^{θ}.

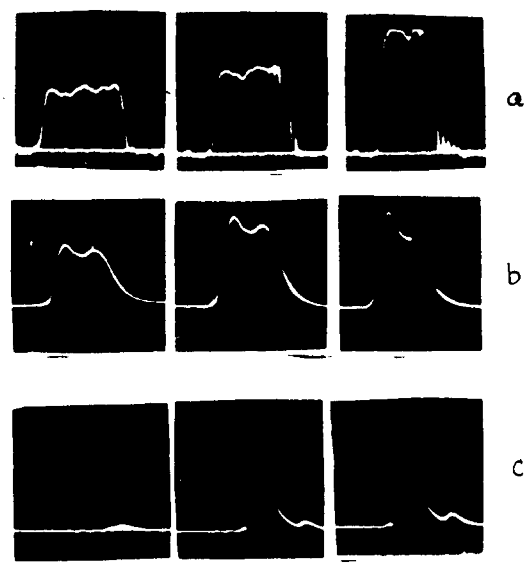

Fig. 1.

Pulse Oscillograms Before and After Destruction of the Beam: a) current pulses, b) pulses of waves excited at the frequency of 2792 megacycles, c) pulses excited at the frequency of 3922 megacycles.

As we can see in Fig. 1, prior to the appearance of a current pulse shortening the power of hybrid disrupting waves is low, but that upon the appearance of this effect the power of the hybrid wave grows sharply. In Fig. 3 we show the dependences of the hybrid wave amplitude on the current pulse measured in various sections (the curve parameter is the section number). As we can see from this figure the relationships have a threshold character and the further is the point of observation located, the smaller are the currents with which the hybrid wave is excited and the smaller are the currents with which the beam destruction occurs, in spite of the fact that the electron energy grows continuously. The maximum pulse current at which the pulse shortening begins is mainly established by the length of the accelerator. In Fig. 4 we show the dependence of the maximum current value on the length of the accelerator composed of 50 accelerating sections with and without focusing. With a well-formed electron flux the maximum value of the current grows.

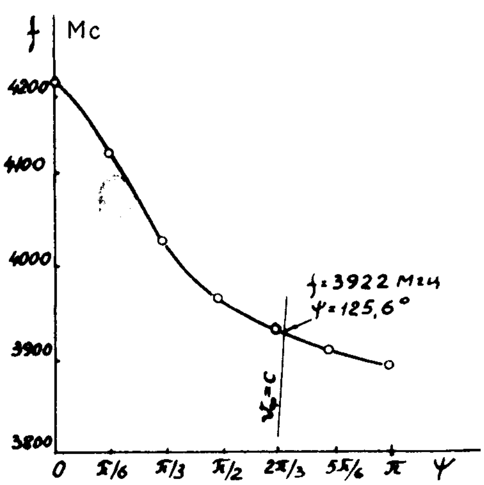

Fig. 2.

Dispersion Characteristic of the First Hybrid Wave of the EH_{Π} Type.

We should remark that the maximum current value of one section of which the accelerator is composed, is equal to 180ma.

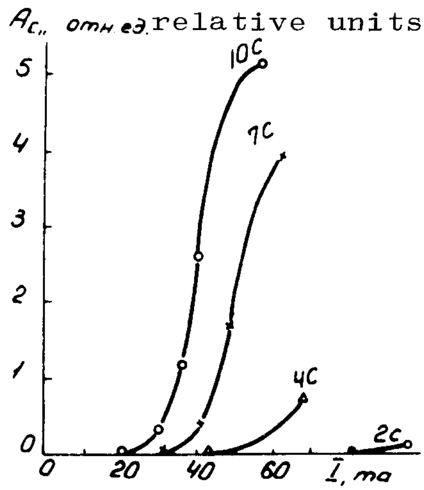

Fig. 3.

Dependence of the Hybrid Wave Amplitude on the Injected Current

Of great importance in the increase of accelerator intensity is the correct orientation of the beam along the axis of the system. Even small deviations of the beam from the axis decrease the maximum values of currents. In Fig. 5 we show the relationships of amplitudes generated by a wave beam upon the shift of the beam from the axis of the accelerating wave-guide. Dotted-line curves portray the amplitude relationship of the main E_{01} wave, the solid-line curves -- those of the hybrid EH_{11} wave. The upper curve corresponds to the relationship measured upon the shift of the beam in the horizontal sense, the lower -- in the vertical sense. The asymmetry of curves in the upper graph indicates the asymmetry of the beam in the horizontal sense. This is usually verified by visual observations of the beam shape on scintillator screens.

On the curve the beam deflection is given in relative units. As we can see from these curves, shifting of the beam from the axis results in a sharp increase of the hybrid wave amplitude.

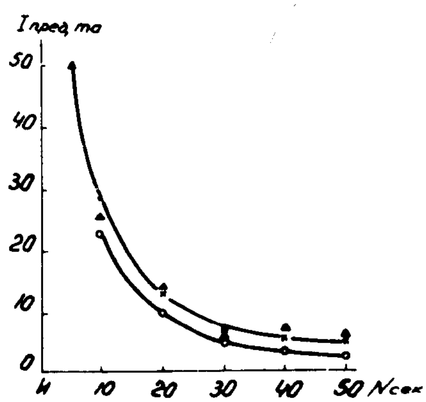

Fig. 4.

Dependence of the Maximum Current on Accelerator Length With and Without Focusing

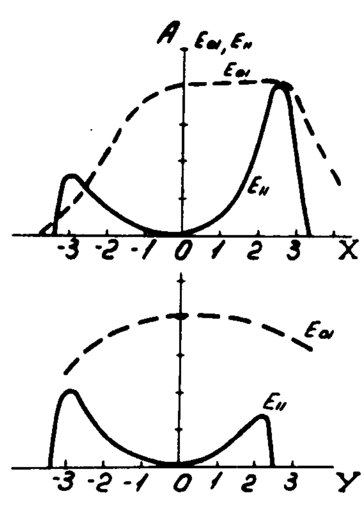

Fig. 5.

Dependence of the Amplitudes of Waves E_{01} and E_{11} on the Position of the Beam Along the Radius. Scale: 3 Divisions Correspond to a 10 mm Shift of the Beam Center

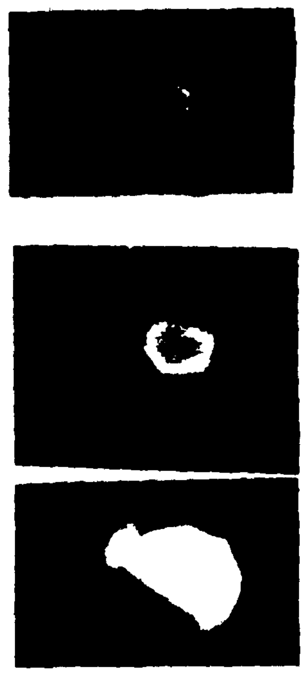

Fig. 6.

Shape of the Beam Upon Shortening.

The polarization plane of the hybrid wave is not stable in time and varies from pulse to pulse. This corroborates the hypothesis that the primary cause of excitation of parasitic waves are the fluctuation noises existing in the moderating system.

In the photograph, Fig. 6 we give the characteristic shape of the beam cross section upon the development of the shortening phenomenon. We can see that with the increase of current there is an increase not only of the brightness of the main beam, but to an even greater degree, of the halo caused by the destruction of the beam.

The measurements performed allow us to draw the conclusion that a multisection accelerator with the uniform structure of the diaphragmed wave-guide is a distinctive modification of the multi-cascade return wave generator with a transverse field and relativistic beam. Its specific nature lies in the fact that the communication between the cascades (in this case accelerating sections) is performed through the beam.

The principal means of weakening the effect of transverse waves on beam stability can be, apparently, the exchange of accelerating sections with a constant structures for sections with variable dimensions and a constant field, or separation of the existing sections into shorter sections with hybrid frequency filters between the sectors. The rationality of the second method can be evaluated only upon the development of a calculated model of the dependence of the critical current on the length of the accelerator, which can be checked experimentally.

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