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OPERATION OF THE LINAC-INJECTOR MODULATOR INTO A MISMATCHED LOAD

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ABSTRACT

The results of analysis of an artificial line modulator operating into a mismatched load with resistance less than the output resistance of the modulator are given. The analysis was carried out for three versions of modulator circuits: (a) and (b) corresponding to modulators with inverse voltage clipper and without one and (c) corresponding to a modulator with polarity reversal of inverse voltage. It is shown that the modulator with polarity reversal of inverse voltage has some positive features. Formulas for calculating the parameters of this type of modulator are given.

I. INTRODUCTION

Pulse modulators of linac-injectors are usually operated under small duty factors. Under these conditions such positive qualities of discharge-type devices (thyrotrons, thyristors) as absence or small outlay for heaters, high efficiency, etc., are shown the most clearly. Nevertheless, modulators with such devices possess definite shortcomings: low efficiency of artificial lines (AL) charging through resistors, nonuniform loading of the power supply, etc. Under AL feeding through a charging choke there are difficulties with voltage stabilization. It is shown in this work that there are possible conditions of modulators with AL charged through resistance, when the inherent shortcomings are developed less than usually. For simplification in getting the qualitative data, it is assumed that there are no losses in circuit elements, except resistors, that the AL is a line of split capacitor sections, and that the AL is fed through the stabilizer tube operating under a switching regime.

II. ARTIFICIAL LINE OPERATION AND ENERGY BALANCE OF MODULATOR

The concept of mismatching means that the characteristic impedance, ρ, and load resistance, R_e, are unequal, or $K = \frac{\rho}{R_e} \neq 1$. The necessity of conservation of definite pulse duration requires that the AL total capacitance and inductance values must be

$$C_\Sigma = \frac{C^1_\Sigma}{K} \text{ and } L_\Sigma = KL^1_\Sigma. \qquad (1)$$

Here, and further, the index "1" means that the parameter refers to fully matched modulator, i.e., with K = 1.

Mismatching causes distortions of two types. The first arise because of incomplete absorption by the load of waves propagating in the AL.[1] Distortions of this type have the form of additional pulses after the main one. If a rectifier modulator device is used, there is only $\tau = \sqrt{L_\Sigma C_\Sigma}$ duration of the first pulse on the load when K > 1 (Fig. 1). The second type of distortion is due to AL transmission band change; this changes the form of the main pulse and may be compensated by increasing the number of AL sections. The increase necessary for compensation may be calculated by comparison of transmission factors of matched and mismatched ALs on the cutoff frequency of the matched AL. Considering the AL to be a delay line of double length[2] and understanding it as "η" - LC sections,[3] it is possible to get the next equation connecting AL section numbers and mismatching "K" as

$$\left[1 + 4\left(\frac{n}{n^1}\right)^4\right]^{n-1}\left[1 - 4(K^2-1)\left(\frac{n}{n^1}\right)^2 + 4\left(\frac{n}{n^1}\right)^4\right] = 5^{n^1}. \quad (2)$$

Let us now analyze the circuit of modulator with inverse voltage reversal (Fig. 2). From the energy balance equation,

$$W_e = P\tau = \frac{C_\Sigma U_{pr}^2}{2} - \frac{C_\Sigma U_{rem}^2}{2} = 2KC_\Sigma U_e^2, \quad (3)$$

where

U_{pr} = primary voltage of AL,
U_{rem} = remaining voltage of AL,
W_e = energy absorbed by load,
P = modulator pulse power, and
U_e = load voltage,

it is possible to find out that

$$U_{rem} = \pm \frac{K-1}{K+1} U_{pr}. \quad (4)$$

It is evident that for this circuit it is necessary to take positive values of expression (4).

Energy dissipated by the charging resistor R_c for one period may be written as

$$W_{R_c} = R_c \int_0^{t_{pr}} i^2(t)dt = \frac{C_\Sigma}{2}(U_{pr}-U_{rem})(E-U_{pr}-U_{rem}), \quad (5)$$

where t_{pr} is the time when the AL voltage reaches the value of U_{pr}.

By combining the expressions (3), (4), and (5) one may get an expression for modulator efficiency,

$$\eta = \gamma \frac{K}{K+1}, \quad (6)$$

where $\gamma = \frac{U_{pr}}{E}$ is the supply voltage utilization index. As it may be seen from expressions (5) and (6), the whole power dissipated by the charging resistor does not depend upon its value under aperiodic charging. So it must be such that it will be possible to charge the AL up to the voltage not less than U_{pr} during the minimum period, T_{min}, with the minimum power-supply load. Calculated with this limitation, the value of the charging resistor is determined by

$$R_c \leq \frac{2R_e}{D_{max}} \frac{K}{\ell n \frac{K+1-\gamma(K-1)}{(K+1)(1-\gamma)}}, \quad (7)$$

where D_{max} is the maximum duty factor.

On Fig. 3, the dependence (7) is shown in normalized form, i.e.,

$$\tau = \frac{R_c}{R_c^1} \leq \frac{\ell n \frac{1}{1-\gamma}}{\ell n \frac{K+1-\gamma(K-1)}{(K+1)(1-\gamma}}. \quad (8)$$

III. PEAK SUPPLY LOADING

Peak supply loadings are fully determined by the values of the charging resistor and the voltage applied to it after the process of polarity reversal completion. Further, there are given expressions for peak supply loading by current and power:

$$\mathcal{J}_{peak} = \frac{E-U_{rem}}{R_c} \geq \frac{\mathcal{J}_e D_{max}}{2} \frac{[K+1-\gamma(K-1)]\ell n \frac{K+1-\gamma(K-1)}{(K+1)(1-\gamma)}}{K_\gamma} \quad (9)$$

and

$$P_{peak} = \frac{E(E-U_{rem})}{R_3} \geq \frac{PD_{max}}{2}$$
$$\frac{(K+1)[K+1-\gamma(K-1)]\ell n \frac{K+1-\gamma(K-1)}{(K+1)(1-\gamma)}}{K_\gamma^2}, \quad (10)$$

where $\mathcal{J}_e$ is the pulse current in the load.

Normalized to the current and power loading of a fully matched modulator, these expressions give the dependences of supply loading on a mismatched "K."

$$i = \frac{\mathcal{J}_{peak}}{\mathcal{J}_{peak}^1} \geq \frac{[K+1-\gamma(K-1)]\ell n \frac{K+1-\gamma(K-1)}{(K+1)(1-\gamma)}}{2K\ell n \frac{1}{1-\gamma}} \quad (9a)$$

$$p = \frac{P_{peak}}{P_{peak}^1} \geq \frac{(K+1)[K+1-\gamma(K-1)]\ell n \frac{K+1-\gamma(L-1)}{(K+1)(1-\gamma)}}{4K\ell n \frac{1}{1-\gamma}}. \quad (10a)$$

Both of these expressions are shown on Fig. 4 for $\gamma = 0.9$. Current consumed during the pulse for the present circuit is practically short-circuit current. Its value may be calculated from the expression,

$$\mathcal{J}_p = \frac{\mathcal{J}_e D_{max}}{2} \frac{(K+1)\ell n \frac{K+1-\gamma(K-1)}{(K+1)(1-\gamma)}}{K}. \quad (11)$$

Dependence of supply loading on mismatched "K" is clearly seen from the expression,

$$\nu = \frac{\mathfrak{J}_p}{\mathfrak{J}_{peak}} = \gamma \frac{K+1}{K+1-\gamma(K-1)} . \qquad (12)$$

The graph of this expression is shown on Fig. 4. Just the same loading of the supply takes place during recharging of the modulator device.

Breakdowns in the load change the supply loading during the pauses. If the load resistance is assumed to be zero, then from the expression of energy absorbed by load before breakdown,

$$W_{eB} = W_e \frac{t_B}{\tau} , \qquad (13)$$

Where

W_{eB} = energy absorbed by load before breakdown,

t_B = time of breakdown start,

and it is possible to find that supply current loading is within the limits,

$$0 \leq i_B < 1. \qquad (14)$$

The dependence of short-circuit current in the load may be expressed as,

$$i_{sc} = \frac{K+1}{K} . \qquad (15)$$

IV. ANALYSIS OF RESULTS

One can see that the modulator with mismatched AL and inverse voltage reversal has some advantages relative to the modulator without one or a fully matched modulator. Namely, under equal supply power it is possible to operate with greater frequencies or under lower current consumption, there is no danger of damaging load under breakdowns, the power supply is not overloaded after breakdown in the load, etc. Increase of the number of AL sections cannot be called a negative feature; it is rather a means of adjustment required in AL sections to fit the available types of capacitors.

The efficiency of voltage reversing may be decreased with pulse shortening to durations commensurable with the recharging time of the modulator switching device. This may be avoided by introduction of an inductance into the reversal circuit to slow down the process of voltage reversing. The value of inductance, L_d, must be

$$L_d \geq \frac{\frac{t_d^2}{\tau_1^2} - L_\Sigma C_\Sigma}{C_\Sigma} , \qquad (16)$$

where t_d is the duration of the recharging period.

It is necessary to note that the whole above reasoning is justified also for multiplying ALs.

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REFERENCES

1. I. A. Itskhoki, Pulse Techniques (Moscow, 1949)
2. I. Gonorovskii, Radio-technique Bases (Moscow, 1957), p. 631.
3. A. B. Ivanov and L. N. Sosnovkin, Pulse SHF Transmitters (Moscow, 1956), pp 287 and 302.

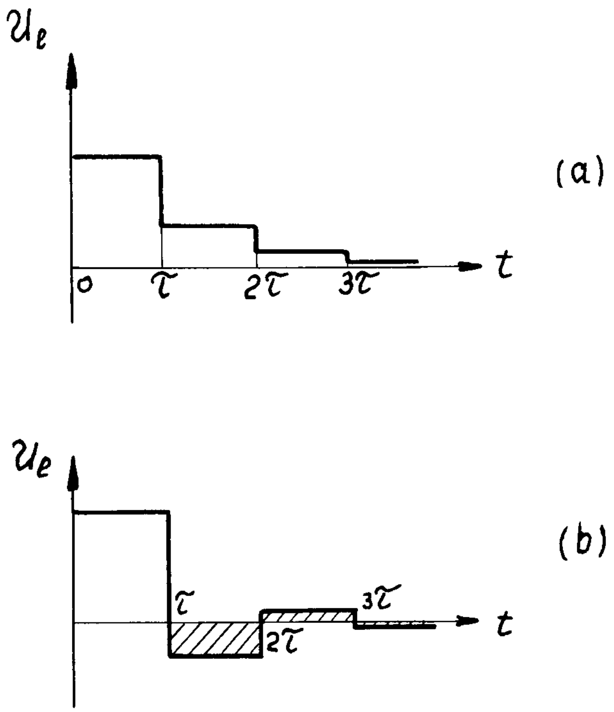

Fig. 1. Pulse shapes in cases: a) K < 1; and b) K > 1.

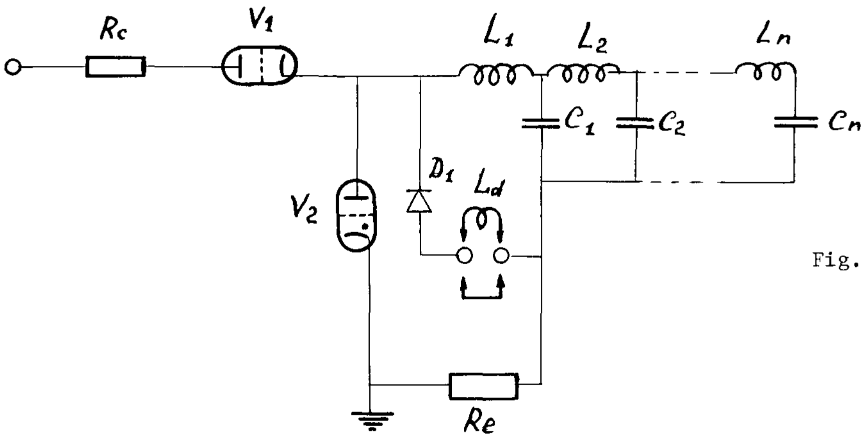

Fig. 2 Modular with inverse voltage reversal.

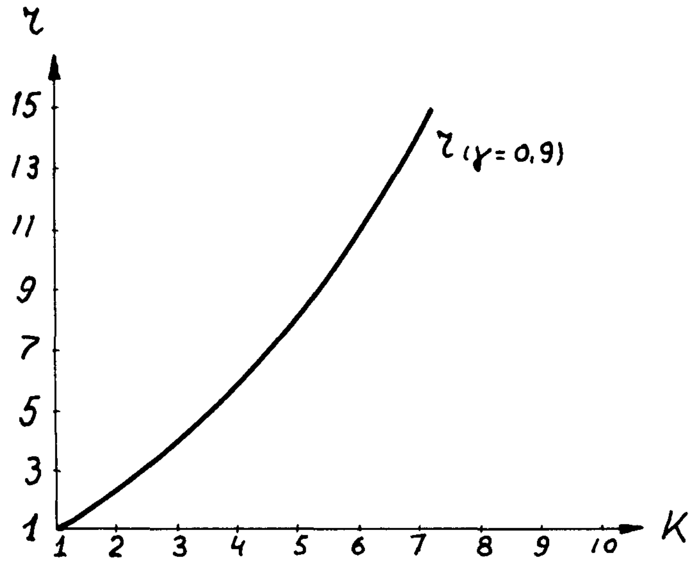

Fig. 3 Charging resistance dependence= on mismatched "K".

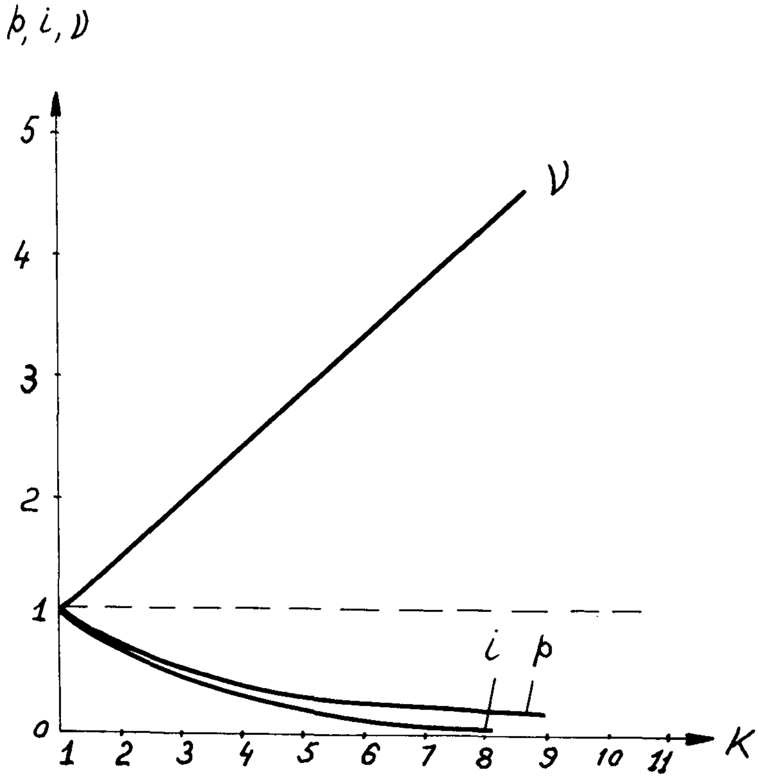

Fig. 4 Power supply loading dependence on mismatched "K". i, peak current loading; p, peak power loading; and ν, current overloading during the pulse.