IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

20-MW PULSED AMPLIFYING KLYSTRON OPERATING IN POSITIVE FEEDBACK MODE

E. M. Laziev, H. G. Oxuzyan, E. S. Pogossyan
Yerevan Physics Institute, Markarian St. 2
375036, Yerevan, Armenia, USSR

The results of investigation of the regenerative oscillation amplification mode and the self-oscillation synchronization mode for the power pulsed amplifying positive-feedback klystron are reported.

Introduction

In Ref. [1] there was described the autogenerator on the КИУ-12 pulsed amplifying klystron [2], used for feeding the accelerating sections of the electron linac. To enhance the self-oscillation frequency stability, a high-quality resonator is introduced into the feedback circuit. This however results in noticeable increase in the oscillation growth time with respect to anode pulse. The investigation results of the КИУ-12 operating either in the oscillation regeneration mode or in the self-oscillation frequency synchronization mode are presented.

A Bit of Theory

The n-resonator amplifying klystron amplitude characteristic can be described by the following formula [3]

$$\dot{U}_{out} = \dot{K}_n(\dot{U}_{inp}, \omega)\,\dot{U}_{inp} \tag{1}$$

where $\dot{U}_{out}$ is load voltage, $\dot{U}_{inp}$ is the klystron input voltage, K_n is the klystron amplification function dependent on $\dot{U}_{inp}$ and frequency ω.

$$\dot{K}_n = \dot{K}_0(\omega)\prod_{\kappa=1}^{n-1}\dot{S}_{\kappa,\kappa-1}(\dot{U}_{inp})\prod_{i=1}^{n}\dot{Z}_i(\omega) \tag{2}$$

where $\dot{K}_0$ is the coefficient dependent only on the oscillation frequency, $\dot{S}_{\kappa,\kappa-1}$ is the mutual conductance of the characteristic for the bunching section between the k-th and (k+1)-th gaps, $\dot{Z}_i$ is the loaded shunt-impedance of the klystron i-th resonator.

Formula (2) is analogous to the expression describing the amplification coefficient of the multistage triode amplifier. In some cases one can, with certain reserve, use this analogy [4] to consider a klystron as operating in the feedback mode. Note also that the phase shift between the input and output signals in the klystron amplifier operating in the linear mode is independent of the input signal amplitude. True, when passing to the maximal power regime, this phase shift becomes amplitude-dependent; however this dependence will be weak if the following conditions hold

$$\begin{gathered} \dot{K}_0(\omega)\,\dot{S}_{\kappa,\kappa-1}\,\dot{Z}_\kappa(\omega) >> 1, \\ \gamma_m \ell_{\kappa,\kappa+1} = \frac{\pi}{2}, \end{gathered} \tag{3}$$

where $\gamma_m = m\omega_p/V_0$ is the phase constant of the electron beam, $m\omega_p$ is the reduced frequency of the electron beam self-oscillations with the reduction coefficient m, $\ell_{\kappa,\kappa+1}$ is the distance between the gap centres of the k-th and (k+1)-th resonators, J_0 is the beam current, V_0 is the electron velocity at accelerating voltage U_0, and

$$\omega_p = 1{,}03\cdot 10^{10}\sqrt{J_0}/r\sqrt{U_0}$$

r is the electron beam radius.

Thus, modelling the КИУ-12 as a multistage amplifier enabled us to construct the approximate calculation formula for the amplification coefficient of this klystron in the regeneration mode. As the obtained expressions are cumbersome, we shall give only the calculation results at various values of feedback and their comparison with the experimentally measured ones. The formula allowing to calculate the autogenerator synchronization was obtained in the same way.

The Set-up Description

Fig. 1 presents a simplified block diagram of the set-up. The figure is supplied with all necessary designations, so it needs no comments. Note only

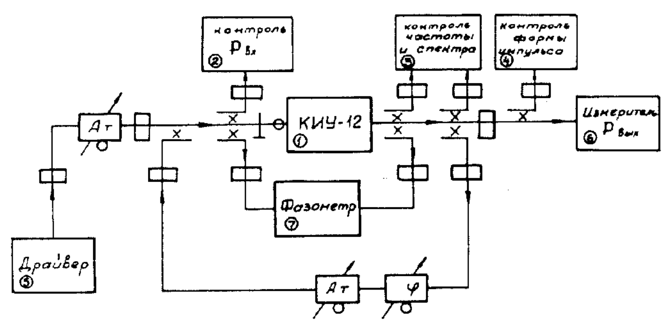

Fig. 1. A simplified block diagram of the set-up.

that attenuation in the feedback circuit can be varied from 30 db to 55 db using calibrated attenuators. The phase in the feedback circuit varied within ±180° using the calibrated phase shifter. All the waveguide tracts were supplied with the units allowing operative control of the standing wave mode.

Regenerative Amplification Mode

Fig. 2 shows the experimental and calculation dependences of the amplification coefficient for the klystron with positive feedback at various attenuation values in the circuit of the latter. The dotted straight line presents the amplification coefficient corresponding to the maximal power at the klystron output P_{max} = const., P_{opt} is the input power at which the output power for the klystron without feedback is equal to P_{max}. In the regenerative amplification mode the phase balance is satisfied, the feedback coefficient must be less than the critical one. As expected, all instabilities sharply increase with reducing attenuation in the feedback circuit.

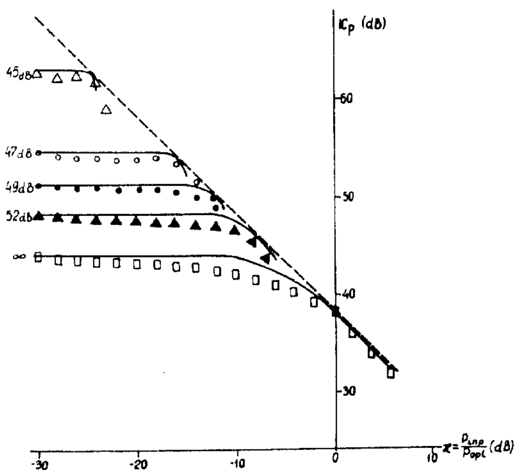

Fig. 2. The amplification coefficient as a function of input power at various values of attenuation in the feedback circuit. The dotted line refers to amplification coefficient corresponding to the maximal output power. P_{max} = const.

Self-oscillation Synchronization Mode

To determine the self-oscillation synchronization region for the КИУ generator we have used the well-known expression

$$\Delta f = \frac{f_0 (P_s/P_{opt})^{1/2}}{Q(1 - P_s/P_{opt})} \tag{4}$$

where f_0 is the central frequency, P_s is the synchronizing signal power, Q is the self-oscillating system high quality. As is shown in [5] , the behaviour of the outer-synchronization pulsed generators resembles that of the synchronized continuous-wave oscillators.

Fig. 3 presents the calculation and experimental dependences of the synchronization band on the ratio P_s/P_{opt} at various Q .

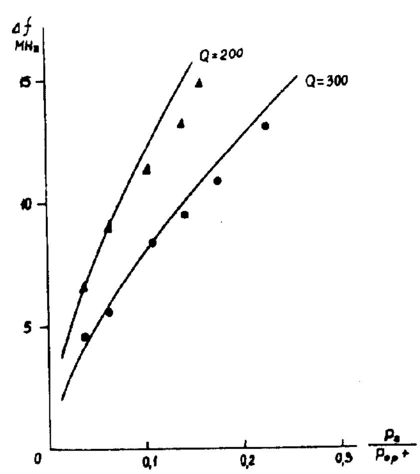

Fig. 3

Conclusions

The performed investigations have shown that can successfully be used for the regenerative amplification of oscillations. However this operation mode demands voltage high stabilization, as the system very easily goes into self-oscillation mode, though gives an essential decrease in input power.

When using КИУ in autogeneration mode with frequency synchronization, the input power decrease is a factor of 2-3. This mode is being used during the last few years for the КИУ feeding the accelerating sections of the Yerevan 50-MeV electron linac.

References

1 H. G. Oxuzyan, E. M. Laziev, V. L. Serov et al., "A Power Amplifying Klystron as a Self-Oscillator," Voprosi Atomnoy Nauki i Tekhniki, Fizika Visokikh Energii i Atomnogo Yadra, issue 4 (6), 1973.

2 P. R. Kalish, N. I. Yarochkin, Amplifying Klystrons. Izd. Sov. Radio, Moscow, 1967.

3 A. Z. Khaikov, Amplifying Klystrons. Izd. Sviaz', Moscow, 1974.

4 M. V. Vambersky, V. I. Kazantsev and S. A. Shelukhin, VHF Transmitters. Izd. Visshaya Shkola, Moscow, 1984.

5 F. M. Magalhaes, W. O. Schlosser, "Synchronization of Pulsed Oscillators", in Proceedings IEEE, 1968, vol. 56, No. 5, pp. 118-119.