INVESTIGATION OF STATIONARY AND NON-STATIONARY PROCESSES IN A X-BAND MICROSECOND RELATIVISTIC GYROTRON

R.M.Rozental [(1)], N.I. Zaitsev [(2)], N.S.Ginzburg [(3)], E.V.Ilyakov [(4)], I.S.Kulagin [(5)], V.K.Lygin [(6)], M.A.Moiseev [(7)], N.A.Zavolsky [(8)], V.E.Zapevalov [(9)]

[(1)] *Institute of Applied Physics, Russian Academy of Sciences,*
603950, Russia, Nizhny Novgorod, GSP-120, Ulyanov St.,46
E-mail: rrz@appl.sci-nnov.ru
[(2)] *As (1) above, but E-mail: zaitsev@appl.sci-nnov.ru*
[(3)] *As (1) above, but E-mail: ginzburg@appl.sci-nnov.ru*
[(4)] *As (1) above, but E-mail: ilyakov@appl.sci-nnov.ru*
[(5)] *As (1) above, but E-mail: ikulagin@appl.sci-nnov.ru*
[(6)] *As (1) above, but E-mail: lygin@appl.sci-nnov.ru*
[(7)] *As (1) above, but E-mail: moiseev@appl.sci-nnov.ru*
[(8)] *As (1) above, but E-mail: zavolsky@appl.sci-nnov.ru*
[(9)] *As (1) above, but E-mail: zapev@appl.sci-nnov.ru*

At present, the sub-relativistic gyrotrons are the most effective sources of high-power radiation in the millimeter wavelength range. Evidently, an increase in the radiation power can be achieved only basing on the increase in operating currents and voltages, including passing over to relativistic energies. It was shown theoretically [1], that the efficiency of the gyrotron remains on the sufficiently high level of about 50 % at the moderately relativistic energy range. This was experimentally confirmed in the experiments performed at the Institute of Applied Physics (RAS), where the X-band relativistic gyrotron with beam voltage of the 280 kV produced the microwave pulses with the efficiency of about 50%. Tab.1 presents the main results achieved in this experiments [2]. This experiments showed that the potential possibilities of gyrotrons are still no exhausted – neither in the output radiation power level, nor with respect to the operating range. This statement can be also valid with respect to the possible generation regimes, in view of the possible multifrequency self-modulation operation modes.

It should be noted that recently the problem of generation of powerful radiation with multifrequency spectrum investigated in several theoretical and experimental works. In particular, periodic and stochastic self-modulation regimes at an average power of up to 2 MW in a relativistic 3-cm backward-wave oscillator have been observed in our experiments [3].

The theoretical study of the non-stationary processes in gyrotrons with traditional configuration of the interaction space (a weakly irregular waveguide matched with an output section) demonstrates that the self-modulation regimes occur only when the injection current exceeds the start threshold magnitude by factor of 10 [4]. To reduce the bifurcation currents by several times, the delayed feedback formed by the additional reflections from a collector side of the interaction space has been suggested in [5]. This effect was exploited to explain expansion of generation spectrum in nonrelativistic gyrotron [6], where additional reflections were introduced by a mismatched of the output window. Nevertheless, at these experiments the self-modulation regimes were observed only at power levels of tens kilowatts [7].

Table 1. Basic parameters of relativistic X-band gyrotron

Operating mode Wavelength	TE_{01} 3.25 cm		
Electron beam energy Beam current	280 keV 45 A	280 keV 60 A	270 keV 120 A
Output power Efficiency	7 MW 55 %	8 MW 47 %	10 MW 32 %
Pulse duration	> 6 μs		

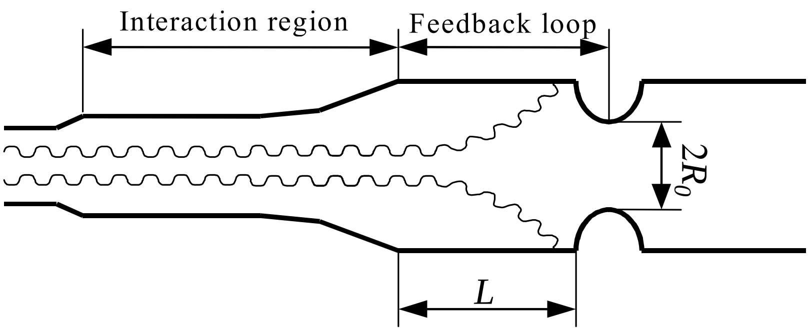

Fig.1. The layout of the interaction space.

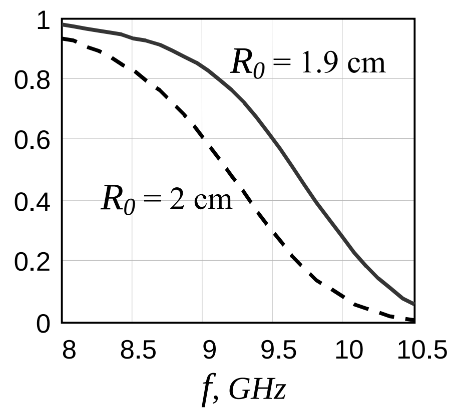

Fig.2. The calculated power reflectivity vs. frequency.

In this paper we present the results of an experimental observation of periodic self-modulation regimes in the 3-cm relativistic gyrotron operating at the TE_{01} mode with the delayed feedback. The delayed feedback were formed by a special reflectors with internal radius equal 1.9 and 2 cm. The reflectors were spaced by $L \approx 9$ cm from a connection of the resonator opening and the output waveguide section (Fig.1). The calculated power reflection coefficient for both reflectors presented in Fig.2.

In experiments at an operating voltage of 230 kV the electron beam current changed from 10 to 70 A. The current control was made by varying the temperature of the thermionic cathode of the three-electrodes magnetron injection gun. The output signal was registered by a crystal detector with the rise time of 2 ns and was recorded using a digital oscilloscope with the pass band of 500 MHz and the sampling period of 0.4 ns. To specify the signal spectrum a heterodyning technique was also used. The microwave energy in the pulse was measured with a special calorimeter enabled the determination of the pulse energy and, hence, output power with the accuracy ±10 %.

The typical accelerating voltage and signal oscilloscope trace in the periodic self-modulation regime is presented in Fig.3. The total duration of a self-modulation in the output signal exceeded 6 μs, that corresponded to the length of a flat-top of the accelerating voltage pulse.

For the reflector with internal radius 2 cm the periodic self-modulation regime started when the beam current exceeded 50 A. The average output power achieved 1.9 MW with efficiency 15 % at the current of 55 A and the modulation depth was about 20 %. When the beam current was increased up to 70 A the average output power decreased down to 1.3 MW and efficiency down to 8 %. At the same time the modulation depth increased up to 35 % (Fig.4).

Note, however that for the small injection current of 11-13 A the stationary oscillations with the efficiency exceeded 50 % was observed. The output power achieved 1.5 MW under these conditions.

When the reflector internal radius was decreased to 1.9 cm the power reflection increased from the 50 % to 75 % at the central frequency of 9.22 GHz. In this case the bifurcation current of the non-stationary oscillations reduced less then 30 A. The averaged output power achieved 1 MW with the efficiency of about 9 % at the injection current of 50 A

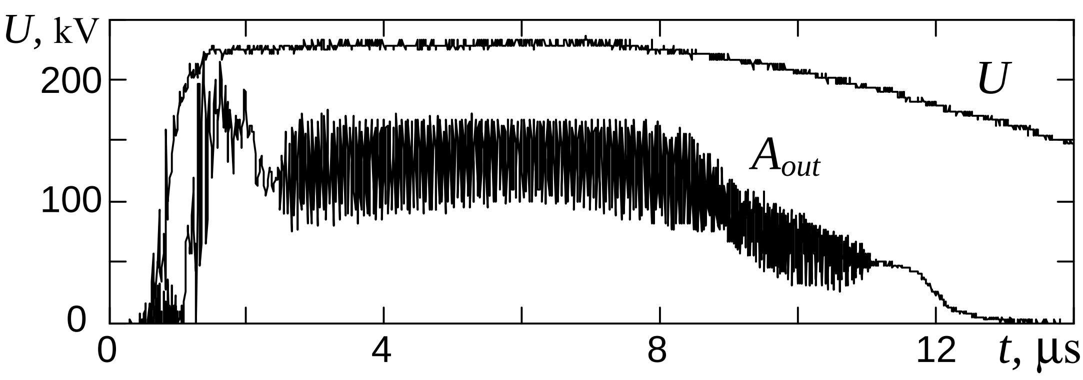

Fig.3. The typical oscillograms of the accelerated voltage and the output signal in the periodic self-modulation regime.

and about 0.8 MW with the efficiency 5 % at the current of 65 A. The modulation depth grows from 50 % to 60 % correspondingly (Fig.5).

One can see, that the increase of the reflectivity factor complicates the self-modulation pattern. In particular, for the reflector with internal radius 2 cm only single satellite frequency is presented at the signal spectrum, that corresponding the period of self-modulation from 15 to 15.4 ns. At the same time, when R_0 was decreased to 1.9 cm the two satellite were observed. In last case the self-modulation period varied from 12.4 to 14.9 ns depending on the magnitude of the resonance magnetic field.

This work was supported by the Russian Foundation for Basic Research (Grant No.01-02-17173 and 00-02-16412a).

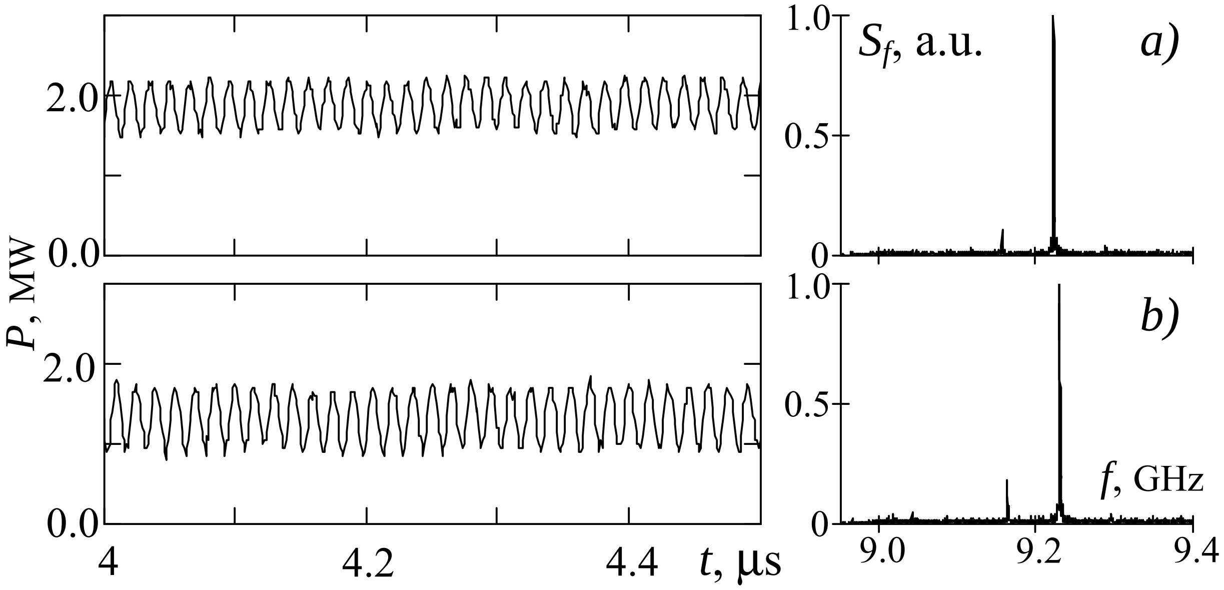

Fig.4. The oscilloscope traces and the corresponding spectra for the gyrotron configuration with reflector radius R_0 = 2 cm: *(a)* beam current 55 A, *(b)* beam current 70 A.

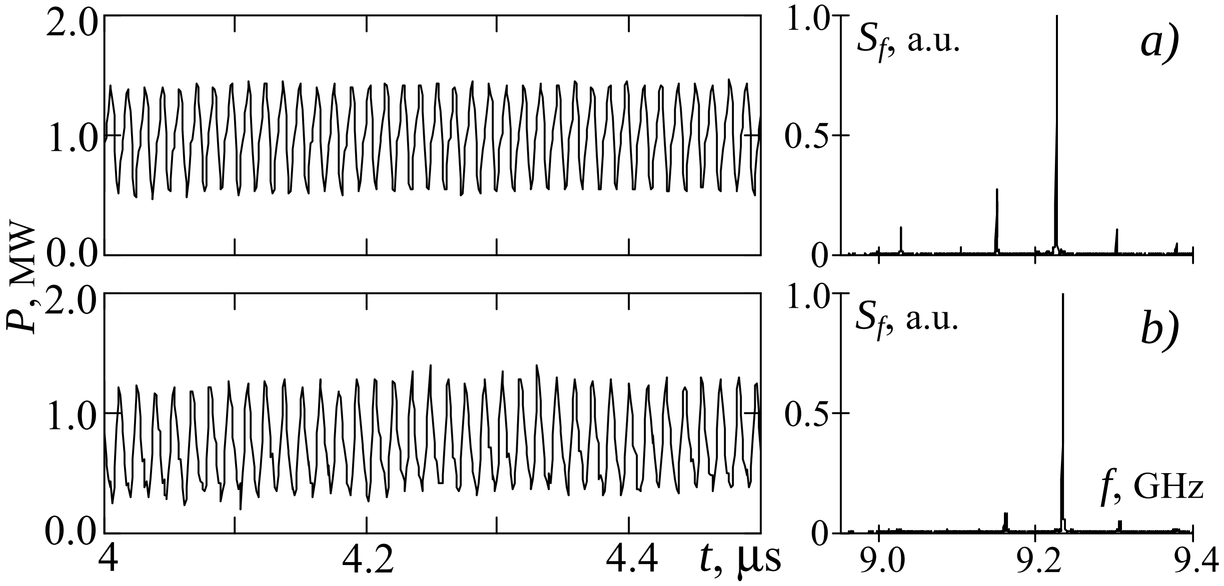

Fig.5. The oscilloscope traces and the corresponding spectra for the configuration with reflector R_0 = 1.9 cm: *(a)* beam current 50 A, *(b)* beam current 65 A.

REFERENCES

[1] M.A. Moiseev, V.E. Zapevalov, and N.A. Zavolsky // Int. J. IR & MM Waves, v.22, no.6, p.813, 2001.
[2] N.S.Ginzburg, N.I.Zaitsev, E.V.Ilyakov, et al. // Tech.Phys.Lett., v.27, no.4, p.266, 2001.
[3] N.S.Ginzburg, N.I.Zaitsev, E.V.Ilyakov, et al. // Tech.Phys., v.46, no.11, 2001, p.73.
[4] N.S.Ginzburg, G.S.Nusinovich, and N.A.Zavolsky. // Int.J.Electron., v.61, p.881, 1986.
[5] N.S.Ginzburg, M.Yu.Glyavin, N.A.Zavolsky, et al. // Tech.Phys.Lett., v.24, no.6, p.436, 1998.
[6] M.Yu.Glyavin, V.E.Zapevalov, A.N.Kuftin, and A.G.Luchinin // Radiophys.& Quant.Electron., v.43, no.4, p.369, 2000.
[7] Chang T.H., Chen S.H., Barnett L.R., and Chu K.R. // Phys.Rev.Lett., v.87, no.6, p.4802, 2001.