Experimental Study of a 30-GHz Gyroklystron Operating at a Sequence of High-Order Modes[1]

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Abstract – A 30-GHz gyroklystron driven by ~ 300 kV helical electron beam operated at the following configurations and parameters:

- **a sequence of TE_{52} – TE_{53} modes delivered the output power 5 MW with 25% efficiency, 30 dB gain and pulse duration of 0.4 μs;**
- **a sequence of TE_{52} –TE_{52} – TE_{53} modes delivered 6.5 MW with 24% efficiency, 34 dB gain and 0.5 μs pulse duration.**

1. Introduction

Multi-megawatt gyroklystrons are developed in the frame of international programme for the next-generation electron-positron colliders [1]. Most of such gyroklystrons [2-6] are designed to operate with the TE_{01} or TE_{02} modes. Such modes are featured with zero electric field at the cavity wall and, so, are RF- breakdown-proof. However, they are not void of the thermal "fatigue" of the wall at the pulse-periodic operation and cannot withstand competition with other modes of the same cavity. From the latter viewpoint, high order non-symmetrical TE_{mp}- modes (similar to those used in megawatt gyrotrons [7]) are more advantageous. These modes have relatively low electric and magnetic fields on cavity walls in comparison with those in the area of interaction with the electron beam.

The possibility of development of a gyroklystron with non-symmetric high-order modes was validated by the results of our previous studies: by development of technology for achieving 150 kV/cm of RF electric strength on a slow-wave structure wall [8]; by creation of the magnetron-injection gun forming a helical electron beam with 280 keV, 60 A and the pitch-factor of 1.3 at the suitable spread of electrons in their transverse velocities [9]; by testing the output cavity in the self-oscillation regime, as the output power over 10 MW with the pulse duration equal to that of accelerating voltage was obtained at the frequency of 30 GHz and mode TE_{53} [10, 11].

The experiments were performed at the single-pulsed electron accelerator "Saturn" [12]. A magnetron being a source of the input signal was fed (through a resistive divider) from the basic pulse-voltage generator. It permitted us to ensure its hard synchronization. Spectra of the input and output signal were measured by the heterodyne method with the use of one common reference generator. The scheme of RF measurements could simultaneously measure envelopes of the input and output signals and the signal reflected from the input cavity, the input and output spectra, the reference frequency of a heterodyne and the energy of the output RF pulse [13].

According to the electron-beam characteristics measured by the magnetic analyser [14], in the most operation regimes the spread of electrons in their transverse velocities amounted to 10 or 15% at the pitch-factor 1 or 1.3.

2. Two-cavity gyroklystron

The specific feature of using the relativistic range of electron energies (near 300 keV and over) in gyroresonant devices is in the fact that for such energies the cylindrical-cavity starting current for the second harmonic of the gyro-frequency becomes lower than that of the basic oscillation. This stimulates to take special measures to select the operation type of oscillations.

The experimental two-cavity gyroklystron is shown schematically in Fig. 1.

According to calculations, the device driven by the electron beam of 280 kV, 60 A and pitch-factor 1.3, is capable to produce the output power of 5 MW at efficiency 30% and gain 30 dB.

The input cavity surface was slightly conic, in order to prevent the cavity from self-excitation of the $TE_{11,3}$ mode at the second harmonic of the gyro-frequency.

The input cavity was made of stainless steel, and output cavity was made of oxygen-free copper. This choice of output cavity material was caused not only by the increased requirements of breakdown strength but also by the possibility to use the body of the cavity as a conducting magnetic screen correcting the pulsed magnetic field in the cavity. Conductivity of the screen depended on the temperature of the gyroklystron system, which permitted us to regulate magnetic

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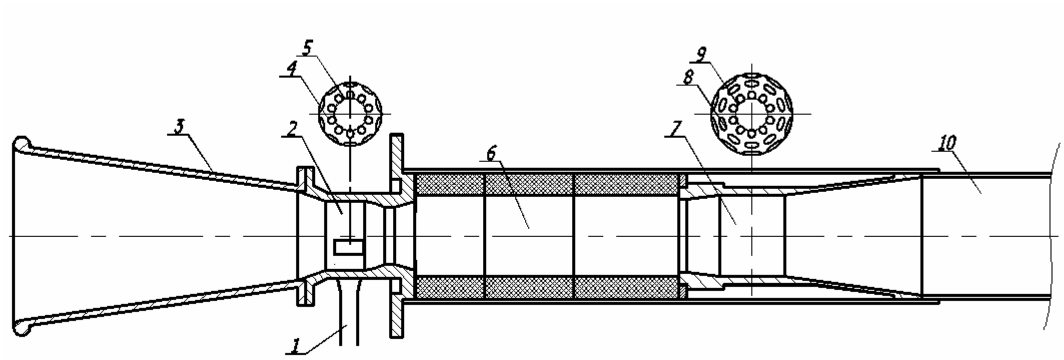

Fig. 1. Sketch of the two-cavity gyroklystron: *1* – rectangular input waveguide with the TE_{10}-mode, *2* – input cavity with the rotating operation mode TE_{52}, *4* – its structure, *3* – input cone, *5, 9* – location of the cross section of the electron beam, *6* – drift tube scattering and dissipating electromagnetic waves, *7* – output cavity with the rotating operation mode TE_{53}, *8* – its structure, *10* – output waveguide.

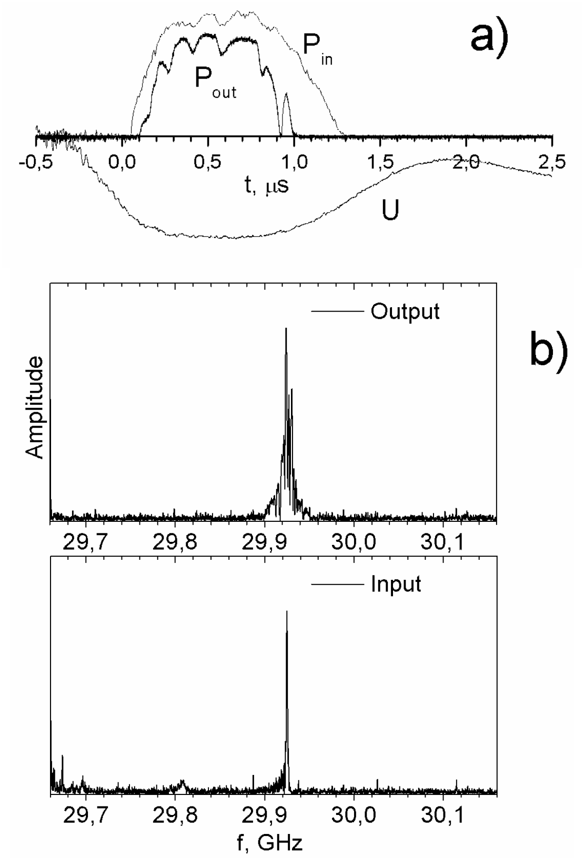

Fig. 2. (a) Traces of voltage, input and output RF power pulses of the gyroklystron (power 4.5 MW, efficiency 20%, gain 29 dB); (b) spectra of input and output signals.

field thus optimising the transit angle of electrons in the output cavity.

In the experiment, the output radiation parameters were close to the designed ones. In the case when the magnetic field was homogeneous along the device, the output power 4.5 MW at the efficiency 20% and gain 29 dB was obtained (the characteristic traces are presented in Fig. 2,a). When the magnetic field in the output cavity was decreased by 7%, the output power was 5 MW at efficiency 25% and 30 dB saturation gain corresponding to 5 kW input power. For the input signal less than 150 W the gain was 43 dB, for 0.5 kW it was 38 dB. At the interval of magnetic field not less than 0.5 of the maximum, the amplification bandwidth was about 40 MHz.

The output pulse spectrum broadening in comparison with that of the input one (see Fig. 2,b) can be explained with the following reasons:

- non-flat tops of the voltage pulses feeding the gyroklystron and the input RF source;
- non-linearity of the amplification gain: the side frequencies are amplified greater than the central one.

3. Three-cavity gyroklystron

To enlarge the amplification gain, and to symmetrize the beam bunching at the entrance of the output cavity, an penultimate cavity resonant at the TE_{52} mode was inserted in the middle of absorbing section *6* (see Fig. 1).

In the experiment with the gyroklystron driven by the beam of 340 kV, 80 A, the device power 6.5 MW at the efficiency 24% and gain 34 dB was obtained (see Fig. 3). Strong repetition of the obtained results was observed.

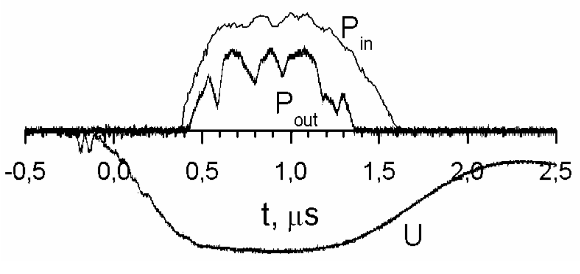

Fig. 3. Traces of voltage, input and output RF power pulses of the gyroklystron (power 6.5 MW, efficiency 24%, gain 34 dB).

4. Conclusions, plans for future

Generally, the gyroklystron behaved as anticipated; however its performance was aggravated by instability of single-pulse solenoids and high voltage supplies. Presently, construction of an upgraded set-up is underway. The gyroklystron will operate in a cryomagnet and will be driven with up to 10 Hz PRF pulser built at IAP in cooperation with the Special Design Bureau on Scientific Device Development of the Ural Division of RAS (Ekaterinburg, Russia) and the SLAC (Stanford, USA).

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