AMPLIFICATION AND EXCITATION OF MICROWAVES BY AN ELECTRON BEAM IN A DISK-LOADED COAXIAL HYBRID WAVEGUIDE

V.S. Antipov, I.V. Berezhnaya, E.A. Kornilov, P.I. Markov, G.V. Sotnikov
NSC Kharkov Institute of Physics & Technology, Kharkov, Ukraine

We have presented the results of the extensive experimental investigations of the amplification and oscillation excitation by the electron beam in hybrid plasma waveguides (HPW). The structure used as HPW a coaxial line with the disk-loaded electrodes and the plasma-filled passage channel. We have examined characteristics of the oscillations excited by the beam. As the investigation of the video pulse passage through the slow-wave structure under the currents close to the start-up value indicates, the working gas pressure heightening in the bore results in extending the system transmission band because of the plasma densification. The measured microwave signal gain and beam minimum currents, to start with the value of which the amplification is possible in a beam-plasma system, are in good agreement with the corresponding parameters calculated.
PACS: 52.40.Mj

1. INTRODUCTION

The comb-like structures [1] - as well as the helical ones [2] - have a slow proper wave, the dispersion of which is close on linear; therefore, the coupling resistance weakly depends on the frequency in the principal pass band. The positive feature peculiar to the coaxial slow-wave lines consists in the possibility of the essential rise in the electron beam currents due to enlarging the cross-section of the passage channel of ones, which, consequently, results in the increase of the output power of microwave oscillations.

Investigation of the disk-loaded coaxial lines as the slow-wave structures in the microwave band is being performed both theoretically [3] and experimentally [4] for a long time. The coupling resistance dependence on the frequency, the dispersive characteristics are rather completely studied is examined by the methods of numerical simulation in the case of a given structure geometry.

The vacuum slow-wave structure can acquire the well known hybrid characteristics when the interaction area (i.e., the passage channel where the electron beam is propagating) is filled with plasma. A broad excitation band is preserved in a coaxial slow-wave structure in the presence of a plasma. And what is more, the excitation coefficient is higher and the bandwidth is broader in the hybrid structure than in the vacuum one. The dependences of the maximum gain and frequency on the plasma density are linear [5].

This work has aimed at checking on the analytical conclusions by the experimental investigation of the oscillation excitation and amplification - a coaxial line with disks on the external and internal electrodes with a plasma filling of the passage channel.

2. THE TEST BENCH

The test bench installation is intended for examination of a possibility of exciting the powerful SHF oscillations in the frequency band 1-3 GHz in the disk-loaded coaxial plasma waveguides. The principal elements of the installation are the following: the plasma electron gun which is elaborated within Project and provides the annular beam with the current up to 3 A, the diameter 80mm and the thickness 2-3 mm in the pulse under the accelerating voltage 10-25 kV; the slow-wave structure, on the basis of which the hybrid plasma waveguide is constructed, is a disk-loaded coaxial (the structure is characterized by linear dispersion in the band 1-3 GHz with the wave phase velocity corresponding to the velocity of the electron with the energy 20 keV; the coefficient of the standing wave is not higher than 2 over the total range; the structure length is 40 cm; the electron gun and the slow-wave structure are placed in homogeneous magnetic field up to 1000 Gs); the current collector is a matching element between the slow-wave structure and an output antenna-feeder line and the diagnostic means.

The structural scheme of the test bench is given in Fig. 1.

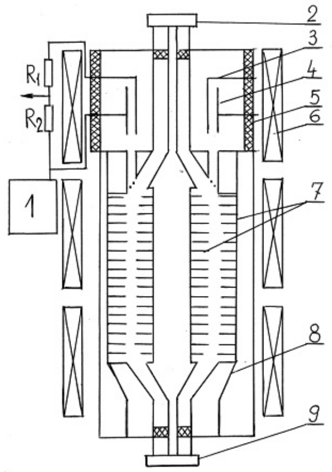

Fig. 1. The structural scheme of the test bench: 1 - modulator; 2, 9 - the SHF jack; 3,4,5 the electron gun; 6 - the coils of magnetic field; 7 - the slow-wave structure; 8 - the collector

In Fig. 2 a photo of the coaxial slow-wave structure is given.

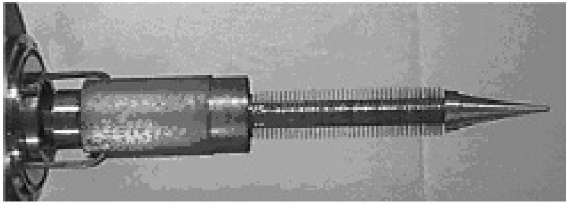

Fig. 2. The coaxial slow-wave structural of the test bench

An annular electron beam has been formed in the cathode unit, where a discharge gap is provided by the coaxial arrangement of cylindrical electrodes. Electrons are accelerated under a constant voltage (within 10-25 kV), supplied by a source and impressed on the cathode unit with respect to the slow-wave structure. The beam current is controlled by varying the discharge current in the cathode unit with a modulator. Measured with the Rogovsky belts, the values of the discharge current and the current in the accelerating gap are introduced into PC through an analog-to-digital transducer. Further, after its passage through the input unit, the beam gets into the slow-wave structure bore.

As a result of the working gas ionization due to the beam-plasma discharge in the longitudinal magnetic field (up to 1000 Gs), a plasma has been generated in the bore (its density is up to 10^{11} cm^{-3} and T_e is up to 20 eV). The dynamic gas system permits controlling the gas pressure within 10^{-5}- 10^{-3} mm Hg. After its passage through the slow-wave structure, the beam is transported to a collector. For investigating the test bench microwave characteristics, an ensemble of measuring equipment has been used; the latter contains a master oscillator (2-4GHz, P=8 W), video pulse generator (t =70-200 ps), a power-measuring instrument, a frequency meter, many-channel analog-to-digital transducers and rapid-record oscilloscopes. The dispersion characteristics of the disk-loaded coaxial line have been found by measuring on the time scale. The method is based on the evolution of a video pulse propagating in the coaxial disk-loaded structure. The input signal and the signal passed through the structure have been registered. According to the methodology presented in [6], the coefficient of slowing-down of the signal propagation in the structure - and, hence, the structure dispersion - have been determined.

3. EXPERIMENTAL RESULTS

Under the conditions of a good matching (in the microwave line, the standing-wave voltage ratio is less than 2.0), experimental investigations of the interaction between the electron beam and slow-wave structure have indicated that excitation of any oscillations is not observed if the beam energy ranges from 12 up to 25 keV and the currents are less than 0.5 A. When a signal, the power of which is about several W in the frequency band 2-3 GHz, is transmitted to the structure input from the master oscillator, the microwaves' amplification takes place under the same beam parameters. One may suppose that the beam current 0.5 A is the minimum (start-up) value under which oscillations start being amplified in the slow-wave structure first pass band.

The frequencies characterized by the maximum gain have been determined by varying both the accelerating voltage impressed on the gun anode and the master oscillator frequency at the slow-wave structure input. These frequencies are marked by points. As one can see, these values are in a rather good accordance with the ones calculated by the dispersion relation for the slow-wave structure zeroth harmonic.

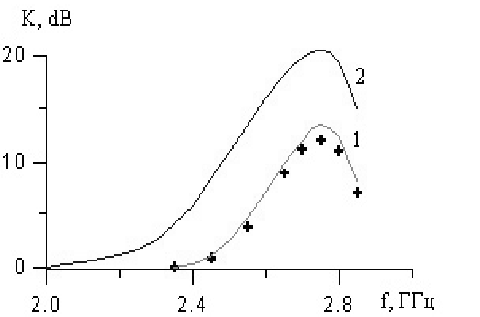

Fig. 3. The output of amplification coefficient as a frequency (theoretical calculations: current beam 1 – 2 A, 2 – 5 A; + - experimental result)

As the investigation of the video pulse passage through the slow-wave structure under the currents close to the start-up value indicates, the working gas pressure heightening in the bore results in extending the system transmission band because of the plasma densification.

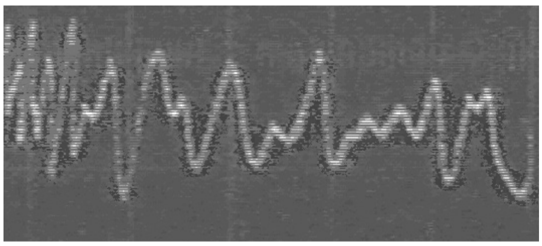

Fig. 5. The oscillogram of the microwave signal in the self-excitation regime (0.5 ns/point)

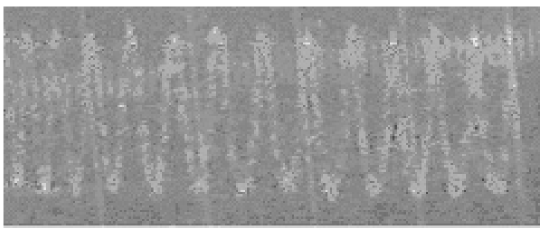

Fig. 4. The oscillogram of SHF signal at the amplifier output (1 ns/point)

In Fig.4, there are the oscillation oscillograms registered with a rapid-record oscilloscope.

The beam currents heavier than 0.5 A cause self-excitation of the «beam + hybrid waveguide» system; for amplifying signals, the master oscillator power must be heightened from master oscillator. When the beam currents are light, the oscillations are regular. The current increase is accompanied by the transition to self-excitation of microwaves.

In Fig.5 there are oscillograms of oscillations in the self-excitation regime, the transition to the latter being stimulated by the system internal microwave feedback under the beam accelerating voltage 20 kV.

CONCLUSIONS

In general, the experimental investigations performed do confirm the results of analytical calculations of electrodynamic characteristics of a hybrid plasma waveguide, having the form of a disk-loaded coaxial with the bore filled with a plasma. The measured microwave signal gain and beam minimum currents, to start with the value of which the amplification is possible in a beam-plasma system, are in good agreement with the corresponding parameters calculated. This fact indicates that the elaborated methods in determining the dispersion relations for the hybrid waveguide and describing the microwave excitation by an electron beam in such a structure are valid for calculation of the microwave beam-plasma amplifier and generator.

REFERENCES

1.R.G. Marimanov, V.G. Gyleiko // *RiE.* 1956, v.1, N2, p.1374, (in Russian).

2.R.A. Silin, V.P. Sazonov. *Zamedlyaushchie Sistemy*. M: “Sov.Radio”, 1966, p.632 (in Russian).

3. M.F. Stel’mach, E.B. Ol’derogge // *RiE.* 1959, v.4, N 6, p.980 (in Russian).

4.N.M.Chirkin // *RiE.* 1959, v.4, N1, p.126(in Russian).

5.P.I.Markov, V.S.Antipov, I.N.Onishchenko, G.V.Sotnikov. UHF-generation in a coaxial slowing down structure filled with plasma // *PAST.* 2002, №5, p. 86-88.

6. V.S.Antipov, I.V.Berezhnaya, E.A.Kornilov. Investigation of dispersion in the nybrid coaxial slowing down structure with the help of videopulse probing // *PAST.* 1999, №2, p. 295-297.

УСИЛЕНИЕ И ВОЗБУЖДЕНИЕ ЭЛЕКТРОМАГНИТНЫХ КОЛЕБАНИЙ ЭЛЕКТРОННЫМ ПУЧКОМ В ДИАФРАГМИРОВАННОМ КОАКСИАЛЬНОМ ГИБРИДНОМ ВОЛНОВОДЕ

В.С. Антипов, И.В. Бережная, Е.А. Корнилов, П.И. Марков, Г.В. Сотников

Представлены результаты экспериментальных исследований усиления и возбуждения колебаний электронным пучком в гибридном плазменном волноводе (ГПВ). В качестве ГПВ используется коаксиальная линия с дисками на электродах, пролетный канал которой заполнен плазмой. Изучены характеристики колебаний, возбужденных пучком. Исследования прохождения видеоимпульса через замедляющую структуру при токах вблизи пусковых показали, что увеличение давления рабочего газа в пролетном канале приводит к расширению полосы пропускания системы из-за увеличения плотности плазмы. Измеренные коэффициенты усиления ВЧ-сигналов и токи пучка, начиная с которых возможно усиление в пучково-плазменной системе, хорошо совпадают с расчетными.

ПІДСИЛЕННЯ ТА ЗБУДЖЕННЯ ЕЛЕКТРОМАГНІТНИХ КОЛИВАНЬ ЕЛЕКТРОННИМ ПУЧКОМ В ДІАФРАГМОВАНОМУ КОАКСІАЛЬНОМУ ГІБРИДНОМУ ХВИЛЕВОДІ

В.С. Антіпов, І.В. Бережна, Є.О. Корнілов, П.І. Марков, Г.В. Сотников

Подано результати експериментальних досліджень підсилення та збудження коливань електронним пучком у гібридному плазмовому хвилеводі (ГПХ). Як ГПХ використовується коаксіальна лінія з дисками на електродах, прольотний канал якої заповнено плазмою. Вивчено характеристики коливань, збуджуваних пучком. Дослідження проходження відеоімпульса через уповільнюючу структуру при струмах поблизу пускових показали, що збільшення тиску робочого газу у прольотному каналі приводить до розширення смуги пропускання системи із-за підвищення густини плазми. Вимірювані коефіцієнти підсилення ВЧ-сигналів та струми пучка, починаючи з яких є можливим підсилення у пучково-плазмовій системі, добре співпадають з розрахованими.