A RELATIVISTIC MAGNETRON-TYPE SOURCE OF NANOSECOND-LENGTH PULSED RADIATION IN THE 8 mm WAVEBAND

N.P. Gadetsky, A.N. Lebedenko, I.I. Magda, O.G. Melezhik, A.A. Shtanko, M.V. Volovenko
National Science Center “Kharkov Institute of Physics and Technology”, Kharkov, Ukraine
E-mail: magda@kipt.kharkov.ua

The paper describes an up-graded facility for studying performance of a high voltage pulsed magnetron of the 8 mm operation waveband. A pulse forming driving source of high output impedance is offered, yielding voltage amplitudes up to 40 kV and pulse durations about 25 ns, which provides for matching of the liquid-filled pulse forming line with the magnetron and lack of hydraulic strains. As a result, operation of the magnetron is stabilized and reproducibility of the output parameters greatly increased.

PACS: 52.80.Pi

INTRODUCTION

This paper is a continuation of the studies aimed at developing relativistic magnetrons (RM) that were started in the Institute of Physics and Technology back in 1970s [1 - 3]. The high-current relativistic electron accelerator *Astra* (beam particle energies up to 0.7 MeV; beam currents about 35 kA, and pulse lengths of 35 to 40 ns), launched in 1970, was among the first high voltage electronics facilities in the USSR. High voltage pulses were shaped in a double pulse forming line (DPL) of low impedance (ρ = 4 Ω) that employed distilled water as a filling dielectric. The DPL was charged to the desired voltage level from a Marx generator, which device essentially limited the pulse repetition frequency.

The *Astra* accelerator was used, in particular, to provide for generation of centimeter-wavelength microwave pulses of 10 to 30 ns duration and power levels up to 10^9 W. The associated projects also concerned development of a number of relativistic microwave generators, based on a variety of physical principles and employing different electrodynamic structures – such as ubitrons, Cherenkov effect-based vacuum and plasma masers, magnetrons, vircators, *etc.* [4 - 8].

In 2008 the *Astra* accelerator gave birth to the first millimeter-wavelength relativistic magnetron. The device was characterized by a high input impedance reaching, in the live mode, 100 or 200 Ω. Accordingly, the magnetron represented an ill-matched load for the low-impedance DPL, which resulted in multiple reflections and forbiddingly long durations of the high voltage pulses present in the magnetized diode space. The result could be quick degradation of the electrodynamic (slow wave) structure.

The accelerator with a high output impedance that was specially designed later allowed eliminating the matching problems, which lead to improved stability and greatly enhanced life time of the pulsed source of microwave radiation.

EXPERIMENTAL SET-UP FOR RM STUDIES

When constructing the magnetron-oriented driver installation today, we have proceeded from the design arrangement of paper [9] which made use of a Tesla transformer as the charger for the pulse forming line. The circuit permits a periodic operation mode and allows greatly reducing the mechanical size of the installation.

The set-up (Fig. 1) involves two functionally specified parts, namely the electron accelerator and the magnetron unit. Electric elements of the first part of the installation comprise a DPL; a Tesla coil, 2; a gas-filled triggering discharger, 1; a storage coil 3 for the DPL; a peaking discharger, 4, at the output; a power supply, БП1; a capacitor bank, C1 (2.5 μF) for the Tesla transformer primary; a control discharger, УР1, and a driving unit, Б3. The basic parameters of the high-voltage part are listed in Table.

Basic parameters of the power supply for the RM

DPL output voltage	100…400 kV
DPL output current	up to 5 kA
DPL voltage pulse length	20 to 25 ns
DPL duty	solitary pulses or pulse packets
pulse repetition frequency	1 Hz
voltage across Tesla transformer primary in high voltage power supply	up to 8.0 kV
DPL characteristic impedance	80 Ω

The electric circuits of the other part, which are intended for shaping up the longitudinal magnetic field of the RM, involve another power supply, БП2; a 2400 μF bank of capacitors, C2; a control discharger, УР2, and a solenoid. Operating modes of the magnetron and synchronized regimes of the two parts of the device can be selected with the aid of a control box, ПУ. The charging voltage of the DPL and the anode voltage are monitored by a resistive and a capacitive sensor, respectively, while the total current through the magnetron is estimated with the aid of a Rogowski coil placed in the magnetron unit.

The DPL is a coaxial structure of geometry as follows: a cylindrical outer conductor 300 mm in diameter; a 100 mm middle electrode, and a 40 mm central one. The dielectric filling medium in the DPL is transformer oil. The newly developed DPL involves a gas-filled triggering discharger, 1, where the statistical scatter of the response time is an order of magnitude shorter than in the liquid discharger that was used in the previous version of the DPL. The gas discharger provides for a better stability in triggering the DPL and easier adjustment of the output voltage level, thus permitting one to avoid electrode disruption due to hydraulic shocks. In addition, the activation threshold of the gas discharger can be controlled through changing gas pressure, which is a much simpler procedure than gap adjustment in the water discharger.

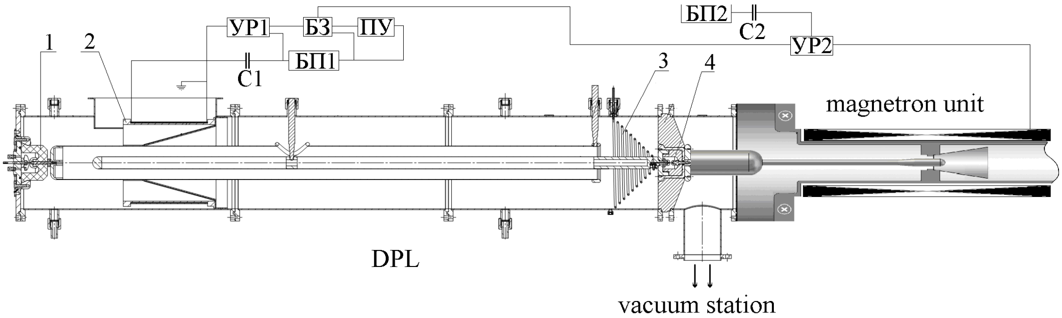

Fig. 1. Experimental set-up for studying the relativistic magnetron (БП, power supply; БУ, control box; Б3, driving unit; УР, controllable discharger)

As can be seen in Fig. 1, the outer cylindrical electrode (casing) of the DPL is covered from one side by a flange carrying the triggering gas discharger 1. Connected from the other end are, successively, a disc insulator, a vacuum chamber and station, and the magnetron unit. The insulator accommodates a peaking discharger, 4, consisting of two parts, a fixed and a detachable one. The fixed part provides for hermetic transformer oil confinement in the DPL. The detachable part of the discharger 4 is placed in the vacuum chamber. The breakdown voltage level of both discharger 1 and discharger 4 can be adjusted by changing the gas (nitrogen) pressure.

The charging inductance coil 3 of the DPL (9.8 μH inductance) has been made of a copper pipe 6 mm in diameter, coiled up into a divergent helix. The 12 mm inter-turn gap in the helix is sufficient to ensure the necessary dielectric strength. With a 300 kV voltage applied across the DPL the estimated electric field intensity between the turns never exceeds 180 kV/cm.

The high-voltage power supply БП1 serves to charge the capacitors C1 in the primary circuit of the Tesla transformer.

The power supply БП2, capacitor C2 and control discharger УР2 make up a circuit for shaping magnetic pulses up to10 kOe in strength and 3 msec duration. The driving unit Б3 forms two separate pulses with adjustable time delays. The first of these serves to switch on the magnetic system of the device, while the other one activates the control discharger УР1. This latter triggers discharge of the capacitor bank C1 through the Tesla transformer primary. Then the secondary winding receives the high voltage pulse that is used to charge the DPL. The DPL forms the pulsed voltage of very high magnitude to be fed into the magnetron.

The design of the magnetron unit, as used in this installation, was described in detail in our previous papers [1 - 3]. Its slow-wave structure is characterized by parameters as follows: the number of cavities is 48; the anode diameter 22 mm; the cathode diameter 14 mm, and axial length 6 mm. The magnetron implements diffractional release of the microwave power along the structure's axis.

EXPERIMENTS AND RESULTS

To check the quality of DPL to RM matching (the predicted 80 Ω value for the DPL wave resistance *vs* the 70 to 100 Ω RM impedance known from earlier experiments) we used a resistive load at the DPL output, equivalent to the magnetron's impedance. Given in Fig. 2 is the voltage drop U_R across the resistive load as a function of the DPL charging voltage, U_{DFL}.

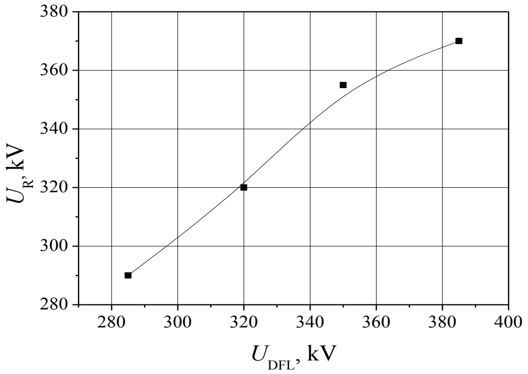

Fig. 2. Voltage across the resistive load as a function of the DPL voltage

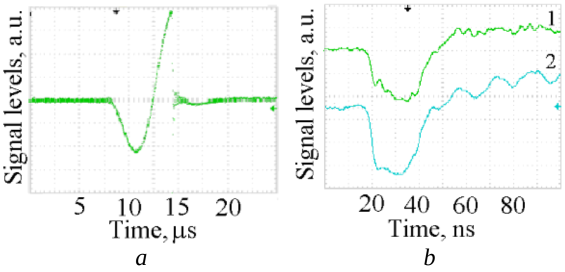

Fig. 3. Waveforms of the charging impulse of the DFL (a), and the DFL output voltage (b1), and current (b2)

The time dependences demonstrated by the pulsed voltages at the DPL and the anode, and the current through the ohmic load are presented in Fig. 3. Specifically, panel *a* shows the waveform of the charging voltage at the DPL, and panel *b* the voltage across the resistive load (curve 1) and current through the load (curve 2). These oscillograms were taken with a 5 kV charging voltage across the Tesla transformer primary. The respective pulsed voltage at the DPL output reached 230 kV and the current through the load was 3.5 kA.

As can be seen from Fig. 2 the charging voltage at the DPL and the voltage across the resistive load are very nearly equal, which fact is also confirmed by the absence of reflected pulses in Fig. 3,b. Thus, the power stored in the DPL can be transferred to the load practically without losses, provided the DPL has been sufficiently matched with the resistive load, equivalent to the RM.

In the experiments based on the new accelerator, radiated frequencies were measured using undersized wave guiding sections (the 'cut-off approach'), as well as in the heterodyne technique. The output power was measured with rectifying sensors and a calibrated attenuator, by comparing sensor readings provoked by a RM with such from a reference generator. The radiation parameters were P = 250 to 300 kW; τ = 10 to 20 ns at f = 37.8 GHz. As can be seen, the figures are practically the same as were demonstrated in the previous experiments with a low-impedance DPL. Representative oscillograms of the signals from RMs are shown in Fig. 4.

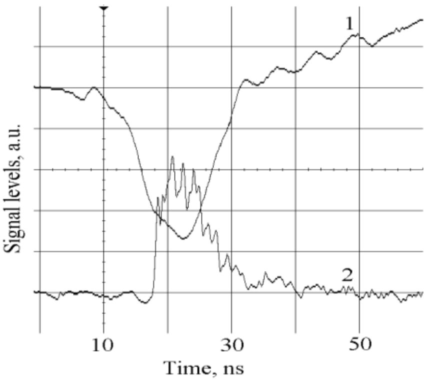

Fig. 4. Waveforms of characteristic signals in the RM: curve 1 represents the full current and curve 2 the rectified microwave signal

CONCLUSIONS

The high voltage pulsed installation that has been created, where the pulse forming line (DPL) is charged from a resonance pulsed transformer, permits greatly improving the conditions for experimental studies on the relativistic magnetron, specifically:

- the use of a high-resistance DPL provides for a better matching between the driver and the magnetron;
- the gas discharger employed instead of a former water discharger ensures stable operation of the device and facilitates anode voltage adjustment of the RM;
- application of a Tesla transformer allows the DPL to operate in a repetitive mode, also leading to a substantially smaller size and weight of the experimental plant.

In what follows, it should be possible for the pulsed magnetron to operate in a repetitive mode, either due to application of permanent magnets, or through generation of repetitive pulses in the magnetic subsystem.

REFERENCES

1. N.P. Gadetski, E.I. Kravtsova, I.I. Magda, V.D. Naumenko, S.S. Pushkaryov, S.N. Terekhin, A.S. Tischenko. Relativistic magnetron of 8 mm waveband // *Problems of Atomic Science and Technology. Series “Plasma Electronics”*. 2008, № 4, p. 18-20.
2. S.A. Berdin, K.V. Chizhov, N.P. Gadetski, V.G. Korenev, A.N. Lebedenko, M.I. Marchenko, I.I. Magda, O.G. Melezhik, V.G. Sinitsin, V.A. Soshenko. Special traits of the millimeter wave relativistic magnetron // *Problems of Atomic Science and Technology. Series “Nuclear Physical Investigations”*. 2014, № 3, p. 54-59.
3. N.P. Gadetski, A.N. Lebedenko, I.I. Magda, A.A. Shtanko, M.V. Volovenko. Non-conventional operation modes for millimetre wave relativistic // *Problems of Atomic Science and Technology. Series “Nuclear Physical Investigations”*. 2016, № 3, p. 35-37.
4. Y.V. Tkach, J.B. Fainberg, I.I. Magda, N.I. Gaponenko, G.V. Skachek, S.S. Pushkaryov, N.P. Gadetsky, A.A. Belukha. Microwave radiation from a high-current relativistic particle beam interacting with a plasma-filled slow wave structure // *Fizika Plazmy*. 1975, issue 1, v. 1, p. 81-87 (in Russian).
5. Y.V. Tkach, J.B. Fainberg, N.P. Gadetsky, I.I. Magda, E.A. Lemberg. Intense oscillations excited by high-current relativistic particle beams // *Ukrainsky Fiz. Zhurnal*. 1978, v. 23, № 11, p. 1902-1908 (in Russian).
6. Y.V. Tkach, N.P. Gadetsky, Y.P. Bliokh, E.A. Lemberg, M.G. Liubarsky, V.V. Yermolenko, V.V. Dyatlova, S.I. Neisteter, I.I. Magda, S.S. Pushkaryov, G.V. Skachek. Radiation from a relativistic particle beam in a corrugated waveguide, under combined resonance conditions // *Fizika Plazmy*. 1979, v. 5, № 5, p. 1012-1019 (in Russian).
7. I.I. Magda, I.F. Kharchenko. High-current relativistic accelerators and their applications // *Ukrainsky Fiz. Zhurnal*. 1998, v. 43, issue 11, p. 1175-1180 (in Russian).
8. S.B. Bludov. N.P. Gadetsky, K.A. Krivtsov, Y.F. Lonin. I.I. Magda, S.I. Neisteter, E.A. Prasol, Y.V. Prokopenko, S.S. Pushkaryov, Y.V. Tkach, I.F. Kharchenko, V.I. Chumakov. Powerful microwave pulses of ultra-short duration: Generation and impact on electronic devices // *Fizika Plazmy*. 1994, v. 20, № 7/8, p. 712-717 (in Russian).
9. G.A. Mesyats, S.D. Korovin, V.V. Rostov, V.G. Shpak, M.I. Valandin. The RADAN series of compact pulsed power generators and their applications // *Proceedings of IEEE*. 2004, v. 92, № 7, p. 1166-1179.

Article received 13.10.2017

РЕЛЯТИВИСТСКИЙ МАГНЕТРОННЫЙ ИСТОЧНИК ИМПУЛЬСНОГО ИЗЛУЧЕНИЯ НАНОСЕКУНДНОЙ ДЛИТЕЛЬНОСТИ В ДИАПАЗОНЕ 8 мм

Н.П. Гадецкий, А.Н. Лебеденко, И.И. Магда, О.Г. Мележик, А.А. Штанько, Н.В. Воловенко

Представлены результаты модернизации установки для исследования рабочих режимов высоковольтного импульсного магнетрона диапазона 8 мм. Предложен и создан новый высокоомный источник формирования импульсов напряжением до 40 кВ и длительностью 25 нс, обеспечивающий согласование линии формирования импульсов с магнетроном и отсутствие в ней гидравлических ударов. В результате повышена стабильность работы магнетрона, управляемость его режимами и воспроизводимость результатов.

РЕЛЯТИВІСТСЬКЕ МАГНЕТРОННЕ ДЖЕРЕЛО ІМПУЛЬСНОГО ВИПРОМІНЮВАННЯ НАНОСЕКУНДНОЇ ТРИВАЛОСТІ В ДІАПАЗОНІ 8 мм

М.П. Гадецький, О.М. Лебеденко, І.І. Магда, О.Г. Мележик, А.О. Штанько, М.В. Воловенко

Наведено результати модернізації установки для дослідження робочих режимів високовольтного імпульсного магнетрона діапазону 8 мм. Запропоноване і створене нове високоомне джерело формування імпульсів, що мають значення напруги до 40 кВ і тривалості до 25 нс. Джерело живлення, що було запропоноване, забезпечує узгодження лінії формування імпульсів з магнетроном і відзначається відсутністю гідравлічних ударів. Як результат маємо підвищення стабільності роботи магнетрона, покращення керованості режимами роботи і відтворення результатів.