EXPERIMENTAL METHODS AND PROCESSING OF DATA

https://doi.org/10.46813/2023-148-131

A METHOD FOR MEASURING THE POWER OF A HIGH-AMPLITUDE PULSED-MODULATED MICROWAVE SIGNAL FOR THE ECR PLASMA HEATING

D.Yu. Zalesky, V.A. Buts, G.V. Sotnikov*
National Science Center "Kharkov Institute of Physics and Technology", Kharkiv, Ukraine
**E-mail: zdmitriy2022@gmail.com*

This paper describes a technique for measuring the power of the microwave source of the "VOLNA" setup, designed to study the electron cyclotron resonances (ECR) in plasma. The purpose of this work was to increase the electric field strength in the plasma, leading to an increase in the number of ECR resonances, which in turn directly depends on the power of the microwave power source. As measurements of the microwave power source "Luch-58" with the M3-13/1 wattmeter showed, satisfactory measurement accuracy can be achieved by increasing the average microwave power to 10…20 W by increasing the pulse repetition rate from the MI-125 magnetron from 1 to 5…10 Hz.

PACS: 52.35.Hr; 84.40.Dc

INTRODUCTION

It is known that pulsed microwave generators are used to power experimental facilities for research in the field of accelerator technology and plasma electronics. In particular, they can be used to study microwave plasma heating using the electron cyclotron resonance (ECR) mechanism at the "VOLNA" experimental facility [1].

At present, the "VOLNA" facility is being modernized in order to study some new features of particle dynamics at cyclotron resonances. First of all, those features that can manifest themselves during high-frequency plasma heating by high-intensity fields. The most striking new feature is the appearance of regimes with intermittency [2]. Such regimes are characterized by fairly long intervals of regular particle dynamics followed by intense random bursts. Bursts can characterize sharp spikes in plasma density or abrupt changes in the momenta of charged particles. Such features are already observed in thermonuclear installations with high-frequency plasma heating in them. Elucidation of the details of the mechanisms of occurrence of these emissions will allow them to be effectively controlled. In particular, a sharp increase in the particle momentum can initiate the appearance of runaway electrons. In all these cases, the main parameter that determines the appearance of such regimes is the strength of the external electromagnetic wave. Therefore, our main attention in renovation the "VOLNA" installation is drawn to the characteristics of the microwave power source of the installation.

This paper presents a technique for measuring the microwave power of the generator of the "VOLNA" installation. The source of the microwave power of the installation is a microwave pulse magnetron MI-125 with a power of 1 MW at a frequency of 2.7 GHz with a duration of 2 μs and a pulse repetition rate of 1 Hz.

Measurement of microwave power with such characteristics presents a certain difficulty, since at a power of 1 MW in a microwave pulse, the energy is only 2 J, and the average microwave power is 2 W. Therefore, in order to measure the microwave power of the MI-125 magnetron, it is necessary to carry out preliminary measurements. To do this, instead of the MI-125 magnetron, a microwave generator with continuous generation, "Luch-58", was used as a source of microwave power. To measure microwave power, we chose M3-13/1 and M3-54 wattmeters.

EQUIPMENT AND MEASUREMENT TECHNIQUE

As mentioned above, the "Luch-58" generator was used as a source of microwave power. This is a medical device that is used for centimeter (CMW) therapy [3], which consists in irradiating parts of the human body with microwave electromagnetic radiation in the centimeter range with a frequency of 2.375 GHz and a power from several watts to tens of watts. Irradiation occurs dosed over short periods of time.

The appearance of the "Luch-58" generator is shown in Fig. 1, and its electrical circuit in Fig. 2.

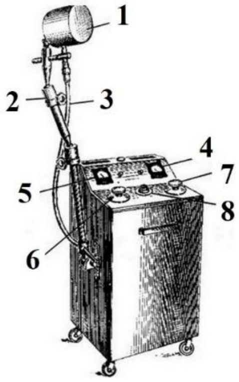

Fig. 1. Appearance of the microwave generator "Luch-58": 1 – emitter; 2 – crankshaft of the emitter; 3 – coaxial wire; 4 – wattmeter; 5 – voltmeter; 6 – voltage compensator; 7 – power regulator; 8 – timer

As can be seen from Fig. 1 the generator contains an emitter of microwave electromagnetic radiation 1 with a coaxial cable for input of microwave power. A rod and a crankshaft 2 provide fixing the position of the emitter. The setting of the anode voltage of the magnetron M (see Fig. 2) is carried out by the regulator 6 of the voltage compensator by switching the primary windings of the transformer T (see the diagram in

Fig. 2) with the switch S2 by setting the arrow of the device 5 to the mark on the instrument panel.

The adjustment of the anode current and, accordingly, the power of the magnetron M is carried out by switch 7 according to the readings of device 4. Switch 7 is switch S2 in Fig. 2, which switches the chain of resistance R1-R2.

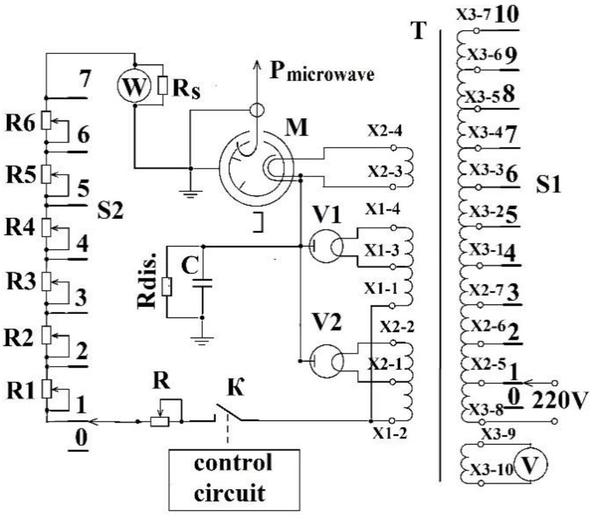

Fig. 2. Circuit of the microwave generator "Luch-58"

It can be seen from the circuit in Fig. 2 that the supply voltage from the high-voltage windings of the transformer T and the rectifier on the kenotrons V1, V2 to the magnetron M is carried out through the relay contact K. The switching of this relay is controlled by the "Luch-58" generator control circuit.

Since we did not need the functions of the "Luch-58" generator used for medical procedures using a timer, we only needed the generator to work in manual mode of heating the magnetron before turning on the anode voltage in a continuous mode of microwave power generation. Therefore, the generator control circuit was simplified and converted into the circuit shown in Fig. 3.

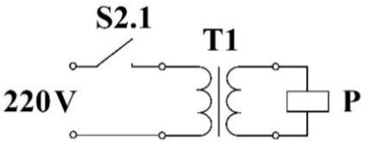

Fig. 3. The control circuit of the microwave generator "Luch-58"

As can be seen from Fig. 3 the control circuit consists of only three components, including an alternating current relay P, which controls contact K (see Fig. 2), which supplies the anode voltage to the magnetron M, transformer T1 to power the relay winding and contact S2.1. Contact S2.1 is closed by turning the handle 7 (see Fig. 1) from position "0" to any other position S2 (see Fig. 2) from 1 to 7.

The lower limit of the measured power of the M3-13/1 wattmeter is 2.59 GHz, and the frequency of the "Luch-58" generator is 2.375 GHz. Therefore, for the safe operation of the "Luch-58" generator on the load of the M3-13/1 wattmeter from the point of view of possible microwave reflection and taking this reflection into account when calculating the power at a frequency of 2.375 GHz, the VSWR (voltage standing wave ratio) of the wattmeter load was measured using panoramic meter R2-53 [4].

The appearance of the VSWR R2-53 is shown in Fig. 4.

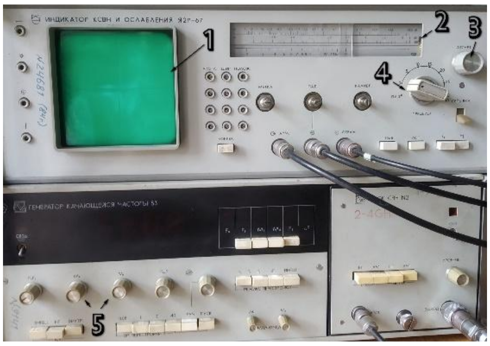

Fig. 4. Appearance of the panoramic VSWR meter R2-53: 1 – ETL screen; 2 – measurement scale; 3 – handle for moving the reference line; 4 – switch for measurement limits; 5 – knob for setting the frequency values of the reference marks

The measurements were carried out in the frequency band starting from the frequency of the "Luch-58" generator and up to the frequency of the MI-125 magnetron of 2.7 GHz.

To measure the VSWR, the circuit presented in Fig. 5 was assembled.

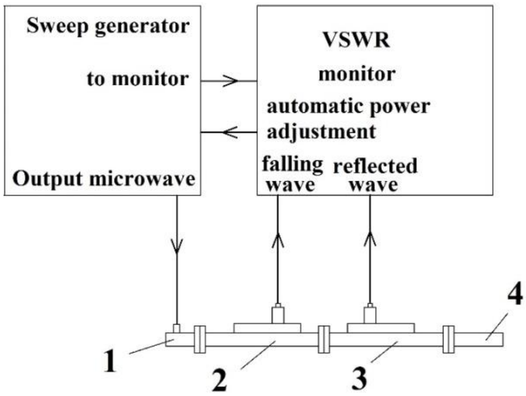

Fig. 5. Scheme for measuring VSWR: 1 – coaxial-waveguide transition; 2 – directed incident wave detector; 3 – directional reflected wave detector; 4 – load of wattmeter M3-13/1

The measurements were carried out according to the standard method described in the operating instructions for R2-53.

As measurements showed, the VSWR at a frequency of 2.7 GHz is 1.2, and at 2.37 GHz it is 1.5, which is quite acceptable for our measurements.

To measure the microwave power, a stand was assembled, shown in Fig. 6.

The operation of the measuring stand shown in Fig. 6 is as follows.

The microwave power from the "Luch-58" generator 1 through a coaxial cable 10 and the CWT is fed to the input of the microwave coupler 6. Part of the microwave power with an attenuation of 40 dB through the CWT installed in the incident wave arm 8 of the coupler 6 is fed to the calorimetric converter of the M3-54 wattmeter from which the signal is fed to the indicator block of the M3-54 wattmeter.

The presence of the second wattmeter – M3-54 in the stand is necessary, so in the future it will perform the function of power control during experiments on the installation.

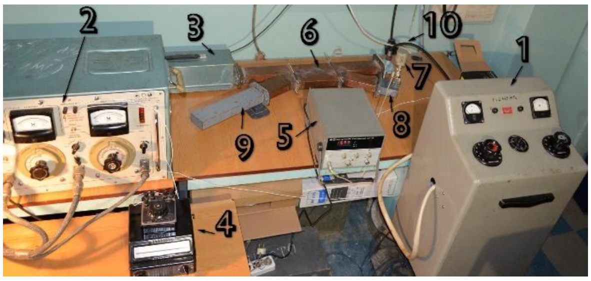

Fig. 6. Stand for measuring microwave power: 1 – generator “Luch-58”; 2 – measuring block of the M3-13/1 wattmeter; 3 – calorimetric load of the M3-13/1 wattmeter; 4 – M95 microampermeter, 5 – M3-54 wattmeter; 6 – microwave power coupler from the “VOLNA” installation; 7 – calorimetric converter of the M3-54 wattmeter; 8 – coaxial-waveguide transition (CWT) of the incident power arm; 9 – matched load on the VSWR; 10 – input of microwave power from the “Luch-58” generator

The full power from the input is supplied to the water load of the M3-13/1 wattmeter. The reading in watts was carried out at the limit of 200 according to the readings of the internal wattmeter M3-13/1, and for the limits of 60 and 20 W according to the external ammeter 4.

Measurements of the microwave power of the “Luch-58” generator with an M3-13/1 wattmeter were carried out at the limits of 200, 60, and 20 W. Before the measurement, the wattmeter was calibrated at each limit. A series of such measurements was carried out 3 times. The measurement results are shown in Tables 1–3.

RESULTS OF MEASUREMENTS AND THEIR DISCUSSION

As can be seen from all the tables, the power shown by the device of the “Luch-58” generator is 3 times more than that measured for low power values and about 2 times more for large values. This is due to the fact that this device does not show the microwave power from the generator output, but probably the power consumed by the generator according to the anode current.

Table 1

Measurement at the limit of 200 W

Position handles “popup” of the generator “Luch-58”	“Luch-58” wattmeter readings, W	Wattmeter readings M3-13/1, W			Wattmeter readings M3-54, mW
		Minimum value	Maximum value	Average value	
3	65	-	-	15	0.84
4	100	20	40	28	1.67
5	130	-	-	45	2.81
6	160	75	80	77	4.34
7	175	105	110	108	5.71

Table 2

Measurement at the limit of 60 W

Position handles “power” of the generator “Luch-58”	“Luch-58” wattmeter readings, W	Wattmeter readings M3-13/1, W			Wattmeter readings M3-54, mW
		Minimum value	Maximum value	Average value	
3	65	12	18	14	0.84
4	100	28	34	30	1.67
5	130	47	55	52	2.81

Table 3

Measurement at the limit of 20 W

Position handles “power” of the generator “Luch-58”	“Luch-58” wattmeter readings, W	Wattmeter readings M3-13/1, W			Wattmeter reading M3-54, mW
		Minimum value	Maximum value	Average value	
3	65	11	18	15	0.84

As shown by the results of measurements of microwave power by the M3-13/1 wattmeter presented in Tables 1–3 on all limits, there is mainly a spread in power values of 4…5 W. However, in percentage terms, this spread is greater at low power values, and especially, as can be seen from Table 1, at the limit of 20 W it is more than 30%.

The readings of the M3-54 wattmeter are proportional to the power value of the measured M3-13/1, however, with an attenuation of 42 dB instead of the expected 40 dB of the microwave coupler, but this may be due, as shown by the VSWR measurements, with 20% power reflection from the load M3-13/1.

CONCLUSIONS

The results of microwave measurements show that the accuracy of power measurements with the M3-13/1 wattmeter at low power values is low. Therefore, to perform measurements using the M3-13/1 wattmeter, it is necessary to increase the average power generated by the microwave magnetron from 2 to 10…20 W. And this can be done by increasing the pulse repetition rate from 1 to 5…10 Hz.

REFERENCES

1. V.S. Antipov, A.N. Antonov, V.A. Buts, et al. Investigation of posibility of energy transfer to plasma ions by oscillations with large amplitude on frequency of electron cyclotron resonance in magnetic trap // *Problems of Atomic Science and Technology. Series “Plasma Physics”*. 2018, № 6, p. 172-175. https://vant.kipt.khakov.ua/ARTICLE/VANT_2018_6/article_2018_6_172.pdf.

2. V.A. Buts, A.G. Zagorodny. New cyclotron resonances and features of charged-particle dynamics in the presence of an intense electromagnetic wave // *Phys. Plasmas (28).* 2021, 022311. https://doi.org/10.1063/5.0037808.
3. V.M. Bogolyubov, M.F. Vasilyeva, M.G. Vorobyov. *Techniques and methods of physiotherapy procedures: a reference book.* M.: "Izdat. BINOM", 2017, 464 p.
4. https://standart-pribor.com.ua/product/r2-53-2-izmeritel-ksvn

Article received 21.06.2023

МЕТОД ВИМІРЮВАННЯ ПОТУЖНОСТІ ВИСОКОАМПЛІТУДНОГО ІМПУЛЬСНО-МОДУЛЬОВАНОГО НВЧ-СИГНАЛУ ПРИ НАГРІВІ ПЛАЗМИ НА ЕЦР

Д.Ю. Залеський, В.О. Буц, Г.В. Сотніков

Описана методика вимірювання потужності джерела НВЧ-установки «ВОЛНА», призначеної для дослідження електронного циклотронного резонансу (ЕЦР) у плазмі. Метою даної роботи було збільшення напруженості електричного поля в плазмі, що призвело б до збільшення числа ЕЦР-резонансів, що, в свою чергу, безпосередньо залежить від потужності НВЧ-джерела живлення. Як показали вимірювання НВЧ-джерела живлення «Луч-58» ватметром М3-13/1, задовільної точності вимірювання можна досягти збільшенням середньої потужності НВЧ до 10…20 Вт за рахунок збільшення частоти повторення імпульсів від магнетрона МІ-125 від 1 до 5…10 Гц.