The Device for Dynamic Matching of the E-type Discharge Plasma System and Output Tract of Electric Pulses Generator

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To reduce the reactivity of a glow pulse discharge, the device for stepwise matching of the communication channel of the power stage of electric pulses generator exciting plasma and the plasma discharge as a dynamic load was developed and tested. The peculiarity of this device is the use of a wide range software-controlled inductive element. The use of mixed analog and digital units circuitry provides stable regulation of inductance from 600 μH to 20 mH. Experimental testing of the device with the E-type discharge system at frequencies from 5 kHz to 60 kHz showed a decrease of the phase shift between the current pulses and the discharge voltage and the reduction of the spurious emissions on power pulses trajectories. It makes possible to increase the energy efficiency of plasma process and reliability of the operation of pulse generator with plasma as a load.

Keywords: plasma, electric generator, matching

1 INTRODUCTION

It is known that during the pulse excitation of the plasma medium, one of the key electrophysical parameters is represented by the reactivity of the formed discharge. This feature depends on the geometry of the discharge electrode, the magnitude of the applied voltage pulse, the degree of vacuum and the type of the actuation gas [1]. The degree of the power reflected from the formed plasma medium is determined by the magnitude of the reactivity of the pulse discharge and the degree of matching between the supply and discharge systems. The maximum degree of power absorbed by the pulse discharge is ensured on condition of the equality of impedances of the discharge system, electricity supply channel and the output tract of the pulse power-supply source. Losses in heterogeneous lines at sites of electric discord are caused by the fact that part of the energy returns to the power-supply source. Accordingly, in order to ensure the matching of the system, the structure of the power-supply channel should contain a matching device, which provides the equality of impedances of the power-supply source with the plasma medium, while the series current resonance is produced. At the same time, the gas-discharge system can take the form of a container with the negative complex resistance – X_c; a matching device can be represented by a controlled throttle with the compensating positive resistance X_L [2].

When discharge chamber is loaded with process material there is a change in volume and shape of the discharge electrode, which in turn leads to changes in the pulse current value flowing through the discharge. Since the parameters of the gas discharge are constantly changing, i.e., the load is dynamic, the matching of the load and power supply source parameters should be carried out in the dynamic mode, i.e. constantly correct.

The practical use includes two variants of matching of the active part of the impedance: the matching according to the resistance of the output tract of the pulse power-supply source or according to the resistance of the power transmission channel [3]. The article considers structural and technical peculiarities of the developed device, which ensures the increase in the power absorption by the pulse discharge and thus increases the degree of ionization of the plasma medium. The result is achieved due to the circuit combination of two variants of the matching between the active part of impedances of the power-supply source and the plasma discharge in the same device.

2 THE RESULTS AND DISCUSSION

Fig. 1 shows the structural scheme of the device of the developed dynamic matching of

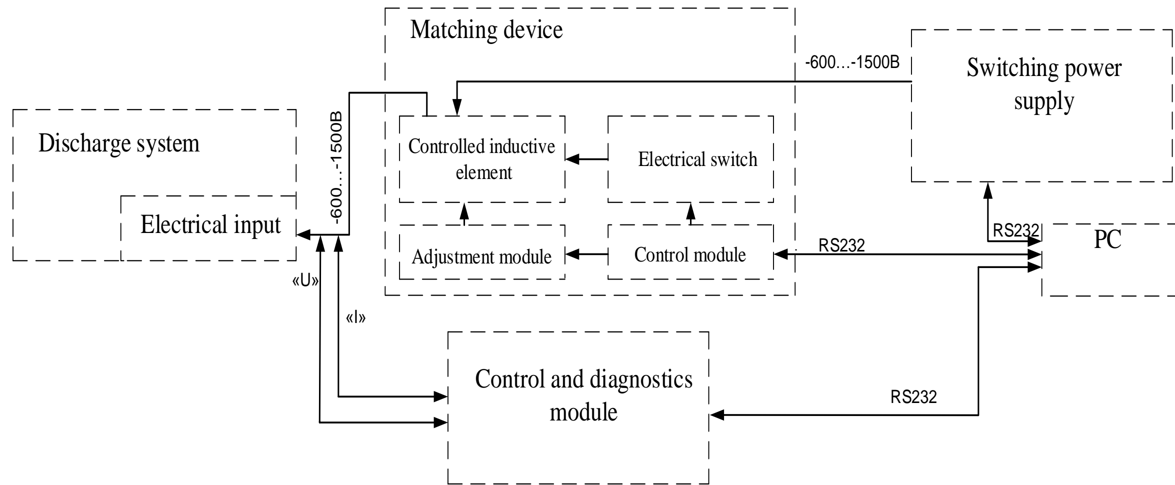

Fig.1: Structural scheme of the device of the developed dynamic matching of the output tract of the pulse power-supply source and the discharge system of the E – type

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The matching device consists of four modules, integrated into one system. The base of the developed device is the inductive element, consisting of five independent sections. The commutation of four sections by power keys, included in the module of the electrical commutator, ensures the rough alteration of the inductance parameters and the reduction of the wave resistance of the channel. The module of trimming, by managing the inductive element through the fifth section of the "bias" smoothly reduces or increases the degree of inductance in the range from 600 μH to 20 mH. The specified range of inductance is realized through the alteration of the degree of direct-current voltage, passing along the fifth section that permits to change in the wide range the physical qualities of the core with distributed magnetic gap.

Through the RS232 interface, a PC operates the pulse power-supply source, the operational module and reads data from the diagnostics and control module. This module consists of a digital oscilloscope and two differential probes, installed directly in the power point of the discharge system.

Fig. 2 shows the electrical scheme of the developed dynamic matching device.

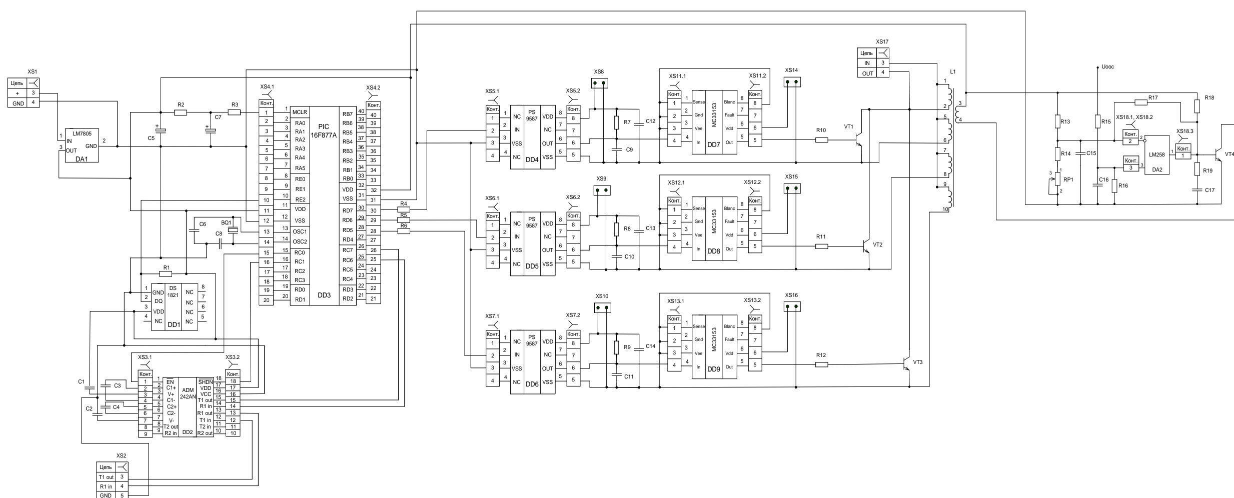


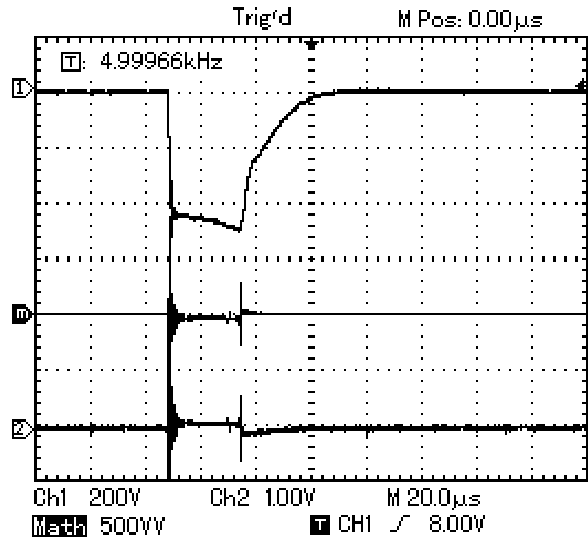
Fig.2: The electrical scheme of the developed dynamic matching device

Control element of the matching device is a microcontroller PIC16F877A. The launcher is built on elements R2R3C7. Power supply +12 V comes to input DA1 via connector XS1. Microcircuit chip LM7805 provides stable power supply of the microcontroller with the value of +5 V. Frequency control circuit is implemented on elements BQ1 C6 C8. Packet exchange with the PC is provided through the converter DD2 via interface232. Optocouplers DD4-DD6 provide galvanic separation of the power part of the power circuits of the microcontroller. Galvanically isolated from each other power of + 5V comes through connectors XS8, XS9, XS10. Drivers of the power key are implemented on microcircuit chips DD7 - DD9. Each of the power keys provides parallel switching of choke coils L1. Electric power supply is carried out through connector XS17. The control module of the bias coil is implemented on the operating amplifier LM258. Elements R13 R14 RP1 set the power reference voltage. The second input receives the feedback negative signal. Resistor R17 set the gain coefficient of the system. Transistor VT4 is a controlling power element in the system.

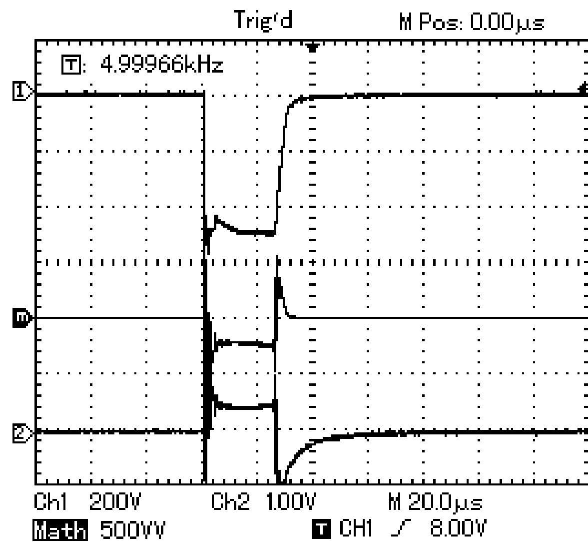
Using the developed coupling device allowed provision for a decrease of the reactivity of the plasma discharge in the range from 20 to 45%. The spread of this parameter is explained by the factors that the experiments were performed at frequencies from 5 to 60 kHz with a variable pulse ratio from 2 to 10. The maximum decrease in the reactivity of the plasma discharge occurred on narrow pulses with pulse ratio of 10 in the frequency range from 40 kHz to 60 kHz.

Fig. 3 shows oscillograms of voltage pulses (line 1), current (line 2), and the calculated pulse value of the power of plasma discharge (line m) on condition of the formation of pulse discharge with the following parameters: pulse repetition frequency – 5 kHz, off-duty ratio 10, pressure 100 Pa, voltage 600 V.

The pulse value of the passing current can be estimated on the basis of the following ratio: 1 V on the scale is equal to 10 A after the recalculation; correspondingly, 1 square on the graph of the pulse power makes up 5 kW.



a)



b)

Fig.3: Oscillograms of voltage pulses (1), current (2), and pulse power of plasma discharge (m) in the absence of matching device (a) and with matching device (b)

The pulse value of the passing current can be estimated on the basis of the following ratio: 1 V on the scale is equal to 10 A after the recalculation; correspondingly, 1 square on the graph of the pulse power makes up 5 kW.

Measuring instruments recorded that during the exploitation of the matching device, voltage pulses acquired sharper fronts and the current pulse amplitude increased fourfold. This indicates that the discharge began to absorb the energy supplied to it, more fully; which demonstrates a more power efficient

process of plasma formation. Picture 3*b* shows that the graph of current waveform at the moment of closure of a power transistor changes its polarity. It means that after the closure of the power module large-scale pulse currents can flow into the output tract of the pulse source, such currents are comparable to discharge current, but of a shorter width. Accordingly, it is necessary to ensure through circuit measures the protection of the output tract of the pulse power-supply source by the method of discharge of plasma medium after the closure of the power module to active load.

The conducted experiments determined that in order to ensure the qualitative matching of the discharge system, the power supply channel, and the output tract of the pulse power-supply source, the matching device should be installed in the closest proximity to the discharge system.

3 CONCLUSIONS

The device for stepwise matching of the communication channel of the power stage of electric pulses generator exciting plasma and the plasma discharge as a dynamic load was developed. The peculiarity of this device is the use of a wide range software – controlled inductive element. Experimental testing of the device with E – type discharge system at frequencies from 5 kHz to 60 kHz showed a decrease of plasma discharge reactivity at the average from 20 to 45%. It makes possible to increase the energy efficiency of plasma process and reliability of the operation of pulse generator with plasma as a load.

Acknowledgements

This research has been supported by the State Program of scientific researches “Functional and composite materials, nanomaterials”.

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