https://doi.org/10.46813/2023-143-009

BEHAVIOR FEATURES OF THE UNGROUNDED ANTENNA POTENTIAL SHIFT IN URAGAN-2M TORSATRON

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The potential shift appears at frame antenna during plasma creation in Uragan-2M torsatron. This paper provides experimental study of that potential dynamics (U_{mp}). The measurements showed that U_{mp} value can be both positive and negative. The dependency of U_{mp} from RF generator feeding voltage and working gas pressure is given. The cause of positive U_{mp} value is identified.

PACS: 52.50.Qt, 84.30.Ng, 84.40.Ba, 88.80.hp

INTRODUCTION

RF method is used for plasma creation and heating in stellarator-type fusion device Uragan-2M (U-2M) torsatron.

The research to reduce breakdown delay or RF generator idle time with was carried out at U-2M torsatron. The gas breakdown was thought to be accompanied with runaway electrons (RE) that appear at U-2M magnetic fields slopes. It will be shown further that the positive potential of frame antenna U_{mp} was several kilovolts depending on anode voltage and the negative potential didn't exceed 1 kV. In works [1-3] it was shown that when a constant potential of any polarity higher than 50...100 V is applied to a frame antenna the flow of runaway electrons (RE) is suppressed. RE flow is generated at the fronts of a magnetic field pulse. The suppressed RE don't participate in the gas breakdown. The mentioned works also showed that the RE suppression increases the gas breakdown delay. Thus, the main aim of this work is to study the dynamics of occurrence and changing of constant potential on antenna. It is planned to identify the possibility of the influence of such a potential on the RE, as well as to search for the possibility of reducing the positive burst of the potential on the antenna to reduce the breakdown time of the working gas.

1. EXPERIMENTAL SETUP AND DIAGNOSTIC METHODS

The RF generators Kaskad-1 and Kaskad-2 served as electromagnetic field RF sources for plasma creation. Both generators have push-pull scheme [4]. Active elements (electron lamps) have same parameters if such scheme is totally symmetric. Control grids voltages are the same. Nevertheless, their phases are opposite then equal voltage values with opposite phases appear at lamp anodes of both generator shoulders. There is a point on the induction coil $L_к$ of the antenna oscillatory circuit without voltage difference relatively to the lamp cathodes in such case. Kaskad generators [5] implement common (grounded) cathode scheme. So the middle point of generator load is equipotential with the common outlet of such device. The middle point of antenna inside the torsatron chamber and the autotransformer middle point are such points (Fig. 1).

As far as antenna doesn't have a lead-out from its middle point, and matching autotransformer is situated outside of the vacuum chamber, the autotransformer middle point is very convenient for high-voltage divider connection and measurements. The frame antenna (Fig. 2) is usually used for pre-ionization i.e. it creates cold low density plasma during standard U-2M regime. The relatively small power of 50 kW is enough to create such starting plasma (and pre-ionization regime) [6]. The frame antenna is not connected with the device chamber, it has bipolar feeder, and so it is convenient for push-pull RF generator Kaskad connection.

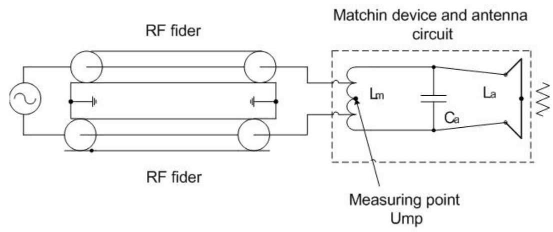

Fig. 1. RF antenna connection scheme

The frame antenna potential shift U_{mp} was measured at antenna matching device middle point in order to study the shift dynamics.

Fig. 2. The frame antenna inside U-2M chamber

The frame antenna potential shift U_{mp} was measured at antenna matching device middle point in order to study the shift dynamics.

The voltage was measured with capacitance and resistive high-voltage dividers at the antenna lead-outs and the matching device middle point. The input impedance of the resistive dividers was in the range of 15...20 kΩ. The plasma startup and the change of plasma parameters were controlled with optical method by means of H_{α} optical line timeline (656.2 nm). All optical measurements were made along vacuum chamber central chord.

2. EXPERIMENTAL RESULTS

The potential shift of the U_{mp} point was both negative and positive during plasma creation with RF generator.

Fig. 3 shows that RF voltage of antenna changed corresponding to potential shift in the middle point. This points at connection of both parameters and confirms assumption about negative antenna potential shift caused by plasma interaction.

The RF generator operation with ballast resistance was aimed to find out the cause of U_{mp} behavior. The U_{mp} was measured with resistive dividers. The potential shift turned out to be absent in the middle point of symmetrical ballast resistance. But the voltage positive burst stayed both in the middle point and generator output at the beginning of the RF pulse.

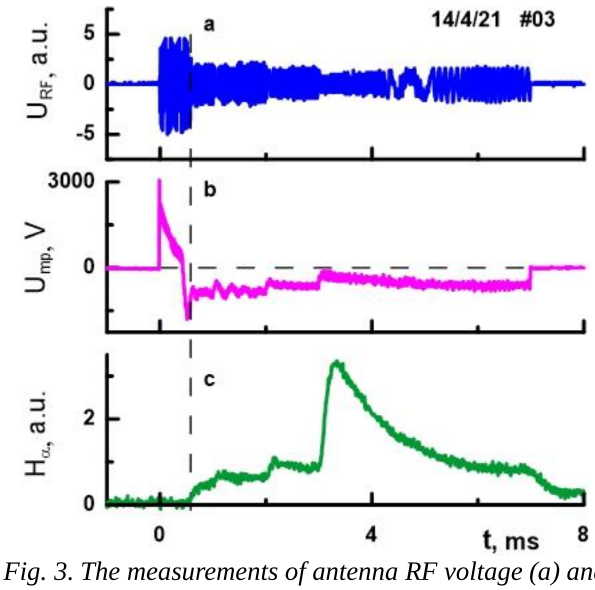

Fig. 3. The measurements of antenna RF voltage (a) and the antenna middle point potential shift (b), H_a emission (c). Working gas – hydrogen, $P=3.5\cdot10^{-4}$ Torr, magnetic field – 0.01 T

The paper [7] stated that the frame antenna negative potential shift was < 1 kV at antenna voltage of 2 kV in Uragan-3M torsatron. The thorough out examination of Fig. 3 oscillogram reveals that the RF generator idle time (the maximum positive amplitude of antenna RF voltage duration) is almost equal to the positive U_{mp} burst duration. The gas breakdown delay can be decreased along with positive potential shift duration. The positive potential shift U_{mp} maximum was about 3 kV.

The careful examination of Fig. 3 reveals that H_{α} emission appears at the moment of antenna RF voltage amplitude sharp change and antenna potential shift polarity reverse. H_{α} emission detection moment corresponds with gas breakdown start. This means that elimination of positive potential shift burst in the RF pulse beginning can shorten working gas breakdown delay.

The further Fig. 3 analysis showed that higher antenna load matches lower negative U_{mp} potential shift amplitude. The antenna load is indirectly determined from antenna RF voltage change [8]. It depends from plasma density, distance between plasma column and antenna and etc.

The paper [7] states that plasma potential is maximal in the antenna proximity at the distance less than 1 cm. The papers [9, 10] are devoted to the study of electrostatic antenna field influence on periphery plasma behavior. They mention edge layer in the antenna proximity and electrons movement from that layer to the excitation electrode or antenna in this case. The summary of mentioned above allows to agree with other authors opinion that potential formation on the isolated from the device chamber antenna is caused by plasma influence and can be realized through volume space charges creation with low density in the antenna or electrode proximity [11, 12].

The plasma influence on RF antenna and antenna oscillation circuit at U-2M is described in details in [8]. Other papers containing data of H_{α} emission and antenna RF voltage confirm this influence. For example, paper [13] shows well H_{α} emission appearance together with sharp decrease of RF voltage at antenna. This moment corresponds with sharp RF generator load increase caused by plasma influence on antenna i.e. working gas breakdown.

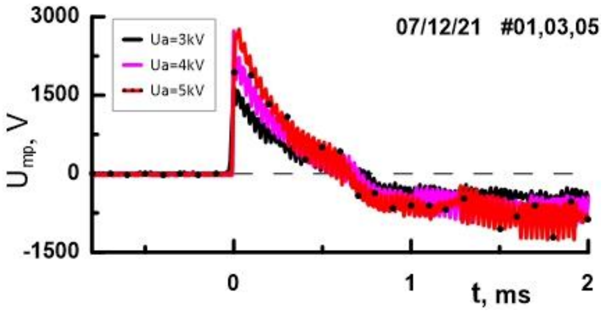

Fig. 4. The dependency of antenna positive potential shift from RF generator lamps anode voltage. $P=6.5\cdot10^{-5}$ Torr, B=0.33 T

The study of antenna positive potential shift dynamics during RF generator triggering obtained the dependency of the potential shift value from RF generator anode voltage (Fig. 4) at almost similar discharge conditions. The working gas was hydrogen at $P=4.5\cdot10^{-5}$ Torr, and magnetic field $B=0.01$ T. The dependency was obtained during vacuum chamber cleaning regime with low density RF discharges.

It can be said that positive burst duration weakly depends from generator lamps anode voltage under the same vacuum chamber conditions. The positive burst amplitude shows another behavior. The lowest amplitude is at U_a=3 kV, and the highest one is at U_a=5 kV. It happens because blocking capacitor charges to the value of RF generator anode voltage.

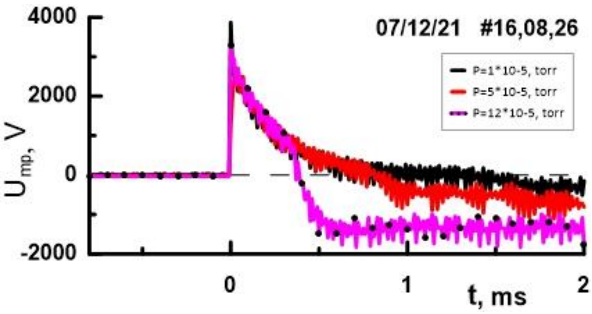

Fig. 5. Dependence of antenna positive potential magnitude and duration from pressure at the RF pulse beginning. B=0.33 T

The dependence of the duration and amplitude of the positive burst of a constant potential on the antenna from the working gas pressure was found (Fig. 5). The positive potential shift duration shortens with working gas pressure increase. This can be explained with the growth of ionization speed while pressure increases in the device chamber.

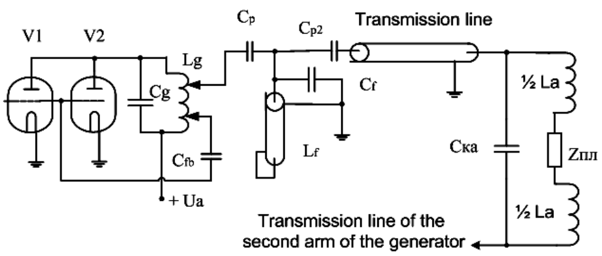

Fig. 6. The partial scheme of RF generator Kaskad with filter attached

The positive potential shift isn't observed when parallel circuit filter (Fig. 6) is connected to the RF generator lead-out. The circuit consists from capacity C_f and inductance L_f. The inductance is made from short-circuited section of feeder line. Authors think that the cause is the discharging of blocking capacitor C_p at RF generator lead-out. The capacitor charges with the positive voltage from generator power source.

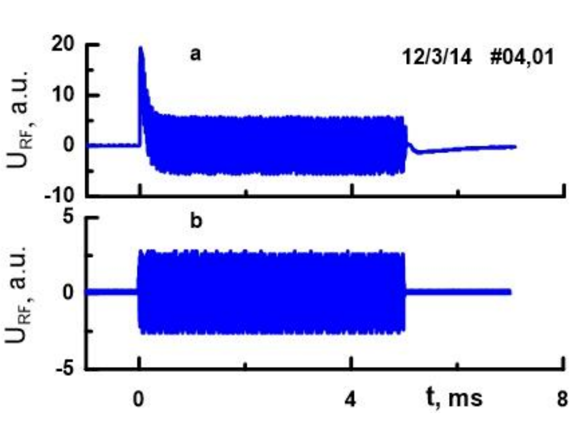

Fig. 7. The RF voltage pulse at antenna input without filters (a) and with them (b)

The filter modified scheme connects capacitor to the common line of the circuit through direct current with filter inductance L_f whose direct current resistance is less than Ohm. So the charging current of capacitor effectively disappears from antenna loading.

Fig. 7 shows no positive burst at RF pulse oscillogram while filters are connected, and the one when there is no filters.

The study of ungrounded antenna negative potential shift dynamics is planned for the next work.

CONCLUSIONS

It has been established that frame antenna voltage shift U_{mp}, measured during the RF pulse at the antenna middle point of the matching device, has both positive and negative polarities. A positive value can reach several kilovolts and depends on the voltage of the RF generator power source.

It is shown that the duration of the positive constant voltage shift on the frame antenna is the majority of the breakdown time of the working gas. In order to reduce this time, a solution was proposed to eliminate the positive potential shift U_{mp} at the beginning of the RF pulse. To do this, it is proposed to make changes to the electrical circuit of the RF part of the generator power source.

In future works, it is planned to study the dynamics of a constant negative voltage on the frame and two-half-turn antennas in the U-2M torsatron. A two-half-turn antenna was installed on the U-2M torsatron in 2020. Its shape is similar to W-7X ICRH antenna.

ACKNOWLEDGEMENTS

Authors would like to thank V.V. Filippov for the idea of putting filtering resonance circuit at RF generator lead-out. Such connection allowed to determine the source of positive potential shift in antenna middle point and showed the possibility for its elimination. Authors also would like to extend their thanks to Yu.V. Kovtun for discussion of results and critics.

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Article received 19.12.2022

ОСОБЛИВОСТІ ПОВЕДІНКИ ПОСТІЙНОГО ПОТЕНЦІАЛУ НЕЗАЗЕМЛЕНОЇ АНТЕНИ В ТОРСАТРОНІ УРАГАН-2М

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При створенні плазми в торсатроні Ураган-2М рамкова антена набуває постійного потенціалу. Наводиться експериментальне дослідження динаміки цього потенціалу U_{mp}. Вимірювання показали, що величина U_{mp} має як позитивну складову, так і негативну. Наведено залежність потенціалу U_{mp} від напруги живлення ВЧ-генератора та від тиску робочого газу. З'ясовується причина наявності позитивної складової.