# EFFECT OF PLASMA ON THE RADIO-TECHNICAL CHARACTERISTICS OF THE URAGAN-2M TORSATRON MATCHING RF SYSTEMS

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There were carried out qualitative studies of the effect of plasma parameters during the RF disharge wall conditioning in a helium atmosphere on the quality factor of the antenna oscillating circuit at Uragan-2M torsatron. The quality factor is determined from the ratio of the electric current in the circuit to the feed current. The dependence of the quality factor of the toroidal steady magnetic field as well as on the helical field is analyzed. The dependence on the helical field is much stronger; with its increase the quality factor increases that is accompanied with reduction of the antenna load. Also, the ratio of idling current in the antenna (when the plasma even less) to the current in the antenna is measured during the discharge. The dependence of this parameter on the toroidal magnetic field and the neutral gas pressure is studied.

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## INTRODUCTION

Uragan-2M is a medium size stellarator with the reduced ripples. It is characterized by the torus major radius R=170 cm, the plasma minor radius $r_p$<24 cm, and by the toroidal magnetic field $B_0$ < 2.4 T [1].

Uragan-2M has a frame antenna with a matching device based on single oscillatory circuit. The RF power is supplied to the antenna by the generators Kaskad-1 and Kaskad-2 [2]. In such a circuit L, the inductance of the antenna, is connected in parallel to the capacitor C. The resonant frequency of the circuit is tuned close to the generator frequency $f_0$. Plasma influence on the circuit reveals in that its resistance is added to the circuit resistance R by plasma electromagnetic interactions with the antenna.

During the Uragan-2M RF plasma wall conditioning campaign in which the discharges are created in the machine with the use of helium as a working gas, the qualitative assessment is made of the effect that built-up and confined stellarator plasma cause the changes in oscillatory circuit Q-factor. The frame antenna with the wide range of parallel wave numbers was used in Uragan-2M for this research [3].

## EXPERIMENTAL CONDITIONS

Antenna circuit is an oscillatory circuit that consists of antenna inductance L and capacitor C.

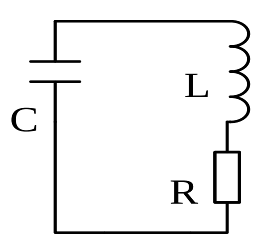


*Fig. 1. A scheme of the antenna circuit with loading*

It is known that an oscillatory circuit (Fig. 1) is characterized by Q (quality) factor Q = ρ / R, where R is loss resistance in circuit, ρ is characteristic impedance of circuit, $\rho = (L/C)^{1/2}$, where L and C are oscillatory circuit inductiveness and capacitance respectively [3]. The loss resistance, in turn, consists of antenna resistance and connecting circuits active resistance $r_{ant}$, and of loading resistance $r_L$. In our case, $R = r_{ant} + r_L$. Naturally, the more oscillatory circuit is loaded, i.e. the larger is R, the lower its quality factor is.

If it is assumed that antenna resistance doesn't change during impulse, then in such a case changes in circuit Q-factor are determined by antenna loading resistance, which is added to antenna resistance: $Q = \rho/ (r_{ant}+r_L)$.

That is why changes in the Q-factor depends on changes antenna loading resistance, which depends on the distance between antenna radiating surface and plasma, on plasma temperature and density and on other parameters [5].

The current in circuit equals $I_k=U_k/\rho$, ($U_k$ – the voltage at circuit), and the feeder current or supply circuit equals $I_f = Uk/\rho \cdot Q$. It follows that $Q = I_k/I_f$ [6]. By measuring corresponding currents we get the value of Q. Note here that the generator doesn't change its frequency while working. It was observed that when the single-stage generator Kaskad-1 is working for a long time, its generating frequency is changed due to the warming of frequency control elements. The Kaskad-1 frequency deviations were measured during the wall conditioning: impulse duration, 60 ms, and pause between pulses is 10 s; as well as in the another mode: impulse duration is 20 ms and pause between pulses is 10 s. The frequency changes were monitored during 150 minutes of work and under the generator anode voltage of 5 and 9 kV respectively.

The frequency deviations of 63 kHz in the first mode and of 35 kHz in the second mode with the initial generation frequency $f_0$ = 8640 kHz were observed. Thus, these changes were less than 1 per cent, and their effect on the value of antenna impedance could be neglected.

## RESULTS OF MEASUREMENTS

The following parameters were measured: antenna circuit input current (feeder current) $I_f$, circuit current (antenna current) $I_k$ and antenna circuit voltage $U_a$.

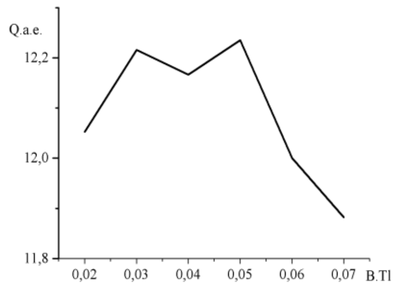


*Fig. 2. Q dependence on magnetic field*

Antenna circuit scaled quality factor dependence on magnetic field for the Uragan-2M frame antenna was evaluated under the mode of helium RF wall conditioning and during the simultaneous work of Kaskad-1(frequency-3.7 MHz, anode voltage-3 kV) and Kaskad-2 (frequency was 5.6 MHz, anode voltage-5 kV).

Fig. 2 shows the diagram of Q-factor dependence on the confining magnetic field. This graph demonstrates increase Q-factor when the field is about 0.03…0.052 T. The diagram shows a sharp Q-factor decrease for the fields lower than 0.02 T, as well as for 0.05 T and higher.

At the next stage the circuit current $I_{axx}$ was measured at the time moment before the discharge initiation (a so called idle running mode). And the same current was measured again, when the antenna was loaded by plasma – $I_{aL}$. In the idle running mode circuit loss resistance is determined by antenna (active) resistance $r_{ant}$ mostly; during the discharge the antenna loading resistance $r_L$ is added to it. These currents ratio gives an indication of changes in the antenna load resistance value.

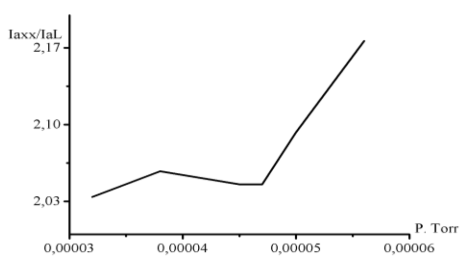


*Fig. 3. $I_{axx}/I_{aL}$ (a.e.) dependence on working gas pressure. When B=0.07 T*

Fig. 3 demonstrates $I_{axx}/I_{aL}$ dependence on the neutral gas pressure for fixed magnetic field B=0.07 T. At this magnetic field value $I_{axx}/I_{aL}$ dependence on working gas pressure (helium) was measured. It was found out that $I_{axx}/I_{aL}$ doesn’t change much and has minimum values at the pressure range of $(3.2…5.0)\cdot10^{-5}$ Torr. As the pressuse increases (higher than $5.0\cdot10^{-5}$Torr) a $I_{axx}/I_{aL}$ sharp increase takes place. We explain this fact as a decrease of the antenna loading.

Thereby, the measurements that were made have shown that in the view of RF generator loading, the optimal conditions for this operation mode are as follows: The magnetic field B is above 0.05 T and the helium pressure range is $(3.2…5.0)\cdot10^{-5}$ Torr.

In the wall conditioning mode with helium puffing when B=0.05 T, $P=3.5\cdot10^{-5}$ Torr according to the above procedure ($Q = I_k/I_f$), the quality factor values were measured during the simultaneous work of two and three generators. They were: Kasksad-1 generator working on the frequency of 3.7 MHz , the VHF generator working in continuous mode on the frequency of about 135 MHz and the power of about 2 kW, and the MGE generator which was also working in continuous mode on the frequency of 5.8 MHz, and its operating power was of about 1 kW.

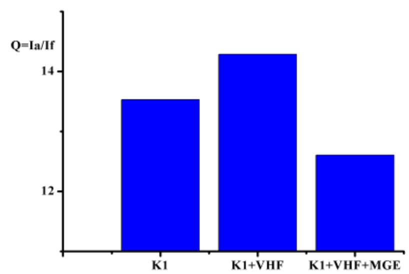


*Fig. 4. Q-factor for different combinations of generators that work simultaneously on antenna circuit Q-factor, B=0.05 T, $P=3.5\cdot10^{-5}$ Torr*

Fig. 4 shows the results of these measurements. It is found that a VHF generator decreases Kaskad-1 frame antenna loading (Q is increased), whereas when they are working along with MGE generator, Kaskad-1 antenna loading is increasing.

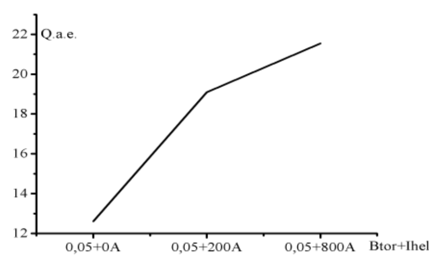


*Fig. 5. The effect of helical field on Q, when $B_{tor}$=0.05 T*

The effect of helical field on frame antenna loading was also investigated. The measurements were made in the mode of three generators working simultaneously. It turned out that increasing of helical field lead to the reduction of antenna loading (Fig. 5).

$I_{axx}/I_{aL}$ and $I_{axx}/I_{aL2}$ (see above) characteristics in Fig. 6 were obtained during the simultaneous work of two Kaskad generators in the wall conditioning mode with the use of helium-oxygen mixture under the pressure of $5.8\cdot10^{-5}$ Torr. In this mode the field of 0.04 T and below

0.06 T is optimal for loading the antenna. I.e. the same conditions as for Kaskad-1 working alone, as shown above. But the value of antenna loading resistance was nearly doubled under the simultaneous work of two Kaskad generators.

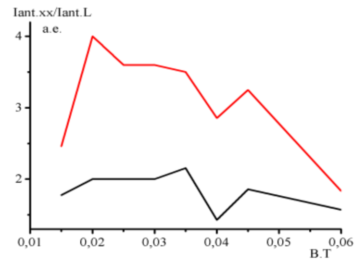


*Fig. 6. The effect of magnetic field on $I_{axx}/I_{aL}$ current ratio (red curve), and on $I_{axx}/I_{aL2}$ current ratio, when two generators was turned on (black curve)*

## CONCLUSIONS

The effect of plasma, as the antenna loading, on the characteristics of the RF circuit (quality factor) is studied. The possibility for qualitative assessment of the resistance induced by plasma into antenna circuit was examined. The measurements showed that quality factor depends on such parameters of the discharge as the toroidal and helical magnetic fields, and on gas pressure.

The effect of switching on other additional RF generators on antenna loading is also described. When three generators are working simultaneously, antenna loading reaches its peak at B=0.05 T, P=$3.5\cdot10^{-5}$ Torr.

The antenna loading was reduced after the imposition of the helical field, which could be explained by the increasing of the distance between the antenna and plasma column.

The results of this work allowed us to examine the value of the antenna loading resistance. This, in turn, gives a possibility to evaluate the RF power which is radiated by the antenna.

## ACKNOWLEDGEMENT

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### ВЛИЯНИЕ ПЛАЗМЫ НА РАДИОТЕХНИЧЕСКИЕ ХАРАКТЕРИСТИКИ СОГЛАСУЮЩИХ УСТРОЙСТВ В ТОРСАТРОНАХ УРАГАН-2М

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Проведены качественные исследования влияния плазмы в режиме ВЧ-чистки в атмосфере гелия на добротность антенного колебательного контура в торсатроне Ураган-2М. Добротность определялась из отношения тока в контуре к току подводящего фидера $Q=I_k/I_f$. Проанализирована зависимость добротности как от тороидального поля, так и от винтового. Зависимость от винтового поля значительно сильнее, с его ростом добротность увеличивается, что соответствует снижению нагрузки антенны. Также измерялся параметр $I_{axx}/I_{aL}$, т.е. отношение тока в антенне в момент холостого хода генератора (когда плазмы еще нет) к току в антенне в момент разряда. Приведены зависимости этого параметра от тороидального поля и от давления.

### ВПЛИВ ПЛАЗМИ НА РАДІОТЕХНІЧНИ ХАРАКТЕРИСТИКИ УЗГОДЖЕНИХ УСТРОЙСТВ У ТОРСАТРОНАХ УРАГАН-2М

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Проведені якісні дослідження впливу плазми в режимі ВЧ-чистки в атмосфері гелію на добротність антенного коливального контуру в торсатроні Ураган-2М. Добротність визначалась з відношення струму в контурі до струму підвідного фідера $Q=I_k / I_f$. Показана залежність добротності як від тороїдального, так і від гвинтового полів. Залежність від гвинтового поля значно сильніше, з ростом поля добротність збільшується, що відповідає зниженню навантаження антени. Вимірювався також параметр $I_{axx} / I_{aL}$, тобто відношення струму в антені в момент холостого ходу генератора (коли плазми ще немає) до струму в антені в момент розряду. Виявлено також залежності цього параметру від тороїдального поля та від тиску.