RADIO-FREQUENCY EQUIPMENT FOR URAGAN STELLARATORS

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A description of high-voltage high-frequency pulse generator design is provided in the article. The matching devices and antennas that are used for plasma creating and heating, together with the ones for Uragan-2M stellarator`s chamber cleaning are also described.

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INTRODUCTION

The Uragan-2M stellarator`s high-frequency equipment is aimed for plasma production and heating [1] by the means of powerful pulse of high-frequency waves.

The stellarator equipment consists of two similar pulse high-frequency generators "Kaskad". Each one of them is connected through a feeder line to a separate antenna.

The generator "Kaskad-1" differs from the "Kaskad-2" by the frequency and by the type of antennas being used. As a rule, one antenna is used for high-frequency discharge, another - for plasma heating.

THE GENERATORS

The generators work within 1…20 MHz frequency range and the pulse duration up to 100 ms. Under such impulse duration the generator's designed power is about 0.8 MW [1]. The high-frequency generators are single-staged; they are assembled according to the push-pull generator design with the GI-26A tubes. 2 tubes are powered up by parallel connection in each generator shoulder with the purpose of high-frequency current increase under the given anode voltage.

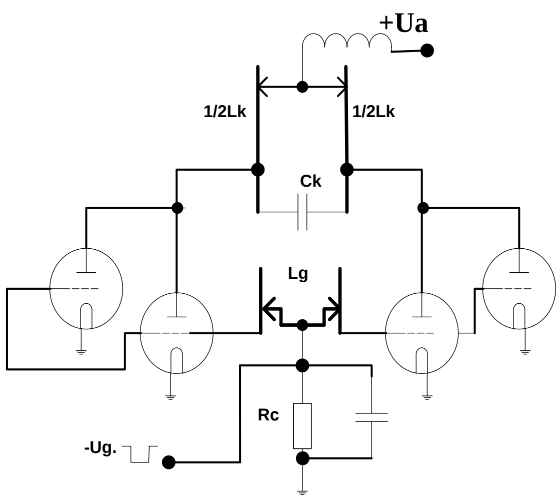

Fig. 1. The circuitry of the generator

A scheme with the joint cathode with capacitive-inductive feedback is applied (Fig. 1). This feedback type is the most convenient within the chosen frequency range, because the "grid-anode" valve's interelectrode capacitance is sufficient for the stable production of powerful high-frequency oscillations, and no additional capacity in the feedback circuit is required [2]. The level of the feedback is tuned by tuning the grid circuit inductance. This inductance is made of U-shaped copper plates, which middle section is movable relative to their side sections. Such a structure allows one for prompt feedback tuning if necessary.

Generator plate tuning circuit is a short-circuited section of a balanced line which is made of 2 parallel copper pipes and circuit capacitors linked up together by parallel connection. There are three options of tuning the frequency of oscillations.

The rough (discrete) tuning is realized by changing capacitors, a more delicate (gradual) one is achieved by moving the shortcut along the balanced line, i.e. by changing the plate tuned circuit inductivity. As the resistance of generator circuit equals $R_k = \rho \cdot Q$, where $\rho = \sqrt{L/C}$, i.e. it depends on the circuit inductance value, in this case the interaction with loading factor *p* is also being changed under such tuning; this fact should be taken into account when tuning the generator. The connection with load is tuned by moving contact clips along the anode circuit's tubular components. These two tuning options are applicable when the anode of generator tubes is powered down, as both options require access to the generator box. Prompt generating frequency tuning is performed by the structure which is similar to the variable inductivity in the feedback circuit.

A storage element with the capacity of 1800 μF which consists of 4 serially connected sections is used as an high voltage battery. The tuneable high-voltage rectifier TDE-5/20 with the maximum output voltage of 20 kV is used as a direct current voltage source for charging the storage capacitors.

Anode voltage from the storage element through a thyristor switch is transmitted to the generator tubes (Fig. 2). Controlling the thyristor switch allows one to initiate high-frequency pulse at the required time moment providing synchronization with the stellarator magnetic field. The duration of generator pulse is controlled by the grid thyristor switch which transmits negative voltage to the generator tube controlling grid.

The thyristor anode switch is three-staged. Such a structure allows controlling anode voltage during the period of pulse generation. Such an approach provides more efficient anode storage element energy usage during generation of pulse under and voltage values of 5 kV and larger; also it reduces voltage on the high-voltage antenna insulators at the beginning of the pulse when plasma loading is small or absent. The switch operates as follows (Fig. 3).

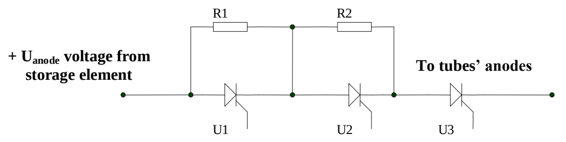

Fig. 2. The anode thyristor key circuitry

At the first moment t_0, when generator is working practically under no-load mode (there is no plasma yet, antenna loading and, therefore, generator loading are minimum), the thyristor U3 turns on, and anode voltage reduced by the amount of voltage drop on resistors R1 and R2 is applied from the storage element to tube anodes. Later on, the thyristors U1 (moment t_1) and U2 (moment t_2), which shortcuts the corresponding resistors, are turned on to increase loading voltage up to the maximum. The required generator working power parameters could be achieved by resistances and by controlling when and in what order the thyristors are being switched on.

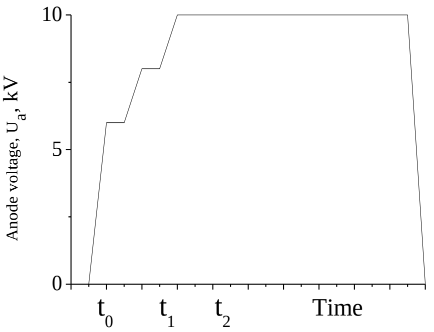

Fig. 3. The time profile of anode voltage when the anode thyristor switch is working

THE MATCHING DEVICES

High-frequency energy from the generator to the antenna is transmitted through a feeder line which consists of four feeders: two parallel coaxial cables in each generator shoulder (the radiofrequency cable RK-50-11-13 is used). The feeder line is about 52 meters long.

Various matching devices that provide generator output resistance matching with the load (adjusted to antenna loading resistance) have been designed aiming to transmit maximum generator power to antenna [3].

Generally, a matching circuit with an additional parallel building-out network that consists of an antenna L_a inductance, an additional matching inductance L_c and a capacitor C_c which are joined together by parallel connection (Fig. 4).

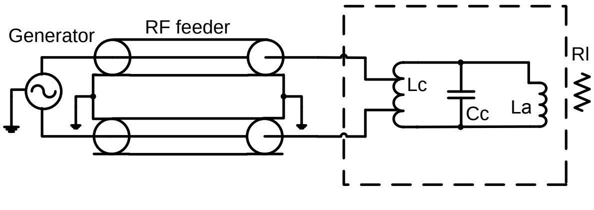

Fig. 4. The system for high-frequency power transmission from the generator to the antenna-loading flow chart

And the magnitude of inductance L_c is 5…8 times larger than the antenna L_a's inductance. The feeder switching-on into antenna circuit coefficient is discretely tuned on the matching device lumped inductance.

High-frequency wave power which is transmitted to the antenna, P_a, is chosen as a criterion for the matching degree. The power was determined by measuring the incident and reflected wave levels ratio in the coaxial cable. The incident and back waves were measured by a directional coupler.

The high-frequency power was calculated according to the formula:

$P_a = \frac{k}{\rho} \cdot (U_p^2 - U_o^2)$, where U_p – incident high-frequency wave voltage; U_0 – reflected high-frequency wave voltage; k – coefficient which is determined during the directional coupler calibration; ρ – feeder impedance.

THE ANTENNAS

When carrying out experiments on Uragan-2M antennas of various designs and inductance values were used. The antennas were made of stainless steel with and without nitride titanium coating. Antennas' inductance ranges from 0.3 to 1.32 μH.

Currently, four high-frequency antennas could be used for experiments. A small frame antenna with water cooling is used for cleaning stellarator vacuum chamber by high-frequency discharge of 132 MHz in continuous mode.

A frame antenna with inductance of 1.32 μH is used for initiation of a high-frequency discharge in plasma. Antennas of such type and their usage are examined in [4]. Antenna loading resistance r_l which is brought into such antenna's circuit by plasma is 0.5…6 Ohm [5].

The "crankshaft"-type antenna with inductance L_a=0.49 μH or the 4 strap-type antenna (inductance value with the feed-through is 0.2 μH) are used for further plasma heating [6].

THE MATCHING DEVICE FOR THE 4 STRAP-TYPE ANTENNA

For this antenna a special matching device was developed that realizes the scheme of a compound capacitive connection with generator's circuit [7].

The matching device is constructed of 3 units (Fig. 5): an antenna unit (frequency-setting), a tuning unit and a control unit. The frequency-setting unit is a metal stainless steel casing which embraces the antenna input. There are capacitor binding posts inside the case, around the antenna high-voltage insulator. Thereby, the antenna circuit capacitors are fixed close to the antenna input which that allows one decreasing spurious inductance.

From the outside the casing is covered with a metal grid which serves as a screen for high-frequency oscillations, and allows visual monitoring of the antenna input the high-voltage insulator and circuit cells state, as well as distant control over antenna input temperature by the means of a laser pyrometer. The antenna input is equipped by water cooling.

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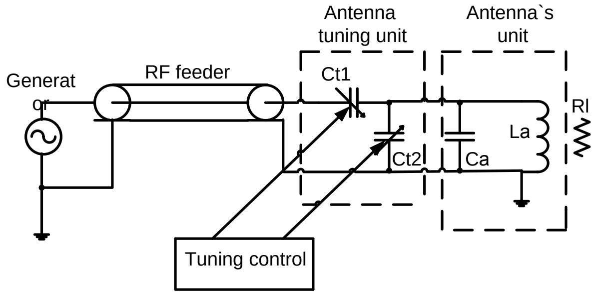

Fig. 5. The matching device's circuit for the "four-half-turned" antenna

The tuning unit is located in a separate case with special "blinds" for mounting and controlling the condition of the tuning adjustable vacuum capacitors, and with a slot for connecting a measuring device. The capacitors are located vertically, one above other, and the leading feeders are fixed on the top that also promotes the decrease of "spurious" electrical mounting reactivity. A special flexible, covered with Teflon insulation (which prevents possible high-frequency electrical break-downs) copper wire connects to the antenna unit. Each tunable capacitor movable output is linked by a gear drive to an output shaft for connecting to operating mechanism drive. The shaft that joins a drive and a capacitor output is made of insulating material to ensure the electrical insulation of the control unit, as the tuning unit capacitors are under high high-frequency potential.

The control unit consists of a remote control module and a runtime module. Two sections (for two capacitors) constitute the runtime module. Each section consists of two RD-09 electric motors that are joined by parallel connection and are working for a common output shaft which is in turn connected to a shaft of a corresponding tuning unit capacitor. There is also a shaft position sensor in each section which provides prompt control over of capacitor capacity value. End switches are placed at the end-points of shaft trajectory for preventing mechanical damage of variable capacitors.

The remote control module is placed in the operator's workplace. There is a device that allows to control capacity in this module and there are also switches for prompt drives management. Electric motors and position sensor power supply unit are also present in the module.

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REFERENCES

1. V.I. Tereshin et al. First results of the renewed Uragan-2M torsatron // *35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008, ECA* 32, 2008, p. 1.061.
2. M.S. Neiman. *Kurs radioperedauschih ustroistv*. M: “Sovetskoe radio”, 1957, p. 123-124, 175-176 (in Russian).
3. B.M. Betin. *Radioperedauschie ustroistva*. M: “Vyschaya shkola”, 1972, p. 69-72 (in Russian).
4. A.I. Lysojvan et al. “Analysis of ICRF (ω≤ωci) Plasma Production in Large-Scale Tokamaks” // *Nuclear Fusion*. 1992, v. 32, p. 1361.
5. V.E. Moiseenko et al. Al'fvenovskiy nagrev v torsatrone Uragan-2M // *Phisika plazmy*. 2009, v. 35, №10, p. 901-906 (in Russian).
6. V.E. Moiseenko et al. Plasma Production Below the Ion Cyclotron Frequency with Crankshaft Type Antenna // *23rd EPS Conf. on Contr. Fusion and Plasma Phys*. Kyiv, Ukraine, 1996, v. 20C, part. II, p.926.
7. B.P. Aseev. *Kolebatel'nye tsepi*. M: ”Svyaz'izdat”, 1955, p. 124-126 (in Russian).

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РАДИОТЕХНИЧЕСКОЕ ОБОРУДОВАНИЕ СТЕЛЛАРАТОРОВ УРАГАН

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Приведено описание высоковольтного ВЧ-импульсного генератора, конструкций согласующих устройств и антенн, применяемых в стеллараторах «Ураган» для чистки стенок камеры, создания и нагрева плазмы.

РАДІОТЕХНІЧНЕ ОБЛАДНАННЯ СТЕЛАРАТОРІВ УРАГАН

В.Б. Коровін, Є.Д. Крамской

Дано опис високовольтного ВЧ-імпульсного генератора, конструкцій узгоджуючих пристроїв та антен, які застосовуються у стелараторах «Ураган» для чищення стінок камери, створення та нагріву плазми.