New gyrotron complex for plasma creating and heating in the L-2M stellarator and first experimental results

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1. Introduction

The first experiments on ECR plasma heating by means of a high power gyrotrons were undertaken on L-2M device at the beginning of the 80th. Development of the theory and experiments went hand in hand. Frequencies, polarization, a quasioptical transport lines (QTL) of the microwave radiation was changed. Optimum parameters of gyrotron radiation for experiments were step by step picked up for ECR plasma heating. As a result in 1994 on a L-2M device the gyrotron complex of the second generation which has received a name "MIG-2" was created. The complex was based on two gyrotrons with design capacity of 200 kW. In experiments it was revealed that level of short turbulence significantly influences to transport processes and, respectively, on plasma confinement [1], unlike long-wave turbulence [2]. For receiving reliable results about functional dependences of ECR heating power on plasma confinement and their comparisons with modern scaling [3] and as for studying micro and macroparameters at achievement of critical modes (a maximum pressure p, L-H transition, critical local and internal barriers) it was necessary to increase the entered capacity of the gyrotrons radiation. For the decision described above tasks of plasma investigation in a stellarator of L-2M the new gyrotron complex of ECR heating of plasma "MIG-3" was developed and created in 2011.

2.Equipment

For a new gyrotron complex a "BORETS" series gyrotrons of a GYCOM production were chosen. Parameters of a gyrotrons are specified in table 1. Table 1.

Name	"BORETS 75/0.8"	"BORETS 75/2"
Max output power, kW	800	700
Max pulse length, ms	100	100
Main frequency, GHz	75	71.6, 75, 78.2
Coefficient of efficiency	50%	45%

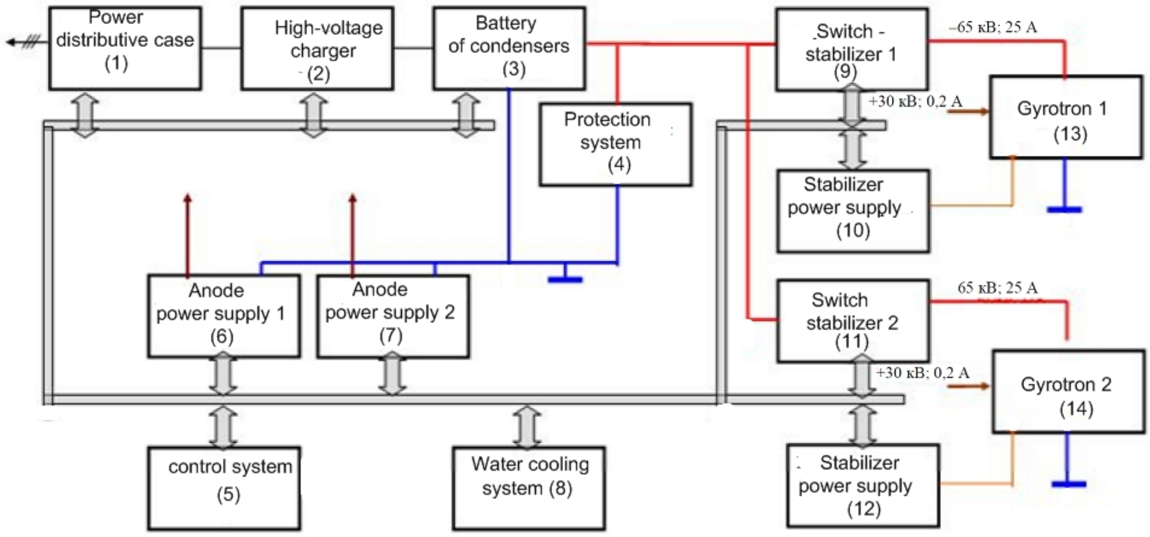

Fig.1. The block diagram of the gyrotron complex MIG-3

The block diagram of the gyrotron complex MIG-3 is given in figure 1. The battery of condensers with a capacity of 40 mF on voltage of 100 kV (3) is the main source of energy of the power supply. Such size of battery capacity of condensers allows to create an impulse of microwave radiation of the maximum power lasting up to 20ms when using one gyrotron and to 15ms when using two gyrotrons. The charge of the battery provides the high-voltage charger (2). Giving of a power food and switching of blocks according to a configuration of the power supply are carried out by a power distributive case (1). The control system (5) allows to manage the gyrotron complex remotely. The protection system (4) interrupts operation of the gyrotron power supply at a emergency regimes of operation and breakdowns of the microwave radiation at output windows of gyrotrons. High-voltage switch and stabilizers of cathode tension (9, 11) are based on triode-type vacuum tube. The stabilizer provides a regulated voltage up to 65kv and current up to 25A. Heat and control of triodes is made by power supplies (10, 12). Anodes lamp with separate power supply parameters 35kV and 0.2A feed.

There is a task about of a microwave radiation of gyrotrons of big power (some hundred kW) putting into plasma of toroidal device. At the output of modern gyrotrons microwave radiation in the form of quasigaussian beams exists. Microwave radiation to long distances with the minimum losses by means of a QTL is transferred to tens meters. On L-2M stellarator too QTL are used. For a singlefrequency gyrotron "BORETS 75/0,8" the four-mirror QTL from a complex MIG-2 was adapted [4]. Total length of a path makes about 4m. The first two mirrors are used for compression of a Gaussian beam and turning polarization of a beam from horizontal in the vertical. Use of a QTL allows to enter an extraordinary wave (X-wave) into a stellarator chamber.

For a multifrequency gyrotron "BORETS 75/2" in API RAS a new QTL was developed and created. The QTL consists of four quadratic correction mirrors, two quarterwave polarizer and an additional rotary mirror for the redirection the gyrotron radiation in the water load. Settlement losses (diffraction and ohmic) in a path don't exceed 5%.

For a complex MIG-3 in API RAS the new a flow water calorimeter was created. The rotary mirror in a QTL which allows to redirect the microwave gyrotron radiation at power measurement to a calorimeter is built. The calorimeter represents a microwave water load in the form of the cylinder 150 cm long and with a diameter of 40 cm, reeled up by a teflon tube with a diameter of 10 mm, long 25m in three parallel sections on which continuously with a constant speed the distilled water weeps. The calorimeter is located vertically, and in the bottom end of the water load exists an ellipse-shaped lens. The focused beam of a gyrotron is entered by a rotate mirror through a diaphragm with a diameter of 100 mm in the cylinder and, being reflected from the lens is distributed on all calorimeter. The equal distribution and absorption of the microwave radiation in a calorimeter interferes with emergence of the return reflection in a gyrotron. Error in measurement of the microwave oven of power is 10%.

3. Experimental result

The first experiments with the new gyrotron complex were made with the power of the gyrotron radiation equivalent to the power of previous experiments. The results of the experiments were repeated. Continuation of experiments goes in the direction of increase of transmit of the gyrotron power in to the vacuum chamber. At the moment entered the gyrotron power radiation reached 800 kW that corresponds to the power density 3 MW/m^3. The shot example with such parameters is given in figure 2. The discharge begins on 50 ms from the beginning of an impulse of a magnetic field. The plasma density after the breakdown of the discharge increases to 1.5x10^{-19}m^{-3}. The increased density occurs during gyrotron operation and continues 2ms after turning off the gyrotron. The final density of the plasma is equal to 4.1x10^{-19}m^{-3}. At a density is equal to 3.2 x10^{-19}m^{-3} is cut-off of gyrotron radiation absorption. The plasma energy, measured using diamagnetic loops, increases rapidly after gas breakdown; then it increases but at a slower rate. The maximum value of the plasma energy reaches 800J. After the heating pulse is switched off, the energy falls, while the plasma density varies slightly. The central electron temperature, measured from the intensity of electron cyclotron emission at the second harmonic of the electron gyrofrequency (76 GHz) usually increases during the early part of the ECRH pulse and then decreases slowly toward the end of the microwave pulse, when the plasma density increases. Before you turn off the gyrotron radiation, the plasma temperature was 800eV.

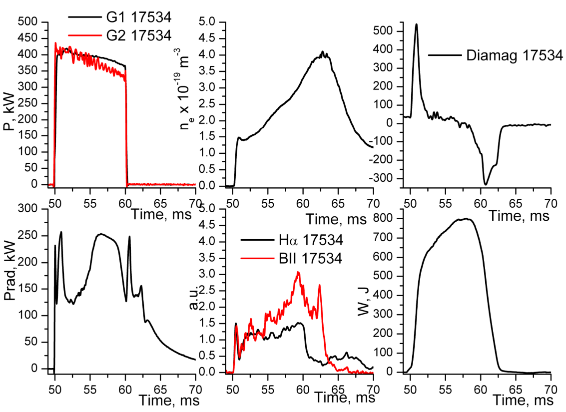

Fig.2 Shot 17534 with max parameters

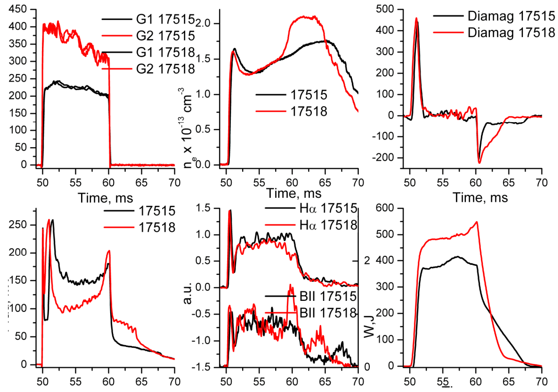

Fig 3. Two shots with different plasma confinement

Power input more 400кВт in some experiments led to change of a mode of a plasma confinement. Two shots are given as an example on figure 3 with identical entered power capacity, but different behavior of plasma during the shot. Parameters of diagnostics signals of the first shot correspond to parameters of signals earlier observed on L-2M device at the smaller entered power of microwave radiation (black curves). In the second shot (red curves) on the sixth millisecond of the shot there is a short increase of the plasma density. In the same time the signal decreases. Disintegration of plasma happens significantly quicker.

4.Conclusions

On the L-2M device the gyrotron complex MIG-3 is put out into operation.

In the last experiments the capacity of the microwave oven of heating 800кВт is entered that there correspond to a specific power contribution about 3 MW/m^3.

At a microwave power contribution more 400кВт change of a mode of a plasma confinement is possible.

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