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Status of the TJ-II Electron Bernstein Waves heating project

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Abstract

The present status of the main components of the TJ-II Electron Bernstein Waves (EBW) heating system are presented. The O-X-B scenario has been chosen for first harmonic (28 GHz) heating. One 300 kW, 100 ms gyrotron has been checked and is ready for installation. The design of a new high voltage power supply unit is finished. The microwave power will be transmitted by an oversized corrugated waveguide. Two ellipsoidal mirrors optimise the gaussian beam parameters at the input of the waveguide and two corrugated ones get the required polarization. A movable internal mirror is needed to accomplish the restrictive launching conditions. The present cooling system of the ECRH system is being upgraded to cool the 28 GHz-complex. The start of the experiments is scheduled for the end of 2005.

Keywords: Stellarator; Plasma heating; Electron Bernstein Waves

1. Introduction

Electron Bernstein Waves (EBW) have been successfully used to heat overdense plasmas in W7-AS and H-J stellarators [1,2], having the advantage of overcoming the cut-off density limit of usual electron–cyclotron heating methods. The feasibility of plasma heating using EBW has been examined in the TJ-II and both scenarios X-B and O-X-B in the first harmonic (28 GHz) are achievable from the theoretical point of view [3]. The O-X-B1 has been chosen to carry out the experiments due to accessibility restrictions of the launching position inside the TJ-II vacuum vessel [4]. The ray tracing code TRUBA [5] has been used to determine the best launching position and direction, in terms of power absorption, and the optimum

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gaussian beam in terms of transmission efficiency [6]. With these data the internal launching mirror has been designed.

2. High voltage power supply

The main parameters of the 28 GHz gyrotron are as follows: cathode voltage, 60–70 kV; current, 13–25 A; pulse length, 100 ms; power, 300–350 kW.

A new high voltage power supply unit, which provides the formation of a stabilized negative voltage pulse up to 70 kV and a maximum current of 25 A, has been designed. The principle of energy storage in capacitors to produce high power pulses at the gyrotron is the base of the design. The energy is stored in the HV capacitors up to 75% through a deep discharge of the high voltage capacitor bank (HVCB) during the pulse (up to 50%). A voltage-boosting device, which is connected in series with the capacitor bank and supplied by the low voltage capacitor bank (LVCB) compensate this voltage decrease. Switching on/off the pulse and its further regulation are produced with a high power electron tube. The block diagram of the high voltage pulse power supply is shown in Fig. 1. It includes the following units: power distribution cabinet (PDC), high voltage charging device (HVCD), high voltage capacitor bank, low voltage charging device (LVCD), low voltage capacitor bank, boosting high frequency dc–dc converter (HFC), electronic high voltage modulator–regulator (HVMR), crowbar protection system, gyrotron filament and auxiliary power supply (AUX) and control and monitoring system

The supply voltage ($3 \times 380 \pm 20$ V, 50 Hz) feeds through a power switch the primary regulator, which consists of a switch regulator charging device and a HV transformer-rectifier. The controlled current from the output of the transformer–rectifier charges the HVCB up to the required output voltage. After triggering the HVMR, the stabilized voltage pulse is supplied to the gyrotron.

The triggering pulse starts also the booster system. The previously charged LVCB feeds the HFC and its output voltage is added to the voltage at the HVCB. The measured voltage decreases at the HVCB, is the control signal for the converter. The output voltage in the converter increases as the battery discharges. The HVMR input voltage remains almost constant during the pulse, thus minimizing the voltage drop at the tube.

The primary regulator maintains a given voltage at the input of the transformer–rectifier, stabilizes it against the variations in the circuit and load parameters and also switches off the power supply in emergency regimes. The HVMR provides the high-speed commutation and stabilization of the load voltage by a command from the control unit and ensures the fast switching-off of the load in the case of its breakdown. In the case of simultaneous breakdowns of the gyrotron and the commutation tube, the protection of the load electrodes from damages is provided by the vacuum-gap crowbar protection system. This system discharges the HVCB through a shunting circuit, which by-passes the gyrotron and the tube. The crowbar protection system, together with the grounder, the load switch, the equivalent load (not shown in the Fig. 1) and the current sensor comprise the auxiliary system. The AUX unit provides the power for the gyrotron filament and feeds the ion getter pump. It also generates a warning signal when the discharge current goes beyond the prescribed limits.

The HVPS is controlled from the control unit. The system controls and the output voltage setters are located on its control panel. This unit provides a step-by-step control of the HVPS elements, via a serial real-time CAN bus by checking the command performance at each step. The control system displays the specified values of the gyrotron voltage and the filament current, and the residual gas pressure in the gyrotron and in the modulator tube. The remote control is provided through the system console, which is connected to the CAN bus. The system console presents to the operator a wide control and monitor function of the system. Its program shell provides different modes of manual and automatic HVPS operation with graphic representation of the system parameters and status. The connection with the central control system is carried out through ethernet interface. To provide the galvanic decoupling of these control units, the signals are transmitted through optical fibers.

The design of the HVPS is finished and the manufacturing of the components is in progress. The assembly and installation in the TJ-II is scheduled for the first term of 2005 in order to start the operation with the gyrotron in the second term.

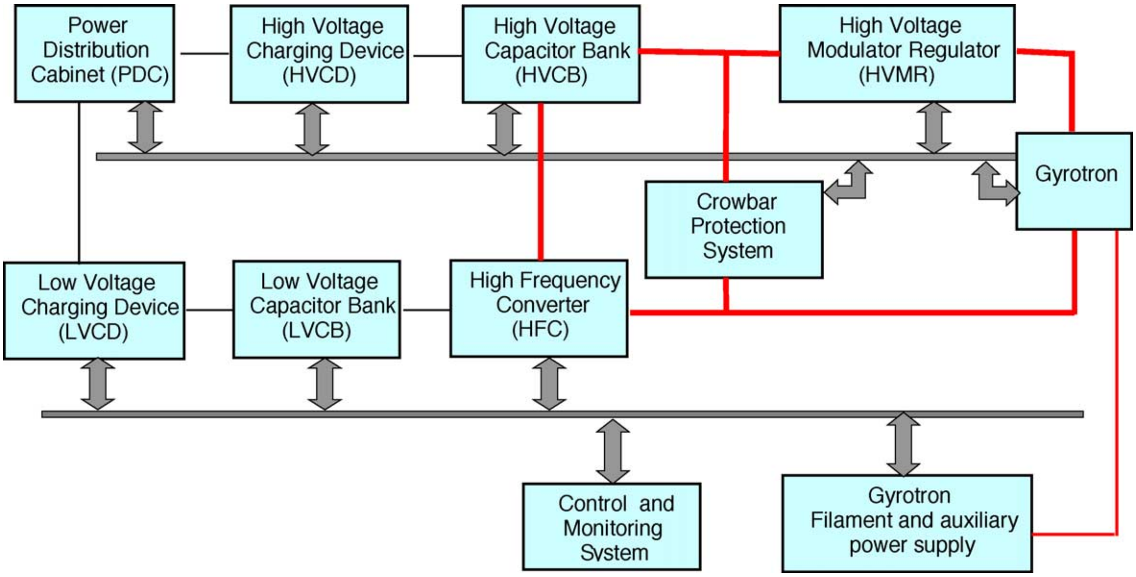

Fig. 1. Block diagram of the high voltage power supply.

3. Transmission system

The 300 kW microwave power is transmitted by an oversized corrugated waveguide and it is launched through the lateral D6 port of TJ-II. Two curved mirrors have been designed to get the required electromagnetic field at the input of the waveguide.

Inside the vacuum vessel, an internal mirror focuses the beam in the required position. The beam has been optimised to have the best transmission efficiency through the O-X conversion layer [6]. To obtain the required polarisation to get maximum O-X conversion efficiency, two flat corrugated mirrors act as polarizers. The corrugations are smoothed in order to avoid arcing at high power level. The size of the internal mirror is the maximum size that can be installed inside the vacuum vessel: 19 cm × 17 cm. The waist in the plasma is $w_0 = 30$ mm and the distance between the centre of the mirror and the waist is 383 mm. It is movable in order to allow an experimental optimisation of the launching direction.

The oversized corrugated waveguide has 10 m length and an inner diameter of 45 mm. It operates at atmospheric pressure. Two continuous curvature bends are needed and the losses due to mode conversion are less than 0.5%. An internal part of stainless steel is required in order to focus the beam with the internal mirror with minimal diffraction losses (Fig. 2). The distance between the end of the waveguide and the mirror is 215 mm and the length of the internal waveguide part is 645 mm.

The expected losses of the quasi-optical part are around 3%, taking into account diffraction and ohmic losses. The total losses of the corrugated waveguide are around 3%. The coupling loss between the quasi-optical components and the waveguide is estimated to be 3%. The total losses are estimated to be 9%.

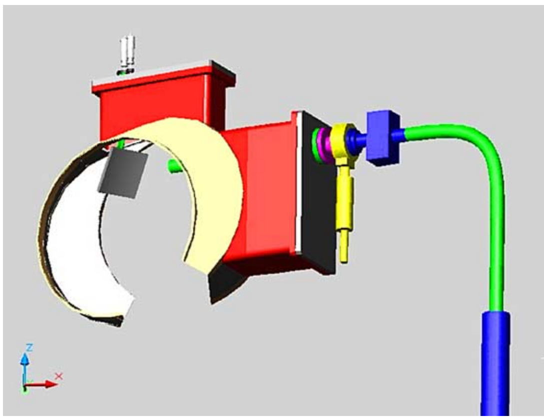

Fig. 2. Insertion of the waveguide in the TJ-II and internal mirror.

4. Cooling system

The cooling system for the present ECRH system was based on a closed primary circuit with deionised water (1–10 μS/cm) as coolant. In this circuit, 30 m^3/h of cold water is pumped by a vertical centrifugal water pump to a manifold, from which the eight pipes to the gyrotrons components are split. This primary circuit also includes an expansion tank and a connection to a 1 m^3 deionised water tank. The water cooling was made through a 25 kW plate heat exchanger, whose secondary side is fed by 7 m^3/h of tap water at 14 °C as maximum, coming from the TJ-II cooling plant.

In the EBW heating system, some gyrotron components, tetrode (power supply system), water load and calorimeter must also be water cooled, therefore, the already installed ECRH cooling system and the new one have been connected in parallel and share a larger heat exchanger and its inlet and outlet manifolds.

Thermal and hydraulic calculations have been done in order to size properly the mechanical components of the new cooling circuit. Taking into account the thermal loads (normal and faulty conditions) and duty cycles, a 35 kW plate heat exchanger has been designed as heat sink for both cooling systems. Following the manufacturers requirements about water flow and maximum inlet pressure for the new components to be cooled, a new 60 m of liquid and 20 m^3/h vertical centrifugal pump has been installed. A complete set of instrumentation has also been installed in order to monitor the temperature, flow and pressure conditions of each circuit.

A new control system has been built to operate the new pump and manage the instrumentation signals, alarms, etc. In order to get homogeneity with the present system, the new control system is also based on PLC.

Several improvements in the current ECRH cooling system have also been accomplished in order to optimise its operation. The filling and emptying processes of the sixteen cooling circuits for the gyrotrons I and II are facilitated by the installation of a filling pump and more drainage and air purge points. A number of pressure and flow measurements have also been added in order to get a more complete monitoring of the hydraulic circuits. To get the appropriate capacity to

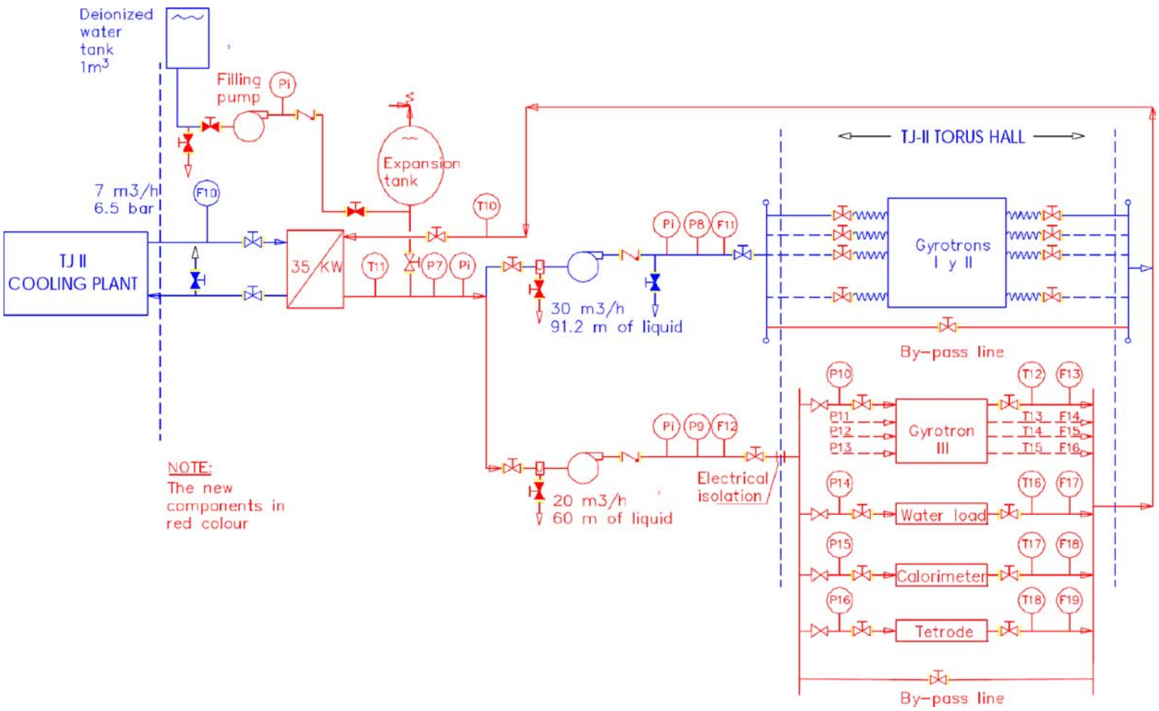

Fig. 3. Scheme of the complete cooling system.

manage the new signals, the current control system has also been upgraded and the control software modified.

The scheme of the final status of the complete cooling system is represented in Fig. 3.

5. Conclusions

The components of the Electron Bernstein Wave heating system for the TJ-II are designed and some of them fabricated. The high voltage power supply is being manufactured and will be delivered to CIEMAT in the last term of 2005. The mirrors of the transmission line and the oversized corrugated waveguide are designed and are being fabricated. The cooling system has been upgraded. The plans are on schedule and the experiments will start in 2006.

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