The ECRH System for JET-EP
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A G A Verhoeven¹, S Alberti², F J v Amerongen¹, H Bindslev¹, W A Bongers¹, A Brusci³, S Cirant³, C Damiani⁴, B S Q Elzendoorn¹, D Fasel², A Fernandez⁵, C Fleming, P Hellingman¹, M Henderson², J A Hoekzema⁶, W Kasparek⁷, A Kaye, W Kooijman¹, O G Kruijt¹, G Land¹, K Likin⁵, P Marmillod², W Melissen¹, G Muller⁷, J Paméla⁴, B Piosczyk⁸, A B Sterk¹, E Solano⁴, M Thumm⁸, Q Tran².

EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxfordshire, OX14 3DB, UK.

¹FOM Instituut voor Plasmaphysica ‘Rijnhuizen’, Association EURATOM-FOM, PO Box 1207, 3430 BE Nieuwegein, The Netherlands.
²CRPP, Lausanne, Switzerland.
³CNR, Milan, Italy.
⁴EFDA JET-CSU, Culham Science Centre, Abingdon, Oxfordshire, OX14 3DB, UK.
⁵CIEMAT, Madrid, Spain.
⁶FZJ, Jülich, Germany.
⁷IPF, Stuttgart, Germany.
⁸FZK, Karlsruhe, Germany.
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An ECW (electron cyclotron wave) system is being designed for JET. The system will consist of 6 gyrotrons, 1 MW each, in order to deliver 5 MW into the plasma. An extension of 2 more gyrotrons is recently being considered. The system will especially be designed to enable the control of neo-classical tearing modes (NTM). Furthermore, heating and current drive is foreseen in a large number of different target plasma configurations and the control of the ratio of the electron and ion temperatures [1,2]. The frequency, 113.3 GHz, is selected to enable a wide range of operating toroidal magnetic fields from 3 to 4 T and at second harmonic at lower fields and also to allow for a future upgrade to 170 GHz using the same systems, including the double-disk diamond windows.

The main elements of the ECW system are:
# gyrotrons with a depressed collector, 1 MW each, 10 s pulse duration with a diamond window, with Gaussian output mode.
# main power supplies, up to 60 kV, with a solid-state crowbar to feed two gyrotrons.
A series IGBT switch will enable independent control of each gyrotron.
# evacuated waveguides or quasi-optical mirror lines will be each capable of transmitting 1 MW, having a double-disk diamond window located near the torus as an additional tritium barrier. The total length is in the order of 80 to 100 m.
# a plug-in launcher, steerable in both toroidal and poloidal angle. A trade-off will be made between a single launching mirror per transmission line or two beams per launching mirror in order to have the highest flexibility, but also the narrowest beam size in the plasma.

The gyrotron power supplies

The configuration of the collector power supply is based on the connection of two gyrotrons to one existing (former lower hybrid) 60 kV power supply. See figure 1. To limit the energy deposit into an internal arc, IGBT switches are connected in series with the gyrotrons, to disconnect the gyrotron from the power supply within 2 μs. An LR snubber is connected in series with the gyrotrons to decrease the current rise time in case of an arc. If the IGBT switch fails to switch off, the crowbar will be triggered and short-circuit the output of the power supply. With this set-up the energy deposit into an arc will be limited to lower than 10 Joules.
The body power supply will be connected between collector and body. In this scheme the accelerating voltage is composed of the sum of collector voltage and body voltage. Stabilisation of the accelerating voltage is performed by controlling the body supply in dependence of the collector voltage as well as of body voltage. A fast power-supply system for the body of the gyrotron is being designed, to enable accurate control of the accelerating voltage and fast modulations up to 20 kHz. In case of an arc in the RF transmission system or in the gyrotron itself the body supply will be switched off in a few microseconds.

Waveguide connection to the launcher

In front of the launcher flange a relatively large space is needed to develop a construction which can handle the movements of the reactor vessel without getting damaged. Fig. 2 shows a possible waveguide routing. The combination of double-disk diamond windows, mitre-bends and compensators indicates that the existing neutron detector, KN3, needs a shift backwards by 1200 mm. Also a free horizontal space of 150 mm between the diamond windows, required for a free view towards the centre of the machine is hereby achieved.

A quasi-optical mirror line as an alternative to a waveguide line.

The aim of this investigation was to see whether it is possible to create a quasi optical transmission line as an alternative for an evacuated corrugated waveguide transmission line. The following design aspects were considered:
*To minimise the number of mirrors and mirror dimensions*
*To prevent very small waists along the path (breakdown prevention)*
*The windows have a free aperture diameter of 63.5 mm*
*The line is situated at current free space.*
*To realise a system suited for 110 (113.3) GHz up to 170 GHz or higher.*
*The torus hall is separated by a window to the outside (tritium containment), later on it was decided that a window at the torus hall wall is not required.*

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*Figure 2. The connection between the evacuated waveguides and the launcher. The neutron profile monitor is shifted backwards by 1.2 m.*

*Figure 3. 3D design of the quasi optical transmission line configured as a single beam line with the torus hall separated by a window from the gyrotron hall. On the left side a 6-gyrotron set-up is shown.*
The entire quasi-optical transmission line, from the output window of the gyrotron up to the torus, is based on the confocal principle. This implies that mirrors are placed such that focal points are linked and form telescopes with broadband transmission over a large frequency range. The transmission line consists in total of 12 mirrors per line, of which 10 are of focussing elliptical shape and 2 of a flat shape. In a confocal set-up the input plane is imaged to the output plane this allows also transporting more than one beam along the same path, supposing that the right mirror sizes are chosen.

Up to the JET window five separate telescopes are used, see fig. 4. The first two telescopes are leading the beam from the gyrotron window up to the torus hall window. In this region, the maximum dimensions of the mirrors are 0.4*0.6 m² (for a single beam based on 3.5* spot size). Inside the torus hall three telescopes are used to guide the beam to the torus windows. The mirrors of the last telescope are slightly modified compared to fig. 3. The maximum mirror dimensions above the torus are 0.5*0.7 m². A quasi-optical transmission line seems a feasible solution for ECRH on JET. More options have been investigated in detail by EURATOM-CIEMAT, see [3].

**Quasi-optical launcher plug-in system**

A pre-design for a fully plug-in, quasi-optical launcher system is given in figure 5. The launcher can handle up to 8 quasi-optical mm-wave beams. It can be inserted and taken out again as one complete unit.

**The control and protection system**

The control system is build up by CODAS cubicles, which perform the interfacing of the control, timing, data acquisition and status signals of each local unit to and from the subsystem computer. Fig. 6 shows the general set-up of the control system. Each cubicle consists of several modules, such as input and output cards for on/off signals, parallel input/output, serial input/output, timer and stopwatch cards, communication cards (Ethernet, RS232, CAMAC serial highway), digital to analogue and analogue to digital converters etc. Several CODAS interface cubicles are controlled by one subsystem computer. Each gyrotron with its associated power supplies, vacuum systems, cooling circuits, SCM, transmission lines etc. is named a gyrotron unit.
Figure 5. The 8-beam launcher system proposed for ECRH on JET-EP. At the bottom on the right side, we see the incoming quasi-optical mm-wave beam going through a double-disk diamond-window set. Three fixed mirrors are guiding the beam to the last mirror, which is moveable in both toroidal and poloidal direction. At the bottom on the left side, we see the motor drive for the movements of the rotatable mirror.

A gyrotron unit is interfaced by one CODAS cubicle. Since two gyrotrons share one high voltage power supply (HVPS) and one crowbar, the HVPS and crowbar are placed in one per two gyrotron units. The gyrotron units are named unit 1/a and 1/b, 2/a and 2/b, 3/a and 3/b. Systems which are shared by all gyrotrons and the hall μW detectors, and systems which are located far away from the other systems, such as the launcher and double diamond windows are interfaced by separate CODAS cubicles. These will be named unit C and D. Also includes the Central Interlock and Safety System (CISS).

The internal timing (including movement and modulation as function of time) of the different systems (polariser mirrors, launcher mirrors and voltage Body PS) are provided by the associated CODAS cubicles. Triggering of the internal timing and the data acquisition is done under control of the Central Timing System CTS.

A fibre optic serial communication network connects all CODAS cubicles with a subsystem computer. The subsystem computer takes care of the control of the whole
ECRH installation. Local control of the ECRH system is possible by means of a console connected to the fibre optic serial communication network. Remote control from the JET control room is provided by an Ethernet connection.

Conclusion.

The ECW system proposed for JET-EP bears many similarities with the system considered for ITER-FEAT. Therefore, the implementation of the ECW system on JET-EP will bring important information in the detailed design, fabrication and operation for ITER-FEAT. It is foreseen to install the plug-in launcher during the 2003-04 shutdown and have the first ECW power delivered immediately after the start-up following the shutdown.

![Diagram of the control and protection system proposed for ECRH on JET-EP](image)

**Figure 6.** The control and protection system proposed for ECRH on JET-EP

**References:**


