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# Feasibility of an ECRH System for JET: Plant Layout, Auxiliaries and Services

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*\* See annex of F. Romanelli et al, "Overview of JET Results",  
(Proc. 22<sup>nd</sup> IAEA Fusion Energy Conference, Geneva, Switzerland (2008)).*

Preprint of Paper to be submitted for publication in Proceedings of the  
16th Joint Workshop on Electron Cyclotron Emission and Electron Cyclotron Resonance Heating,  
Sanya, China.

(12th April 2010 - 15th April 2010)



## **ABSTRACT.**

A study conducted over the last year to assess the desirability and feasibility of installing an ECRH system on the JET tokamak has concluded that such a system is indeed both desirable and feasible. Details of physics studies, launcher and transmission line design, and power supplies are presented elsewhere in these proceedings. This paper concentrates on the logistical implications of installing this system at JET. The paper addresses issues such as port allocation and plant location. The study has concluded that a new building will be needed to house the ECRH plant. Building layout proposals are presented together with considerations regarding the required auxiliary equipment.

## **1. INTRODUCTION.**

Having an ECRH system would strongly enhance the ability of JET to fulfil its mission in preparing ITER operational scenarios. Therefore a study evaluating the feasibility of installing such a system on JET within a timeframe allowing results to be beneficial for ITER has been carried out during 2009 in a collaboration between JET, various European Fusion associations and the Russian Federation with substantial input from both Fusion For Energy and ITER [1]. A previous JET ECRH design [2] formed the basis for the study, though the evolution of both requirements and technical and scientific experience has led to a proposal which differs significantly from the previous design. Investigating different system frequencies and evaluating their ability to fulfil various physics requirements such as NTM stabilisation[3], Sawtooth control, Current Profile Control and central electron heating, 170GHz was found to be the best compromise [4,5]. A significant additional advantage of choosing 170GHz, which is the ITER frequency [6], is that components, not least the gyrotrons themselves, can be taken directly from the ITER design allowing verification not only of ITER ECRH physics but also of ITER ECRH technology. A plant of twelve 1 MW gyrotrons [7,8], capable of injecting 10MW of ECRH power for 20s into the plasma was found adequate, though more power would be desirable to achieve substantial current profile control [1,3,4,5]. In the following the investigation leading to the choice of launcher and plant location to be used in the reference design are described followed by considerations regarding building layout and a brief evaluation of the required auxiliary equipment. Power supply and transmission line considerations are presented in separate contributions [9,10].

## **2. PORT ALLOCATION.**

One of the biggest challenges facing the feasibility study was the search for a port where an ECRH launcher could be located and it rapidly became clear that no such position could be made available without sacrificing or, at best, relocating existing equipment. With the proposed power of 10MW transmitted through 12 separate transmission lines, a launcher with the required steering range requires the use of an entire JET main horizontal port [11]. With this boundary condition all 8 main horizontal ports were considered. Figure 1 shows the present use of these ports. Ports 3, 4, 7 and 8 were rapidly ruled out as they are completely occupied by neutral beam injectors (Ports 4 and 8), The lower hybrid current drive launcher (port 3) and the interferometer used to measure plasma

density (port 7). The diagnostic systems occupying ports 1 and 5 (Neutron monitor and LIDAR respectively) are hard if not impossible, to relocate. This in conjunction with the fact that these ports are used for access into the machine meant that neither port 1 nor 5 were considered ideal candidates. Port 6 presently contains a large number of smaller diagnostic systems. Relocating any single diagnostic from this port would probably not pose a significant problem but relocating all of them was found to be very difficult with significant risk of reducing the availability of essential diagnostics. The final port (port 2) is presently occupied by the ITER like ICRH antenna (ILA). This antenna is not operational at present and it is unlikely that it will be refurbished in the near future. Therefore replacing this antenna by an ECRH launcher would present a simple solution. If port 2 is used, the ECRH launcher could use infrastructure presently used by the ILA such as the main support and bellow seen in figure 2a. Port 2 also hosts some pellet injection pipes as seen in figure 2b, which would have to be accommodated by the ECRH launcher. These pipes are not very large and it is not considered a problem to leave space for them. Given these considerations it was decided that the feasibility study should concentrate on the use of port 2 for the ECRH launcher. This being said the use of one of the ports (1,5,6) could be reconsidered if the decision was taken to repair the ITER like ICRH antenna.

### **3. PLANT LOCATION AND PRELIMINARY BUILDING DESIGN.**

Having decided on the location of the ECRH launcher, the search for a convenient location for the ECRH plant started. The required space is mainly defined by the fact that the distance between adjacent gyrotrons has to be at least 4 metres in order to avoid interference between the magnetic fields of the gyrotrons. Figure 3 shows various potential plant locations. Installing 12 gyrotrons with their auxiliary equipment inside existing JET buildings was found to be, if not impossible, highly disruptive and very costly. This led to the decision that a dedicated ECRH building would be required. The final choice of a building location at the North West corner of the torus building was governed by the ability to find a simple routing for the ECRH transmission lines [9]. A preliminary building design using all the available space in this location and allowing the required distance between gyrotrons is presented in figure 4a. In this design the gyrotrons would be distributed in two rows of 6 gyrotrons. The gyrotrons and their associated cooling circuits and cooling plant would be on the ground floor while power supply equipment would be installed on the first floor. Removable walkways on the first floor would allow easy access to install and remove gyrotrons with a modest size overhead crane capable of lifting 300kg loads (fig. 5). A more compact layout, which avoids having to relocate an existing gas plant, is proposed as seen in figure 4b. The 4x3 honeycomb layout of the gyrotrons in this proposal would maximise the distance between gyrotrons for a given building size and it would assure the most symmetric distribution of stray magnetic fields.

### **4. AUXILLIARY EQUIPMENT.**

Figure 6 shows an overview of the ECRH plant for one gyrotron. Of the systems shown in this figure, the launcher [11], transmission line [9], gyrotron [7] and high voltage power supplies [10] are described elsewhere in these proceedings. In the following the remaining equipment is considered:

#### **4.1. COOLING**

A number of system components needs to be actively cooled. The main energy to be removed is ~1-1.5 MW from each gyrotron collector and 1 MW from each test load. It is unlikely that it will be necessary to operate all gyrotrons simultaneously for 20 seconds into test loads and hence the total energy to be removed during one 20s pulse from collectors and loads should remain below 400 MJ. The total energy to be removed from all remaining components is modest in comparison. All cooling water has to be demineralised and a heat exchanger is required to take the heat from the demineralised water into the site water. Including a sizeable tank in the system will smooth the cooling of 20s pulses over a longer period though in doing this it has to be considered that the maximum water inlet temperature for the gyrotron cooling is 35°C. The gyrotron is cooled by several cooling circuits with different pressures and flow rates, some of which have to be electrically isolated from each other. In addition the diamond windows have to be cooled by an independent system with a special anti corrosive additive in the cooling water. The required transmission line cooling is under investigation and given the modest pulse length, it is likely that figure 5 is pessimistic in assuming that all transmission line components will require active cooling. The final component likely to need active cooling is the launcher. The launcher design [11] uses the ITER upper launcher steering mechanism with a slightly modified mirror for poloidal steering [6]. This assembly is designed to be water cooled. The cooling for the remaining launcher mirrors remains to be designed. In JET, for reasons of tritium compatibility, it would be desirable to avoid water cooling inside the torus vacuum. Whether interpulse gas cooling can fulfil the requirements is under investigation. A possible compromise could be to retain the water cooling for the poloidal steering assembly while designing the remaining structures for gas cooling.

#### **4.2. SUPERCONDUCTING MAGNETS:**

Gyrotrons require a magnetic field of approximately 7 Tesla inside their cavity provided by external superconducting magnets. Two types of magnets have been considered: i) Traditional superconducting magnets cooled to liquid Helium temperatures using external cryogenic supplies. ii) So-called ‘cryogen free’ magnets, which are self-contained units that do not require any external cryogenic plant. The ‘cryogen-free’ magnets contain internal refrigerators and require only mains power to maintain the magnets at superconducting temperatures. As the existing JET cryoplant was found to be insufficient to supply liquid helium for a 12 gyrotron system, option ii) is considered to be the most economical and convenient solution. As the ‘cryogen free’ system is also the system chosen by ITER the study concluded that option ii) would also be the correct choice at JET.

#### **4.3. CONTROL AND DATA ACQUISITION:**

In line with the attempt at following the ITER design as closely as possible it is proposed that the Control and Data Acquisition system should be based on the ITER-CODAC/I&C design. Accordingly ‘slow’ instrumentation and control should use the Siemens S7 PLC range while using a model of the CODAC Plant System Host (PSH) computer for communications with the PLC. Above this

host level, standard JET CODAS ‘black-box’ software should be used. For the safety systems, CISS (central Interlock and Safety System) and PSACS (Personnel Safety and Access Control System), standard JET procedures will be followed.

#### **4.4. OTHER AUXILIARY EQUIPMENT:**

In addition to the equipment described in the previous paragraphs other required systems are briefly discussed in the following. As the proposed transmission line solution [9] is based on evacuated cylindrical waveguides, a number of vacuum pumping groups including valves and gauges will be required both in the torus hall and in the plant building. Mechanical actuation is required to move the launcher mobile mirrors. For the ITER steering mechanism used for poloidal steering these actuators are pneumatic, while the toroidal steering may be achieved either using similar pneumatic actuators or using a simple motor driven pushrod system. As the wave polarisation has to be varied when injection angles change, motorised control of polarising mirrors is also required. To allow safe and reliable gyrotron operation a system measuring incident and reflected power is needed. Finally an optical arc detector system is essential to prevent damage to diamond windows both in the gyrotron and in the transmission line.

#### **CONCLUSIONS.**

The feasibility of installing a 12MW ECRH plant at JET has been studied. A solution for the choice of main horizontal port to host the ECHR launcher has been proposed and a promising location for a new building for the ECRH plant allowing a very simple transmission line trajectory to the tokamak has been identified. An initial evaluation of the required auxiliary equipment has been undertaken. As a conclusion the study has found no major impediments to installing the proposed system into the JET environment. Given the use of a new building to house the plant the installation of such a system could proceed with minimal interference with JET operation.

#### **ACKNOWLEDGMENTS:**

The authors would like to acknowledge the substantial work carried out by the rest of the ‘ECRH for JET’ team [1] and thank the EC community as a whole for always being ready to promptly provide information and advice which has been invaluable for the progress of this study.

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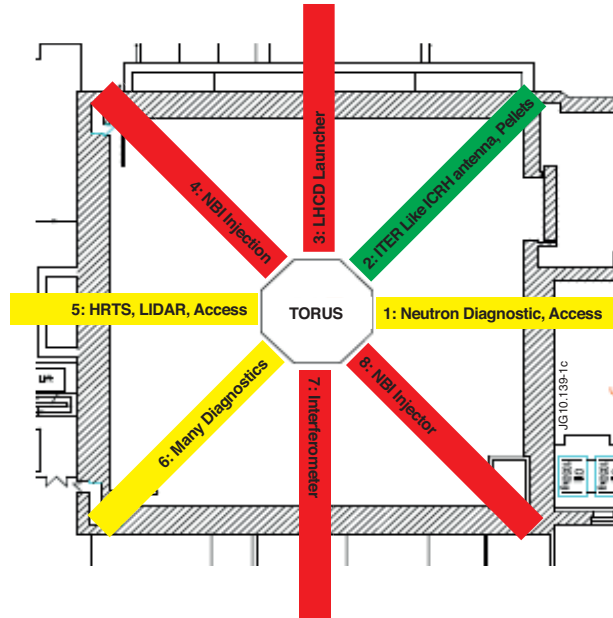


Figure 1: JET Main Horizontal Ports –Present Use

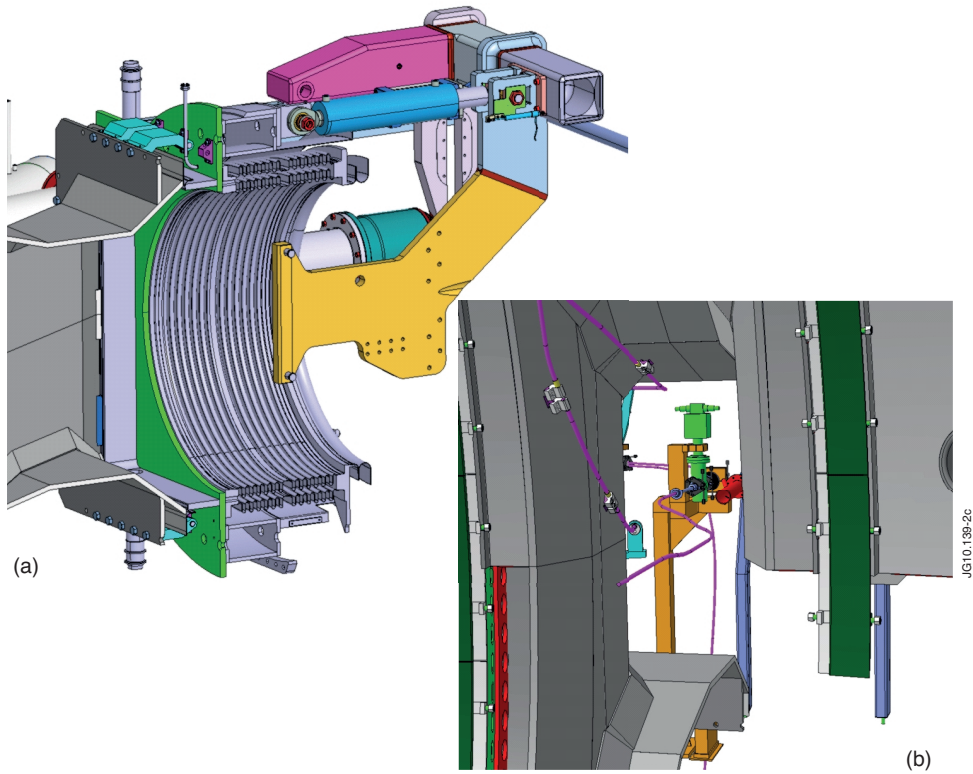


Figure 2: (a) ILA bellow and support structure, (b) View of port 2 from inside the JET vessel showing the pellet injection pipes.

