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Feasibility of an ECRH System for JET: High Voltage Power Supplies Requirements and Proposed Structure

H. Braune[1], G. Giruzzi[2], J. Hay[3], P. Khilar[3], M. Lennholm[4,5], L. Moreira[3], A. Parkin[3], A. Vadgama[3] and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]Max-Planck-Institut für Plasmaphysik, Euratom Association, D-17491 Greifswald, Germany
[2]CEA, IRFM, 13108 Saint-Paul-lez-Durance, France
[3]EURATOM-CCFE, Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK
[4]EFDA Close Support Unit, Culham Science Centre, Abingdon OX14 3DB, UK
[5]European Commission, B-1049 Brussels, Belgium
** See annex of F. Romanelli et al, "Overview of JET Results",*
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ABSTRACT.
The future JET programme, after the installation of the ITER-like wall, will be mainly focused on the consolidation of the physics basis of the three main ITER scenarios. These scenarios will make substantial use of Electron Cyclotron (EC) waves, for heating as well as for control of both the MHD activity and the current density profile. Therefore, a programme for preparation, validation and optimization of the ITER scenarios in present tokamaks would strongly benefit from an ECRH/ECCD system. A study has been conducted to evaluate the feasibility of installing an ECRH system on the JET tokamak. An important intention of the study was to investigate the feasibility to utilise some unused conventional NBI – power supplies for the ECRH project.

1. MICROWAVE POWER – MICROWAVE SOURCES

The investigations concerning the required microwave power, absorbed in the central plasma region, led to the result that a microwave power in the region of 10MW with a frequency of 170GHz would be required. Commercially available microwave sources with the required frequency generate a radiation power of 1MW at the output window. Therefore, taking into account the losses in the transmission lines, 12 microwave sources are intended to be used, so that 10MW of microwave power can reliably be deposited in the central region of the JET plasma.

The microwave sources will be diode type gyrotrons operating in depressed collector mode in order to achieve efficiency up to 55 %. Diode type gyrotrons require two DC high voltage sources, the main voltage and the body voltage power supply.

2. POWER SUPPLIES - REQUIREMENTS

The main voltage supply has to deliver 65kV, 50A with negative polarity on high potential. The body voltage source has to deliver 30kV, 50mA.

Both high voltage supplies generate the electron beam acceleration voltage of the gyrotron as shown at Fig.2. The radiation output power of a gyrotron depends strongly on the acceleration voltage. Therefore highly regulated voltage sources are required for controlled gyrotron operation (accuracy ≤ 1%).

3. RF POWER REGULATION AND MODULATION

Using body voltage variation for power regulation would lead to significant additional waste power at the collector surface with the risk of collector damage. Therefore main voltage regulation for power control should be used, to significantly reduce the collector power during modulation

The most flexible ECRH operation regime will be achievable if each gyrotron is fed by separate HV power supplies.

4. WHAT IS AVAILABLE? -> FOUR POWER SUPPLY UNITS FROM THE OLD NEUTRAL BEAM SYSTEM!

Each PS units consists of two rectifier transformers with a so called protection unit in series and one matching transformer. Fig. 3 shows the out door part. The rectifier transformers deliver 120kV and 60A each. Thyristor star point controllers perform the DC output voltage adjustment. The rectifier transformers can operate separately or in series and are designed to deliver positive voltage. The two rectifier transformers per unit, referred to as master and slave, are different. The protection units include the tetrode and the required auxiliaries for exact DC – high voltage regulation. The tetrode installation has the wrong polarity and is situated at the wrong place for use in the proposed ECRH system.

Master rectifier transformer

- output connector with the positive polarity is isolated up to 120kV with respect to earth and the output connector with the negative polarity had been designed for a maximal voltage of 3.5kV to earth.

Slave rectifier transformer

- both output connectors are isolated up to least 120 kV with respect to earth.

Only the slave transformer of each unit has currently the capability to deliver 80 kV DC in both polarities with very minor modifications, while more significant changes are required to allow the master transformer to deliver negative voltage.

5. CROWBAR

The specified maximum released energy in the case of an arc inside the gyrotron demands an additional tube protection circuit. Each power supply therefore has to be equipped with a crowbar installed close to the gyrotron.

The design of the crowbar unit should be based on a thyratron tube in order to minimize the volume compared to a thyristor based crowbar unit.

A snubber must be installed between thyratron and gyrotron. The snubber ensures sufficient voltage at the thyratron terminals for safe triggering of the crowbar in case of voltage breakdown at the gyrotron due to arcing.

6. PROPOSED POWER SUPPLY STRUCTURE

6.1. MAIN POWER SUPPLY

Two types of power supplies are proposed:

- **Eight** power supplies using the existing rectifier transformers with star point controllers and tetrodes in series, allowing fast voltage regulation and modulation up to 20kHz (Type 1)
- **Four** power supplies based on solid state solutions without any added regulators and a limited modulation capability up to 1–2 kHz (Type 2)

6.1.1. Main power supply Type 1

The existing four NBI – power supplies can be split in 8 independent supplies capable of providing the required voltage and current for 8 gyrotrons. Using the NBI power supplies, only 4 new power supplies are required for the remaining gyrotrons. However, certain modifications and thorough refurbishment of these power supplies is needed in order to make them suitable for feeding gyrotrons.

- Modification (polarity change) of four master transformers
- Replacement of eight 12-pulse star point controllers and star point inductors
- Reconstruction of 8 protection units for operating with changed polarity
- Relocation of the reconstructed protection units to a new gyrotron building

The power supply has the capability to modulate the main gyrotron voltage up to 20kHz. The body voltage supply becomes simple and compact.

6.1.2. Main power supply Type 2

For the purposes of the assessment we have assumed a power supply design based on Pulse Step Modulator technology (PSM). The modules are equipped with IGBT switches rated 1700V / 200 A. The complete system is air-cooled.

A short-circuit energy < 15 Joules is achievable with PS based on the PSM principle and the short-circuit switch-off time will be less than 8µs.

DC voltage generated by power supplies based on solid-state technology has a non-negligible ripple. The body power supply becomes more complicated in order to compensate the main voltage ripple. The power supply has the capability to modulate the main gyrotron voltage only up to 2kHz.

6.2. BODY POWER SUPPLY

The kind of body voltage power supply depends on the type of main power supply. The body voltage has to switch off fast in a case of a gyrotron interlock. Therefore a fast switch based on power MOSFET technology is connected in series between the body power supply and the gyrotron body at both types of main power supplies.

6.2.1. Requirements when used in combination with main PS type 1:

If the main high voltage is fast regulated by a tetrode tube based regulator without any ripple and noise, the requirements on the body voltage power supply are not very stringent. The body voltage supply would not need a fast high voltage amplifier.

6.2.2. Requirements when used in combination with main PS type 2:

The solid-state main high voltage power supply generates an exact voltage which may however be affected by a not insignificant ripple. Depending on the level of this ripple on the direct voltage, compensation could be required in order to achieve a stable RF power. The ripple compensation is feasible by using a body voltage supply equipped with a fast high voltage amplifier with slew rates up to 600V/µs. Two kinds of amplifiers are currently in operation at comparable gyrotron installations:

- Tube based as used at the W7-X ECRH plant in Greifswald [2]. Unfortunately the production of the required tubes (TH 5188) has been stopped.

- Solid-state based as at the ITER gyrotron test facility in Lausanne [3]. This amplifier needs a lot of space compared to tube based solutions.

CONCLUSIONS

Several devices from the old NBI power supplies could be reused in the new ECRH system.

- In the proposed solution eight power sources will be able to perform a power modulation up to 20 kHz and four power sources will be basically used for continuous plasma heating without power modulation.
- From the physics point of view, this is a promising solution concerning the requirements of plasma heating and plasma stabilization.

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Electrical requirements

Acceleration voltage	80–85kV
Cathode voltage	–55kV
Depression voltage	<35kV
Beam current	40–46A
Frequency	170GHz
RF output power	1MW
Pulse length at JET	20s

Figure 1. Gyrotron 1MW 170 GHz, GYCOM Russia.

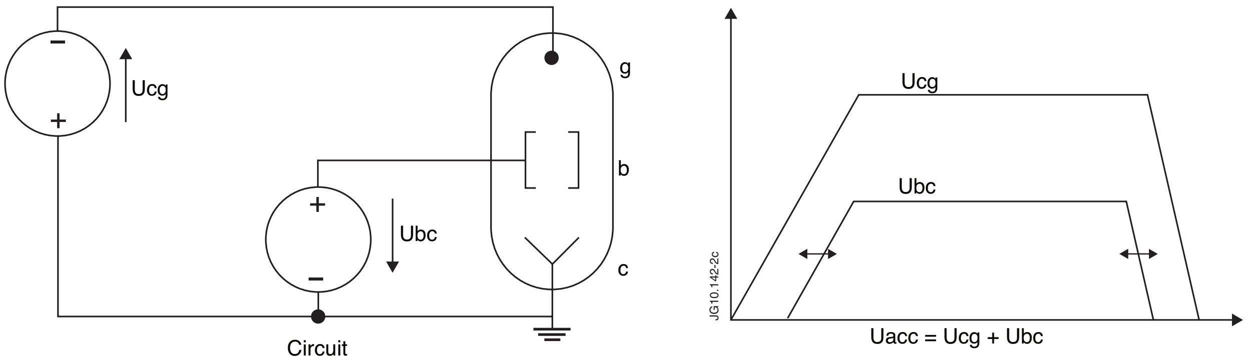

Figure 2. HV power system – principle sketch [1]

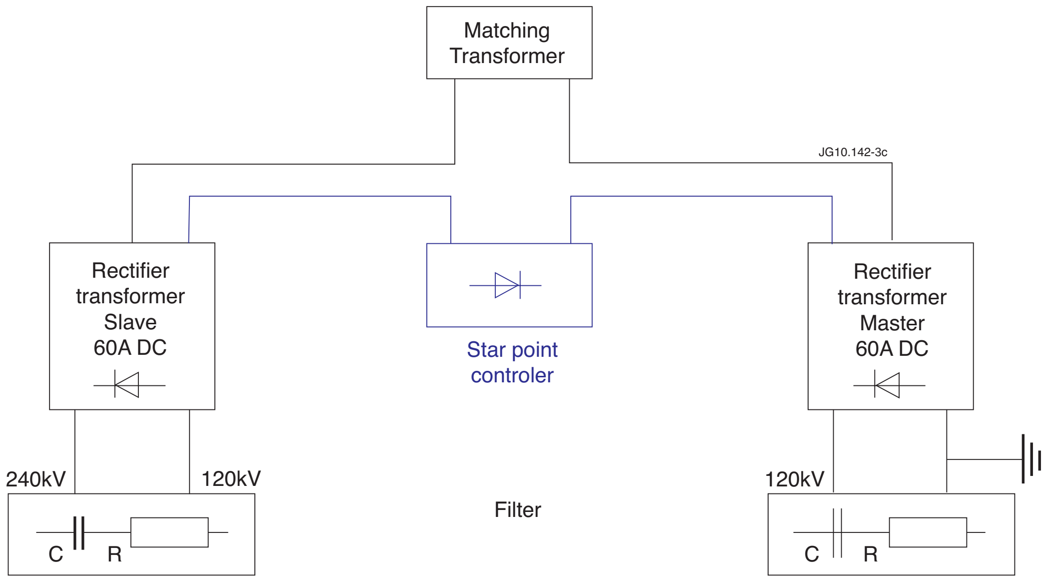

Figure 3. NBI power supply unit (out door part).