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# Gas Analyses of First complete JET Cryopump Regeneration with ITER-Like Wall

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** See annex of F. Romanelli et al, "Overview of JET Results", (24th IAEA Fusion Energy Conference, San Diego, USA (2012)).*

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**Abstract.**
JET ICRH plant faults from 2008 - 2012 have been catalogued and a new assessment of the reliability of the plant by sub-system is given. Data from pulses where ICRH was used, excluding the ITER-Like Antenna (ILA) and its generators, has been collated. This is compared to fault data in order to investigate any correlation between faults and operations. The number of faults is shown to have decreased between 2011-2012 in comparison to 2008-2009 as the time between faults is shown to have increased. Future electronic fault logging requirements to enable easier analysis are discussed. Due to the changing configuration of the ICRH plant; the introduction of ELM tolerant systems, generator upgrade, changes to the settings of the VSWR protection et cetera, a method to expand the fault database to include more historical data [1] in a consistent way are discussed.

## 1. INTRODUCTION

Depending on the research program and chosen RF plant configuration [2], the four A2 antennas on JET are currently powered by two or three generator modules comprising of four amplifier chains each. This paper studies faults of the generators, high voltage DC (HVDC) power supplies transmission lines, and control systems to provide a review for 2008-2012 and focus for improvements in the future. In this study under the term generator we group the whole amplification chain until the transmission line.

The data in this study has been gathered from ICRH logbooks over this period in a similar way to the previous study by Cambi and Pinna [1]. During 2010 the ITER-Like Wall was being installed so the data was sub-divided into pulses during 2008-2009 and pulses during 2011-2012. This is a natural point to split the data as the installation of ILW caused modifications to the plasma density in the Scrape-Off Layer (SOL) that may have affected antenna coupling and hence plant performance. At the same time new RF flux excluders were installed to the poloidal limiters which may also have affected performance. Due to a design fault on one of these excluders one half of antenna B could not be used during 2011-2012 [3]. Vacuum pulses and test-load operations without plasma were ignored as their main purpose was for fault finding and plant conditioning. For the first stage of this study a fault is classified as any alarm, abnormality or malfunction recorded in the paper-based logbooks as problem with the plant. This is later refined as the aim of this study is to investigate plant faults that impact on the output of ICRH plant that cannot be compensated for. For example a fault removing one amplifier from service where the other amplifiers are able to provide more power and make up the difference would not count, where as if this caused a loss in generated power it would. Similarly any fault classed as a limit, such as maximum transmission line voltage, predriver limit et cetera would be counted but not included as a fault since the plant is working as required, this applied to approximately 5% of the data.

By comparing the faults in the logbooks with the stored pulse data further coding of the faults could be carried out before continuing with the analysis. Around 7% of faults had to be removed from this study as there was no data available for them; this included several pulses where the power requested was too low to be accurately measured. Where multiple faults were recorded for the same module only the most serious was kept since a single problem may show alarms and anomalies on multiple items.

## 2. PLANT AVAILABILITY AND FAULT RECORDING

The usage of the ICRH generator modules over the scientific campaigns 2008-2009 and 2011-2012 is given in TABLE (1) below along with the percentage of ICRH pulses with faults and the usage of each module, as a percentage of the number of ICRH pulses. The usage value does not distinguish between inactivity due to the physics programme or due to maintenance. The low usage of module C can be explained by the use of the ECT system [2], to provide ELM tolerance, which alters the configuration so that module D is connected to antennae C and D and module C is removed from service. The number of faults in 2011-2012 is lower than the 2008-2009 period despite more challenging conditions and greater usage for some antennas.

## 3. DATA ANALYSIS

The faults were analysed for the whole plant; the generator faults, e.g. tube over-currents, power limitations, stage tuning et cetera, were deliberately separated out from crowbars and generator arcs. Whilst crowbars and generator arcs may represent genuine faults in some cases they may also be the result of another fault triggering the crowbar or causing arcs across a dedicated spark gap as part of the generator protection. FIGURE 1 shows that generator arcs and crowbars are responsible for around a quarter of plant abnormalities.

## 4. TIME BETWEEN FAILURE

Papers on reliability and plant statistics usually quote Mean Time Between Failure (MTBF), however for a pulsed system this can be hard to quantify as it may not be used for long periods of time. Whilst the pulse number could be used as the measure of time, the requirements of the experimental program can remove one or more antennas again leading to a false MTBF value. The use of MTBF in this case is further questioned when values of the standard deviation of the time between failures are more than twice the mean since this shows that the mean is not representative of the system. Figure 2(a), shows how the number of pulses since the last pulse changes through the campaign for module B with clusters of faults clearly seen. Horizontal sections of these lines indicate that a generator is currently not in use.

Although hard to quantify within these statistics it should also be noted that the ICRH system is an integral part of the large and complex JET plant running on its own schedule, therefore it may not be possible enact a repair at any given time and a module may need to be run with a known fault. In the 2008-2009 operations there was an intermittent fault with the high voltage power supplies (HVDC) for the ICRH plant, due to the time required for repair this was left until the 2010 intervention to repair. The removal of recorded faults that can conclusively be linked to this fault are shown by the dotted line on Figure 2a. Figure 2b shows the time between faults for 2011-2012 operations where long periods without faults can be seen. The intermittent nature of the faults may also be due to the antenna loading conditions which are more challenging during H-mode operations due to the lower coupling and ELM perturbations.

## 5. POWER CAPACITY FACTOR

Plant failures are not the only issue affecting the ICRH plant performance: finite power capacity and maximum antenna voltage restrictions are the other two important factors capable of limiting the power levels injected into plasma. Each amplifier module has an installed capacity of 8 MW giving a maximum capability of either 24MW, in normal configuration, or 16MW, in ELM tolerant configuration, for the A2 antennas. With greater emphasis on H-mode plasma ELM tolerance is vital to stable ICRH operation. The ECT offers this but when in use antennas C and D are powered from module D. In Figure 3 the power capacity factor is plotted against the maximum voltage, a value obtained by dividing the power generated by what was available for each pulse. The lower frequency pulses can be seen to have higher voltages and a lower power capacity factor which is explained by lower coupling. However the power generated is provided to match the request of the physics programme where high power is not always required and the ~30kV limit on the transmission lines may also play a part in these results. FIGURE 3 shows that the generators may be capable of more and that the majority of pulses do not run at the maximum voltage limit, although operations in 2011-2012 saw more pulses at higher voltages. Further studies will investigate plant limitations and non-fatal faults that also play a part in plant performance.

## DISCUSSION

The plots contained within this paper have shown that the reliability of the ICRH plant has improved despite conditions that have become more challenging. Statistical analysis of ICRH plant operation is a valuable tool in the task of increasing plant performance on JET and for providing recommendations for RF design on DEMO.

More data is required to assess the influence of RF plant settings and plasma loading conditions on the plant reliability. An attempt was made in this study to collate the data into groups depending on such parameters as antenna phasing, plant control modes, antenna-plasma gap, and presence of ELMs et cetera. However, it quickly became clear that many of these statistical groups did not contain enough data to produce statistics with a high level of confidence. The creation of a database using historical faults, building on [1], will increase the size of these groups so that this study can be successfully carried out.

In the next campaign a new electronic logging system will be used, taking over from the older paper based system, which will make the compilation of fault statistics and plant reliability easier. A method of qualifying the pulse using more electronic data and determining the root cause of faults rather than just recording their symptoms would also be part of this. Whilst the root causes for these faults are eventually found a review of which pulses they effected is not always performed.

The greater use of electronic data and analysis would provide a better database from which to compile statistics that could eventually be automated. By recording the timing of generator crowbars and arcs these faults can be cross-referenced with voltage reflection signals to see if they were triggered by changing conditions..

## ACKNOWLEDGMENTS

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| | Usage Including Restart | Number of Pulses with ICRH | Faults in ICRH Pulses | Module Operation (out of ICRH Pulses) B | C | D |
|---|---|---|---|---|---|---|
| 2008-2009 | 31% | 2769 | 13% | 82% | 58% | 85% |
| 2011-2012 | 31% | 1239 | 5% | 86% | 48% | 91% |

*Table 1: ICRH module usage and fault occurrence.*

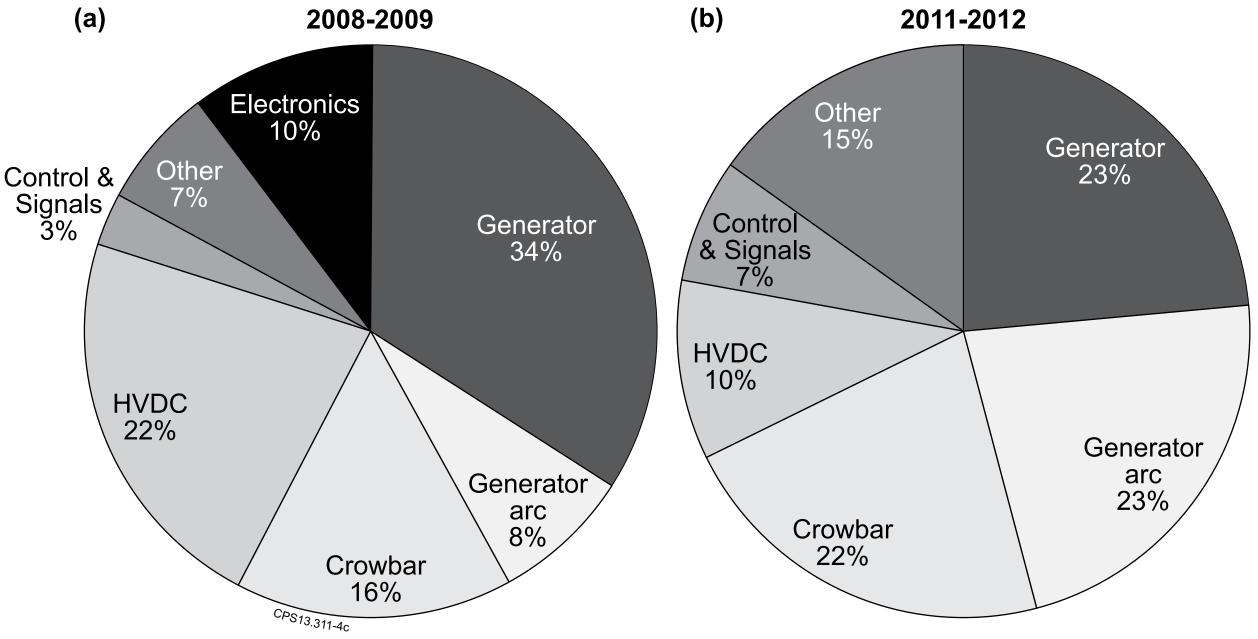


*Figure 1: Plant abnormalities by type and recurrence.*

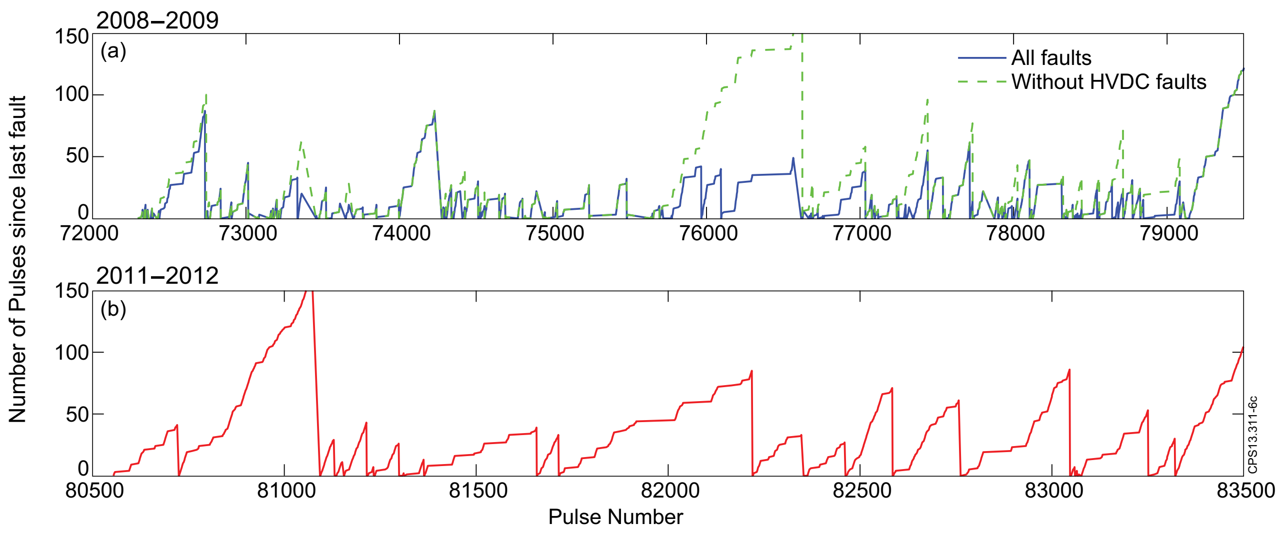


*Figure 2: Number of pulses between faults for module B for the operations in (a) 2008-2009, and (b) 2011-2012.*

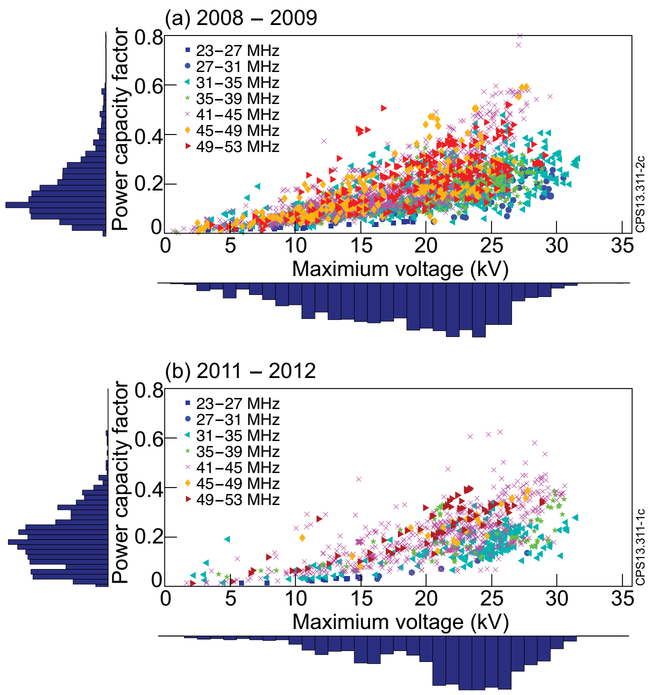


*Figure 3: Power capacity factor (power generated divided by what was available) against antenna maximum voltages for different frequency sub-bands. The histograms along the axes demonstrate the parameter distribution among all the RF pulses during the corresponding campaigns.*