

LONG PULSE OPERATION IN ITER: ISSUES FOR DIAGNOSTICS

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1. Introduction

Long pulse (> several hundred seconds) operation of a tokamak leads to an enhanced requirement for plasma measurements in two respects. Measurements of many plasma parameters (plasma shape and position, density, temperature etc) are required for times typically 10 – 100 times as long as on existing machines. Secondly, in order to achieve the long pulse operation it is likely that measurements of additional parameters – eg NTMs, RWMs, ITBs – will be required. Many of the measurements will have to be made at a sufficiently high level of stability and reliability for use in control loops.

In order to make measurements during long pulses, diagnostic systems and components will have to have a high level of stability of operation and performance. Where possible, diagnostic techniques should be chosen which are rugged against these difficulties. Measures such as active alignment systems, in-situ calibration, special components (eg long pulse integrators) will be required.

For a DT machine such as ITER, there will, in addition, be effects arising because of the environment which will have to be taken into account in the diagnostic designs: for example, Radiation Induced EMF (RIEMF) and thermal EMFs in magnetic sensors, erosion and deposition damage to diagnostic first mirrors, and enhanced absorption and photoluminescence in windows and optical fibres. The diagnostic designs also have to satisfy stringent requirements on tritium confinement, vacuum integrity, remote handling etc.

In this paper the long pulse issues are summarised and examples of systems where special measures have been adopted are given. Areas where further developments are needed are identified.

2. Long pulse effects and example designs

The principal diagnostic for measuring the *plasma position and shape* will be the magnetics system. This system will employ multiple coils and loops mounted in the vacuum vessel, on the outside of the vacuum vessel and possibly in the skins of the vacuum vessel [1]. The principal long pulse issues that have to be handled in the design are nuclear heating, spurious signals arising from RIEMF and thermal EMFs, and the long integration times. The nuclear heating is dealt with by thermally anchoring the sensors to the vacuum vessel. ANSYS calculations have shown that the maximum temperature reached in the coils will be about 250 °C which is acceptable for the materials chosen.

Dedicated R&D on RIEMF [1, 2] has shown that the effect can be minimized by reducing the temperature and radiation field asymmetries, adopting an even layer coil structure and choosing areas of expected uniform radiation level. Lowering the coil resistance and hence reducing the differential voltage, and reducing the integrator sensitivity to common mode voltage by lowering the balanced impedance to ground at the input, are also beneficial. All these measures have been adopted in the ITER design. Recent R&D in which a prototype coil has been irradiated in the JMTR test reactor has shown that thermal EMFs can occur in junctions and the coil itself due to asymmetries in the temperature and possibly due to material property changes due to irradiation of the coil. More R&D is needed in order to separate the two effects. The coils on the outside of the vacuum vessel (or in the skins of the vacuum vessel) will give the measurements needed for reconstruction of the plasma position and shape but on a slower time scale. These coils are in a much lower radiation field and so will not be subject to significant RIEMF and thermal effects. It is believed that with these measures the requirements for long pulse measurements of plasma shape and position on ITER can be met. Integrators for long pulses are under development and suitable integrators may already exist [3].

For the measurement of the *line integrated density* a dual CO₂ laser interferometer/polarimeter system will be employed [4]. The system measures the line integrated density robustly through the Faraday rotation and does not need to track the history of the density changes. In this way one potential problem of long pulse operation, fringe loss, is avoided. At the same time, high sensitivity is achieved through the interferometer measurements. By using two operating wavelengths, vibration compensation is also achieved. The principal long pulse issues are damage to the plasma facing first mirror (FM) and maintenance of alignment. The FM can be damaged due to bombardment by energetic particles, which can lead to erosion of the mirror surface, and/or deposition of eroded first wall and divertor materials. R&D is in progress on diagnostic first mirrors since this is a common problem for all optical diagnostics [5]. Material and configurations have been found which minimise the effect. In particular, it has been found that in situations where erosion is the dominant damage mechanism, mirrors made from single crystal metals, for example stainless steel and Mo, maintain their performance even against erosion of several microns. It is expected that for mirrors located in mid-plane and upper ports, erosion will be the dominant damage mechanism and so a metal mirror will be employed. Retroreflectors return the beam along the beam path and an active alignment system will maintain the alignment.

Impurities and the isotopes of hydrogen (tritium, deuterium and hydrogen) in the divertor will be measured with an extensive passive spectroscopic system operating in the wavelength range of 200 - 1000 nm [6]. The main functions of the system will be to identify impurity species and to measure the two-dimensional distributions of the particle influxes in the divertor plasmas. The principal long pulse issues are deposition of eroded

divertor material on the in-vessel mirrors and maintenance of alignment and calibration. Baffle plates will be installed in front of the mirrors to reduce the solid angle of exposure to the plasma. An in-situ calibration scheme which utilises a standard lamp located outside the biological shield to illuminate small retroreflectors installed in the baffles will be employed. An active alignment system that uses a laser to illuminate a small target on the divertor cassette and an external moving mirror will be included. Additional measurements will be made from the mid-plane and upper ports and are not expected to be affected by deposition on the FM.

Other long pulse effects that have to be taken into account in the design of ITER diagnostics are summarized in Table 1. The measures being developed for mitigating or coping with the problems are also shown. Note that the last three effects – erosion, material damage (including transmutation) and activation – are essentially fluence effects and so the number as well as the duration of pulses is important for these.

Table 1: Long Pulse Effects and Mitigating/Coping Measures

Effect	Diagnostic Component Affected	Mitigating/Coping Measures
RIEMF, Thermal EMFs	Magnetic coils	Design for minimum effect. Provide back-up measurements [1,2]
Nuclear heating	Magnetic coils	Thermally anchor to VV
	In-vessel antennas	Use refractory material
	Bolometers	Use dummy detectors
Long time integration	Inductive magnetics	Special integrators, steady state sensors [3]
Bombardment by high energy ions and neutral particles	First mirrors in optical systems	Use single crystal W or Mo, or Rh coating on Cu substrate [5]
Deposition	First mirrors, in-vessel optics [9]	Use of baffles and shutters, in-situ calibration, cleaning techniques [6,8]
Laser damage on mirrors and refractive optics [9]	Thomson scattering systems	Reduce laser intensity by using larger mirrors and optics, careful choice of materials
Relative movements of system components	Laser systems, spectroscopy systems	Use of active alignments [6,8]
	Microwave systems	Use of passive alignment systems
Erosion*	Langmuir probes	Design for minimum effect, provide for replacement
Material damage* (including transmutation)	Magnetic coils, bolometers [7]	Design for minimum impact on the measurement, careful choice of materials
Activation*	All metallic diagnostic components in the VV	Design for repair and maintenance by remote handling

3. Areas where more development is needed

While good progress has been made in developing measures to mitigate or cope with the potentially damaging effects of long pulse operation, some areas require more

development. More R&D is needed on RIEMF and thermal EMFs, particularly for magnetic coils where in experiments to date it has been difficult to separate the two effects. Further development is needed of sensors to measure steady state magnetic fields. In this case also there is good progress but the ITER requirements, particularly on the accuracy have not yet been met. Although there is now a substantial body of data on the effects of erosion on FMs there is very limited data on deposition and measures to reduce it or cope with it need more development. Controlled simulation experiments are required. Tests of damage to optical components, especially mirrors, due to repetitive laser pulsing have produced a body of information but need extending to a higher number of laser pulses. Good concepts for active alignment and in-situ calibration systems have been designed and some tests performed but more development is needed. The effects of material damage including transmutation have only been seen in recent tests on diagnostic components and more work on these is needed.

4. Conclusions

Long pulse effects that could impact diagnostic performance on ITER have been identified. Where possible, measurement techniques are chosen which are rugged against these effects. Measures to mitigate or cope with the effects have been developed and are being incorporated into the system designs on a case by case basis. R&D is in progress but more is needed especially on RIEMF and thermal EMFs on magnetic coils, and deposition on first mirrors.

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