Plasma viewing in JET using endoscopes and a detailed design for ITER

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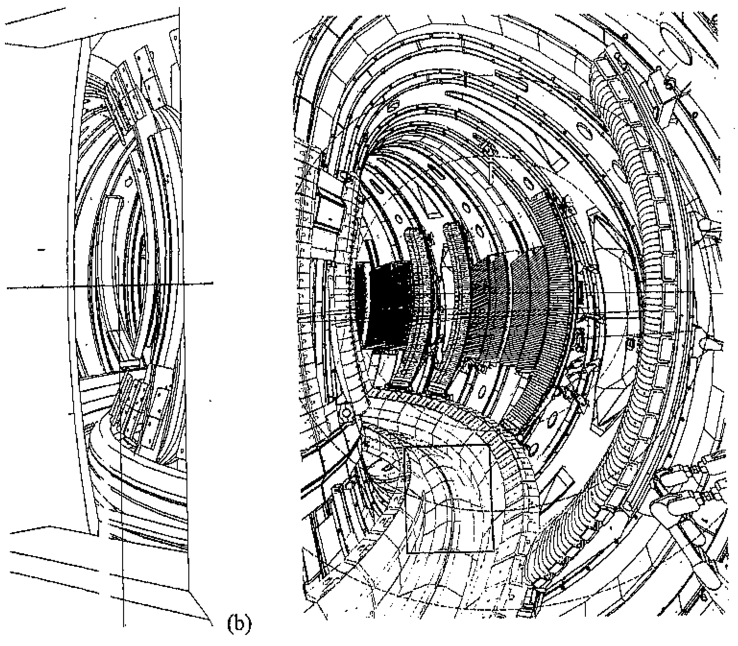
1. The new endoscope viewing system on JET

Video cameras were fitted to the JET tokamak in 1994 to provide detailed views of the newly-installed divertor and a wide-angle view of the inside of the torus in real time. Immediate visual information on the position of the plasma within the vessel (and possible regions of interaction with the wall), and on the strike-point positions in the divertor proved extremely useful for the operations staff. However, there were two limitations to the viewing. Firstly, the wide-angle view was limited by the location of the camera, which was within one of the horizontal ports approximately 1.5 metres from the first-wall: a computer-generated image of the torus seen through the port from the camera is shown in Figure 1(a). Secondly, the views of the divertor were obtained from ports at the top of the machine, which allowed complete views of the floor of the divertor used during 1994/5 (Mk I). However, the 1996/7 (Mk II) and planned future divertors have a more closed aspect and strike points may be on the side walls, so a complete view is not possible from the top ports.



(a) (b)

Figure 1 (a) CAD drawing of the wide-angle view of JET from 1994-6. (b) CAD drawing of the view obtained with the endoscope installed in June 1996.

The ideal position from which to obtain both wide-angle and divertor views is just inside the vessel near the outer midplane, however cameras cannot be placed at such points. Instead a re-entrant tube has been fitted to a flange which projects beyond the vessel support structure: the tube ends in a sapphire window at the ideal viewing point. An optical relay (endoscope) system has been constructed to allow cameras mounted outside this flange to view through the window. The window is in the shadow of an outer poloidal limiter which protects it from the plasma, and is covered by a shutter during vessel conditioning treatments such as glow discharge cleaning and Be evaporation. A sketch of the endoscope is shown in Figure 2.

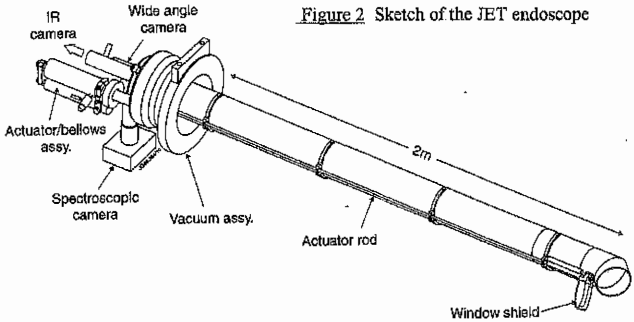


Figure 2 Sketch of the JET endoscope

The endoscope allows three different views into the torus; a wide-angle view and detailed views of the divertor in the visible and in the infra-red. Each of these views is accomplished via a separate set of relay lenses within the endoscope, and the assembly is water-cooled to maintain the mechanical stability required to give high resolution images. A computer-generated diagram of the wide-angle view is shown in Figure 1(b), and the improvement over the previous view (Figure 1(a)) is obvious: approximately one-third of the interior of the vessel is visible. The small rectangle towards the bottom of Figure 1(b) shows the field of view of the camera viewing the divertor in the visible range: this camera is fitted with a filter so that light of one specific wavelength is recorded (currently the CII line at 658 nm). The field of view in the infra-red is split into two halves, one giving a close-up of the inner half of the divertor floor, and one of the outer half, but at the present time the infrared camera is still viewing from the top of the torus whilst an improved image processing package is developed.

A colour wide-angle view and a close-up of the divertor in CII light are recorded for every pulse. From the wide-angle view one can

- verify plasma equilibrium and identify major hot-spots
- study qualitatively the location of ELM interactions outside the divertor
- monitor UFOs and look for first wall component failures
- detect high levels of visible bremstrahlung emission from the core associated with high performance discharges (e.g. optimised shear regime)
- diagnose density limits due to MARFE formation and disruptions

A typical frame from the divertor-viewing camera is shown in Figure 3. The strike points are clearly visible, and radiation can also be seen from the inner diveror leg extending to the X-point. The divertor view is used to study the positions of the strike points, the occurrence of detachment and ELM activity in the divertor.

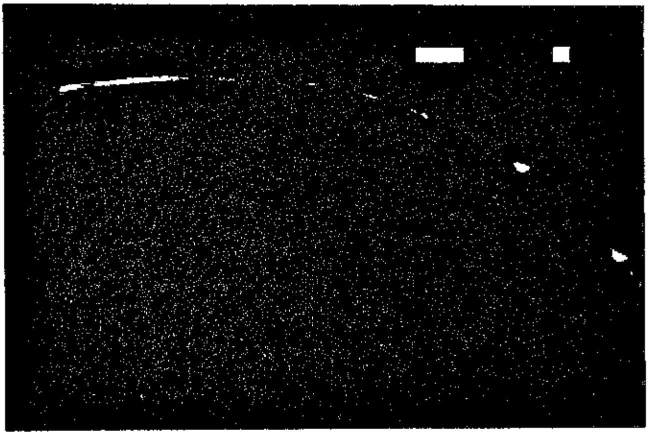


Figure 3
View of the divertor recorded in CII light during a JET pulse

2. A design of an endoscope system for ITER

The views provided by the endoscope system are invaluable for the team operating the JET tokamak, and it is equally important that there should be a real-time view of the plasma in ITER. However, the present JET endoscope is based solely on refractive optics, and the lenses would not survive for long in the high neutron (and γ-ray) fluxes close to the first-wall of ITER. An outline design for a system to view the interior of ITER from the outer midplane has been produced which uses reflective optics near the first-wall, changing to refractive optics at some distance into the shielding.

The design uses a concave aspheric mirror as the first element (Figure 4), and a catadioptric telescope (Figure 5) to produce a planar image to relay via conventional diffractive optics to the cameras which are located behind the shielding wall. A high resolution wide-angle view inside the vessel can be obtained for the assessment of the plasma, and the same optics can be used to examine closely any parts of the first-wall that appear to interact strongly with the plasma, and to view into the divertor. Figure 6(a) is a simulated image of the interior of ITER, and the approximately semi-circular lines show the view obtained at different included angles for the aspheric mirror. Figure 6(b) shows an expansion of the optimum angle for viewing the outer divertor leg, whilst the optimum view into the inner leg is shown in Figure 6(c).

Conclusions

A new endoscope system has been installed on JET which gives greatly improved wide-angle and divertor plasma viewing at high resolution. Similar real-time viewing of the ITER plasma may be possible using an aspheric mirror as the first optical component. The critical issues which control the resolution obtainable in ITER are the mechanical tolerances and stability that can be acheived on assembly and maintained long-term in the high radiation levels, and the thermal stability of the endoscope system. The next step is therefore to build a prototype system which is as close as feasible to the ITER configuration that can be tested in the laboratory and then installed on JET.

Figure 4 Concave aspheric mirror at the first-wall to provide a wide-angle view

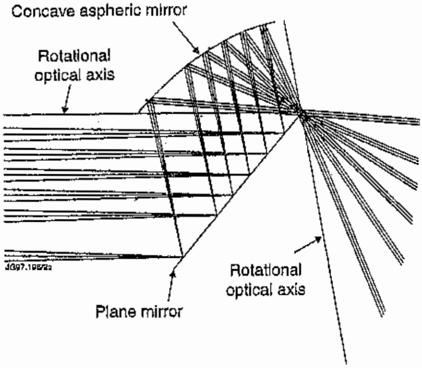
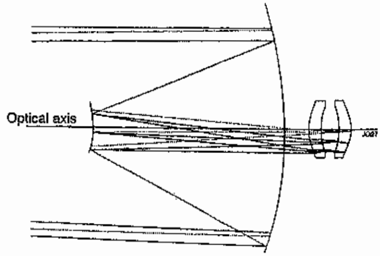


Figure 5 Catadioptric telescope stage to provide a suitable image for relaying



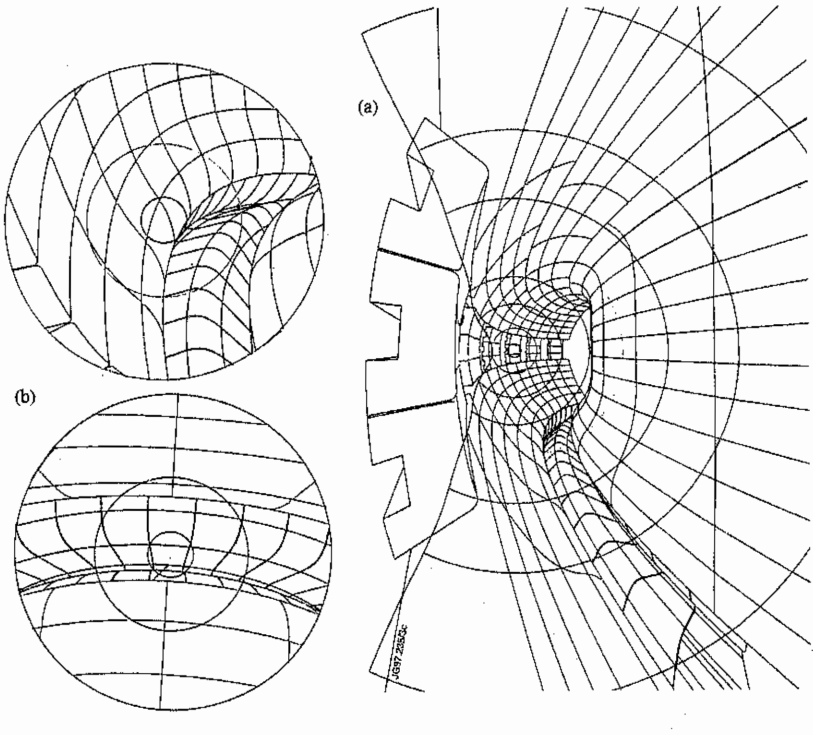


Figure 6 (a) Simulated wide-angle view inside the ITER vessel. (b) and (c) Views into the divertor.