Alignment Systems for Pumped Divertor Installation at JET

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The installation of the JET Pumped Divertor, designed to study impurity control, has recently been completed. The main components are four magnetic coils, forty eight divertor plate assemblies, one toroidal cryopump, eight ICRH antennae, sixteen inner wall guard limiters and twelve poloidal limiters. Due to the high thermal loads, accurate positioning of plasma facing components to the magnetic centre of the machine was a major requirement. Typically alignment within ± 2 mm was required, with steps between tiles on a component being controlled to ± 0.25 mm. In some cases a set of components was required to be concentric, while also lying within a narrow band defined by the position of some other components. A typical example of this was the positioning of the poloidal limiters, which perform the dual function of limiting the plasma and also protecting the antennae. Clearly, a measuring system accurate to better than ± 0.5 mm was required.

1. INTRODUCTION

In previous shutdowns at JET component surveys and alignment checks depended on some combination of conventional metrology equipment and jigs usually based on a precise survey ring. JET decided to continue with this philosophy for the Pumped Divertor installation. A sophisticated survey ring system was designed and built. This was used successfully for the installation of the lower vessel components e.g. divertor coils and divertor modules. During preparations for the installation of the outer wall components it became apparent that to achieve the required accuracy at a height of over two metres above the survey rings would result in an extremely cumbersome system, requiring a long and elaborate set-up procedure for each new working position. In addition, this philosophy required the presence of the survey rings in vessel over an extended period (in excess of five months). This would not have been compatible with many of the tasks planned for execution in parallel with the main inner and outer wall tasks and therefore would have seriously compromised the flexibility of the overall planning. As a result other techniques were investigated, resulting in the purchase of a three dimensional non-contact measuring system. As it is JET's philosophy to minimise risk to shutdown program by using only proven methods it was decided to continue with the development of the mechanical system in parallel. This paper describes the development necessary before this system could be used inside the JET vacuum vessel. The transition from jig-based to optical system is discussed along with techniques being developed for future use at JET.

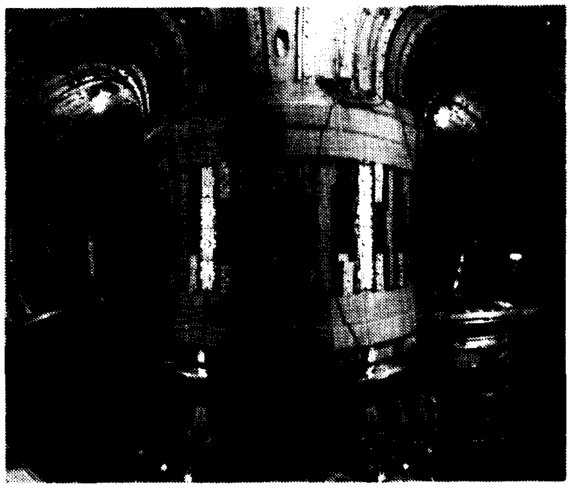

Figure 1. Survey Ring System in use In-vessel

2. MECHANICAL SYSTEMS

A setting system based on a pair of very accurately machined survey rings together with a system of dedicated precision jigs was used to position the divertor coil support bosses[1]. The inner ring (4200 mm diameter) fitted with two targets 90° apart, was accurately positioned toroidally and radially in-vessel by optically aligning the targets with the centre of the mechanical structure of the JET machine. This datum is also used for ex-vessel components. Through investigation of the plasma/wall erosion surveys, the mechanical centre of JET had previously been shown to be coincident with the magnetic centre to within ± 2 mm. Then the outer ring (8500 mm diameter), which consisted of sixteen beams, was assembled using a jig from the inner ring. A radial arm location tool was then suspended from the inner and outer rings to facilitate the positioning of components on the vessel floor (fig. 1). Later in the shutdown, the survey ring system was used for the positioning of the divertor plate assemblies[1].

3. OPTICAL SYSTEMS

In December 1992 JET began to investigate the possibility of using optical systems, of which there were a number on the market. A number of these were quickly ruled out on the basis of their inaccuracy or other limitations such as focal length of the instruments being incompatible with the internal dimensions of the vacuum vessel. The ability to operate accurately in the expected residual magnetic field at JET was also an important consideration. JET evaluated the use of Leica's ECDS3 [2] system in a similar application at Tore Supra [3]. This system consists of two electronic theodolites, with dual axis liquid compensators, linked to a personal computer and a software package called ECDS3 (Electronic Coordinate Determination System).

JET carried out a series of trials which confirmed the systems performance and accuracy. Finally, following assurances from Leica that the residual magnetic field in the JET vacuum vessel would not affect the operation or the accuracy of the system, JET ordered the ECDS3 system and began to plan the use and development of the system in detail.

4 COMPUTER AIDED THEODOLITE

Generally referred to at JET as the CAT (Computer Aided Theodolite) system, ECDS3 operates by measuring the horizontal and vertical angles to a network of targets and a calibrated scale bar and solving the resulting simultaneous equations using a mathematical technique known as 'bundling' At JET, 184 targets were welded to the inner and outer walls of the vessel. These targets, called control points, define the volume in which all subsequent surveys will be carried out. When all these targets and the scale bars have been sighted by at least two theodolites in a multiple set-up process known at JET as a 'Global Survey', the ECDS3 'bundling' process is used to calculate the co-ordinates of all the targets relative to theodolite No. 1. These co-ordinates can be mapped unto the Torus master system, whose origin is the centre of the Torus, using a co-ordinate transformation with known datums. Datum positions were determined relative to the Torus using the same technique as used for setting the survey ring (fig. 2).

JET's major requirement was for a three-dimensional setting system suitable for locating the jigs used to position the mounting pads for the various components on the vacuum vessel wall. In some cases the system would also be used for direct positioning of the actual components. Use of the CAT system for setting involves sighting onto at least three targets whose positions are known in

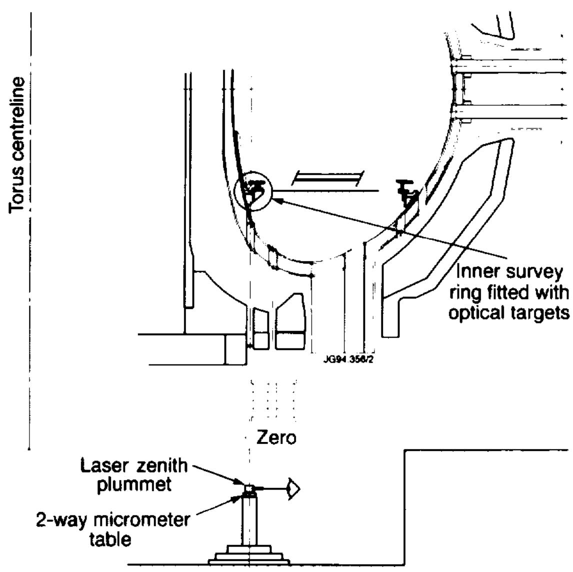

Figure 2. Inner Survey Ring Alignment from Pit

the Torus master system. As the ECDS3 software can then calculate the positions of the theodolites relative to the centre of the Torus, it is only necessary to place the theodolites so that good sighting can be achieved. The theodolites are then used to determine the co-ordinates of the component datum points via targets fitted to the components. These co-ordinates are then converted from the default Cartesian (X,Y,Z) to a cylindrical (R,θ,Z) co-ordinate system for setting adjustments. This conversion simplifies the setting process as the cylindrical system is the 'natural' coordinate system of the torus .

5. ACCURACY

The accuracy of the CAT System depends largely on geometry, redundancy of the sightings taken and the operator's understanding of how these two factors effect the data. Using JET's CAD system, CATIA, the optimum theodolite & target positions were determined considering the unique multiple set-up techniques which would be required due to the shape of the vacuum vessel. It was necessary to ensure that all targets were visible from at least two theodolites positons, even at the end of the shutdown when all components would be installed. In parallel with this design and development, JET personnel received training from Leica in the use of the system. In addition a full size mock-up of the JET vacuum vessel was built to allow the multiple set-up technique to be developed and its accuracy assessed. During this four month period an improved multiple set-up technique was developed, which shortened survey time by 50%. A dedicated procedure for carrying out a CAT global survey of the vacuum vessel was prepared. This procedure was followed closely and with continued practice allowed survey time to be cut further. In parallel JET's spare octant was used for extensive setting trials for the major inner and outer wall components using the actual jigs and actual or prototype components. These trials also provided the opportunity to develop the measuring and adjusting technique for each component as well as providing an opportunity for installation personnel to become familiar with the CAT system.

6. DEVELOPMENT FOR IN-VESSEL USE

As well as developing a method for using the CAT system in-vessel, it was necessary also to package the system suitably. Wall-mounted vibration-free theodolite supports which could be used in any of sixteen toroidal positions at four heights with a variable radius were developed (fig. 3). Special removable spherical targets were also developed. The targets consisted of a boss welded to the vessel wall, a uniquely identified screw-in target, a unique identity label, designed to be visible through the theodolite, and a protective cover. The colour laptop computer was built into a special aluminium case along with the necessary interface modules. This allowed safe and convenient storage of all the hardware, reducing the number of electrical connections to be made and so reducing the setup time and the risk of damage. In addition, the computer was fitted with an integral modem which allowed fast downloading of data at the end of every shift to a dedicated computer ex-vessel. Data was not only duplicated by this process, but easy access to it was immediately available to selected personnel to allow report writing to proceed. Transfer of data on floppy disc was complicated by the risk of beryllium and tritium contamination.

7. SURVEY TECHNIQUE

To satisfy the requirements identified in the CATIA model, the majority of targets were positioned reasonably accurately with regard to height, otherwise following the geometric features of the vacuum vessel wall. To minimise the possibility of errors two global surveys of six set-ups were carried out on opposite shifts. Each target was sighted by two theodolites, 20% being viewed by four theodolites, 5% being viewed by six theodolites throughout the survey. This redundancy of sightings increases the accuracy. Each survey took two surveyors approximately 1.5 shifts (12 hours). Results of the surveys were compared and checked in detail and found to agree, in general, to better than 0.2mm. From these surveys the Torus nominal master system was established. This system was then checked for correlation with the fixed inner wall reference balls, used in previous shutdowns, and to the inner survey ring used for the first phase of the shutdown. The co-ordinates determined by the different systems agreed to within ± 0.9 mm. Additional checks on the scale accuracy of the CAT system were carried out by surveying accurately machined details of the survey ring confirming a measuring accuracy of better than 0.05mm/metre.

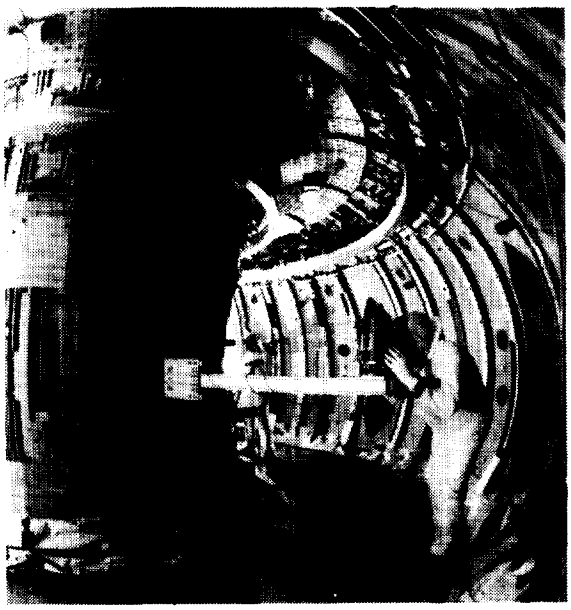

Figure 3. CAT System in use In-vessel

8. COMPONENTS INSTALLED WITH AID OF THE CAT

Major components installed with the aid of the CAT system included RF antennae, inner wall guard limiters and poloidal limiters. For the limiters the vacuum vessel wall was surveyed directly with the CAT so that mounting pads could be machined to approximately the correct dimensions to take account of local variations in the vacuum vessel wall. Generally the CAT system was used to position jigs which ensured pads were welded to the wall at the required height and radial and toroidal position. Use of a jig was the quickest way of ensuring that up to ten pads were correctly positioned relative to each other. When the actual component was mounted on the pads the CAT was used for final positioning in an iterative process of suveying and adjusting. For most components the major requirement was for correct radial positioning. Height and toroidal position, though important, were usually secondary. During setting, components were frequently resurveyed from different theodolite setups and by different teams of surveyors so that accuracy was continually monitored, confirming that components were measured to better than ±0.3mm. Apart from the major components, for which the CAT system was primarily intended, it was also used to carry out 'as-built' surveys of divertor coils 2, 3 and 4. The CAT was also used for positioning or providing 'as-installed' survey data for many of the major diagnostics. As many of these were situated in inaccessible places e.g. main vertical ports, it would not have been possible to determine their position accurately using conventional methods.

8. FUTURE DEVELOPMENT

During future JET shutdowns, in-vessel work will be hampered by high (300Sv/hr) radioactivity levels. Contamination of the vessel by beryllium and tritium will necessitate the use of full pressurised suits. This will mean that the measurement systems used in the future must be pressurised suit compatible and eventually fully remote-handleable, while maintaining present levels of accuracy and flexibility. To this end JET is currently investigating ongoing changes in measurement technology in an attempt to determine the most suitable systems for use in the next planned shutdown and the subsequent remote-handling shutdown.

Towards the end of this shutdown the opportunity was taken to survey the in-vessel CAT targets using Convergent Photogrammetry so that JET could assess its potential for use in the next shutdown. Comparison with the CAT global survey data showed good agreement [4]. In conjunction with these investigations, on-going developments of systems currently in use at JET are being made. A modified CAT system is being developed which will allow operators to use the CAT system when wearing full pressure suits. This system utilises a miniature video camera fitted to the theodolite together with a monitor which means the operator does not need to sight directly through the instrument. Connection to an ex-vessel monitor will mean that in-vessel work can be supervised by an experienced CAT user with a resulting reduction in both the time and expense incurred in training new surveyors.

10. CONCLUSION

During the last shutdown at JET a major conceptual change in in-vessel measurement technology was made. Numerous checks were made to ensure the compatibility and concentricity of the new optical system with the old jig-based mechanical system. The advantages of the CAT system in terms of time, accuracy and flexibility were clearly seen. The CAT system will continue to be used at JET in conjunction with convergent photogrammetry with reduced use of jigs. The possibility of links with other non-contact systems is now the subject of research at JET.

11. ACKNOWLEDGEMENTS

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