APPLICATION OF 'BEST-FIT' SURVEY TECHNIQUES THROUGHOUT DESIGN, MANUFACTURING AND INSTALLATION OF THE MKII DIVERTOR AT JET

B. Macklin, R. Brade*, G. Celentano, R. Shaw**, J. Tait, E. van Lente
JET Joint Undertaking, Abingdon, Oxfordshire, OX14 3EA, UK.
*GEC Alsthom, Leicester, UK.
**ITER-EDA, San Diego, U.S.A.

The precise installation and alignment of large components in an activated and beryllium contaminated fusion device is a problem which must be faced in JET as well as future devices such as ITER. To guarantee the successful alignment of the MKII Divertor in JET it was essential that, early in the design phase, realistic manufacturing and installation tolerances and restrictions were identified and considered.

The main components of the MKII divertor structure are an inner and outer ring mounted on a base plate (figure 1). The overall diameter of the assembly is 6m and is dismantled into 24 sub-assemblies (modules) for installation [1]. The structure must be installed very accurately whilst wearing full pressurised suits. As the other major in-vessel components remain unchanged i.e. RF antennae, poloidal limiters and guard limiters it is important that the new divertor be installed to the same centre as these components i.e. to the machine centre which is defined as the centre of the in-vessel datum system. Major considerations in the design process were the installation accuracy required, the installation method and restrictions imposed by the existing in-vessel structure. Joints between modules could only be made from one side due to access restrictions. Design of the support system had to be such that minimal modification to the existing in-vessel structure would be required. The tight tolerances necessary to ensure the mechanical integrity of the module joints were compromised by the necessity to have realistic assembly tolerances.

I. BEST-FIT CONCEPT

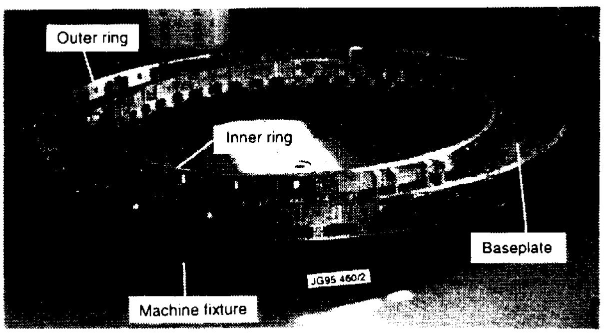

Figure 1 Divertor Structure Components.

JET's Computer Aided Theodolite (CAT) system [3] was used extensively and successfully in the previous shutdown when the MKI Divertor was installed [2]. It was decided that this system should be used again. From previous experience it was clear that optimum use of the CAT system implied a different approach to manufacturing and installation. When a component is manufactured within a tolerance band, which is inevitably significant on a 6m structure, to attempt to install the component to its theoretical dimensions is simplistic. The installation team will not know if any error they see is due to incorrect positioning of the component or an inherent manufacturing 'error' or inaccuracy. Therefore the concept of installing a component to its 'as-built' coordinates was developed. This allowed the use of a 'best-fit' approach where the actual component dimensions are allowed to float into their best average fit to the theoretical dimensions. This technique has the advantage of allowing the effect of any single dimensional error, be it a manufacturing or installation error, to be minimised (figure 2). This implies, of course, a maximum allowable error at a point.

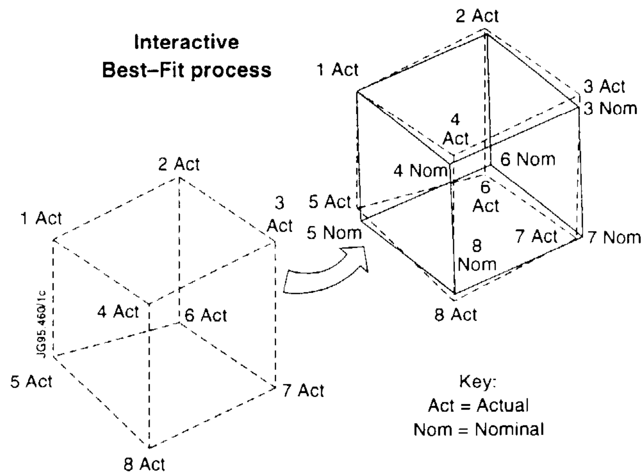

Figure 2 Illustration of Best-fit Technique.

The best-fit is achieved by using the CAT system computer software to overlay the as-built file onto the nominal file (figure 3). It was therefore necessary to plan to use the CAT system during the manufacturing cycle of the divertor structure both to confirm that the required dimensions had been achieved and to record the necessary as-built information necessary for installation.

II. MANUFACTURING CONCEPT

a. Overview

From an early stage in the manufacturing process it was clear that the assembly of the components of the divertor i.e. baseplate and ring segments would be critical to the achievement of the conflicting tight tolerances on position, roundness and concentricity. Consequently the CAT system was first used to survey the fixture (figure 2) on which the components were to be located for final machining. Final machining included skimming of the datum diameters and base surface as well as drilling of the H7 dowel holes required at the joints between the modules. Inner and outer rings were assembled on the fixture using precision dowels for location, final machined and then removed from the fixture as complete assemblies. Similarly the baseplate assembly was located on the fixture for final machining. Inner and outer ring assemblies were then assembled onto the baseplate (first assembly) [1]. Confirmation of the accuracy of the positioning of the dowel holes guaranteed the location of the components for the final machining operations and was a crucial part of the manufacturing concept.

b. Machining Fixture Survey

Results of the machining fixture survey were analysed using the CAT system software to determine first the centre of the ëbest-fití circles through the baseplate location dowel holes. Similarly, 'best-fit' circles were fitted to the dowel holes on the inner and outer rings. These were checked for roundness and concentricity with the baseplate centre. The positions of all surveyed points were compared with their theoretical positions as defined in a ënominalí file. This file was generated using JET's CAD system and allowed a very quick check on the position of all dowel holes. Critical dimensions such as the chords between dowels for adjacent modules were also checked carefully. All survey results were assessed in the light of slightly tighter than contract tolerances at this stage to allow for subsequent dismantling and reassembly.

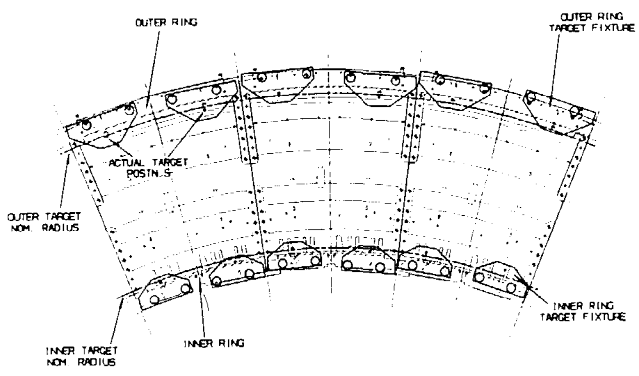

Figure 3 Best-fit Applied to Divertor Structure.

c. First Assembly

The manufacturing process for the divertor structure included two major assembly operations:- the first and second assemblies. During the first assembly the main components of the inner and outer ring and baseplate were brought together for the first time. This was followed by a CAT survey of the complete assembly while still located on the machining fixture (figure 4). The CAT system software was used to analyse the results of this survey. Best-fit circles through the inner and outer ring and baseplate were checked for diameter and concentricity. The positions of surveyed points were compared with nominal file positions. Critical chords across module joints as well as diagnostic location features were examined. This survey confirmed that the components had been manufactured and assembled correctly and within tolerance.

d. Second Assembly

The structure was then broken down into 24 sub-assemblies (modules), each one consisting of an inner and outer ring and baseplate segment. Modules were then cleaned, baked and vacuum leak-tested and fitted with other components e.g. baffles prior to the second assembly. The second assembly was a simulation of the installation method and sequence planned for use during the installation at JET. A final survey of the complete structure after the second assembly provided the file of 'nominal' coordinates for the installation. It provided a very valuable opportunity to identify any weaknesses in the planned installation method. As the second assembly was carried out under ideal conditions i.e. without wearing pressurised suits in a confined space, it provided a useful guide to the best assembly accuracy which would be achievable.

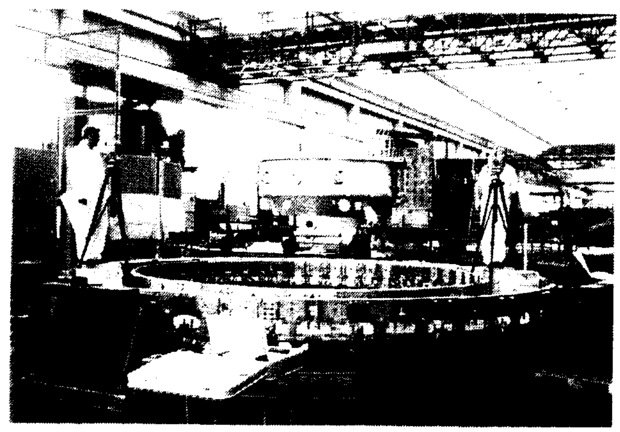

Figure 4 Survey of Structure after First Assembly.

III. SURVEY PREPARATION AND DEVELOPMENT

a. Equipment

To maintain the high standard of optical survey work which was a feature of the MKI Divertor installation at JET presented a challenge for the MKII installation team when all work would have to be carried out whilst wearing pressurised suits due to the beryllium contamination of the vacuum vessel. Initial development included modifying the theodolites by fitting miniature video cameras to the eyepiece. Whilst early tests looked promising, it was considered that less sophisticated alternatives should be considered. In parallel modified half-suits with smaller than normal helmets and optically clear panels were developed and tested. Successful trials with these suits confirmed that this was the most reliable way of continuing optical work in-vessel. To accomodate a requirement for very accurate height surveys a new precision automatic digital level with an invar barcode staff was procured. Special techniques and software were developed to allow the output from this instrument to be manipulated by the CAT system software.

b. Manpower

The volume of optical survey work planned for the MKII installation combined with a higher level of radiation and a much shorter shutdown meant that the survey team had to be doubled from four to eight people. Accordingly four additional inspectors were recruited and trained in the specific survey techniques which had been developed for the previous shutdown at JET.

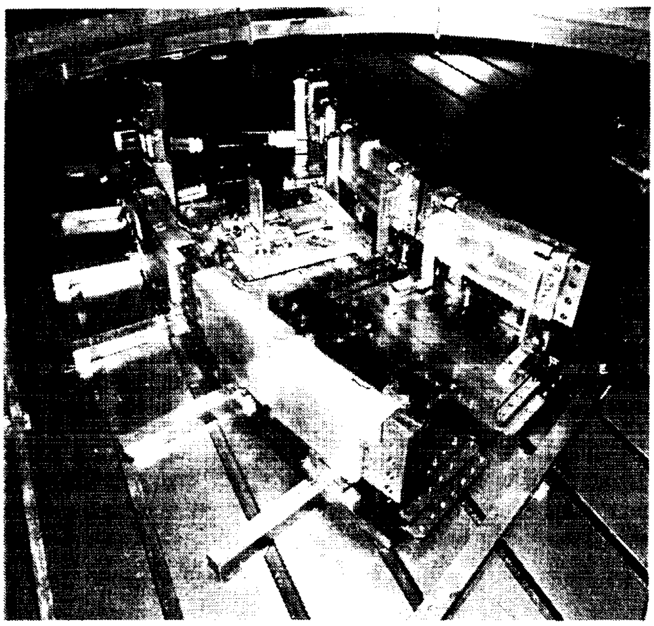

Figure 5 'Dummy' Modules Used for Trials

c. Techniques

The optimum survey technique for all surveys related to the machining fixture, the first and second assemblies at the manufacturers and the in-vessel installation was studied and developed extensively at JET. JET's CAD system was deployed to determine optimum theodolite locations and then to prepare a series of drawings which detailed instrument positions, number of set-ups and points to be surveyed. An extensive series of trials was also carried out on a detailed engineered mock-up of the structure to ensure minimum time delay during the manufacturing and installation cycle and to qualify the survey accuracy achievable (figure 5). These trials also allowed the development and evaluation of the necessary optical target fixtures to fit the datum features, which unfortunately were slots. Tests carried out proved fit, absolute accuracy and repeatability. All tests were carried out within a greater framework of assembly, handling and training trials. Installation trials were carried out with the structure mock-up in JET's training facility (a full size replica of 4 octants of the vacuum vessel). Useful experience was gained here particularly with regard to optimising the technique for adjusting module positions. It soon became apparent that if the the modules were level satisfactory positioning could be achieved in a few iterations.

IV. IN-VESSEL DATUM SYSTEM

a. MKI Datum System

During manufacturing alot of care was taken to ensure the dimensional accuracy and concentricity of the components of the Divertor structure. Equally important was to ensure the concentricity of the new and old divertors. New surveys of the in-vessel datum system, which had been created by and used with the CAT system during the MK1 Divertor shutdown, afforded the means to ensure this. Previous use of the CAT system had resulted in a system of 184 in-vessel datum points. However, the subsequent campaigns of operation and the flexibility of the vacuum vessel resulted in movement of the vacuum vessel and the loss of the absolute values of the datum system. Employing the best-fit approach, the datum points can be resurveyed and the resulting file can be best-fitted to the that used during the previous shutdown. This ensures concentricity of the old and new datum systems.

b. Establishing a New Datum System

High levels of radiation and the difficulty and consequent time implications of carrying out an extensive survey with optical instruments while wearing pressurised suits ruled out the possibility of using the CAT system for the re-survey of the datum system. Instead convergent photogrammetry, which has the principle advantage of speed of data capture, was used [4]. The resulting data file was in a form compatible with the CAT system software and could be easily best-fitted to the file which defined the old datum system. The CAT system, using these datum points, can then be used to determine the position of components relative to the centre of the JET machine.

V. MKII DIVERTOR STRUCTURE INSTALLATION

Typically modules will be installed in groups of three, progressing both clockwise and anti-clockwise from a block of three datum modules. The datum modules will be positioned with the assistance of the CAT and the in-vessel datum system and then locked in position. Up to eight separate CAT surveys will be required to check the position of the modules as the build progresses round the vessel. Completion of the circle will be followed by a CAT survey of the complete structure to confirm concentricity, circularity etc. before final lowering and torquing of the structure. After lowering the structure may be surveyed using photogrammetry. This survey would use self adhesive targets fixed to the surface of the structure and will allow a more extensive evaluation of the structure geometry than the CAT surveys which uses targets at discrete points only - typically six per module. Experience gained during the second assembly indicates that this survey may not be necessary and that a CAT survey would be satisfactory. Either survey will provide the 'as-installed' position of the divertor structure. Accurate 'as-installed' information is critical, in particular to provide accurate information necessary for the design of the MKII Gasbox tile carriers which will be installed remotely.

VI. PLANNING FOR SURVEYS IN THE FUTURE AT JET

The next major planned shutdown at JET will be for the installation of the MKII Gasbox Divertor cofiguration. This shutdown will follow the tritium experiment (DTE1) currently planned for late 1996. High levels of radioactivity are anticipated such that man access to the vacuum vessel will not be possible. Accordingly a full remote handling shutdown is being planned. Research has been going on at JET over the last year to identify survey systems suitable for use in a remote handling scenario [6]. Videogrammetry, along with selected laser scanning techniques have been identified as being potentially suitable for remote deployment. Videogrammetry is a digital form of convergent photogrammetry, which uses a motorised, remotely operable CCD camera which could be mounted on JET's Articulated Boom. One of the major limitations of most survey systems with regard to remote operation is the problem of targetting. Not surprisingly there are no commercially available optical targets which are vacuum and plasma compatible. Tests were recently carried out at JET using a simple form of target which was an accurately machined 6mm diameter hole in an inconel block. When the hole is selected on a screen with a cursor best-fit algorithms are used to determine its centre which is the datum point. Comparison of survey results using these targets and conventional targets showed a correlation of better than (0.3 mm. A design and development programme is now underway to optimise the targets. Factors being considered are the need to shield the datum face from the plasma while still maintaining its visibility. Different configurations of hole will be assessed to determine that which gives the optimum contrast between the hole and surrounding metal in poorly lit conditions and considering that the surface may be coated with beryllium.

A manual (i.e. with the camera hand-held) videogrammetry survey is scheduled to take place at the end of the present shutdown in any case. This survey will provide the coordinates of the in-vessel datum targets which will be used for the 'best-fit' at the start of the next shutdown. Trials carried out in JET's training facility (figure 6) have shown that the digital model of the vacuum vessel and its components can be interrogated to yield positional information about any component in the model by selecting the appropriate feature of the component using a cursor. The accuracy will of course be reduced but should still be of the order of 1mm.

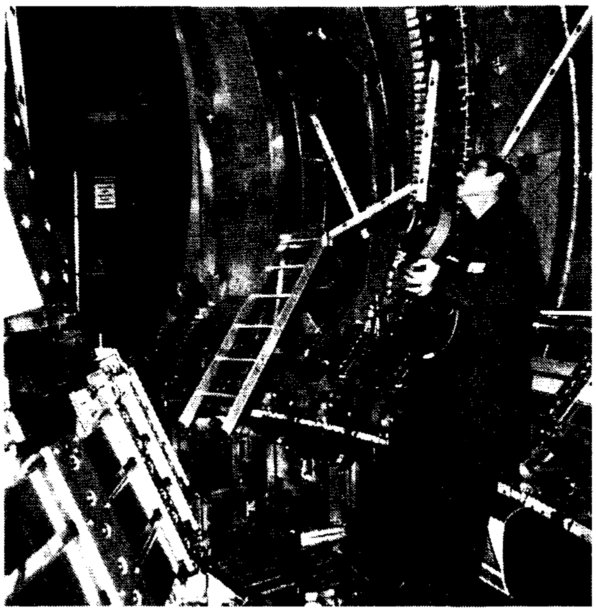

Figure 6 Videogrammetry Trials in JET's Training Facility.

VII. CONCLUSION

The successful completion of the manufacturing stage of this project confirms the benefit of extensive and detailed preparation and development of the survey and installation concepts in parallel with the manufacturing sequence. Early CAT checks confirmed the high quality of the manufacturing sequence agreed with De Pretto [5]. The second assembly confirmed that the structure could be built accurately inside the vacuum vessel. Refinements to the proposed installation method were established. CAT surveys on completion of the second assembly confirmed that manufacturing and assembly had been achieved to within (0.3mm which was well within the allowable tolerance. In fact only 20(of the allowable tolerance was used.

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