JET–CP(98)45

Experience from Remote Handling Equipment Support during the JET Remote Tile Exchange

L Galbiati, P Carter, A Gaberscik, B Haist, M Irving,
D Locke, P Martin, S Mills, R Minchin, J Palmer.

JET Joint Undertaking, Abingdon, Oxfordshire, OX14 3EA,

ABSTRACT

The first fully remote handling shutdown at JET has been completed with the replacement of the JET divertor modules. This so called 'Remote Tile Exchange' (RTE) was undertaken over a 15 week period between Feb and May 1998.

The remote handling equipment used during the RTE was prepared as individual items and as an integrated system to satisfy the functional, performance and reliability requirements of a long term remote handling operation. The equipment was qualified for operation using a systematic and formal method. The equipment has been supported in operation by a team of engineers and technicians with formal procedures for dealing with failures and by the implementation of a routine inspection and test regime.

The equipment has functioned well during the shutdown and its good performance has facilitated the remote handling operations in the planned timescale. The equipment has been subject to faults and failures which have been dealt with by the support engineers with minimal interruption to operations.

This paper describes the experience gained from preparing and supporting the JET remote handling equipment in this first ever fully remote handling operation.

1. INTRODUCTION

The first fully remote handling operations on a fusion Tokamak have been completed at JET. The JET MkIIa divertor has been successfully removed and replaced with the MkII gas box divertor configuration using only remote handling methods inside the JET torus. The successful completion of this remote handling operation has been dependant on the careful preparation and maintenance support of the JET remote handling equipment.

The remote handling equipment used during the RTE included the JET Articulated Boom with Mascot [1] deploying special tooling [2][3] inside the JET torus and the JET Short Boom with special end-effector transferring components to and from the torus [4]. The equipment control systems are interconnected to provide an integrated system with command and control from Man-Machine Interfaces in the remote handling control room.

To avoid unnecessary delays in the shutdown due to equipment failure it was essential that the equipment was properly prepared for use and efficiently supported during operations [5].

2. PREPARATION AND QUALIFICATION OF EQUIPMENT

2.1 Equipment development life cycle

The majority of the remote handling equipment in use at JET is of a prototypical or one-off nature being specified, designed, constructed and operated by JET staff. As with all one-off types of equipment there is a significant gestation period between concept to first operation and then a similar period to allow for development options to be incorporated and infant mortality to be removed.

The JET articulated boom and the servo-manipulator systems have been under development over many years [1] and were integrated to form a complete system with command and control from the remote control room during 1995. New remote handling equipment was required for the RTE; the divertor handling tools, the Short Boom and Tile Carrier Transfer Facility and the Man-Machine Interfaces were identified in 1995 and required to undergo the complete specification to operations life-cycle within two years.

To ensure good reliability in service the equipment was designed using where possible previously proven designs, industrial quality sub-components and rigorous inspection during assembly. To ensure good availability the equipment was designed with Line Replaceable Units (LRU's) for ease of repair taking into account that maintenance personnel would be working in difficult conditions probably dressed in fully pressurised suits. In addition the designs incorporated features to ensure the feasibility of recovery of failed components from within the torus [6].

Previous preparation of equipment for manual shutdown operations has shown that equipment functional and performance requirements can change frequently during the design and development phases. This invariably results in the final construction of equipment occurring at the last moment before operations begin with minimal time for testing or proving. This was not acceptable for fully remote handling operations and so the modification of the primary RTE equipment was frozen at least six months ahead of the start of operations. During the final six months the equipment was fully utilised on mock-up trials and so was undergoing reliability testing at the same time. The only equipment where changes were allowed up to within one month of the operations were with simple tooling and general support equipment such as storage trays.

2.2 System integration

Complex equipment such as those used for remote handling at JET require formal integration before being able to be used as a system. For this purpose the JET remote handling group introduced the Statement of Readiness (SOR) system [6]. A clear definition of the required RTE equipment was issued by the overall Operations Engineer from which Systems Engineers defined in detail the mechanical, electrical, electronic, wiring, services and software sub-systems which together would form the overall systems. The sub-systems were prepared and tested as individual units and SOR's issued. The systems engineer implemented the integration, commissioning, tuning and testing of the system as a whole only when all individual SOR's were complete.

The RTE equipment preparation process was completed before the equipment had been transferred into the JET Torus Hall operations area. A check of the sub-systems and system after the equipment has been connected in the Torus Hall revealed the necessity to recalibrate each of the Boom main joint resolver systems. All other systems remained unaffected by the relocation to the Torus Hall.

3. SUPPORT OF EQUIPMENT DURING RTE OPERATIONS

3.1 Response to faults

In many cases a component fault results in the display of a diagnostic message on the equipment Man-Machine-Interfaces indicating the effect of the fault and the actions to be taken. The operators are trained to recognise and deal with simple or known faults such as those requiring a reboot of software and are provided with simple written instructions with a recommended course of action.

During the RTE if the operations staff were unable to resume operations after a fault then the maintenance engineer was called to the control room. The on-call engineer has been trained to deal with a wide range of faults and to isolate the fault to a Line Replaceable Unit (LRU). To facilitate this work a full set of equipment drawings is available physically in the remote handling control room together with access to the LRU spares database and store.

During the RTE the maintenance engineers were called on average once per week and in only two cases was a fault significant enough to interrupt operations for more than 30mins. Both of these cases involved a mechanical failure of an electrical wire feeding a motor on the Boom camera arm. The maintenance engineer was able to quickly establish that the fault was located on components situated inside the torus and that the articulated boom and Mascot system must be removed from the torus to allow personnel to undertake electrical tests directly on the camera arm. Unfortunately, the camera arm had failed in a position which made it impossible to remove the Boom from the torus. The failure made it impossible to stow the arm without external mechanical assistance. However, the ability to backdrive the camera arm joint through its harmonic drive gearbox allowed the use of the Mascot on the main Boom to push the camera am back to its stowage position. Without this backdrive facility it would have been necessary to deploy a second Mascot into the torus through the second access port and to mechanically remove the camera arm before the Boom could be removed from the torus. This recovery process had been practised [5] and would have been feasible but would have interrupted the shutdown for at least one week.

The Mascot system performed flawlessly during the entire shutdown period. The slave unit inside the torus required no modification or repair during the shutdown while the Mascot controllers periodically required the maintenance engineer to re-start after power glitches and other spurious events.

Only one of the 100 remote handling tools required maintenance during the shutdown due to the mechanical seizure of a lead screw.

3.2 Equipment reliability during the RTE

Throughout the shutdown the Fault Reporting and Corrective Action System (FRACAS) was in use and 108 faults were reported. The vast majority of the faults were the result of action from the control system built-in error checking. In every case an immediate assessment revealed no hard fault with the system and operations were allowed to continue. This type of fault was attributed to electrical noise on sensor signals which transiently exceeded the controller safety limits. In all of these cases the faults were cleared and operations re-started within 30mins.

Each Sunday the Boom, Mascot and Short Boom were withdrawn from the torus and subject to a complete visual inspection and a series of standard tests designed to exercise all parts of the equipment. The currents, voltages and sensor outputs for each of the actuators was recorded and compared to a standard set recorded during the equipment pre-operations phase. The objective was to identify changes to the operational parameters which may have been a precursor to failure and may otherwise have been hidden by the normal control system compensation. In addition the overall Boom positional repeatability was measured by use of a standard teach file. Finally, the system was tested for dormant failures by exercising the equipment which otherwise would not have been used during normal operations. Notably, the Boom main joint mechanical decoupling system which can be used to disconnect a failed actuator from its adjacent Boom links. In all cases the in-vessel equipment system tests revealed no significant degradation in performance.

The test work was performed under the direction of engineers inside the remote handling control room. The tests required the assistance of maintenance personnel inside the contamination control enclosures in contact with the Boom, Mascot and Short Boom. This work and particularly the two occasions after camera arm failures which required the exchange of the camera arm unit highlighted the importance and value of the LRU design approach. Mechanical and electrical fitting work by personnel wearing fully pressurised suits and rubber gloves is extremely difficult and even for cases where the work is straightforward the limited time allowed for such operations makes it critical that it be as simple and quick as possible.

3.3 Equipment utilisation during the RTE

There were 70 days of remote handling operations during the RTE shutdown and 11 working Sundays. The Boom and Mascot systems were located inside the torus for 1680hrs and were available for operation for 1120hrs. Control system log data shows that each Boom main joint was enabled on average for 28hrs during the entire period whilst the camera arm and cyclops joints were each enabled for an average of 73hrs over the same period. No such detailed data is available for the Mascot utilisation but it has been estimated that it was utilised for 650hrs.

4. CONCLUSION

The careful preparation and support of the remote handling equipment before and during the operations has been vital to the success of the first JET remote handling shutdown.

The remote equipment has been designed, developed and prepared for operations taking into account its function, performance, reliability, repairability and method of recovery after failure.

The equipment has been commissioned as individual sub-systems and also as an integrated system well in advance of the operations. The use of the equipment during full scale mock-up trials has facilitated the identification and elimination of those failures always experienced early in the operational life of protoypical equipment and has demonstrated the long term overall system reliability well in advance of operations.

The LRU design concept has been shown to be effective in facilitating efficient fault isolation and repair for two significant faults experienced during the RTE. The importance of this approach for ease of maintenance by personnel wearing full pressurised suits with a number of layers of protective gloves has been emphasised during actual repair operations.

The JET system for response to faults using the FRACAS system with on-call maintenance engineers and trained operators has been shown to be effective in dealing with both spurious and serious faults.

The weekly inspection of handling equipment used inside the torus did not reveal any unknown failures or pre-cursors to failure during RTE but it was invaluable to monitor the characteristics of the equipment and establish that no hidden performance changes were occurring.

5. REFERENCES

[1] T.Raimondi, “ The JET Remote Maintenance System”, Proc IAEA Technical Meeting IAEA-TECDOC-495, Karlsruhe, 1988

[2] S.Mills, A.Loving, “Design and development of remote handling tools for the JET divertor exchange”, 19th Symposium on Fusion Technology, Sept 1996, Lisbon

[3] S.Mills, A.Loving, “Remote bolting tools for the JET divertor exchange”, 20th Symposium on Fusion Technology, Sept 1998, Marseille

[4] L.Jones, et al, “Design and Development of a new transporter facility for JET”, 19th Symposium on Fusion Technology, Sept 1996, Lisbon

[5] A.C.Rolfe, et al, “Preparations for the fully remote exchange of JET divertor modules”, 17th Symposium on Fusion Energy, San-Diego, USA, Oct 1997

[6] A.Rolfe,D.Smith,E.Scott. The assessment and improvement of JET remote handling equipment availability. SOFT 1996. Lisbon