Remote Handling Experiments with the MASCOT IV Servomanipulator at JET and Prospects of Enhancements

D Hamilton, S Colombi[1], L Galbiati, B Haist[2],
S Mills, T Raimondi

JET Joint Undertaking, Abingdon, Oxon, OX14 3EA, UK.
[1] EPFL Lausanne, Switzerland.
[2] KfK Karlsruhe, Germany.

Ongoing remote handling trials are being performed at JET, using the MASCOT IV servomanipulator, in order to establish the feasibility of proposed remote handling tasks. This promotes the development of appropriate tools and methods, the determination of time scales, and suggests modifications to be incorporated into the final design of the related JET components.

1. INTRODUCTION

Remote handling at JET is structured around the MASCOT IV servomanipulator, a two armed master-slave device. The master unit is located in a control room, and the slave unit is positioned, using the TARM and BOOM transporters, around the JET vacuum vessel.

Camera's are mounted on: the MASCOT slave unit, the transporters, and around the torus hall to allow viewing of the environment.

Models of the robots and environment are monitored on a Silicon Graphics workstation running KISMET.

After tritium experiments have been performed in the vessel, man access to the torus hall will be severely limited, and critical maintenance will be performed using the remote handling equipment.

1.1. Aims

The trials described in this paper are based predominantly on the servomanipulator handling tasks. The task descriptions, preparations and trial outcomes are outlined.

1.2. Abbreviations

MASCOT: Master-Slave servomanipulator.
TARM: Articulated ex-vessel transporter.
BOOM: Articulated in-vessel transporter
KISMET: Kinematic Simulation and Monitoring system.
MKII: JET Mark 2 divertor.

1.3. Overview.

As remote handling tasks are identified, trials are performed with the servomanipulator. This helps to establish the areas of difficulty, and provides feedback regarding design modifications which may simplify the task, and the types of tools that need to be developed.

Initially, these trials are usually carried out at the bench test area, with MASCOT mounted on a support stand in front of a bench. If necessary, the trials are extended to involve the transporters.

2. VACUUM VESSEL PORT DOOR MOCK-UP

An exact duplicate of a vacuum vessel port door was used for these trials, the purpose of which was to discover the difficulties involved in the task and to stimulate the development of the methods and tools to resolve them (1).

The servomanipulator was mounted onto the TARM transporter, and the environment and robots were modelled on KISMET.

The 1.5m diameter port door has a silver coated Cefilac seal that deforms when the 48 bolts are tightened, creating a vacuum tight fit.

The trials attempt to perform the task of undoing the bolts, opening the door, changing the seal, cleaning and inspecting the mating surfaces, closing the door and tightening the bolts.

Three people were involved: a MASCOT operator, a TARM operator, and a supervisor.

then bolted into position. Each wide carrier has a diagnostic connector plug which must be screwed into the socket before the narrow carrier is inserted.

The clearances between neighbouring tiles will nominally be 3mm and 10mm. Diagnostics (most critically langmuir probes) fill the bigger gap, reducing this clearance down to 3mm also.

Contact with the sharp tile edges and the diagnostic probes must be avoided at all cost as damage would likely ensue. The most critical operation is the insertion of the narrow carrier between two wide carriers.

Rigid lifting frames are being designed to be bolted to the tile carriers so they may be handled without damaging the tiles. The frames will be left attached to the two wide carriers during the insertion of the narrow carriers, and the narrow carrier frame will be guided by these so that contact between carriers is impossible.

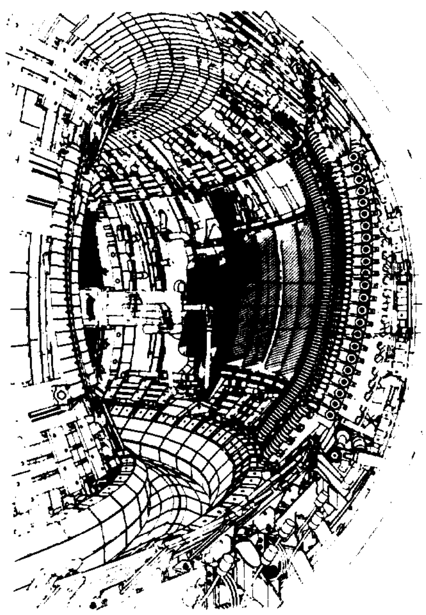

Figure 2. In-vessel handling of MKJIb divertor.

3.2. Winch for MASCOT

The heaviest tile carrier, with attached diagnostics will weigh in the region of 35kg. This is close to the maximum lifting limit of the combined MASCOT arms. In order to retain high sensitivity, to avoid overloading the arms, and to provide extra safety, a winch has been designed to be attached to the front of MASCOT, and will be used to assist the lifting of the tile carriers by taking most of the load.

The lifting point of the winch is at the end of a 0.4m long arm which can be rotated about a horizontal axis. The arm can thus be adjusted to bring it back to horizontal when MASCOT is at an angle.

The winch is actuated by a backdriveable gearbox and current controlled D.C motor, and will operate like a force controlled tensator. The hook can be gripped by MASCOT (operating the safety latch) and attached to the tile carrier lifting frames.

With the winch taking 90% of the weight, the MASCOT arms can manipulate the tile carriers with high sensitivity.

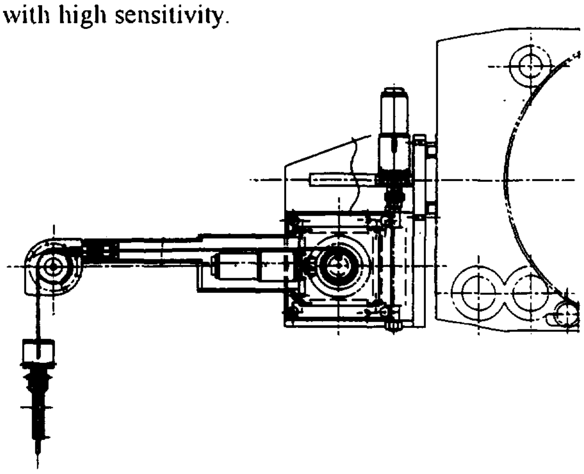

Figure 3. Drawing of the MASCOT IV winch.

3.3. Special tools

A number of proprietary tools have been adapted for this remote handling task. An electric screwdriver, a dial indicating torque wrench, and a power drill, have all been fitted with gripping features.

The screwdriver is powered via an electrical connector at the wrist, and is used to attach the lifting handles to the carriers and to operate the diagnostic connector. To minimise the number of journeys to the toolbox, a stowage position has been created on the MASCOT forearms for this tool.

A torque of 35Nm is to be used to tighten the carrier bolts and an estimated 70Nm will be needed to undo them. A dial indicating wrench will be operated by the servomanipulator, with the applied torque visible through the Cyclops camera.

An electric drill, powered from the tool connector will be used to drill out seized bolts.

Figure 1. Vacuum vessel port mock-up.

2.1. Preparation

Some tools had to be adapted for remote handling usage. An electric impact wrench for torque-ing the bolts was given suitable handles, and the switching modified to allow remote operation via a long cable. Similarly, a ball ended hexagon key suitable for the seal captive screw was adapted for MASCOT gripping. Some pads with scotch brite and soft cloth's were introduced for the cleaning process.

A number of useful transporter positions were identified:- In front of the port, at the bolts, and at the toolbox. Teach and repeat files moving between these points were prepared for TARM with the assistance of KISMET. With the TARM positioned at the bolts, its A6 axis of rotation was colinear with the central axis of the port. The servomanipulator could then be rotated, giving identical access, as far as the master operator was concerned, to all 48 bolts.

2.2. Discussion

Over a period of two days, the complete task was performed, and the area behind the vessel was successfully tested for vacuum tightness.

KISMET proved to be a fundamental tool for navigating the TARM transporter. Its superiority over fixed camera's is due to its ability to present a clear overview from any desired viewpoint. However, the Cyclops camera, located on the MASCOT chest between the arms, is the primary viewing tool for MASCOT operation.

The impact wrench performed well, but it was finally agreed that the vibrations caused by such a tool was not consistent with the delicate diagnostics mounted on the door.

The handling of the door was performed with combined TARM and MASCOT movements. A need for an explicit handle on the door was highlighted when scratches were made to the seal surfaces through inappropriate gripping.

Inspection of the seal surfaces can be performed with the MASCOT cameras. Two equivalent approaches can be used:- the Cyclops camera on maximum zoom and a torch in the hand, or, use a camera in the hand. Varying the light reflection angle helps the detection of the smaller scratches.

Scratches were successfully removed by the servomanipulator, using the scotch brite pads. A smooth repetitive movement over a small arc is more important than high force sensitivity.

A timed operation sequence for the whole task was produced, together with a programme of necessary improvements to be made to the tool kit.

3. MKIIb DIVERTOR HANDLING

In 1996, a short program of tritium experiments will be performed which will activate the vessel. It is then planned to replace the MKIIb divertor tile carriers with MKIIc tile carriers remotely before continuing with the experiments. Although the MKIIb tile carriers are being installed manually, it is intended to install a section of them remotely in preparation for the fully remote task.

The remote handling group at JET have been closely involved during the design of the MKIIb tiles and carriers, proposing modifications to allow the attachments of lifting frames, relocating the dowel pins, and negotiating clearances for the manipulation of the tile carriers in and out of place.

In parallel, the handling tools and methods for this task are beginning to be developed.

3.1. Tile carrier lifting frames

There are 6 types of carriers: wide inner, narrow inner, wide base, narrow base, wide outer, and narrow outer. The tiles on the narrow carriers rest on the wide carriers, so the wide carriers on either side must be installed before the narrow carrier.

The tile carriers have dowel pins which locate them with respect to the support structure, and are

4. TRIALS ON PROPOSED STANDARD COMPONENTS FOR ITER

On the assumption that the remote handling system for ITER will be based on the 'man-in-the-loop' philosophy that was adopted in JET, some bench test trials were performed with MASCOT on standard connectors (2).

The two handed operations required are not necessarily more difficult to perform than single handed operations, the basis used for selecting the more specialised, more expensive, and ultimately less reliable, quick connectors at JET.

4.1. Electrical connections

The single handed quick connectors standardised for JET are rather complex and delicate, and have proved less than totally reliable. The connectors are not robust enough and are prone to accidental deformation due to mishandling and impacts during installation. This experience, together with some trials with different standard industrial connectors, has led to a list of conclusions, some of which are given here:-

- Connectors must be simple, rugged, and robust, taking into consideration the dimensions and weight of the cables.
- To avoid accidental disconnection, lever type fasteners are proposed.
- A rectangular, rather than cylindrical shape, is favoured to give a clear indication of the orientation of the plug before connection, and easier grip for the manipulator.

4.2. Flanged connections.

The performance of bolted flanges has been very reliable over 13 years of operation at JET. The vacuum vessel port mock-up demonstrated the successful remote handling of these flanges.

"V" clamp flanges used at JET have had 4 or 5 segments with a single fastening bolt. One problem that has been noted is that in some cases the compression along the seal appears to be uneven and in places close to the minimum limit. The high friction between clamp and flange causes the clamping force opposite the bolt to be much lower than at the bolt.

Bolted flanges are preferred if space allows. If "V" clamps must be used, it is suggested that clamps with two bolts rather than one be considered.

5. MASCOT ENHANCEMENTS

The force-feedback Master-Slave manipulator adopted in JET for remote maintenance uses a.c. induction motors, with which, because of their low friction, the required force sensitivity can be achieved. In view of the need to manipulate heavier loads, both in JET and ITER, the replacement of the a.c. motors with more efficient brushless d.c. motors is now being studied. The aim is to increase the load capacity, at the same time attaining lower thermal losses and better dynamic response.

The big drawback of brushless motors are the parasitic torques which impair force sensitivity. A method of digital compensation has been worked out at the Ecole Polytechnique of Lausanne under a JET Art.14 contract (3). These torque values are acquired directly on the manipulator using its own control system in velocity or position mode at high gain. A single degree of freedom, tested with a PC based control, gave 1.5 times load capacity and approximately one third of the inertia reflected with respect to the present MASCOT, with comparable friction.

Efficient and compact gearboxes are now being developed which should bring the load capacity to more than 50kg from the present 20kg, once the MASCOT arms have been mechanically strengthened.

REFERENCES

1. D. Hamilton, "Vacuum Vessel Port Mock-up" JET RH Group TN/014.
2. T. Raimondi., "Considerations on the standardization for ITER of connections suitable for remote handling in the light of experience at JET", Workshop on standard components for ITER, ITER, San Diego, May 1993.
3. S. Colombi and T. Raimondi, "Improvement of brushless DC motor actuators", 23rd ISIR, Barcelona 1992.