# Design and Development of a New Remote Handling Transporter Facility for JET

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The JET Articulated Boom (JET AB) strategy, which has the advantages of upgradeability and non-interference with in-vessel components, has now been extended to its original dual concept. This paper describes the design and development of the Tile Carrier Transfer Facility (TCTF), which hands over divertor modules, in-vessel diagnostics and associated tooling to the JET AB just inside the Torus and carries them outside. The TCTF (figure 1) comprises four parts; (i) the short boom with a 10 metre long support beam, trolley and driven link similar to the existing JET AB (ii) the end-effector with a tine onto which components are secured by means of actuated latches (iii) the transfer system with two motorised trolleys travelling into the contamination control enclosure from an attached ISO container (iv) the computer control system including multi-axis control with path planning, joystick or position command and teach-repeat functionality for the 15 degrees of freedom.

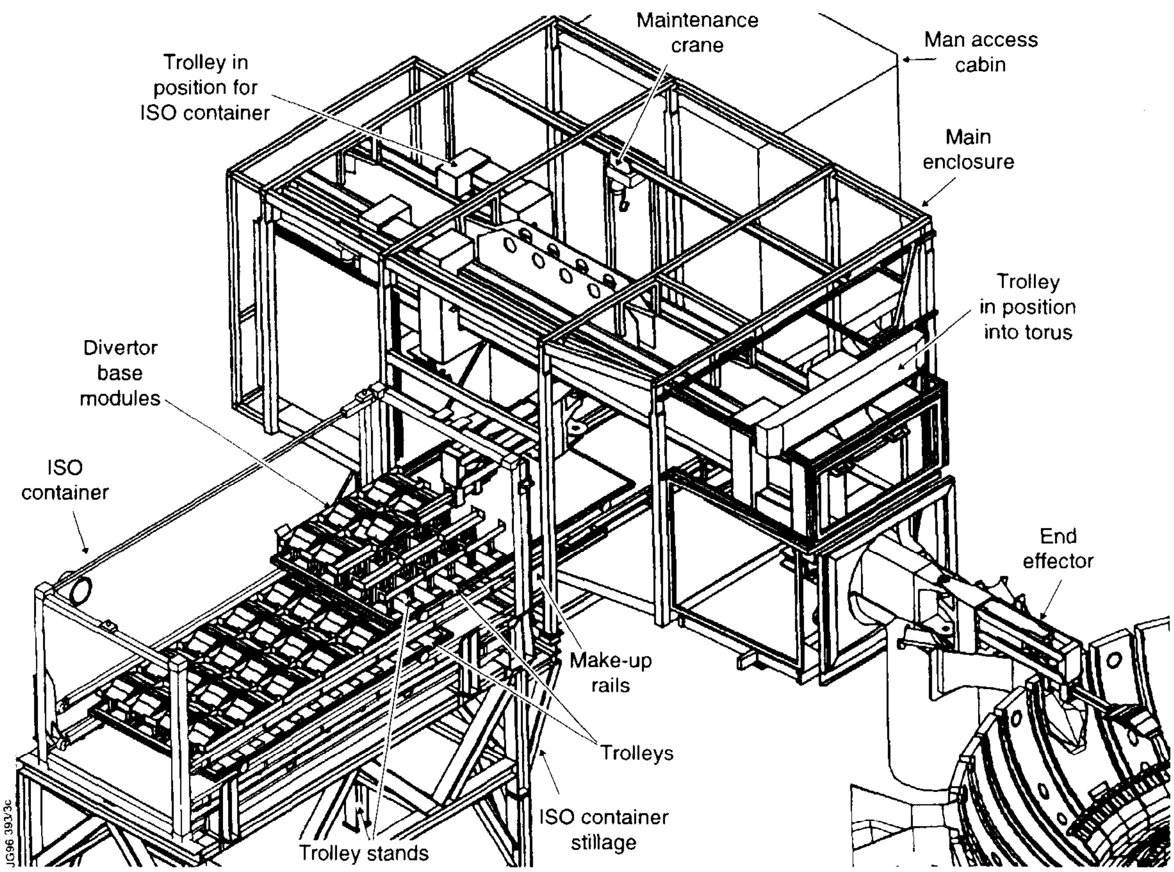


Figure 1. TCTF showing ISO container trolley loading and JET AB handover positions

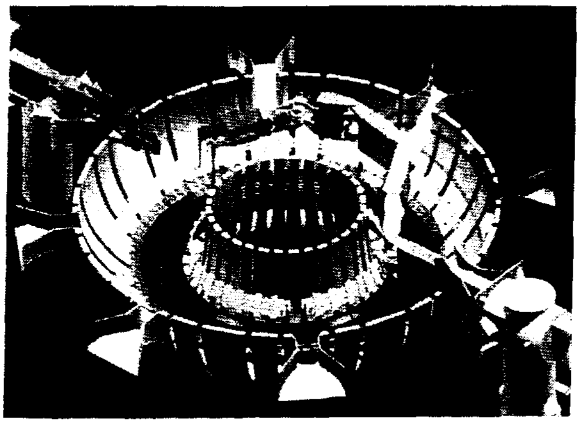

Figure 2. KISMET view of TCTF and JET AB in handover position

## 1. INTRODUCTION

After the deuterium/tritium programme, the 144 JET divertor tile carrier modules will be exchanged with 192 new modules appropriate for the following phase of JET operations as described in section 4 of reference 1. The DT experiments will result in a radioactive vessel (6000 μSv/h) outgassing some tritium and covered in a thin layer of beryllium. Setting up the TCTF and JET AB outside the torus will be hands-on but entry into the vessel will not be possible for a period of one year. All handling in-vessel will be performed remotely by the Mascot servo-manipulator transported around the Torus on the JET AB ([2] and figure 2). The TCTF mechanical hardware was concept designed at JET, while Ansaldo Ricerche of Genoa carried out detailed design and manufacture of the 25 tonne mechanical assembly. The TCTF control system was designed and implemented by JET personnel. Handling trials are currently in progress at JET [3].

## 2. SHORT BOOM

For economy of design and manufacture, structural materials such as Aluminium 6082, Stainless Steel 316 and mild steel have been used. The modular anti-backlash drive units contain compact Harmonic and Cyclo gearboxes and DC motors. To improve reliability, standard designs taken from the JET AB with twin gearboxes, motors and position sensors are used and diagnostics are in place to detect failures. The mechanical components are operating at a depression of 50 Pa contained inside a sealed enclosure. Personnel access to the enclosure is controlled via an air lock cabin and the door to the JET torus may be opened while maintaining contamination control. The assembly is designed and load tested to accommodate future upgrade to full JET AB configuration.

## 3. END EFFECTOR

The end-effector lays down modules onto their stands using a manually removable tine with three sets of motorised latches to capture any configuration of the inner, outer or base modules. The three axes of motion are shown in their zero and full movement states in figure 3 as follows; G1 lowering the tine assembly by 1200 mm via a four bar linkage to access the trolleys; G2 extending the tine horizontally 600 mm. to give improved Mascot access in the Torus; G3 rotating the tine by +/- 90 degrees to allow the modules to pass through the 400 mm wide Torus entry port.

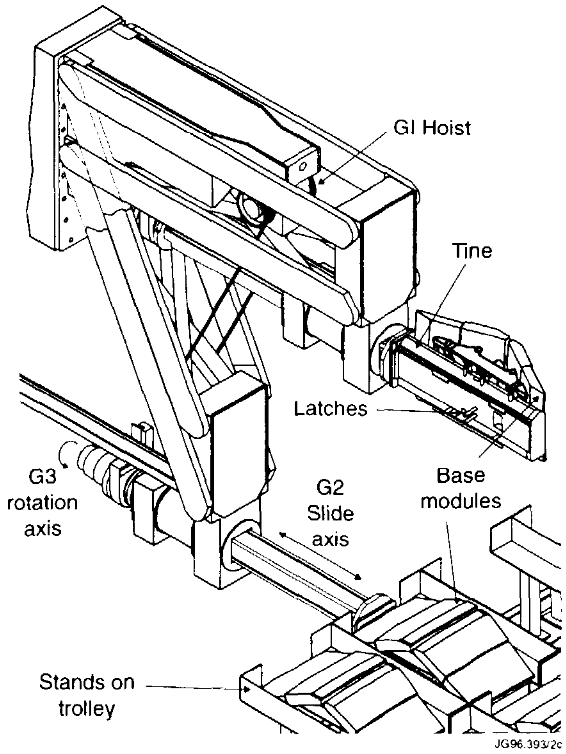


Figure 3. End effector accessing trolley stands

## 4. TRANSFER SYSTEM

Torus components are transferred to and from wheeled flatbed trolleys housed in three removable, stainless steel lined ISO containers, which are manually connected to the enclosure via the lightweight (60 Kg), 2.4 m. square double lidded door system. A 500 Kg capacity hoist and maintenance trolley allow for handling of end effectors and doors. The stands accommodating different configurations of divertor modules are clamped to the two trolleys which in turn are connected to their drive units (situated outside the contamination zone) by toothed belts. The rails in the ISO containers are connected to those in the main enclosure by 0.5 metre long make-up rails so the ISO containers must be accurately located onto the stillage.

Dose rates to personnel are minimised as access is needed for ISO container exchanges only. The used divertor modules have a dose rate of 300 μSv/h. The trolleys are stored at the rear of the containers. so that the dose rate at the double door and trolley belt mechanisms is only 100 μSv/h. The container sides and stillage floor have 16 mm steel plates to reduce dose rates in the Torus hall.

## 5. CONTROL SYSTEM

Local control is available by use of a hand-held console or a Windows NT PC running a state of the art MMI in the JET remote handling control room [5]. The TCTF control system software executes on concurrent processes across the host computer, and on the two PMAC's as shown in figure 4.

Communication between the host and the PMAC's is through dual port RAM located on the PMAC cards, while communication with the desktop is using TCP/IP protocol on the ethernet.

Some of the features of the control system are listed below:-

- The control system brings the robot through well defined operational states:- safe state, ready state, hold state, joystick state, positioning state, and pause state.
- The MMI receives system status information telegrams at a rate of 5Hz. Handshaking ensures that a loss of connection is realised immediately.

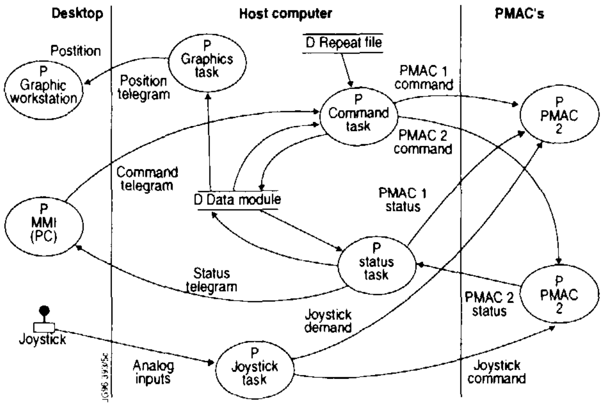


Figure 4. Software data flow

- Continuous monitoring of fault conditions such as emergency stop, following errors, soft limits, limit switches
- Real time monitoring of robot and environment on two graphics workstations with 10Hz update rate
- Smooth S-profile joint trajectories generated by PMAC firmware. Joint interpolated positioning of the 15 joints. A soft stop may be performed during the movement and the motion may be resumed with no deviation in the position trajectory.
- Up to 3 joints may be under velocity control using a 3 degree of freedom joystick.
- Teach/Repeat function is supported. The files are stored on the PC network server and a single file is transferred to the host computer for playback.
- Simulation mode is achieved by integrating velocity demand to give a position feedback. This feature of the control system not only allows it to be rigorously tested with no hardware attached, but also allows operators to be trained safely and for teach and repeat files to be generated off-line.

The hardware, shown in figure 5, satisfies the following criteria:

- design based on a proprietary motion controller DSP based for reliability and safety
- subsystems standard units with off the shelf availability

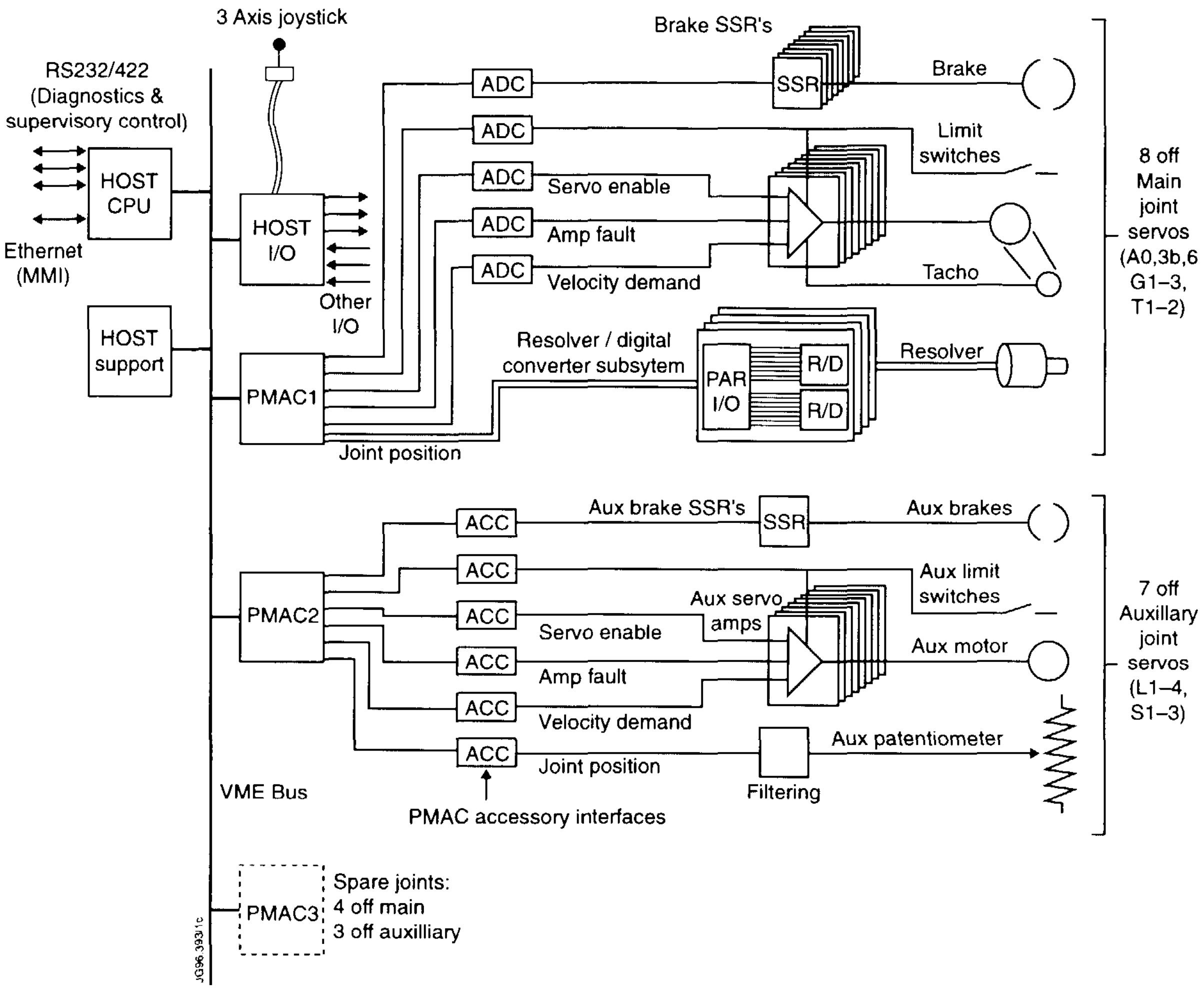


Figure 5. Control system hardware

- hardware modular in construction to facilitate enhancement and repair
- on and off-line checking of critical parameters to optimise safety
- hardware and software states closely mirrored
- built-in diagnostics

The TCTF control system design with 15 joints is being extended to 22 joints to replace the JET AB control system, which is 12 years old.

## REFERENCES


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