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Further Development at JET of Remote Digital Photogrammetry Techniques and Remote Welding Under Conditions of Restricted Access

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1. INTRODUCTION

The decision to install inside the JET vacuum vessel a flight tube to allow Plasma High Field side injection of frozen fuelling pellets was only viable if the majority of work could be carried out remotely. The planned operations programme would be affected by the need to limit neutron production if all the work had to be carried out manually.

The optimum route identified for the flight tube was through a Main Horizontal Port then, following the roof of the vessel, going behind a dump plate and inner restraint ring and finally exiting at approximately the mid plane on the vessel inboard side. See Figure 1.

The majority of the activities required had not been designed for remote handling nor was the detailed as built dimensional information (all features known to ~ ± 0.5mm) available for this area of the vessel.

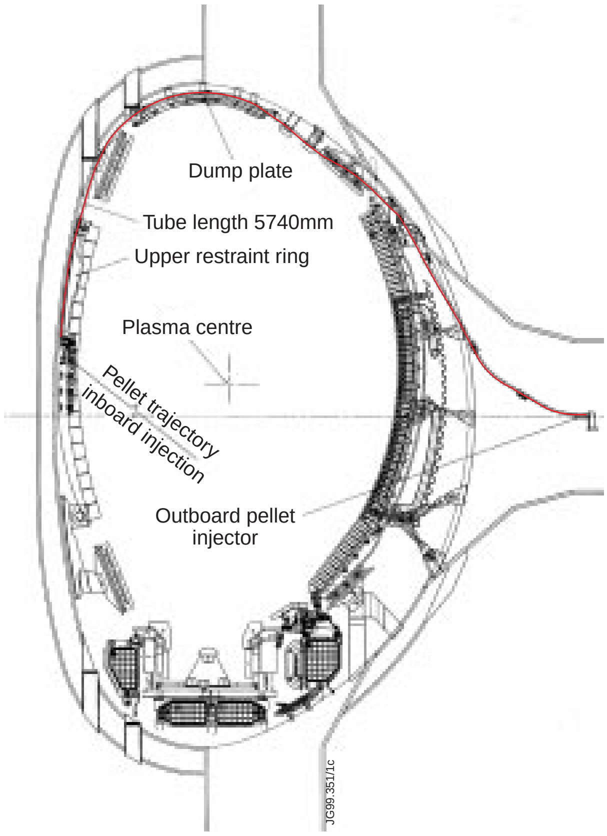


Fig.1: Section Through Vacuum Vessel Showing Pellet Flight Tube Route

2. ASSESSMENT AND DEVELOPMENT PROGRAMME

An assessment was carried out [1] by JET's Remote Handling Group to establish whether remote installation was a viable option. This assessment took place 11 months before the planned installation date of June 1999.

The conclusion was that the majority of work could be carried out remotely within the time scale and with existing resources providing:

- A suitable remote welding method could be developed to weld the flight tube support rails to the wall of the vessel.
- As the support rails would need to be welded to clear local features the position and orientation of the rails would not be known with sufficient accuracy.

  The Photogrammetry Measurement System would therefore need to be developed to enable the support rails to be measured remotely and flight tubes sections to be manufactured from the data.
- The section of flight tube inside the main port could not be accessed by the remote boom or manipulator and would need to be installed manually. However, the remote installation of the majority of the route would allow the vessel activity to decay to ~ 350μSv/hr, a level acceptable for limited manned entry.

A programme was therefore instigated to develop the remote welding and photogrammetry. Four months were allocated to prove the viability of the proposed methods as sufficient time had to be allowed for designing and procuring tooling, procedure development and training. The starting point for each phase of the development was to produce digital models of all components on CATIA, the CAD system used at JET.

3. REMOTE WELDING

The Remote Handling Assessment having looked briefly at alternative methods, typically conventional fillet welding, rose welding and stud welding, selected autogenous overlapping TIG spot welding. The reasons for selecting this method were:

- Simplicity and reliability; no need for arc viewing or automatic wire feed. No welding skill required by the Remote Handling operator. It minimised the services that had to be carried by the Remote Handling Booms.
- Space restriction; the space for the flight tube route was severely limited. The selected method required only a simple tool, which enabled the tool design to be kept small.
- Development time available; as part of the on-going Remote Handling development programme preliminary trials had already been carried out on overlapping spot welding, the results of which looked promising.

The main problems to overcome were the tendency for crater cracking and the need for a minimum weld cross section to give the design strength [2]. Both these problems were exacerbated by not using filler wire, particularly as the material being welded was a high nickel alloy (Inconel 625 to 600).

3.1. Remote Handling Welding Tool

Before any realistic trials could be carried out a prototype welding tool had to be designed and procured [3]. The tool carried two welding heads and a lead screw. This allowed spot welds to be made alternately on either side, then the heads could be indexed along by rotating the lead screw. The support rail to be welded was screwed to the base of the tool. In-vessel, the Mascot (Remote Handling Manipulator) would hold the tool/rail assembly with one hand and operate the lead screw with the other, see Figure 2.

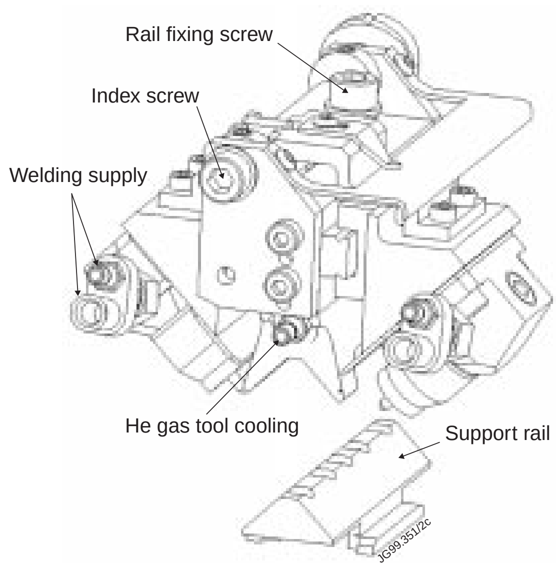
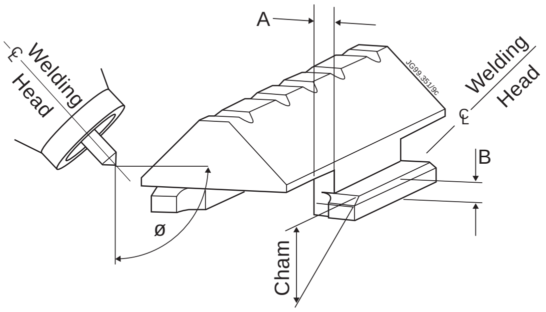


Fig.2: Welding Tool. Handling Feature and positioning rail removed for clarity

3.2. Development Trials

The initial aim of the bench trials was to develop an acceptable weld. Excessive stress in the weld was controlled by machining a slot in the base of the rail allowing flexing of the resultant ligaments and by minimising the size of the weld pool. A parametric study optimised the weld penetration and throat dimension.

A summary of the modifications to the parameters is given in Table 1.



	First test	Intermediate Test	Final Test
Rail:			
Dimn A	No slot	3mm	2mm
Dimn B	2mm	2mm	3mm
Chamfer	No	No	Yes
Weld:			
Tungsten ϕ	40°	90°	60°
Amps	100-170	90-130	90
Arc time	15s	15s	10s
Pulse	Yes	No	No
Arc shield	100% Ar	100% Ar & 95% Ar/5% H	98% Ar/2% H
Results:			
Cracking	100%	~10%	No
Concavity	Yes	Yes	No

Table 1: Evolution of Weld Parameters and Rail Design

3.3. Integrated Trials

Once the weld procedure had been proven it was necessary to carry out integrated trials in the IVTF (In-Vessel Training Facility) [5]. This is a full size mock-up of the JET vessel, accessed by both the long and short Remote Handling booms and linked to the Remote Handling Control Room.

Initial trials identified problems with the length of the welding cables and the high frequency voltage used to initiate the arc. The cable lengths were shortened (final length ~ 30 m). The welding machines were changed from ESAB 315 [4] to an older variant ESAB 250 which gave greater HF power for a duration of up to 4 seconds.

Weld quality was controlled by carrying out a PPS (Production Proof Sample) at intervals immediately prior to welding on the vessel wall. The PPS was subject to visual and macro x 10 magnification inspection. Post weld examination was done via in-vessel cameras and a remotely manipulated videoprobe.

4. PHOTOGRAMMETRY

The remote use of photogrammetry had been successfully proven during the previous JET RTE shutdown [6].

It was used to carry out an inspection of the tile carrier support structure after the removal of the MKIIA and before installing the MKIIGB tile carriers. Failure of the survey would have been disruptive but it was not essential to the completion of the shutdown.

The proposed method of remotely installing the pellet flight tube meant that without an accurate photogrammetry survey the tubes could not have been manufactured nor the shutdown completed remotely. The fall back solution in the event of failure would have been to wait until the radiation decayed to an acceptable level then complete the installation manually. This, of course, would have jeopardised the limited planned operating programme.

4.1. Survey Requirements

The target programme allowed one week to carry out the survey, analyse the results, produce manufacturing drawings, manufacture the tubes (at JET), and welding/setting jigs (off site), plasma spray two of the pipes (off site), and fit the Remote Handling tooling.

The short timescale dictated that only one attempt at the survey could be made. This required continuous monitoring of the quality of the pictures being taken. Equally, the time to produce the results had to be minimised by relying on automatic analysis.

The critical dimensions of the tube assemblies required to be within ± 0.5mm. To achieve this the accuracy of the survey needed to be <± 0.1mm (that is between targets on different carriers). Based on the experience gained during the first Remote Photogrammetry survey and preliminary IVTF trials, the short timescale and accuracy were judged to be achievable. Target carriers would be required to measure the position of the flight tube support rails and several welding/setting jigs for the preparation of the tube assemblies. In addition a jig would be required for calibrating the target carriers.

4.2. Rail Target Carriers

The V-Stars S6 digital photogrammetry system [8] required many retroreflective targets. The difficulty of installing these remotely had been overcome during the previous shutdown by mounting them on space frames which could be handled by the Remote Handling Booms.

This idea was extended by using calibrated target carriers which located accurately on the support rails. On the top face of the carrier were mounted an array of "coded" targets. These targets allowed the software to recognise the individual carrier and establish the relative position of the support rail underneath. Additional plain targets were fitted to two wings to give the necessary width and redundancy to the survey. Figure 3 shows a carrier mounted on a special jig ready for calibration by using photogrammetry. As distances between targets on a single carrier were accurately known (~±0.01mm) no separate scale bars were used in the vessel. The use of a series of small scale bars (targets on the carriers) was not standard photogrammetry practice, therefore two checking surveys were carried out in the IVTF, one using a different system incorporating conventional invar scale bars and one as planned. The two surveys compared to ±0.04mm.

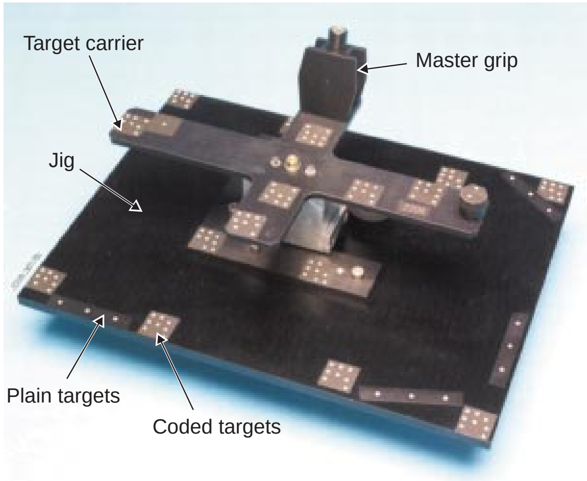


Fig.3 target Carrier mounted on the Calibration Jig

4.3. Welding/Setting Jig

Two jigs were needed to check the tube profile, hold the tube in the correct orientation during welding of the end clamp and set the Remote Handling Tooling. The jigs were adjustable so that they could accommodate different tube assemblies.

The jigs, see Fig. 4, simulated 3 of the flight tube support rails and were finally machined to drawings produced from the photogrammetry survey data. These were checked at the manufacturers premises [10] using photogrammetry and compared directly to the survey data, thus eliminating any possible drawing error.

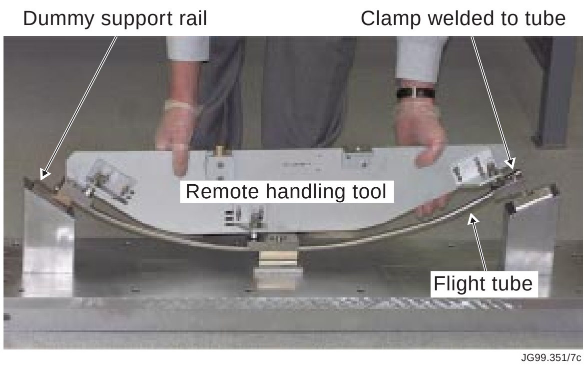


Fig.4: Welding / Setting Jig

4.4. Development and Trials in the IVTF

The survey required the Remote Handling Boom to position the target carriers on the tube support rails, then handle the photogrammetry camera to take up to 70 pictures in a pre-determined sequence. Each picture was downloaded to a computer in the Remote Handling Control Room and checked, before proceeding to the next shot. Simultaneously the pictures were downloaded to a second computer where a checking analysis could begin after about one third of the pictures had been taken. Limited time was available in the IVTF so maximum use was made of the Remote Handling 'Kismet' [7] software to simulate trials. This proved successful in checking the survey geometry and establishing the boom address for each photo position. Figure 5 shows a 3D model produced on V-stars used to interrogate the geometry of the camera rays.

Manual surveys which required less time in the IVTF were carried out to prove the automatic analysis. Finally a full scale "dress rehearsal" was carried out.

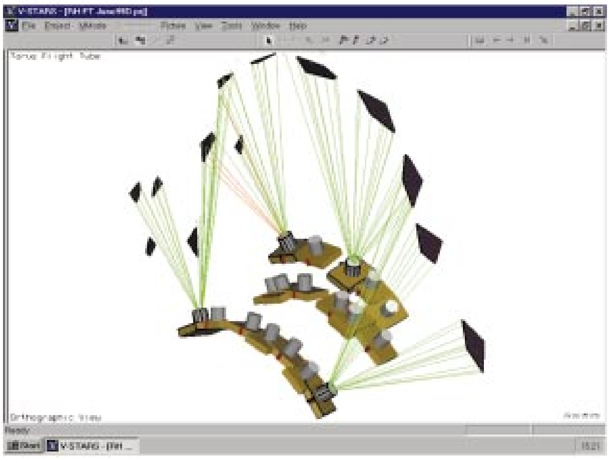


Fig.5: 3D Model of Camera Positions and Target carriers

5. SHUTDOWN RESULTS

The flight tube was successfully installed remotely during June and July 1999 to programme. The remote welding was inspected satisfactorily and showed no unacceptable defects. This was confirmed during the planned manned entry. The remote photogrammetry and automatic analysis was completed in one day.

6. ACKNOWLEDGEMENT

The authors wish to note that without the very close co-operation, enthusiasm and flexible working of all groups involved, particularly for the survey/tube manufacturing cycle, the programme and high quality of the work would not have been achieved.

The main JET groups were the Installation and Remote Handling Groups, the Drawing Office and the Main Assembly Contractor [9] plus the two outside contractors [10] [11].

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