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How To

ITER Remote Handling Code of Practice

This document contains information related to industry best practice in designing the ITER machine for remote handling compatibility complemented by the definition of the ITER remote handling standards. The IRHCOP is intended to be used as a reference
guide by all personnel who have an interface and influence in the successful outcome of the ITER maintenance activities. These stakeholders include not only the IO remote handling responsible engineers but also the personnel responsible for desig ...

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Rajendran S.**	**22-Dec-2009:signed**	**IO/DG/DIP/CIE/AOP/RH**
CoAuthor	**Palmer J.**	**04-Jan-2010:signed**	**IO/DG/DIP/CIE/AOP/RH**
Reviewers			
Approver	**Tesini A.**	**04-Jan-2010:approved**	**IO/DG/DIP/CIE/AOP/RH**
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Version	***Latest Status***	***Date***	***Description of Change***
v1.2	Approved	22 Dec 2009	Chapter-9 revised with details on welded joint principles Annexe-1 added with Remote Handling Compatibility Checklist
v1.1	Approved	02 Jul 2009	First version with full content added.
v1.0	In Work	07 Apr 2008	

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1. Executive Summary

Maintenance of ITER systems located within the ITER Tokamak Building will depend to a very significant extent on the ITER remote handling capability. Wherever possible manual maintenance methods will be used however, at some stage, all in-vessel components will need to be handled and maintained using remote handling methods. With the exception of NB Cell, which has a dedicated remote maintenance system, all other remotely maintainable ITER plant items will be removed from the Tokamak Building and taken to the ITER Hot Cell for maintenance and repair. Additionally, in some areas of the Port Cells and Gallery, it may be necessary to adopt a mixed approach involving both remote handling and manual operations.

The ITER Remote Handling Code of Practice (IRHCOP) contains information related to industry best practise in designing the ITER machine for remote handling compatibility and defines the ITER remote handling standards. It is complementary to and should be viewed alongside the ITER Remote Maintenance Management System [1].

The IRCOP is intended to be used as a reference guide by all personnel who have an interface and influence in the successful outcome of the ITER maintenance activities. These stakeholders include not only the IO remote handling responsible engineers but also the personnel responsible for design, procurement, operation and maintenance of the ITER plant.

The efficiency and safety of ITER remote handling operations will not only be related to the design and operation of the RH equipment itself, but also most significantly on the RH compatibility of the items being handled. The remote handling compatibility of the ITER plant can be assured by the application of the methodology specified and described in IRHCOP, together with the application of approved standards.

2. Scope of the ITER Remote Handling Code of Practice (IRHCOP)

This document provides design guidance related to ensuring remote handling compatibility of the ITER machine complemented with the definition of the ITER remote handling standards. It is complementary to and should be viewed alongside the ITER Remote Maintenance Management System [1]

The IRHCOP provides information to engineers and managers involved in or affected by the need to provide remote handling for ITER.

The IRHCOP defines and describes:

- How To Use The Code of Practise
- ITER Remote Handling (RH) Baseline Strategy
- RH Compatibility of ITER Plant
- RH Design Standards for Location Devices
- RH Design Standards for Fasteners
- RH Design Standards for Lifting & Handling
- RH Design Standards for Welded Joints
- RH Design Standards for Electrical Connectors
- RH Design Standards for Fluid Connectors
- RH Design Standards for Flanges
- RH Design Standards for Cryogenic Connectors
- Key principles for Specification & Design of RH equipment
- Remote Handling Operations

3. How To Use The Code Of Practise

3.1. Aims

To assist all those involved with construction, operation and maintenance of the ITER machine by providing a clear and easy to use reference to industry best practise complemented with the definition of the ITER remote handling standards.

3.2. Target users

All stakeholders engaged in the successful assembly, maintenance and modification of ITER plant.

The stakeholders within the IO team are:-

- The IO RH team
  - The IO RH equipment design engineers
  - The IO RH systems engineers
  - The IO RH operations engineers
  - The IO RH VR engineers
  - The IO RH Operators
- The IO project management
- The IO physicists
- The IO plant design engineers
- The IO plant procurement engineers
- The IO plant Assembly, Integration and Verification engineers
- The IO Quality Assurance team
- The personnel providing the above functions in the Domestic Agencies
- The IO Plant Operators

The main stakeholders in the DA's are:-

- The DA RH engineers
- The DA plant design engineers

3.3. Applicability

The IRHCOP applies equally to all remote handling areas within ITER. The remote handling areas are described in the IRMMS (refer section 6.1, page 25).

3.4. Method of use

The IRHCOP is complementary to and also makes extensive references to the ITER Maintenance Management System.

The IRHCOP contains a wealth of information for all stakeholders about the issues related to designing and building the ITER machine for remote handling compatibility and also for providing a suitable remote maintenance system.

If you are responsible for adding a new system or components to the ITER design then the chapters entitled:-

- RH Design Standards for Fasteners & Location
- RH Design Standards for Welded Joints
- RH Design Standards for Electrical Connectors
- RH Design Standards for Fluid Connectors
- RH Design Standards for Flanges

Provide full information on all components approved as remote handling compatible.

If you are responsible for specifying and designing new (non-standard) components for ITER then read the chapter

- RH Design Considerations for ITER Plant

which provides a full description of the issues to address and include in your considerations.

If you are responsible for preparing or implementing remote handling operations then read the chapter

- RH Operations

If you are a new staff member and are interested in the issues associated with ensuring that ITER is built with remote handling compatibility then a good place to start is to read the chapters concerned with

- RH Compatibility of ITER Plant
- RH Operations

4. ITER Remote Handling (RH) Baseline Strategy

4.1. RH operational areas

Remote handling operations will be required in the areas as shown in the IRMMS (refer section 6.1, page 25).

4.2. Environmental conditions during RH operations

The environmental conditions expected inside to persist in the areas during remote handling operations are defined in the IRMMS (refer section 6.2, page 25).

4.3. ITER Experimental Programme and RH Shutdowns

4.3.1. General requirements

The ITER Maintenance Plan defines the maximum frequency and duration of planned shutdowns in support of the ITER experimental programme. The plan drives the scale and overall planning for the ITER Remote Maintenance System and its operation.

In addition to the activities defined in and from the ITER remote maintenance plan the remote handling systems are required to be prepared to conduct unplanned shutdowns resulting from unexpected plant failure.

4.3.2. Remote handling planned shutdown – general operating scenario

The general structure of a remote handling shutdown is shown in the IRMMS (refer section 6.3.1 page 27).

4.3.3. Remote handling planned intervention

The general structure and planned scenarios of a remote handling intervention is shown in the IRMMS (refer section 6.3.2, page 26).

4.3.4. Unplanned remote handling operations

4.3.4.1. Unplanned tasks occurring during planned shutdowns

The prototypical nature of the ITER machine and its RH systems will certainly result in the occurrence of a number of unplanned events during an otherwise planned shutdown.
The unplanned events will have a variety of potential causes including:-

- In-situ ITER plant unable to be removed due to damage
- Unexpected debris found within the Tokamak
- Unexpected Tokamak deformations

- New ITER plant unable to be installed as designed
- RH equipment failure
- RH equipment incompatible with new or in-situ plant
- Project demands for new tasks not previously identified

The response to any of the above occurring during a planned shutdown will be an ad-hoc implementation of some or all of the following:-

- Analysis of the event which will invariably include remote inspection and manipulation.
- Development of a solution to the event which may include targeted tests using spare or mock-up components and RH equipment.
- Rehearsal and qualification of the solution to the event including validation using the hardware and Virtual Reality mock-ups.
- Rectification of the unplanned event.

The delay resulting from such an occurrence will depend directly on the event itself, the level of preparedness for such an event and the flexibility of the remote handling equipment and team.

4.3.4.2. Unplanned shutdowns

In the event of an unplanned failure of ITER plant the project management will invoke a protocol to assess the situation and decide if an unplanned shutdown is required. The protocol will involve a discussion and appraisal by the remote handling team with the aim to assess the level of preparedness for performing the required tasks.

If it is decided to conduct an unplanned shutdown then the overall logistics and operating scenario will be the same as described in the IRMMS (refer 6.3.4, page 29).

As a matter of good working practise the ITER Remote Maintenance System care and maintenance programme activities which occur in the periods between planned shutdowns will be managed to ensure that the ITER Remote Maintenance System equipment can be made ready for deployment and use within a sensible period should an unplanned shutdown be requested. The minimum response period is defined in the IRMMS (refer section 6.3.4.2, page 30).

Similarly, all necessary RH operations related activities will also be maintained on the same state of readiness.

Factors which affect the amount of time necessary to prepare the facilities for use in an unplanned shutdown include:-

- Availability of spares
- Modularity of the RH equipment
- ITER Remote Maintenance System modification/upgrade programme

- ITER Remote Maintenance System equipment preventative maintenance schedule
- RH staff training
- RH Operations procedures
- ITER Remote Maintenance System and RH operations support facilities
- RH operations utilities

The baseline remote handling equipment designed to perform an RH shutdown is described in the IRMMS (ref 10.2, page 55).

4.3.4.3. Unplanned interventions

In the event of an unplanned failure of ITER plant the project management will invoke a protocol to assess the situation and decide if an unplanned intervention is required. The protocol will involve a discussion and appraisal by the remote handling team with the aim to assess the level of preparedness for performing the required tasks.

As a matter of good working practise the ITER Remote Maintenance System care and maintenance programme activities which occur in the periods between planned shutdowns will be managed to ensure that the ITER Remote Maintenance System equipment can be made ready for deployment and use within a sensible period should an unplanned intervention be requested. The minimum response period is defined in the IRMMS (refer section 6.3.4.3, page 30).

Similarly, all necessary RH operations related activities will also be maintained on the same state of readiness.

The baseline remote handling equipment designed to perform an RH intervention is described in the IRMMS.

4.4. Overall approach to ensure successful RH for ITER

It is neither economic nor practical to develop and prepare a remote handling capability optimised for all possible tasks on ITER. Accordingly the approach adopted for preparation of ITER remote handling is structured as follows:-

- A-priori classification of all ITER plant to identify their future potential need for remote handling – see the IRMMS definitions (refer section 7, page 32).

- The design of ITER plant in a modular form to facilitate removal and replacement of Line Replaceable Units from the Tokamak Building. Remote handling of individual plant is designed to be performed primarily within the ITER Hot Cell – see RH Compatibility of ITER Plant.

- Incorporation of features into ITER components based on their remote handling classification and post manufacture verification of the features – see RH Compatibility of ITER Plant.

- Preparation of equipment for remote handling of ITER plant according to their remote handling classification – see ITER Remote Maintenance System (refer section 10, page 88 of IRMMS).

- Preparation of remote handling operations methods and personnel according to their remote handling classification – see ITER RH Operations Life Cycle (refer section 11.1, page 54 of IRMMS).

5. How to design ITER Plant for Remote Handling (RH) Compatibility

5.1. The need for and meaning of RH compatibility

It is well established RH industry practice that the handling of plant using remote manipulation devices is made easier, faster and safer by the detailed consideration and accommodation of the plant's handling needs from the earliest stage of its development cycle.

It has been demonstrated from the past experience that the feasibility of handling of plant not previously designed for RH compatibility varies from being impossible to being possible but at significant cost in time, money and risk. In the cases at JET where remote handling was performed on previously non-RH compatible plant the time taken to perform the tasks was found to be of the order of 3 – 5 times longer than similar tasks involving plant which had been designed with RH compatibility. There is a similar increase in the amount of preparation time required and, of particular relevance to ITER where manual access to the active areas for recovery when problems occur will be impossible, a significant increase in the level of risk to the whole project.

ITER presents the most demanding challenge to RH ever. After the machine enters its active phase it will be impossible to make changes to any of the plant in the active areas other than by RH means. It is essential therefore that all plant with RH classifications 1, 2 and 3 are designed and built with RH compatibility.

The primary elements to ensure RH compatibility of ITER plant are as follows:-

- At the design stage:
  - Use of only IO RH authorised standard sizes e.g pipe sizes etc
  - Use of only IO RH authorised standard sub-plant e.g electrical connectors, fluid couplings, flanges, fixings etc
  - Inclusion of IO RH authorised standard features e.g for self-alignment, lifting attachment, gripping/grappling features, visual cues etc
  - Use of only IO RH authorised processes e.g welding, cutting etc
  - Use of IO RH authorised techniques e.g elimination of all non-captive parts, use of removable/replaceable threaded inserts, inclusion of mechanical compliance on pipework to facilitate alignment.
  - Provision of clearances around plant to facilitate access for the installation path and in-situ positioning taking account of the RH equipment i.e RH manipulators, RH end-effectors, RH tools and RH lifting jigs etc
  - Provision of suitable clearances and materials to facilitate viewing and sensing by the RH equipment
  - Provision for a means of protecting sensitive and delicate plant items during RH operations. This consideration to include the plant being handled and the plant in-situ.

- At the manufacturing and build stage:
    - Adoption of IO RH authorised quality requirements e.g dimensional tolerances on bolt threads, surface finish and dimensional tolerances of mating parts etc
    - Qualification tests of plant for IO RH authorisation as ready for RH

5.2. RH compatibility within the life cycle for ITER Plant

The successful implementation of RH for ITER requires all stakeholders to be engaged in a rigorous process of interdependent activities described herein as the RH Life Cycle.

The activities, processes and management controls involved in the RH Life Cycle are described in detail in the IRMMS (ref 9.2, page 48). It is essential that all new plant destined for installation on ITER and which may ultimately require remote handling should follow the processes as described in the 'RH life cycle'.

The main features to note are:-

- Plant concept design must be developed in parallel with the IMS (RH) equipment concept design and the development of RH operational methodologies.

- The Plant and IMS Equipment procurement activities must not be initiated until both the Plant and related IMS Equipment concept design phases are formally concluded.

- The conclusion of Plant and related RH Equipment concept phases requires the approval by all stakeholders of both the concepts and the System Requirements Documents.

- All new, or modified, ITER plant of RH Classes 1, 2 and 3 must be accepted and approved by the RH stakeholders after delivery to ITER and in its final 'As-Built' state.

5.3. The assessment of remote handling compatibility

A key tool for ensuring remote handling compatibility is the RH Assessment Form (refer annexe B of IRMMS, page 111). This is compiled and issued first at the end of the plant concept design phase and then stays alive until final issue after the plant has been delivered and accepted as ready for remote handling.

The IO RH engineer will make an assessment of the plant according to its compatibility for RH and, where applicable, will identify any shortcomings and non-standard aspects. In some cases the assessment, if considered necessary, will make recommendations for improvements.

5.4. Application of best practise for remote handling compatibility

In all areas ITER plant must be designed so that good RH best practise is applied e.g maximise modularity, make sure that all fasteners, connectors, cables etc must be captive to the main plant module during handling, minimise double (or multiple) handling of plant items, introduce self alignment wherever possible.

A detailed set of guidelines for best RH practise is provided in the following sections and these principles will be applied during the assessment for RH compatibility of ITER plant.

5.4.1. RH considerations related to plant location

The general approach for ITER remote maintenance is that plant, in modular form, will be remotely detached/attached and transferred between its in-situ location and a dedicated remote handling repair/maintenance facility within the ITER Hot Cell building.

As far as is practicable ITER plant should be designed to ensure that no complex and dexterous remote handling activities are required inside active areas other than the ITER Hot Cell. In particular performing complex RH operations inside the torus and in the port cells will be very difficult and of high risk due to the difficult working conditions.

The ITER Hot Cell will be a fully remote area and a major element of the IMS. The IRHCOP applies equally to all remote handling areas including the Hot Cell. RH inside the Hot Cell will be extensive and it is vital that plant is designed to facilitate its repair, refurbishment and ultimately its packaging and disposal using a rationalised Hot Cell RH system. With this in mind a useful approach for developing a design of new plant to be remotely repaired or refurbished within the Hot Cell is to first consider and attempt to replicate how it would be done manually. IMS dexterous remote manipulators typically have a similar lifting and handling capability to that of a man. Cranes or winches are available to support heavy loads with vertical lifts just as they would be for manual work.

Remote handling in the other active areas should be limited to the removal/replacement/inspection/cleaning and fault finding type of activities. In these areas it is inevitable that special purpose handling devices will be required such as is the case for the Divertor. In these cases the IMS equipment will be subject to a long term proving campaign before becoming qualified for service. This is not only expensive and time consuming at the development stage but also introduces additional cost of support in service and most importantly additional risks for failure during remote handling shutdowns and so will be kept to a minimum.

5.4.2. Safe grappling of plant during manipulation.

Provision is needed for simple and safe engagement and disengagement with the IMS. The design of attachment/grappling features is a deeply integrated activity for both the plant and the IMS. Designs should ensure that when the IMS becomes engaged with the plant it is impossible to be ambiguous about its integrity and similarly when the IMS is disengaged. The preferred approach is to use passive mechanical features to guarantee engagement state with a mechanical interlock to prevent continued motion of the IMS if the state is incorrect.

Provision must be made for secure attachment even if there is a full power failure of the IMS equipment during handling. This can be achieved by the use of passive latches or bayonet type attachments.

Provision must be made to ensure that the plant cannot be removed from its installed location unless and until there is secure grappling with the IMS equipment. This can be done using attachments with (preferably) passive features which inherently prevent decoupling of the plant from its installed position until the grappling feature is fully engaged.

Plant must be designed so that there are no loose items during handling i.e all bolts, nuts, washers, connectors and cables etc must be made captive to the main plant module. This is mandatory for all plant requiring remote handling. The need for adherence to this rule cannot be stressed enough and only in exceptional cases will a concession be given.

5.4.3. Plant modularity

It is preferable to make plant of a modular nature that can be handled more effectively by the IMS.

The general approach for ITER remote maintenance is to remove modules from their operational location and to transfer them to the Hot Cell where detailed maintenance/repair activities will be performed. As far as possible the detailed and dexterous remote handling activities must be avoided within the operational areas, particularly inside the torus and the port cells.

If possible it is preferable to modularise the plant according to RH classification and operational logistics with the aim to minimise shutdown time.

Bolted assemblies should be designed with the appropriate number of bolts to minimise remote handling operation activities i.e minimum number of tool changes and deployments.

Structural welding should be avoided for RH Class 1, 2 and 3 plant.

5.4.4. Safe load transfer of plant during handling

The transfer of load between the plant in-situ supports and the RH equipment can present significant difficulties and risks. The relative mechanical stiffness of the plant itself, its supports and the IMS equipment requires a controlled and gradual hand-over of the item whilst also taking account of the plant alignment and attachment requirements.

The preferred method is for a vertical load transfer during installation and removal with simple lifting from above. The use of a crane for vertical lifting from above will provide compliance in 5 dof which also has the added benefit of aiding self alignment of plant during its installation and removal.

Engagement and load transfer in any direction other than vertical from above will inevitably involve a more complex handling and manipulation strategy and more complex IMS equipment. In these circumstances the transfer of load will often be effected and controlled by the introduction of an active compliance system within the IMS equipment. Such a facility will be limited in its performance by the type and number of sensors which themselves are seriously affected by the hostility of the radiation environment. In all cases it is recommended that load transfer is effected over a significant length of straight motion rather than over a short length or in a complex trajectory.

5.4.5. Safe alignment of plant to and from its installed position

Provision must be made to ensure that plant self-engages and aligns during installation and removal.

The IMS equipment must not be relied upon to be ‘accurate’ in its movements and positioning. It can be assumed that the IMS equipment will be able to move smoothly and slowly as required and be able to return to a ‘saved’ position repeatedly however it will not be able to move accurately to a given co-ordinate in an absolute reference system.

Plant must be designed to be self aligning with its installed site and the RH interface equipment. Alignment should be gradual and phased so that one degree of freedom is constrained at a time. There should be no simultaneous engagement of separate features between plant and Tokamak. The alignment must not be over-constrained and must be toleranced to accommodate in-service distortions as well as manufacturing variations. Plant must be designed to prevent wedging and jamming of parts. Alignment features should preferably also provide visual cues for gross alignment motions before capture.

5.4.6. Identification of plant and its location

Provision must be made to ensure that all plant and the related installation locations are easy to identify using the camera systems available on the IMS equipment.

Two or three independent inspection features should be included to ensure correct plant assembly. These engineered inspection features should provide unambiguous indication of alignment.

5.4.7. Size and shape of plant

The IMS Equipment has a limitation for the maximum size and weight of a plant. All plant taken from the Tokamak will be transferred to the Hot Cell within a dedicated cask. The casks are of a fixed size and with a known carrying capacity.

All new plant must be designed to ensure that any of its modules, together with the handling equipment attached to it, must be able to fit within the cask internal dimensions and be less than its maximum carrying capacity.

Plant attached to any of the ports must be designed to comply with the relevant port size, shape and load limits. This constraint applies for both conditions of when the plant is in-situ and also for when the plant together with its handling system are in transition between its transfer cask and the port face.

The shape of plant is also important. Cable Looms with multiple terminations should be avoided as these cannot be readily handled. Although it is possible to handle multiple connectors it invariably requires additional remote handling tooling and increased task duration and logistic problems.

Plant should not have long flying leads. Interface cables should be "jumper" types that interconnect between the plant and the service termination. Not only does this make the handling of the plant simpler but it also allows the jumper cables to be removed to provide access for other tasks or to replace them in the event of failure. The use of jumper cables also aids diagnostic testing to localise an electrical fault.

5.4.8. Fastening plant to the Tokamak and IMS equipment to the plant

Every machine plant with remote handling bolted interfaces must conform to the standard defined herein.

This IRHCOP provides a selection of standard fastener designs for remote handling compatibility. These bolted interfaces are not just for its attachment to the machine but for all plant modules that could require remote replacement. Bolting operations will be performed using a standard suite of remote handling tools and it is essential therefore to comply with the standard types and sizes.

The plant design must make provision for the possibility of a fastener becoming seized. The preferred methods for bolt and nut assembly designs to facilitate recovery after seizure are provided in the IRHCOP.

The plant design must make appropriate provision to ensure that all mechanical fixings do not become loose during its operational lifetime in the tokamak. Where the fixing is to be broken using remote handling methods then the locking system must be remote handling compatible. The best practise as proven at JET is to use Spiralok type threads. Other remote handling approved standard locking techniques include locking tabs and spot welds, however these methods can only be used in very specific areas where dexterous manipulator access is available.

Where possible the size and number of bolts/ fasteners for attachment of a given plant item should be optimised for speed of RH operation and as a general principle a fewer number of larger bolts is preferred to many small bolts. RH standard reaction features must be provided for bolt torquing and untorquing. Bolts should be of the standard "Pop-up" design to minimise risk of damage during installation and to prevent interference with the alignment process. Bolt captivation must allow the bolts to be fully unscrewed whilst the plant remains in its installed position.

5.4.9. Welding

As far as possible all mechanical connections and couplings in RH class 1 and 2 plant items which will require remote handling to make and break for maintenance should avoid welded joints.

If there is no alternative then welded joints with proven remote handling compatibility must be used.

In the event that a non-standard welded joint is to be proposed then the following considerations will be made by the remote handling group in its assessment of suitability:-

(a) for cutting
- Provision for attachment and the precision alignment of a cutting tool
- Feasibility of cutting to a sufficiently high quality for rewelding
- Provision for restraining the two halves of the joint during cutting (accommodation of the joint strain energy)
- Provision to view/sense the depth and completeness of the cut with the cutting tool in-situ
- Provision for the space required to deploy the tooling and the associated local vacuum cleaner

(b) for welding
- Provision to remotely prepare the in-situ joint remnants for welding (flattening, rounding, trimming etc)
- Provision of suitable compliance to facilitate the alignment of the two halves of the new joint
- Provision for applying sufficient holding force to the joint during alignment and also during welding
- Provision for a precision attachment of the weld tool
- Provision for gas purging of the joint back side during welding
- Provision for weld quality inspection and testing (possibly Vacuum leak testing)
- Provision for the space required to deploy the tooling and the associated local wire feed system (if required)

(c) In general
- Provision for the remote refurbishment of any remnant pieces left in-situ
- Pipe welds should be designed to avoid multi-pass wire filled joints. The use of filler metal greatly increases the access envelope required and increases the risk of failure of the weld process.
- Provision of a design features to accommodate the loss of material when the joint is cut e.g compliance to reweld shorter pipes, elongation of new pipe to make up the loss etc.

The typical inventory of tooling for a welded joint will include:-
- welding tool
- cutting tool (mechanical cutting device with the ability to provide a good machined finish)
- rounding / flattening tool to redress any distortion that has occurred in service
- cleaning tools to remove any contaminating residues
- metrology tools to determine the exact interface for the new plant
- alignment tools to secure the joint in position during welding
- purging tools to ensure that the weld does not oxidise
- inspection tools to ensure that the joint is leak tight and structurally sound
- sample plant items for production proof welding at the remote location

All these tools must be maintained, prepared and commissioned in glove boxes before each campaign of operation – a costly and labour intensive process which must be kept to a minimum.

5.4.10. Viewing / Visibility

The visibility of tasks using remote cameras is a crucial consideration. If the task area cannot be seen in the camera views it will be impossible to perform remotely.

In general, and whenever possible, the IMS will incorporate a large number of high quality cameras and associated lighting systems. However, inside the torus the number and quality of the camera images will be severely restricted as a result of the combined effects of the very high radiation levels and the very restricted access spaces.

It is essential for all remote handling compatible plant that there is as much provision as possible of visual cues. The implementation of visual cues depends significantly on the application however, the following guidelines should be followed:-

- Provide as much high contrast difference between two mating plant.
- Provide physical features that clearly align when correctly assembled.
- Provide colour differences where possible.
- Provide assistance to mechanical alignment features by making use of fixed laser or other light sources projecting onto a viewable target on mating pieces.
- Avoid highly reflective surfaces where possible.
- IMS handling equipment should be visually easily distinguishable from plant being handled.
- All plant items, particularly connectors, wiring and other multiple items must be clearly marked and identified.
- All plant items which require inspection in service should, wherever possible, incorporate inspection access facilities e.g guide tubes for deployment of viewing probes in difficult areas
- All plant items which require metrology inspection must incorporate suitable attachment points for targets and datum references.

5.4.11. Minimising remote handling operations duration and risks

Plant should be designed to make the remote handling operations as simple as practicable. If possible, they should be deskilled to avoid dexterous operations. Plant should be self-locating with staged alignment control. This means that each degree of freedom is constrained one at a time during the installation process. When so aligned, the bolts must be automatically aligned within their capture range of their holes.

Exchange of a plant for a spare unit will be the quickest to repair. However, if a maintenance task demands the removal of other plant to provide access it will have an impact on the duration of the intervention. Access for frequent tasks must not be obstructed by other plant.

Any maintenance task should aim to minimise the range of bolting tooling required by standardising on one bolt size and head type. This will avoid frequent tool changes and benefit the speed with which the task can be performed.

Plant must be designed to avoid the need for double (or multiple) handling of items. The process of transferring plant from one IMS equipment to another, either directly or indirectly by means of an intermediary jig/support, has both the potential for the introduction of new failure scenarios and also will certainly significantly slow down the overall remote operation.

5.4.12. Making provision for handling damaged plant

All plant must be assessed for probability and mode of failure. It is vital to the success of the entire ITER project that any credible plant failure or damage scenario must not result in an irrecoverable situation.

A key element of this consideration is that the designated remote handling mechanical interfaces between plant and IMS equipment must not be damaged by any plant failure or damage scenario. Particular attention must be paid to plant inside the torus which will be subject to possible flying debris (UFO) or unexpected thermal/electro-magnetic perturbations.

Considerations and techniques which can be used in these situations are:-

- The IMS facilities will be capable to perform simple and yet brutal (one handed) cutting operations.
- Protect by covering all precision machined IMS grappling points. Make provision to sacrifice the covers if necessary.
- Provide predrilled bolts allowing them to be drilled out if their heads are too badly damaged for the standard bolting tools to be used.
- All female (nut) side of bolted assemblies must be removable and replaceable in case of the need to drill out the associated bolts.
- Provide redundancy where bolted interfaces for lifting equipment are used, i.e there must always be at least 2 lifting bolt positions. If only 2 are provided then each bolt must be adequate for the full lift on its own.

5.5. The application of remote handling approved standard sub-components

The ITER remote handling group has evaluated and approved a range of plant sub-components for remote handling compatibility.

All ITER plant which are of RH classes 1,2 or 3 and which require sub-components of the types listed herein are required to make use the approved standards.

- Electrical connectors
- Welded joints
- Pipe joints
- Fluid couplings
- Cryogenic compatible couplings
- Lifting and handling features
- Location devices

- Fasteners

All standards contained within the IRHCOP are proven and authorised for use by the IO, its partners and sub-contractors.

Where no suitable standard is available then proposals to include new standards or to modify existing standards must be made to the IO RH section leader. Authorisation for additions or modifications to the standards is made by the IO section leader and only after full assessment and review by the IO RH stakeholders which may include testing and/or expert assessment.

6. ITER remote handling standards for – Location devices

6.1. Principles of Wedging & Jamming

The basis for design of an appropriate RH locating device is a good understanding of the fundamental principles involved. From the outset wedging and jamming conditions must be understood so that they can be designed out of RH location devices.

Wedging occurs when forces between the two assembled parts are internally balanced – ie. with no externally applied force (figure 6.1). When this occurs an additional force (whose magnitude is difficult to accurately quantify) is required to deform the items in order to release them. A wedging condition is difficult to recover, therefore, the design of locating devices must eliminate the possibility of wedging.

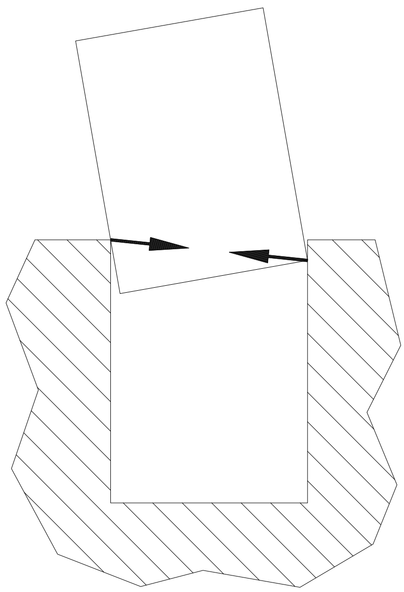


Figure 6.1 : Wedging

Jamming occurs when an external force causes two plant items to lock-up during assembly (figure 6.2). When the external force is removed these forces diminish and the two items are no longer jammed. A jamming condition can be recovered from by removing the external force, however, the design of RH locating devices must minimise the possibility of jamming.

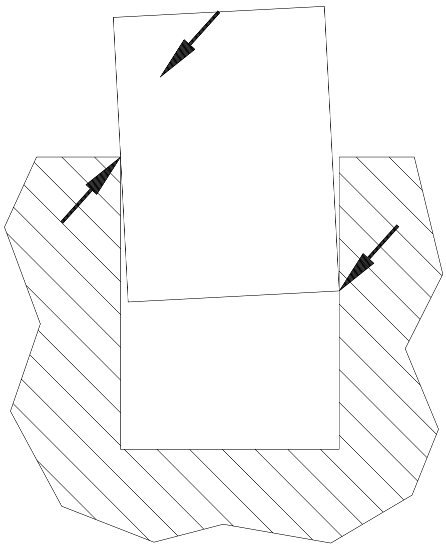


Figure 6.2 : Jamming

6.2. Kinematic Constraint

A free body that is to be located by means of RH has a total of six Degrees of Freedom (DoF), three translations and three rotations (figure 6.3). The purpose of the locating device is to progressively reduce the number of degrees of freedom available to the handled item to ensure that the mating process is carried out in a controlled manner without damage.

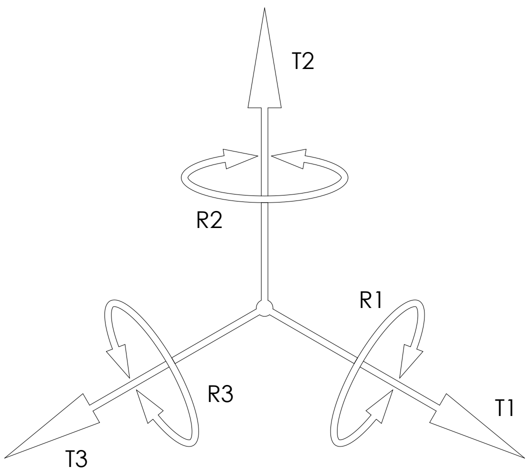


Figure 6.3 : Six Degrees of Freedom

An example of an RH compatible plug connector using the kinematically constrained staged approach is given in table 6.1 & figure 6.4. At each stage of location the number of DoF's has been reduced until the plant item is fully installed (DoF = 0). This general principle of staged kinematic constraint should be applied when developing an RH location device. For each application the method of kinematic constraint should be clearly defined. The number of steps required is dependant upon the complexity and required accuracy of the location.

Step	DoF's	Type
1. Plant item held in free space	6	3 Translation 3 Rotation
2. Plant item located on dowel ball-end	4	1 Translation 3 Rotation
3. Plant item located on single long ball-ended dowel pin	2	1 Translation 1 Rotation
4. Plant item located on second short dowel pin	1	1 Translation 0 Rotation
5. Plant item fully in contact with mating face (Fully Installed)	0	0 Translation 0 Rotation

Table 6.1 : Staged Kinematic Constraint

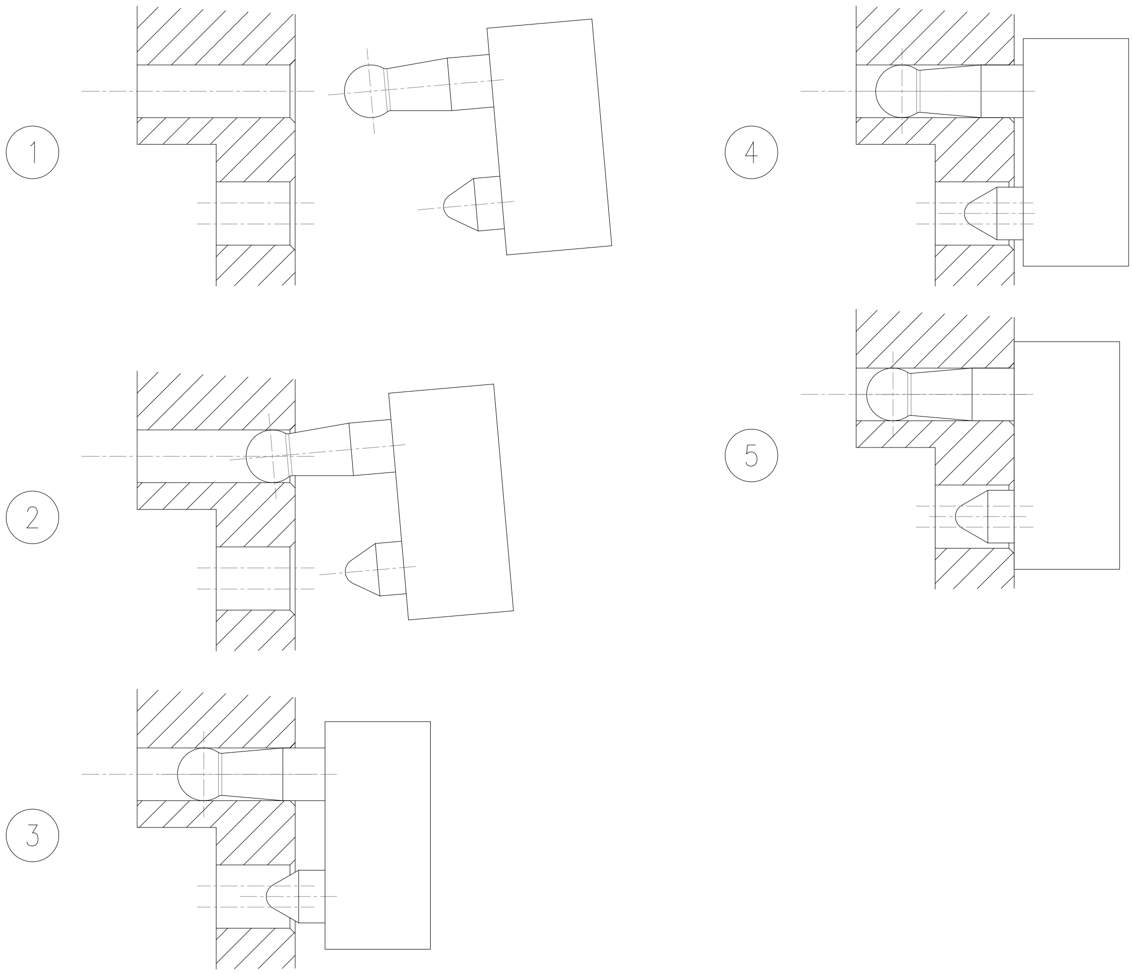


Figure 6.4 : Kinematic Constraint Stages

6.3. Categorisation of Location Devices

RH location devices can be categorised into two principle groups:

- Location devices for small plant items
- Location devices for large plant items

Small plant items which are typically held by an MSM or supported by a small winch (<50kg) working in conjunction with the MSM can be manipulated with great dexterity and can accommodate tight location tolerances.

Large plant (>50kg) require a dedicated method of supporting the weight (eg. A crane attachment or a special lifting frame/end-effector). These items are required to be self-aligning and stable during installation/removal. Due to the greater size and mass tight tolerances cannot generally be accommodated. Inertia affects are greater for large plant and should be considered in the design of the location device.

6.4. Design Considerations

When designing the location device consideration should be given to what RH equipment and tooling will be used to perform the task.

The orientation of the plant items need to be considered, i.e. installation on the ceiling or on a vertical wall is complicated by the gravity vector. Supporting indicators such as built-in spirit levels should be used to aid plant orientation where possible.

Unambiguous sensors/indicators should be used where practicable to show that plant items are fully engaged (eg. lining up features on mating items).

Locations devices should be designed such that it is impossible to mate plant incorrectly (eg. asymmetric dowel pins prevent the wrong orientation). Visual cues should also be used where practicable to assist correct assembly.

Careful consideration should be given to choosing the correct datum and then tolerancing all plant items accordingly with respect to that datum.

The design of a location device should take into account the realistic capture range of the mating features consistent with the size and weight of the plant.

6.5. Edge Guides

Edge guides are a simple method of providing plant location. In a single plane three points of contact are used to define the correct position and two perpendicular forces are required to fully constrain the item.

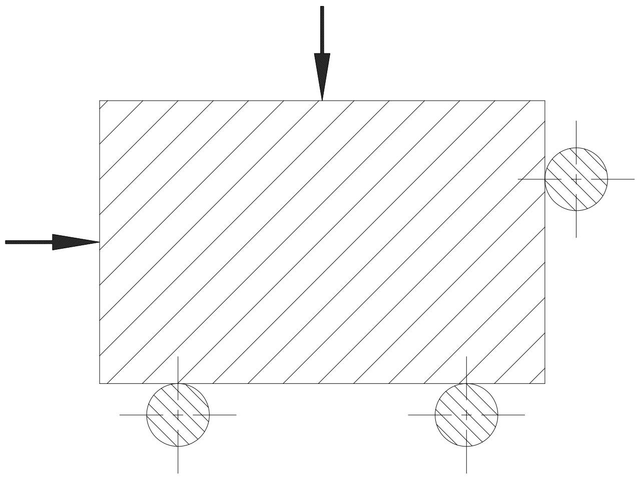


Figure 6.5 : Three point edge location principle

The plane of location can be either vertical or horizontal. When the plane is vertical careful consideration must me made to the applied loadings (both static weight and dynamic loads) on the supports.

Edge guides are particularly appropriate where a clear view of the installation process is required as the supports are external to the located plant item.

6.6. Guide Pins

Guide pins should be used where a large misalignment needs to be reduced. This type of pin should be used to provide coarse initial location as the first stage in reducing the DoF's of a located plant item. The guide pin is used to reduce the initial misalignment to bring dowel pins within their capture range which themselves provide accurate final location (Figure 6.6).

Guide pins can be mounted on either the plant or the mating structure depending upon the specific requirements of the design. The length of the guide pin is determined by nature of the interface and the available visibility during assembly – a long guide pin is required where visual access is poor.

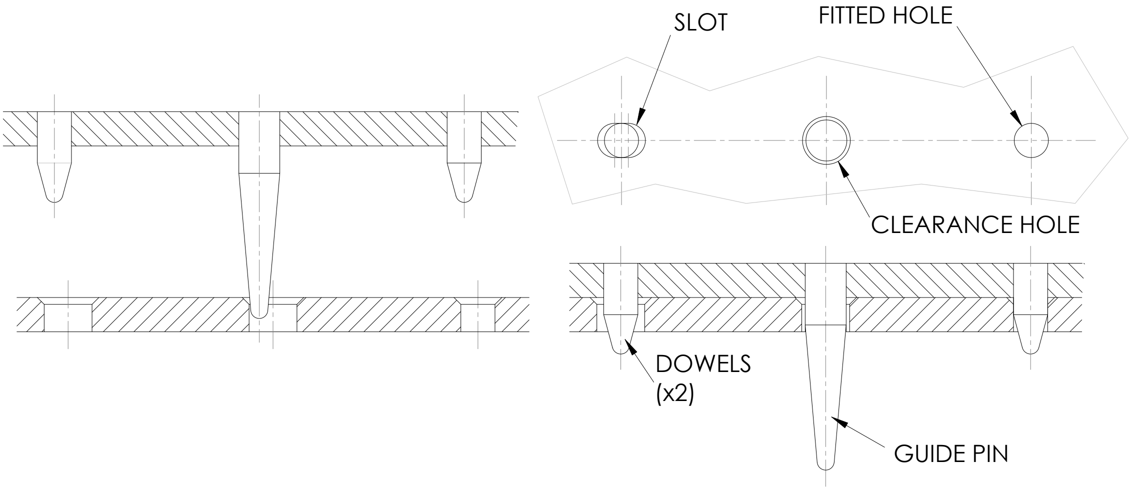


Figure 6.6 : Guide Pin

6.7. Dowelling Arrangement

Dowels provide an accurate method of final location for two mating items. A minimum of two dowels and one contact surface is required to fully constrain an item of plant.

The proportions of the dowel (length and diameter) must be sized appropriately with respect to the method of manipulation used and the anticipated loads that could be applied during assembly.

Dowels should be used to protect against side loads on mechanical fasteners during installation and in-service. Thread damage and seizure may result from this type of loading and should be designed out by the use of an appropriate location device.

One limitation of this method of location is that the dowel(s), contained within the body of the plant, are obscured during engagement. This method, therefore, relies upon good kinematic constraint and good viewing / sensing.

It is preferable that the dowels are put on the plant being installed so that the location holes in the structure can be used for visual guidance during assembly.

The generic parallel dowel pins are generally used in pairs to fully constrain two mating surfaces. One dowel located in a fitted hole eliminates two translational DoF's and the second dowel in a short slot eliminates a rotational DoF about the fitted hole (Figure 6.7).

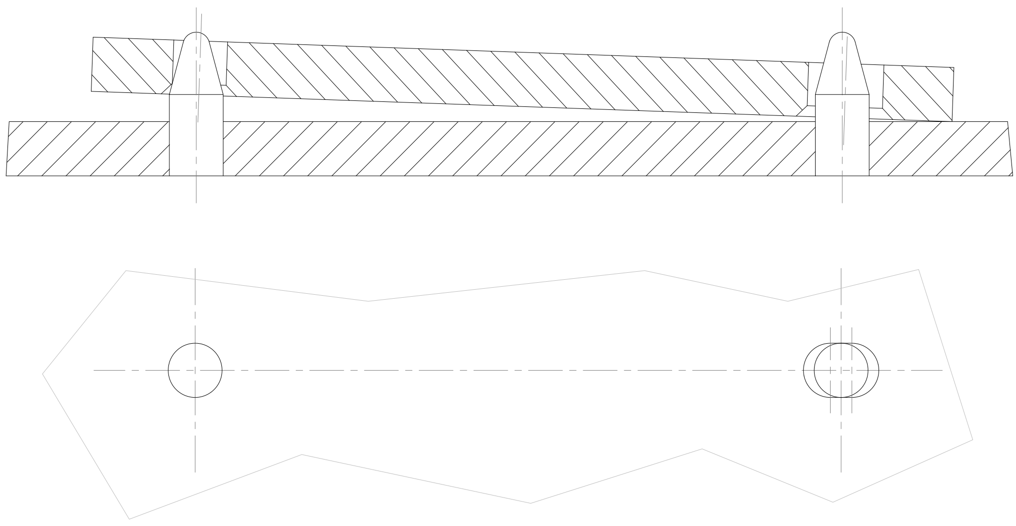


Figure 6.7 : Parallel Dowel Pin

Dowels should be as short as possible to provide adequate location and strength whilst minimising the risk of jamming. In addition the profile of the nose of the dowel should be such that it increases the capture range and also avoids jamming.

Cylindrical dowel pins should be spaced apart as far as possible in order to minimise jamming of the pins when angular misalignment of the plate occurs during assembly.

A generic ball-ended dowel arrangement is show in figure 6.8 and details of dimensioning & tolerancing are given in figure 6.9. This design incorporates a long ball-ended dowel that locates in a circular hole and a short parallel dowel that locates in a short slot.

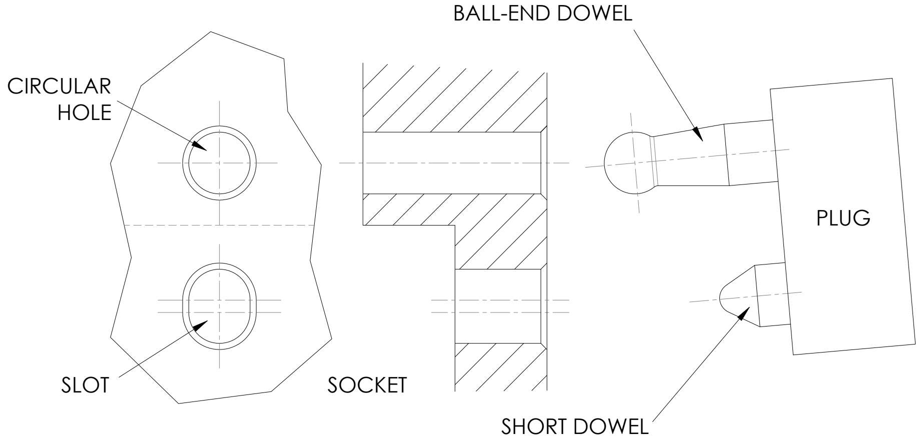


Figure 6.8 : Ball-End Dowel Arrangement

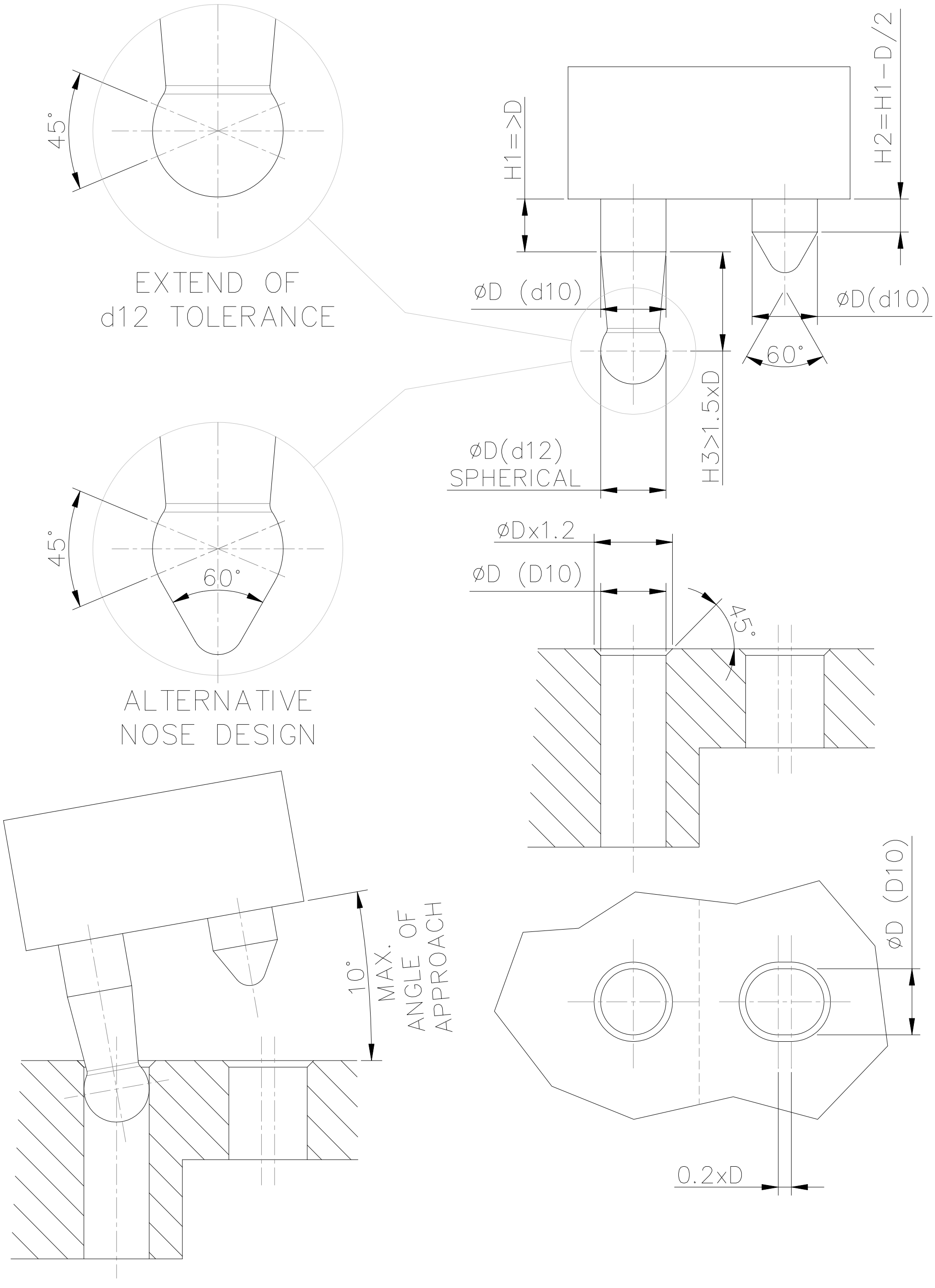


Figure 6.9 : Dowel Dimensioning & Tolerancing

6.8. Dowels for Electrical Connectors

The ball-ended dowel design is used where electrical connection needs to be made. It provides high level of control over the connector within a compact arrangement (figure 6.10).

The length of the dowel pins is dependent upon the length of the electrical contact pins. The ball-ended and cylindrical dowel must first be engaged on their parallel shafts before final connection of electrical pins to prevent damage (see figure 6.10).

The fastener for a dowelled connector should be located as close to the contact pins as possible to minimise side load on the pins. The preferred arrangement would be the pins located around a single central fastener.

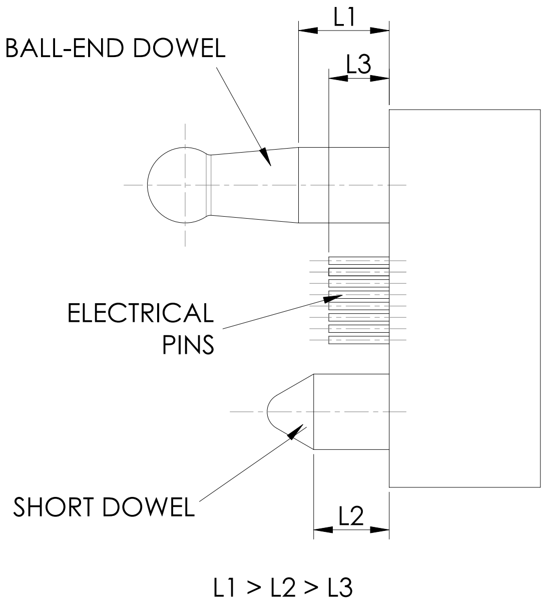


Figure 6.10 : Dowel for electrical connectors

6.9. Bolted Flange Location

Axial and azimuthal location can be provided by external spigot guides (figure 6.11). Two such guides are used per flange at 180 degrees.

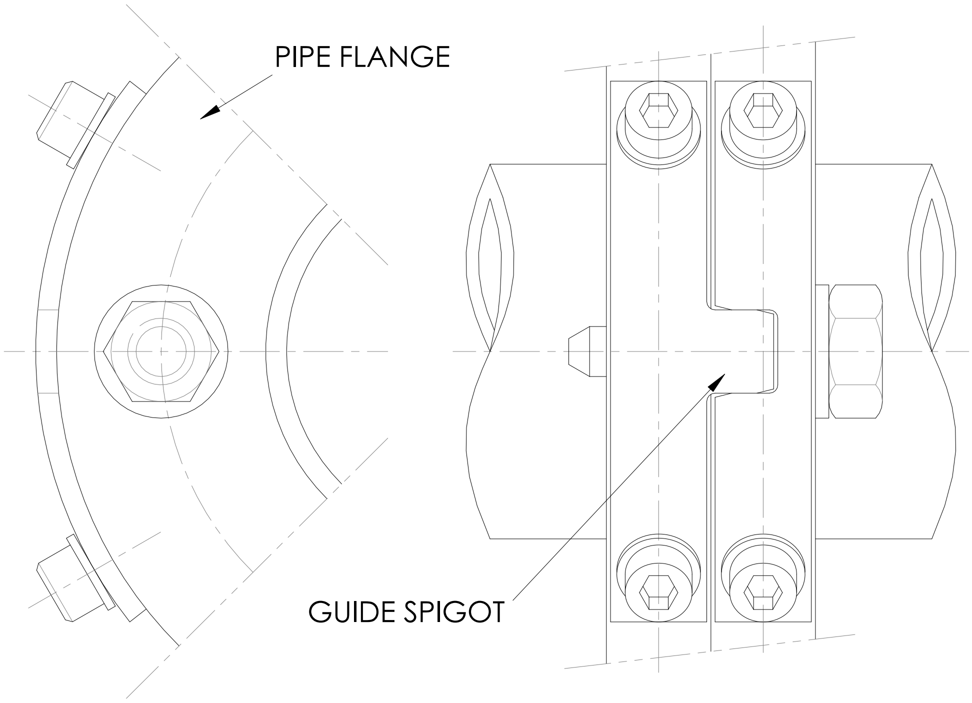


Figure 6.11 : Axial & Azimuthal Flange Location

Bolted flanges can be located axially by an internal spigot arrangement. Figure 6.12 shows the spigots as used on the Class 300 vacuum flanges.

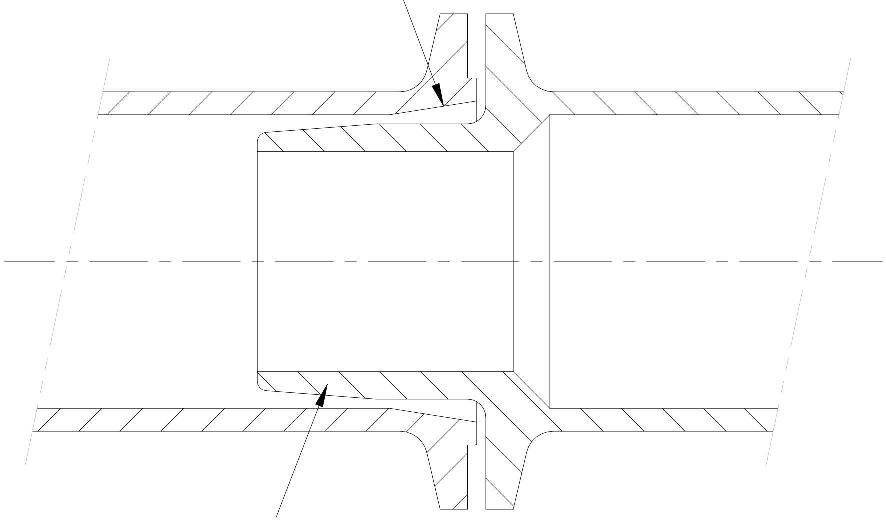


Figure 6.12 : Flange Spigots

6.10. Location Device Examples

Figure 6.13 shows an RH electrical connector. The connector assembly consists of an MSM gripper body which incorporates a Lemo electrical contact plug and a ball-ended dowel pin. Note – the standard keyway incorporated into the Lemo body must be removed.

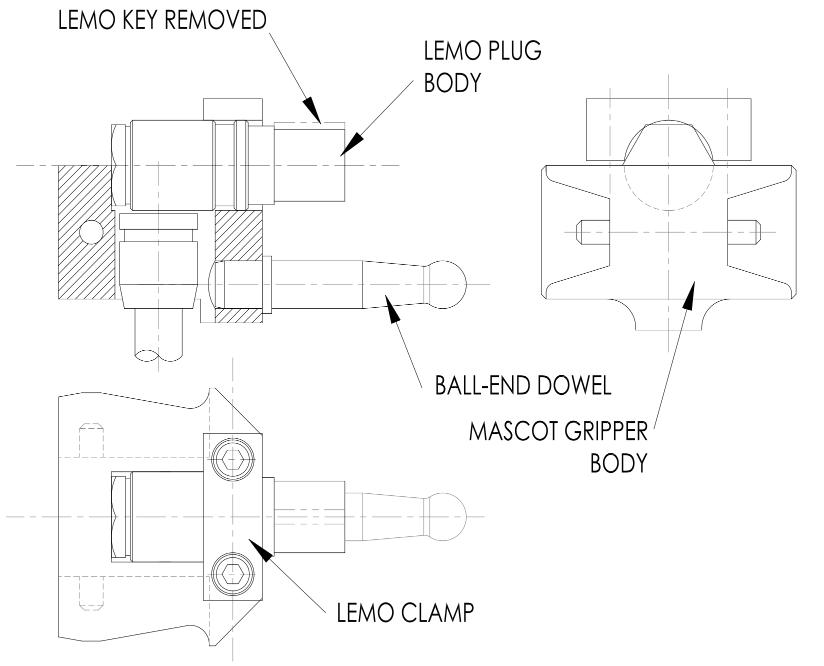


Figure 6.13 : RH Lemo Connector

The location of the long ball end dowel on its parallel shaft reduces the DoF to two (one rotation and one translation). Then the shorter body of the Lemo plug is used as a dowel to constrain the rotational DoF. The one remaining translation DoF, along the axis of the dowels pins, then enables full engagement of the Lemo plug without risk of damage to the electrical contact pins within.

7. ITER remote handling standards for – Fasteners

7.1. Introduction

This procedure is designed to provide the preferred RH method for designing mechanical fasteners. However, should the design of a fastener assembly require features outside of this specification the ITER RH section must be consulted at the earliest possible stage. It is also essential that the ITER RH section be consulted throughout the design process to ensure all mechanical fasteners are fully RH compatible.

7.2. Male Fasteners (Bolts)

7.2.1. In-Vessel Bolts

To assist recovery from failure all in-vessel bolts from M10 upwards shall have a 2mm diameter pilot hole drilled through the full length to enable them to be drilled out (see also 7.11.2))

7.2.2. Thread Dimensions & Tolerances

All threads shall conform to the ISO Metric Course thread form to BS 3643-1:1981. The standard thread size range shall be, M8, M10, M12, M16 & M20. For larger sizes, seek advice from the ITER RH section.

A loose male thread tolerance shall be used to assist misalignment during remote assembly. The corresponding class of fit shall be “8g” in accordance with BS 3643-2:1981. Threads must be of good surface finish free from tears and rags.

The minimum specified full thread length shall be 1 times the nominal bolt diameter. Either rolled or cut thread forms are acceptable as long as a good surface finish is provided. All feathered thread ends shall be dressed back to the first full thread. This information must be included on the manufacturing drawing in the form of a diagram (see figure 7.1).

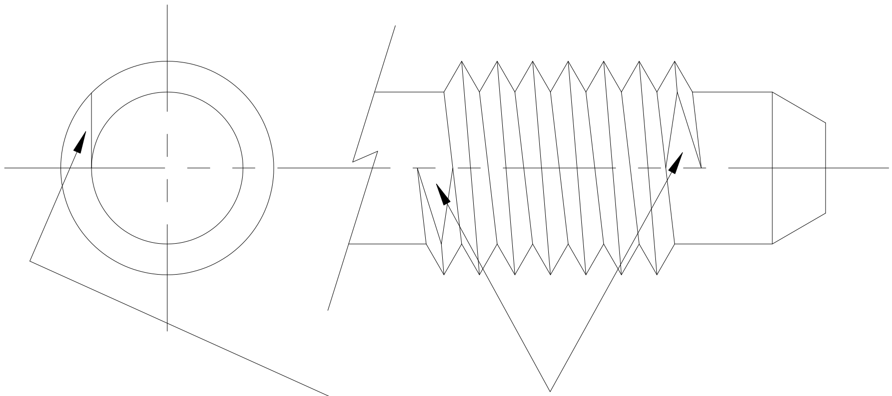


Figure 7.1 : Feathered Thread Ends

7.3. Head Styles, Dimensions & Tolerances

7.3.1. Socket Heads (Preferred Style)

Standard ISO Metric plain socket heads to BS EN ISO 4762:1998 is the preferred style of bolt head. Where practicable, given other design constraints, this style of bolt head should be used.

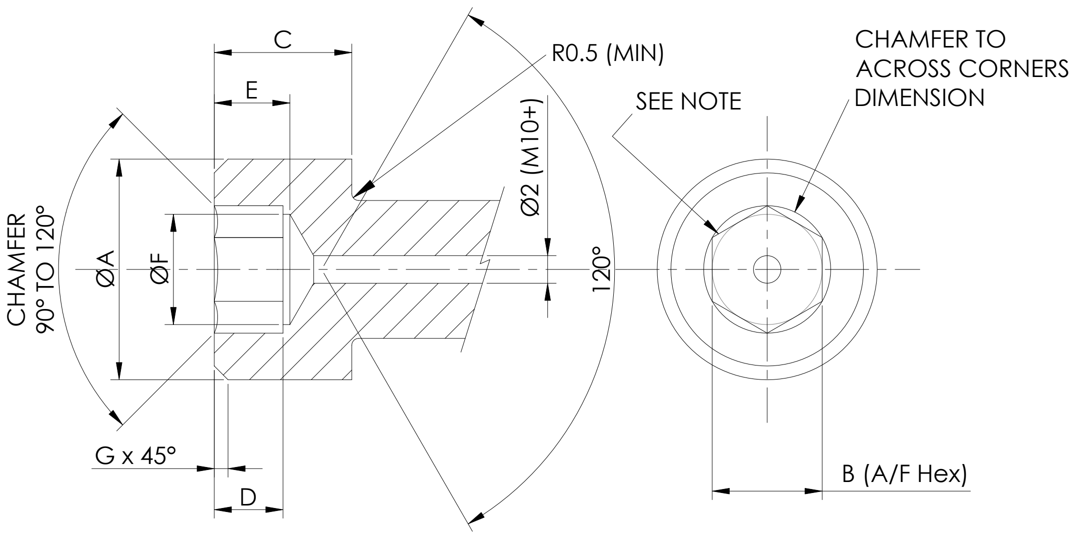
The method of manufacture for the female hexagonal socket shall be broached or forged (Ref. BS EN ISO 4762:1998) to the design shown in Figure 7.2 & Table 7.1. This socket design enables misalignment of a ball-ended key to be accommodated by the initial pilot hole. Flat bottom hexagonal sockets are not acceptable as they do not allow misalignment of the ball-ended key to be accommodated.

Electro Discharge Machining (EDM) / spark erosion of the hexagonal socket may only be used when a high quality surface finish can be achieved (Ra = 1.6 or better).

Where possible a standard socket head size should be specified with respect to the thread size (Ref. Table 7.1). However, where other design restraints dictate a non-standard socket head may be specified (eg. M10 head size and M8 thread).

Dimension	M8	M10	M12	M16	M20
Dia. A *	13.00 12.73	16.00 15.73	18.00 17.73	24.00 23.67	30.00 29.67
B (A/F]*	6.14 6.02	8.175 8.025	10.175 10.025	14.212 14.032	17.23 17.05
C * (Head Depth)	8.00 7.64	10.00 9.64	12.00 11.57	16.00 15.57	20.00 19.48
D (Socket Depth)	4.0 4.5	5.0 5.5	6.0 7.0	8.0 9.0	10.0 11.0
E (Pilot Depth)	4.5 5.0	5.5 6.0	7.0 8.0	9.0 10.0	11.0 12.0
F (Pilot Dia.)	6.0 5.5	8.0 7.5	10.0 9.5	14.0 13.5	17.0 16.5
G* (Chamfer)	0.8	1.0	1.2	1.6	2.0

Table 7.1 : Socket head bolts (Dimensions in Millimeters)
* Ref. BS EN ISO 4762:1998



Note: Opposite flanks of hexagon must be parallel and internal corners must be sharp.

Figure 7.2 : Socket Head

7.3.2. Hexagonal Heads

Where the use of a socket head fastener is not practicable a standard size external hexagonal bolt head (to BS 3692:2001) may be used. Where necessary a lead-in cone may be made to provide ease of engagement of the RH ring spanner (see Figure 7.3). In addition an integral shoulder is preferable to maintain engagement of the spanner. This feature is especially useful for pop-up bolts.

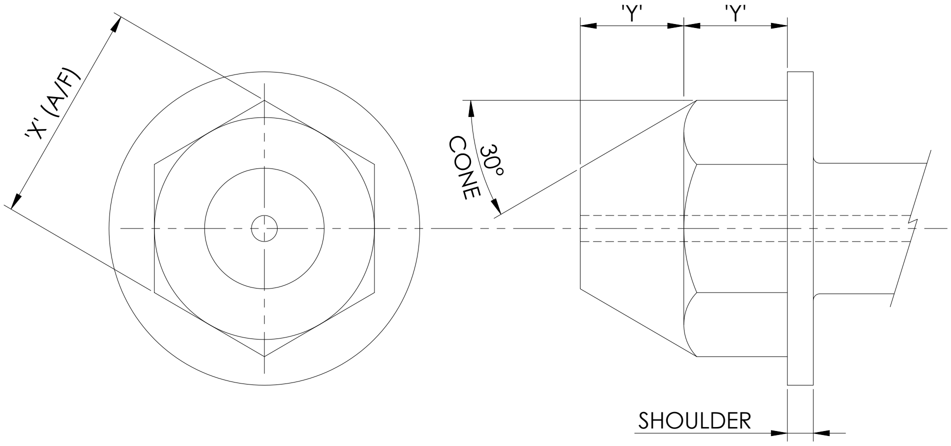


Figure 7.3 : Hex Head Modifications

Dimension	M8	M10	M12	M16	M20
X (A/F) **	13.00 12.73	17.00 16.73	19.00 18.67	24.00 23.67	30.00 29.67
Y **	5.65	7.18	8.18	10.18	13.21

Table 7.2 : Lead-in cone head bolts (Dimensions in Millimeters)
** Ref. BS 3692:2001

7.3.3. Bi-Hex Heads

Where the use of a socket head fastener is not practicable a standard Bi-Hex bolt head (to BS A 323 : 1998, ISO 4095 : 1998) may be used (see Figure 7.4 & Table 7.3). Bi-Hex heads provide a smaller across-flats dimension than standard hex heads and provide the spanner with better location and security under load. The head design has an integral shoulder to assist location of the spanner.

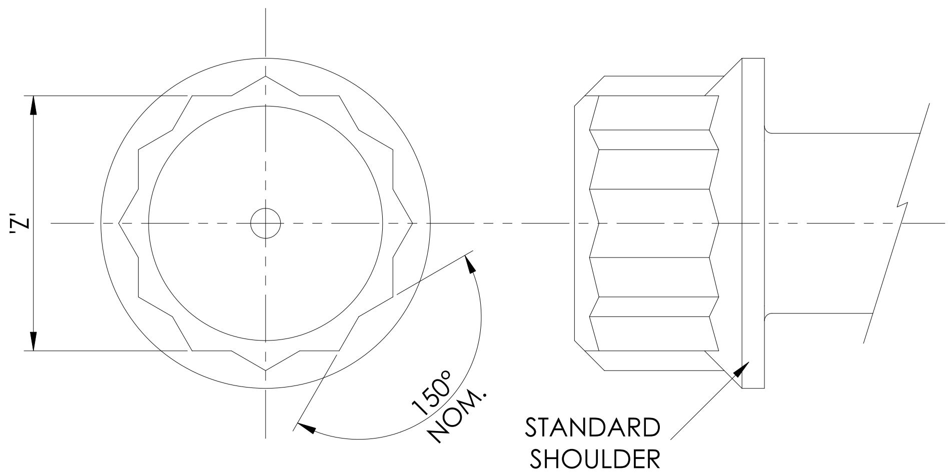


Figure 7.4 : Bi-Hex Head

Dimension	M8	M10	M12	M16	M20
Z #	10.00 9.85	12.00 11.82	14.00 13.73	19.00 18.67	24.00 23.67

Table 7.3 : Bi-hex head bolts (Dimensions in Millimeters)

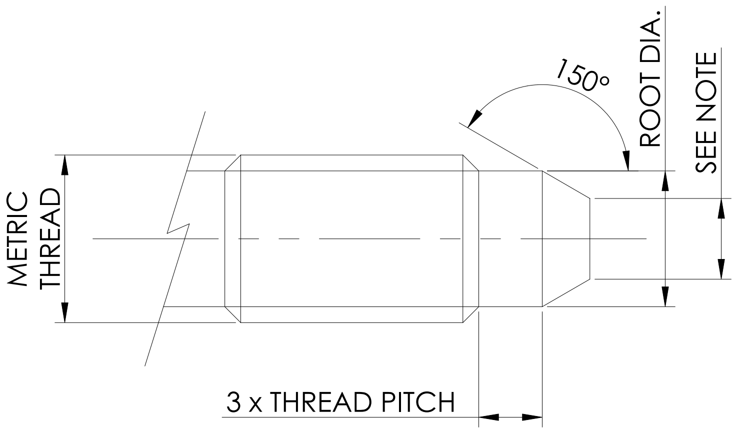
Ref. BS A 323:1998

7.4. Nose Style

7.4.1. General Style

Where possible a standard bolt nose style should be used (Figure 7.5):

- Parallel nose diameter machined to root diameter of thread
- Length of nose is 3 times the thread pitch. This length can be reduced, where the bolt axis is maintained by its housing to prevent cross-threading, to a limit of 1.5 times the thread pitch if required.
- A 60 degree included angle cone end.



Note: The nose should be small enough to be within capture range of the female thread.

Figure 7.5 : Bolt Nose

7.4.2. Alternative Style (To Minimise the Risk of Cross-Threading)

Where there is high risk of cross-threading the following bolt nose design should be considered (see Figure 7.6 & Table 7.4). This design is only possible where the thread form is rolled.

The diameter of the bolt nose is based upon a close clearance fit with the minimum diameter of the corresponding standard female thread to minimise misalignment prior to thread engagement. Under these circumstances the nose length can be reduced to 1.5 times the thread pitch if required.

Dimension	M8	M10	M12	M16	M20
Nose Diameter	6.89 6.86	8.35 8.32	10.07 10.03	13.80 13.76	17.25 17.20

Table 7.4 : Alternative nose head bolts (Dimensions in Millimeters)

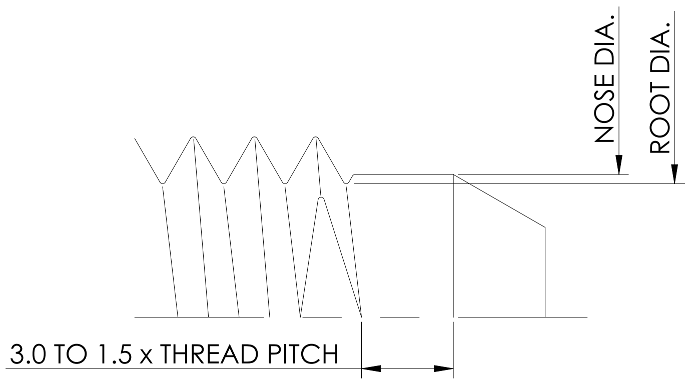


Figure 7.6 : Alternative Nose

7.5. Female Fasteners (Nuts / Inserts)

7.5.1. Nut Threads, Dimensions & Tolerances

7.5.1.1. General

All threads shall conform to the ISO Metric Course thread form to BS 3643-1:1981. The standard thread size range shall be M8, M10, M12, M16 & M20. For larger sizes, seek advice from the ITER RH section.

Hexagonal nut dimensions shall conform to BS 3692:2001. The corresponding class of fit shall be "7H" in accordance with BS 3643-2:1981.

7.5.1.2. Self-Locking

Where the fastener is required to be self-locking a Spiralock® (Figure 7.7) thread form shall be the preferred method. This thread form provides preload to the threads to resist the effect of loosening. With Spiralock® threads the male form remains a standard ISO thread form and the female thread is modified.

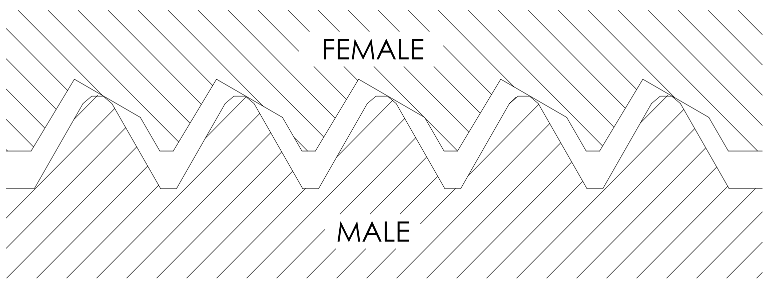


Figure 7.7 : Spiralock Thread Load Distribution

Note: As Spiralock® thread forms are not symmetrical the type of tap (TT or BT) and tapping direction must be stated on the manufacturing drawing - dependent upon the tightening direction.

7.5.2. Thread Inserts

7.5.2.1. Standard In-Vessel Insert

The standard thread insert (in Al-Bronze) should be used for ITER In-vessel applications (Figure 7.8 & Table 7.5). This comprises a coarse metric internal thread to mate with the corresponding fixture bolt and a course metric external thread that retains the insert within its supporting structure. Slots in the long axis of the insert and support structure are then aligned to accept a spring-type pin. This pin is taken flush with the support structure and prevents the insert from rotating. There is a standard procedure from recovery from failure of one of these inserts (section 7.11.3)).

Internal Thread	External Thread	Pin Distance	ITER Drawing Number
M8 x 1.25 – 6H	M14 x 2 - 6g	8.25mm	Contact RH Section
M10 x 1.5 – 7H	M18 x 1.5 – 6g	10mm	Contact RH Section
M12 x 1.75 – 7H	M18 x 2.5 – 6g	10mm	Contact RH Section
M16 x 2 – 7H	M27 x 3 – 6g	14mm	Contact RH Section
M20 x 2.5 – 7H	M33 x 3.5 – 6g	17mm	Contact RH Section

Table 7.5 : ITER In-vessel Standard Inserts

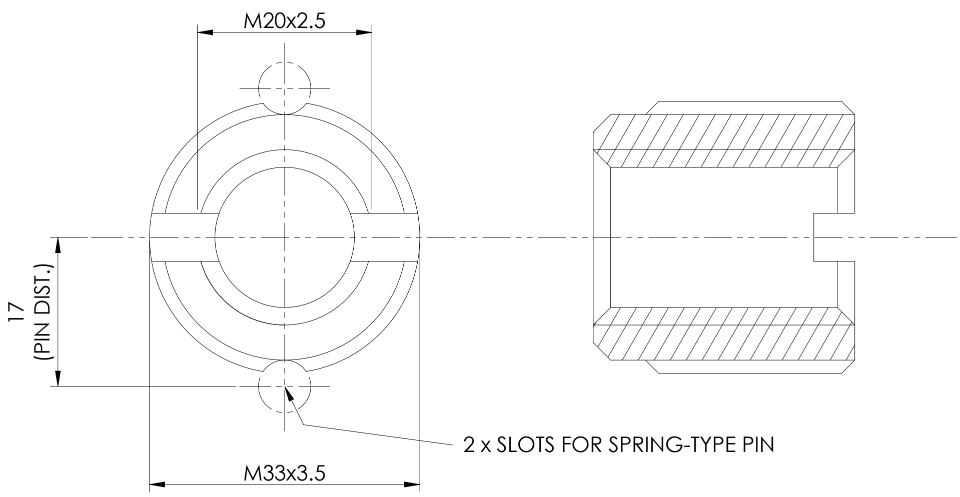


Figure 7.8 : Standard In-Vessel Insert (M20)

Spring-type pins are required to be stainless steel with a single curl construction (Ref. ISO 8752 / DIN 1481). These pins are hollow to enable them to be drilled out remotely if required (Ref. Section 7.11.3).

7.6. Materials

Acceptable fastener materials for RH equipment are:

- Stainless Steel grade A4 to BS EN ISO 3506-1:1998
- Aluminium Bronze grade CA104 to BS EN 12163:1998
- Acceptable fasteners materials for In-vessel equipment are:
- Nimonic 80A to BS 3076:1989
- Inconel 625 to BS 3076:1989
- Aluminium Bronze grade CA104 to BS EN 12163:1998

For in-vessel materials (ie. those which experience vacuum conditions) it is preferable that the two mating halves of the joint should be of dissimilar materials to prevent binding / galling of the threads. Selection of dissimilar material for in-vessel fasteners must take into account relative thermal expansion and material strengths. Where the use of dissimilar materials cannot be avoided components should be copper coated in accordance with ITER QA Manual .

7.7. Captive Fasteners

7.7.1. Pop-up Fasteners (Preferred Method)

It is preferable that all mechanical fasteners be held clear of mating components faces during assembly. The best method of achieving this is the pop-up method. Given here are examples of a range of methods that can be used to provide a captivated pop-up fastener. The desired spring load is from 5 to 15 N.

Having an exposed head (Figures 7.9 & 7.10) is preferable, however, there are circumstances where the head needs to be protected (ie. from the plasma) or where there is no room to use thread captivation. For these situations captivation over the bolt head should be used (Figure 7.11). It must be ensured that the socket head is always accessible through the key access. Ensuring that the head of the bolt is suitably guided is therefore important for this design.

Where practicable all RH fasteners should have parallel axes to simplify the interface and avoid assembly difficulties. Consideration should also be made for the RH tooling to be used – the space envelope that this will occupy needs to be taken into account at the design stage.

Pop-up fasteners can be designed with the bolt nose under flush (see figure 7.9) or protruding from the component (see figure 7.13) to aid hole alignment during assembly.

> **Note:** Where the threaded captivation method is used (Figures 7.9 & 7.10) the female thread form can be reduced to a half full thread depth to accommodate potential misalignment.

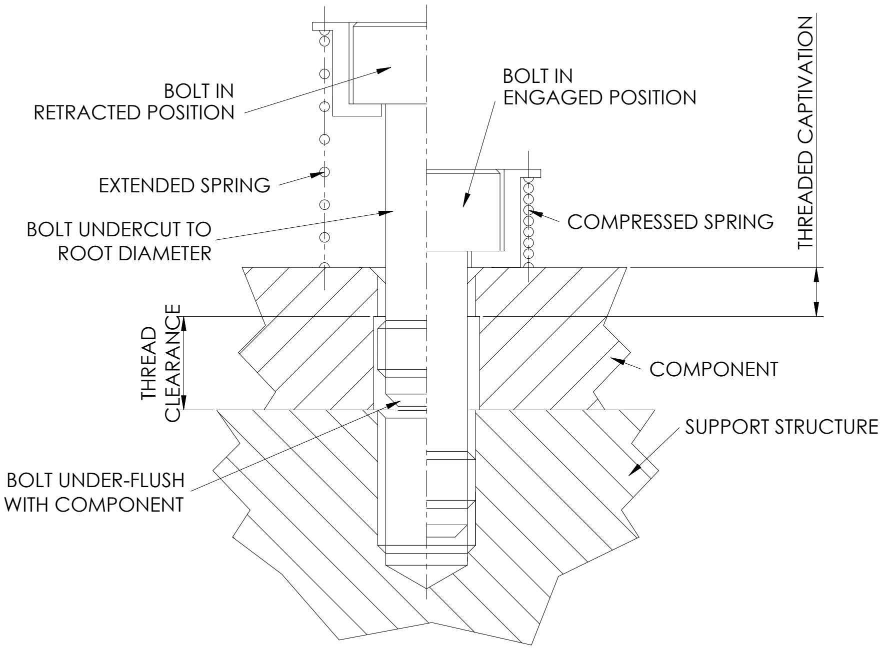
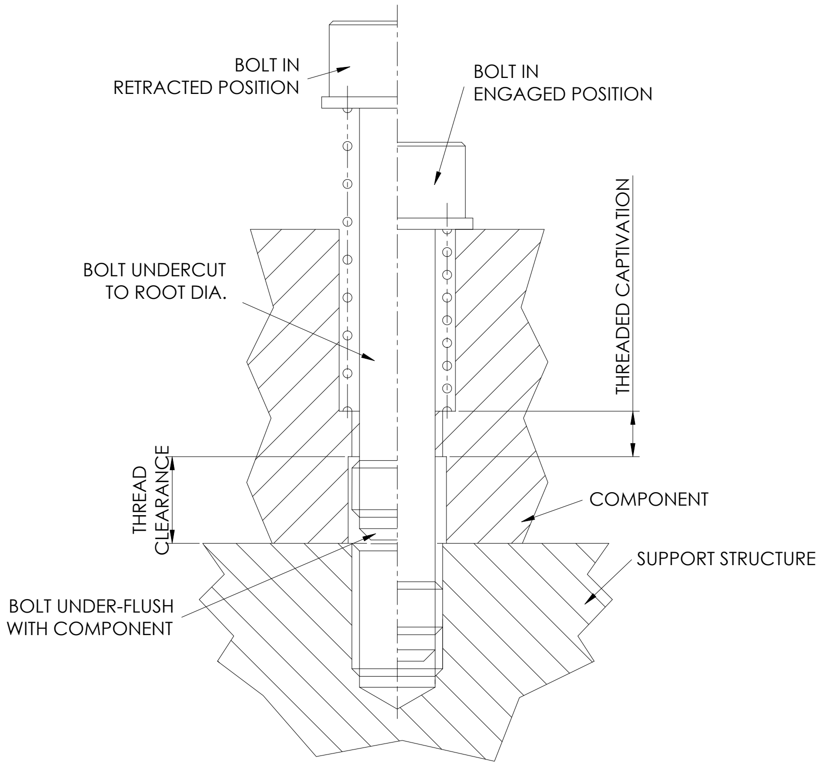


Figure 7.9 : Thread Captivation – Spring not Flush



Note: This design is only suitable for light bolt loads

Figure 7.10 : Thread Captivation – Spring Flush

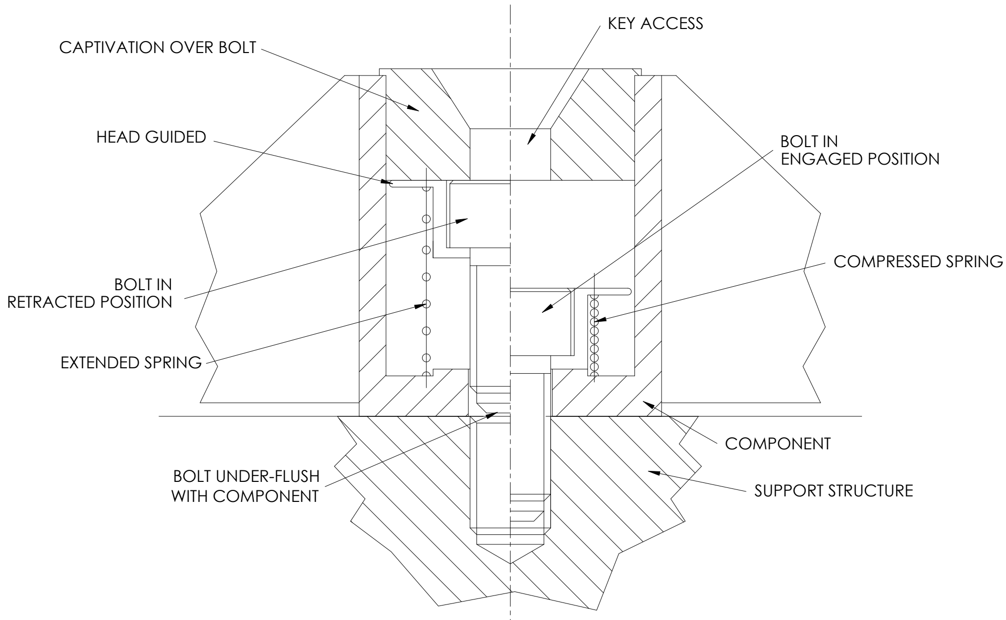


Figure 7.11 : Captivation Over Bolt Head

7.7.2. Non Pop-up Fasteners (2nd Preference)

The design principles applied to pop-up captivated bolts can also be applied to non pop-up fasteners (figure 7.12). Such captive fasteners can only be used where the protruding bolt does not inhibit assembly. For this reason it is essential that all RH fasteners are on a parallel axis to simplify the assembly process.

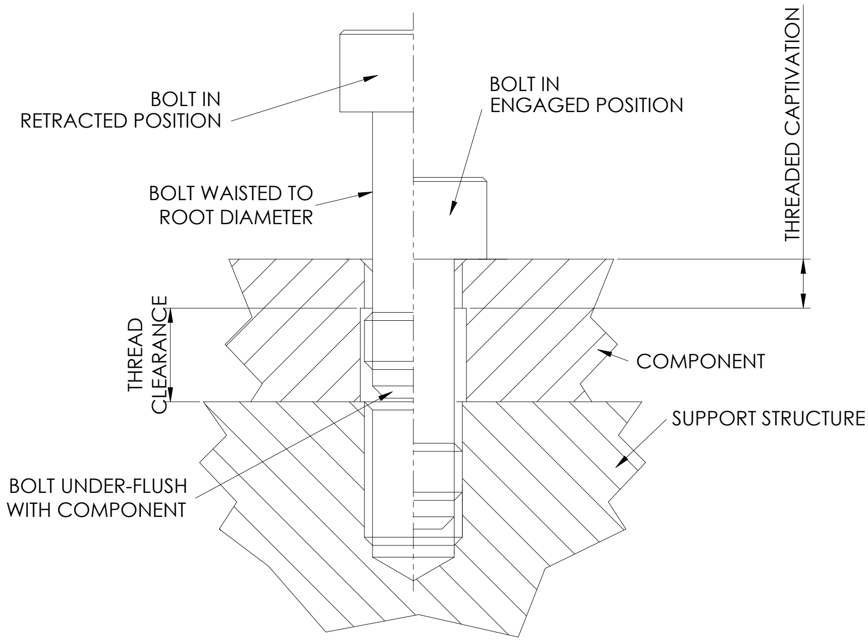


Figure 7.12 : Non Pop-up Bolt

In some circumstances the nose of the bolt can be designed to remain proud of the component and act as a dowel in aligning the component being installed (figure 7.13). The use of a protruding nose for this purpose is valid for all bolt designs – pop-up & non pop-up. One method of locking the captive fasteners is by providing a deformable disc spring or safety washer under the head of the bolt to provide an axial load that resists loosening (figure 7.13).

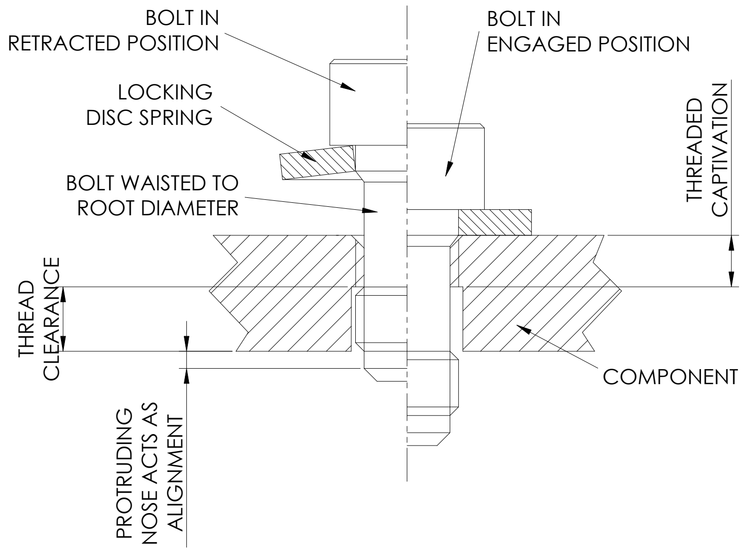


Figure 7.13 : Non Pop-up Bolt (Locking Washer & Protruding Nose)

7.8. Captive Nut (Non-Preferred Method)

The design principles applied to bolt captivation can be applied to captivated nuts used in conjunction with studs (Figures 7.14 & 7.15). Studs that mate with captive nuts should include the standard nose design (Ref. 7.4.1).

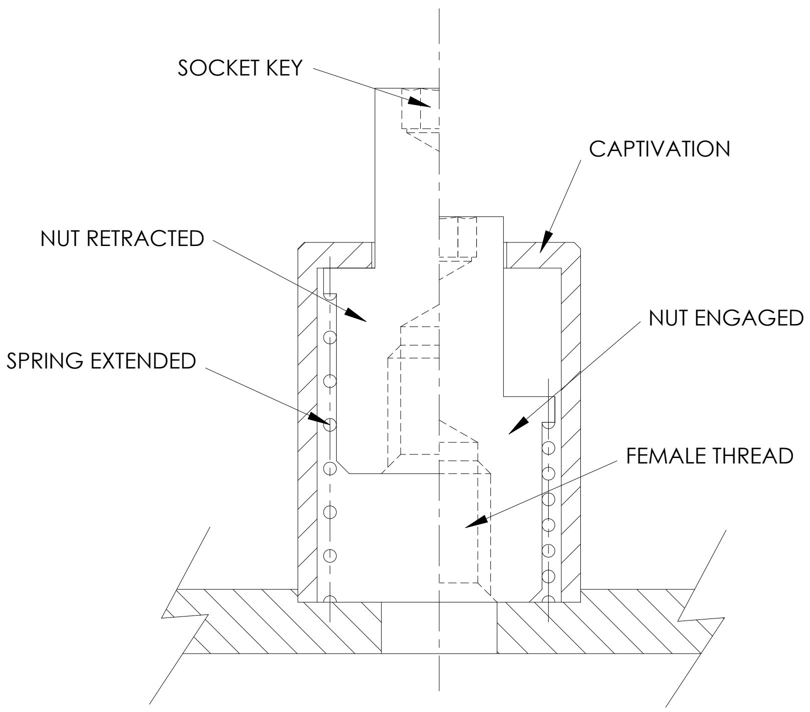


Figure 7.14 : Captive Nut

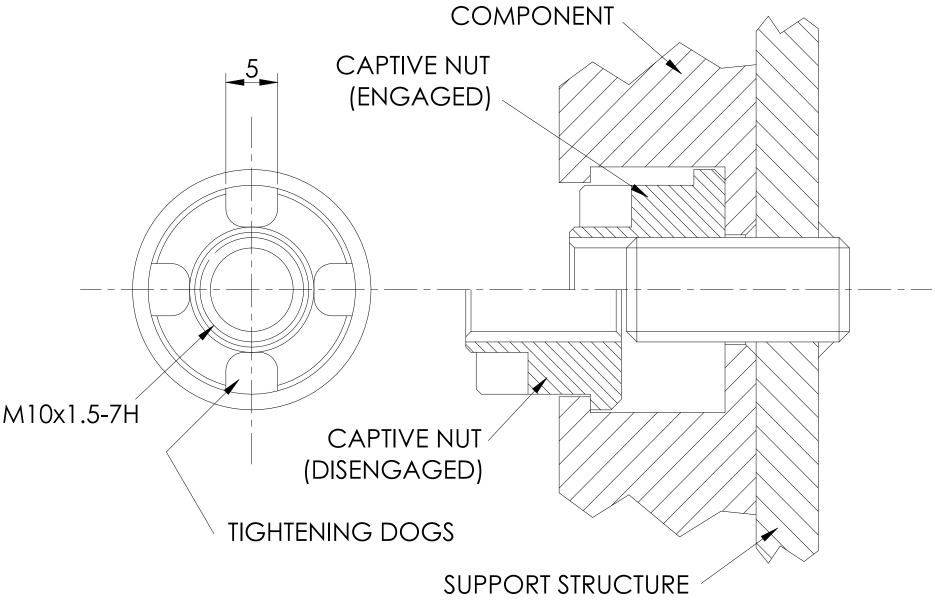


Figure 7.15 : Captive Nut

7.9. Conformity

All RH fasteners must be supplied with 100% inspection and a corresponding Certificate of Conformity from the supplier.

All RH equipment fasteners (both bolts and nuts) must be supplied clean in accordance with the ITER QA procedure.

All in-vessel RH fasteners (both bolts and nuts) must be cleaned in accordance with the ITER QA procedure and the ITER Vacuum Handbook. This is also required for spare fasteners prior to packaging and delivery to ITER. Care must be taken to ensure that fasteners pre-conditioned in this way are not contaminated by manual handling before use at ITER.

All RH fastener assemblies must undergo a trial assembly prior to use in-vessel to demonstrate suitability for in-vessel use.

7.10. Joint Tightening

7.10.1. Torque Tightening

Tightening torques for remote handling bolts are limited to those in Table 7.6. These tightening torque limits allow for the potential need for twice the tightening torque to loosen the fastener. For larger bolt sizes, seek advice from the ITER RH section

	M8	M10	M12	M16	M20	Units
Torque	18	37	60	160	300	Nm

Table 7.6 : Tightening Torques

Detailed instructions regarding torque tightening specific to the equipment being installed (eg. tightening sequence) must be provided to RH operational staff by an appropriate method / procedure.

7.10.2. RH Tooling

A range of Remote Handling tooling has already been developed and successfully deployed over many years at JET for joint assembly and torque tightening. The following sections give examples of this tooling as a reference guide to ITER component designers.

Throughout the design process consideration must be made as to what tooling is to be used and what the physical constraints there are for using it (eg. see figure 7.16). A configuration check must always be made to ensure the task can be carried out remotely using the available RH tooling and equipment (e.g. manipulator).

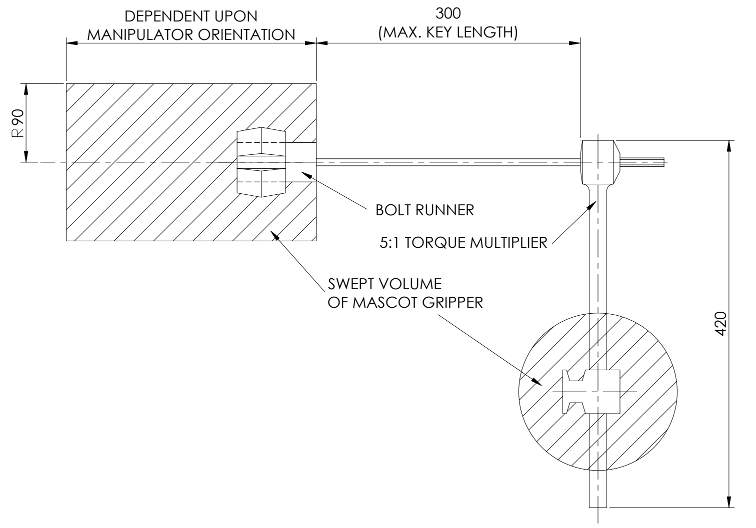


Figure 7.16 : Example of Tooling Space Envelope

7.10.2.1. Bolt Runner

The body of the driver (see figure 7.17) incorporates two manipulator gripper positions that are profiled to match the manipulator fingers. One grip position actuates the tightening clutch mechanism and the other (at 90 degrees) the un-tightening clutch. The tool is therefore driven by a simple backward and forward rotation of the manipulator wrist in the required direction. Tool end fittings are interchangeable and the tool also incorporates a standard bayonet fitting for secure tool storage. This type of tool can typically be used for running up bolts to a torque of 10Nm for standard use and up to 15Nm for short-term use.

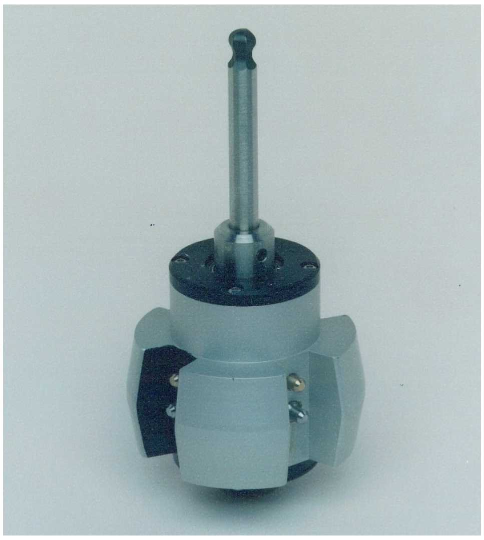


Figure 7.17 : Bolt Runner

7.10.2.2. Torque Multiplier (2:1)

The 2:1 Torque Multiplier used at JET (Figure 7.18) comprises an anodised aluminium Body housing a 2:1 reduction gearbox. The use of an intermediate idler gear allows the output drive direction to be the same as the input drive direction. The input drive is through coaxial 8mm A/F hex sockets, located on both faces of the body, while the output is via a straight through 13mm female hex drive. The output drive can be configured with a number of driver types. A Manipulator Grip is integral with the Body and located at the opposite end to the Gearbox. This tool can be used to achieve an output torque within the range of 10 – 30 Nm.

Figure 7.18 : Torque Multiplier (2:1)

7.10.2.3. Torque Multiplier (5:1)

The 5:1 Torque Multiplier used at JET (Figure 7.19) comprises a planetary-geared head that, for remote handling operations, is fitted to a Torque Wrench Handle with an integral switch. The output drive can be configured with a number of output drives. Fastened to the handle is a Manipulator Gripper Block that incorporates an array of 3 Off – LED's, these illuminating when the set torque is achieved. A Hook is fitted to the bridge piece that secures the gripper block, this provides a point from which the tool can be suspended within the vessel. This tool can be used to achieve an output torque within the range of 25 – 70 Nm.

Figure 7.19 : Torque Multiplier (5:1)

7.10.2.4. Hydraulic Torque Tool

A Hydraulic Torque Wrench used at JET comprises a proprietary "Hi-Force TWH2" Hydraulic Wrench modified for Remote Handling usage (Figure 7.20). The tools drive unit consists of a 24 A/F Hex thro' Socket within which the Output Drive Key locates. Side Plates, with interfaces for locating various reaction features, are fastened on opposing sides of the tool. The available reaction features for this tool are:

- Bi-Hex Socket Key (19mm A/F & 24mm A/F) – Figure 7.23
- Male Dovetail – Figure 7.21
- Female Dovetail– Figure 7.22

Hydraulic services are via 2 metre Supply and Reset lines having straight or 90° connectors and Pipe Restraints, dependant on task. Handling is by a single Manipulator Gripper Block of which there are two variants with straight or cross grip, and capable of being fitted on either face of the tool dependent on task. The hydraulic medium used with this tool is de-mineralised water. This tool can be used to achieve an output torque within the range of 50 – 600 Nm.

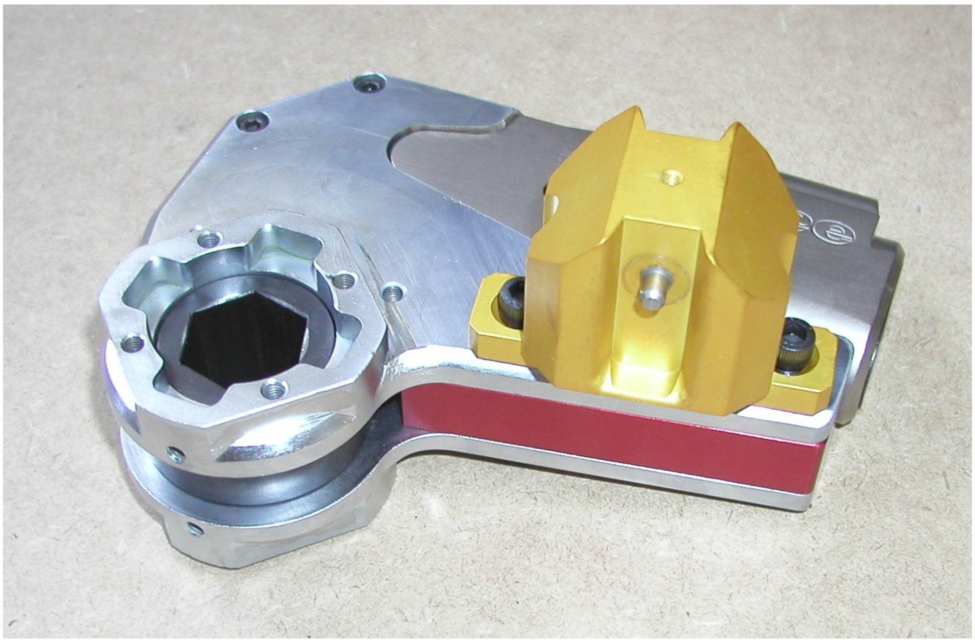


Figure 7.20 : Hydraulic Torque Tool

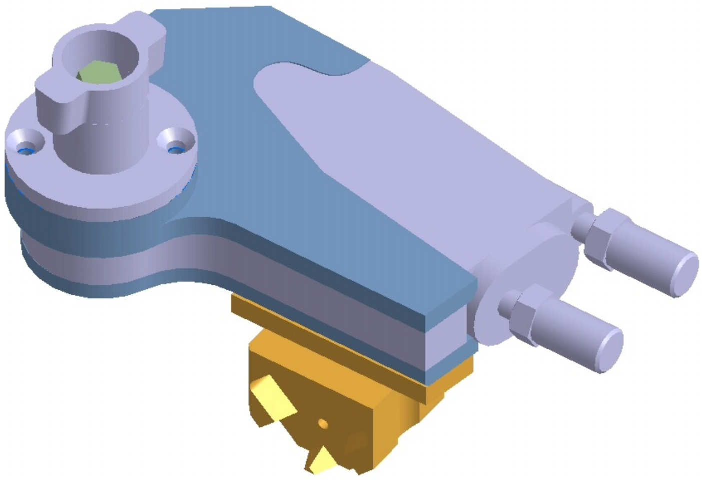


Figure 7.21 : Tool with male Dove Tail Reaction Feature

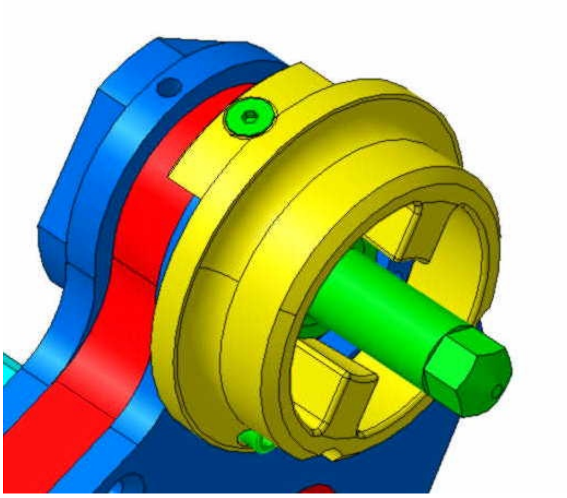


Figure 7.22 : Female Dovetail Reaction & Key

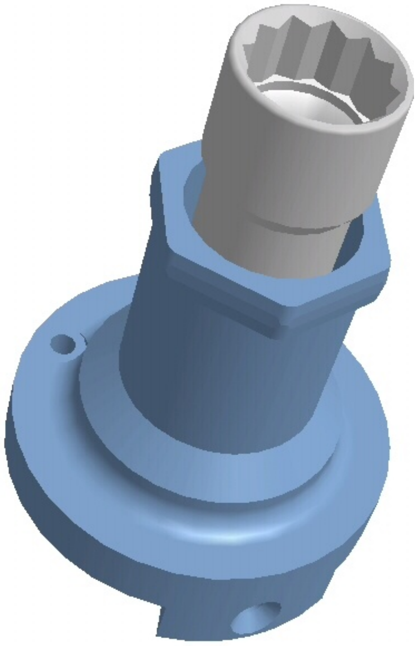


Figure 7.23 : Bi-Hex Socket & Reaction Feature

7.11. Recovery Techniques

7.11.1. General

During the design of a RH fastener the method of recovery from seizure must be considered and this method incorporated into the final design. Seizure is defined as when the torque required to loosen the bolt is greater than that available with the RH tooling.

7.11.2. Drill Out

Where practicable a pilot hole (~ Dia. 2mm) should be provided through the centre of the RH bolt (for M10 – M20 bolts). This will enable either the bolt head or the whole fastener to be drilled out in the case of seizure.

7.11.3. Replacement of Standard In-Vessel Inserts

In the event that an in-vessel insert (Figure 7.24) is damaged or cannot be used it needs to be replaced using remote techniques. This procedure is as follows:

- Clear the area in the location of the insert to be removed.
- Drill out the hollow tension pin that retains the insert rotating using an RH-adapted pistol drill.
- Insert the insert removal tool, using the integral slide hammer, into the female thread.
- Unscrew the removal tool bringing with it the insert.

- Clear the area of debris and visually check the condition of the female thread in the support structure – repair thread as necessary.
- Insert new insert into support structure. Wind in the insert replacement tool (Figure 7.25) until it comes in contact with the surface of the support structure.
- Unscrew the insert from the support structure (< half a turn) until the closest slot in the insert aligns with the slot in the support structure.
- Insert new tension pin flush with the support structure by means of jacking screw on the insert tool.

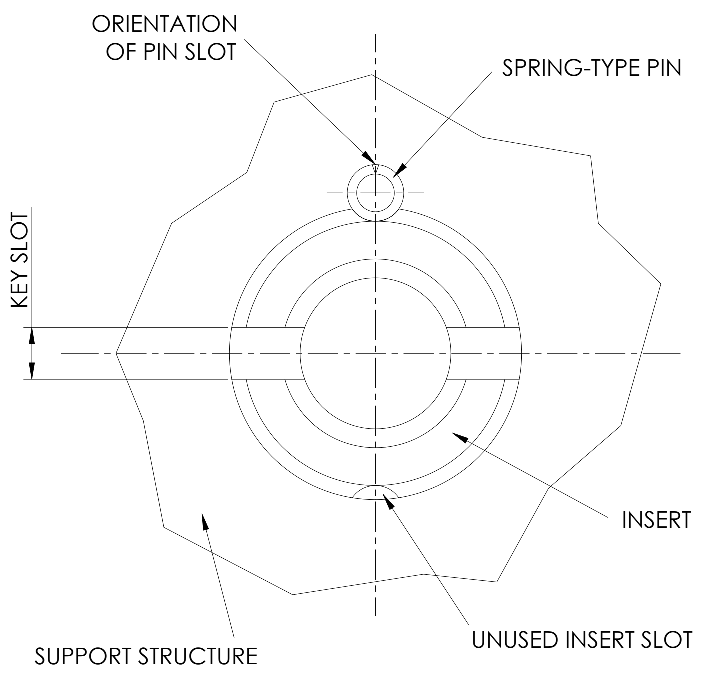


Figure 7.24 : In-Vessel Insert Replacement (Plan View)

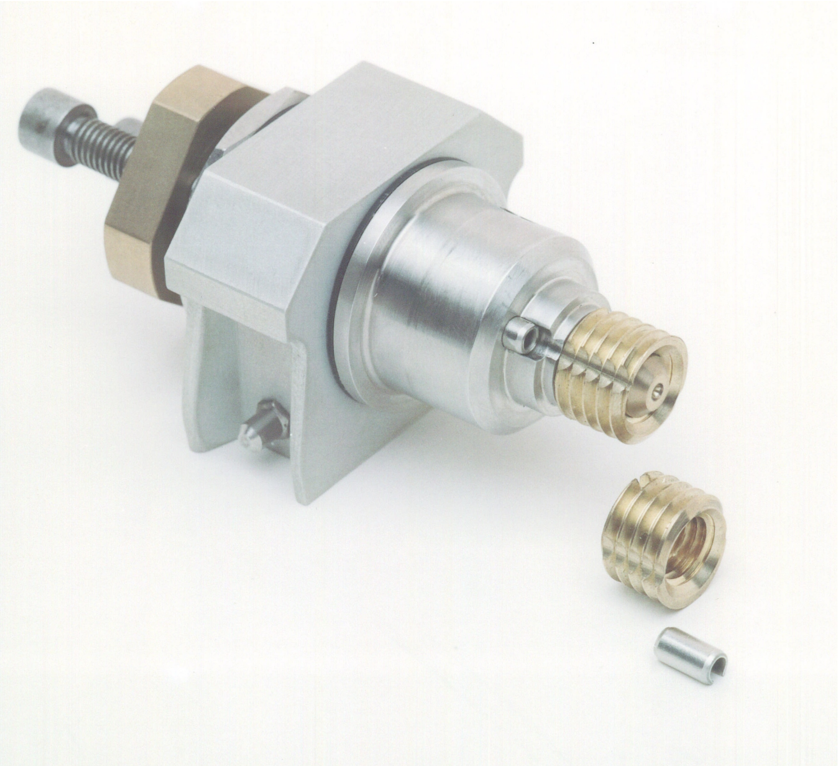


Figure 7.25 : Insert Replacement Tool

8. ITER remote handling standards for – Lifting and Handling features

New chapter to be included in later Issue of the Code of Practise.

9. Remote Handling Welded Joint Principles

9.1. Welding Process

The method of joining pipes for high vacuum applications is pulsed Tungsten Inert Gas (TIG) welding. This process can be successfully automated for remote handling applications as long as certain conditions are met. The greatest success is for autogenous welds – those without additional filler metal.

9.2. Butt Welded Pipe Joint

Generally, for butt jointed pipes the following conditions must be achieved:-

i. The pipes must butt together without gaps.
ii. The pipes must be coaxial.
iii. The pipe ends must be of the same size.
iv. The pipe ends must be circular.
v. The pipe wall thickness must be constant.
vi. The pipe ends must be clean – free from machining fluids and other surface deposits.
vii. The welding electrode must be aligned with the joint.
viii. The welding electrode arc gap must be controlled.
ix. The material composition must be the same as for the weld qualification.
x. The backside of the weld must be purged (but not pressurised) with inert gas (Argon).
xi. The weld earth must be sensibly close to the weld location (≈1m).
xii. If filler wire is added, it must be correctly positioned with respect to the joint and weld arc.

These parameters will have a small tolerance, but the objective should be perfection. In essence, good preparation will result in consistent weld quality. The tolerances that can be accommodated will vary depending on the dimensions and the material composition. In order to qualify a weld, it is necessary to perform trials to determine the tolerance of the weld to combinations of adverse parameters.

Typically, the pipe end flatness needs to be within 0.05mm which will leave a maximum gap of 0.1mm when two ends are fitted for welding. However, it is recommended that an insert ring is used (figure 9.2) and this type of joint will tolerate a maximum joint gap of 0.25mm.

When performing the remote welding of a joint it is essential to know that all parameters are within their tolerance bands. Hence, dimensional inspection and control is essential prior to assembly and a suite of remote inspection tools is required to ensure optimum fit-up of the joint. Only when the joint is demonstrated to conform to an acceptable standard can the operator have sufficient confidence to proceed to strike the welding arc.

For any remote handling joint we can assume that one half remains attached to the vacuum vessel or plant whilst the other half is replaced or refurbished (in the hot cell). It has to be recognised that for any welded joint, the operation to cut it for disassembly will result in a loss of material – usually around 6mm* of axial pipe length. A strategy to deal with this loss for reassembly must be adopted. There are 2 options. One option is to provide axial compliance in the pipe by the use of bellows. This means that the remote tooling has to provide an axial force to close the new joint. There is then a residual force in the reassembled pipe joint. The bellows design must have flexibility to accommodate successive cut and weld operations. It must have a sufficiently low spring rate so that the assembly forces remain manageable for the RH tooling and for the residual strain in the bellows during operations.

The other option is to increase the length of the pipe on the replacement component to make up the material lost during the cutting operation. An important factor with this approach is that the position of the joint moves along the pipe with successive replacement operations. Hence, the access envelope has to be correspondingly larger. There is still need for sufficient compliance in the pipework to enable the joint to be aligned.

* Note: The lost material includes not only the width of the machining tool bit but also the heat affected zone of the weld. The heat affected zone is the region of the pipe where there has been grain growth during the weld process. If this is incorporated in the re-welded joint then the grain size can grow further to unacceptable levels. The metallurgical properties of the pipe material will change and it could leak along the grain boundaries if the grains are comparable in size to the joint wall thickness.

The remote maintenance of pipe joints will require the use of tools for some or all of the following processes:

i. Pipe End preparation – deburring, rounding, machining of joint profile features and measuring.
ii. Pipe alignment – tooling to align the joint to the precision requirements of automated welding.
iii. Inspection Equipment – to confirm that the joint is aligned
iv. Joint Purging – inert gas shield.
v. Welding – autogenous and wire filled TIG
vi. Weld Quality Inspection – Visual, X-ray, ultrasonic, He leak test
vii. Cutting – including joint strain relief

To ensure that a pipe joint can be maintained remotely it is necessary for the design to comply with the following requirements:

i. Provide interface features on the pipework for the remote handling equipment.
ii. Provide adequate compliance to allow the pipe ends to be aligned.

iii. Produce components with tolerances appropriate for reliable mechanised welding.
iv. Provide an adequate space envelope for the remote tooling access.
v. Provide adequate camera viewing lines of sight to perform the operation.

Before beginning the detailed joint design, it is essential to decide a realistic requirement for the number of times the joint will be opened. This will determine the amount of length of sacrificial material that must be provided. It is important to remember that a joint may require to be welded for test purposes in the hotcell or that the weld might fail and hence require it to be cut out and remade. These occurrences will use up the "remote handling lives".

9.2.1. Standardisation

As far as possible it is advisable to standardise on pipe sizes and associated tooling across the ITER project. However, it is inevitable that there will be special requirements and constraints that force the development of novel tooling solutions. This catalogue shows the approach that has been successful at JET and provides a basis for the development of tooling for ITER. The Table below shows the pipe sizes that have already been selected for ITER and where JET cutting and welding tooling of a comparable size could be used or adapted.

RH Pipe Joint Location	Outside Diameter	Wall Thickness	Nearest JET Tooling
HNB Source	20 mm	2.5 mm	21-27 mm
Duct Scraper	33.4 mm*	1.65 mm	48 mm
HNB Source	40 mm	2.5 mm	48 mm
Divertor Water Pipes	73 mm	3.0 mm	70 mm
HNB Neutraliser	100 mm*	3.0 mm	101.6 mm
HNB Residual Ion Dump	200 mm*	3.0 mm	101.6 mm
HNB Calorimeter	200 mm*	3.0 mm	101.6 mm

* sizes are subject to ITER final design confirmation

Table 9.1 : Standard Pipe Sizes

Some of the remote handling tools developed for JET are shown below as examples. It is anticipated that their design and technology can be readily adapted for the specific needs of ITER.

9.2.2.

Joint Alignment and Geometry Inspection Methods

9.2.2.1. Visual

Viewing by camera is the basic inspection method used for all remote tasks. For weld joint inspection, it is necessary to perform workshop trials with representative joint arrangements so that the remote camera views can be correctly interpreted by comparing them with the trial views. The trials need to examine the effects of the lighting direction and level so that, for instance, a gap in a joint can be differentiated from a step or a small chamfer.

The use of cameras in the ITER machine will be limited by the high radiation levels. It will be necessary to develop alternative radiation hard techniques for many inspection tasks.

9.2.2.2. Tactile

It is envisaged that tactile sensors can be used to detect the quality of fit of a joint and the completed weld profile. A stylus with a positional sensor can be used to trace the joint surface and the output compared with the allowable tolerance. This type of tool will need to be developed to suit the particular ITER applications.

A tool was developed for JET to measure the mean diameter of an oval or non-round pipe. This tool employed a resolver driven by a roller that contacted the pipe bore and orbited exactly one revolution of the pipe. From the resulting circumferential measurement the mean bore diameter can be calculated. This enabled the installed component to be precisely matched to the pipe bore.

9.2.2.3. Laser

Laser scanning for metrology is a useful technique where accuracy of the measurement of complex profiles is required. As it is a camera based system it will not be tolerant to high radiation levels.

9.2.3. Weld Quality Inspection Methods

9.2.3.1. Helium leak testing

This is the principal method of determining the quality of welded joints for ultra-high vacuum applications. The pipe bore is evacuated through a mass spectrometer and the helium is gently puffed around the joint. The concentration of helium reaching the detector indicates the level of leak through the joint.
This technique can be readily adapted for remote operation so long as the mass spectrometer can be located away from the high radiation area. Helium can be dispensed from an orbiting tool similar to the orbital welding tool.

9.2.3.2. Eddy current

Location of lack of fusion can be determined by using pan-cake type of eddy current probe either from outer surface or through the pipe bore. A calibration block made of similar material, shape and dimensions as tube, having circular notches on inner and outer diameter shall be used for calibrating the eddy current probe response. In case there is no approach through the bore, encircling type of eddy current probe (bobbin coil) can be used for the inspection of the weld joint.

9.2.4. Generic types of Remote Handling Welded Pipe Joints

It is required that all pipe welds for UHV applications use the process of automated TIG welding (also known as GTAW). This is a well developed and reliable technique that is easy to deploy remotely and is capable of providing the necessary weld quality for ultra high vacuum applications. The weld arc is between a non-consumable tungsten electrode and the pipe. The weld power, which is generally pulsed to better control the weld pool shape and size, is provided by a programmable welding source. The parameters for the weld are established and qualified by performing extensive workshop weld development trials.

9.2.5. Orbital Butt Welded Joint

The most common form of welded pipe joint is the butt weld. It is normally required that the weld fully penetrates the wall thickness to provide a smooth crevice free joint. The preference is to fuse the joint without additional filler metal (autogenous welding). However, welds with wall thicknesses above 3mm will require filler metal in the form of wire fed directly into the weld pool. Because the weld is fully penetrating, it is necessary to prevent the inner surface oxidising by purging the pipe bore with inert Argon gas.

The joint must be in a straight run of pipe with adequate space for tooling. The tooling access is from the outside of the pipe such that the weld tool has to orbit around the joint – hence the name orbital welding.

The joint alignment tooling must provide sufficient rigidity to hold the pipe ends together so they do not move before or during welding. Also it must not obscure the inspection of the joint fit-up quality and must provide adequate space for the placement of the weld tool. It is required to incorporate features on the pipe ends to locate and react the loads imparted by the tooling. These features are shown in figure 9.1. The fixed end of the pipe has a cutting reaction feature that is used to support any compressive load there may be in the joint. This prevents the two halves from collapsing onto the tool bit as it breaks through the pipe wall. The tooling datum location feature on the removable end of the pipe has a vertical face that is exactly 30mm from the joint line. The feature also includes a chamfered surface that is used to clamp the welding tool into position against the datum face. It must be noted that before a plant component can be reinstalled, the cut pipe ends must be replaced or refurbished to provide the original configuration with the datum ring is precisely located to the joint line. Where there is direct straight internal access to the joint it is possible to use an alignment tool fitted into the pipe bore. For this internal pipe features are required to locate the tool and the react loads, see figure 9.6.

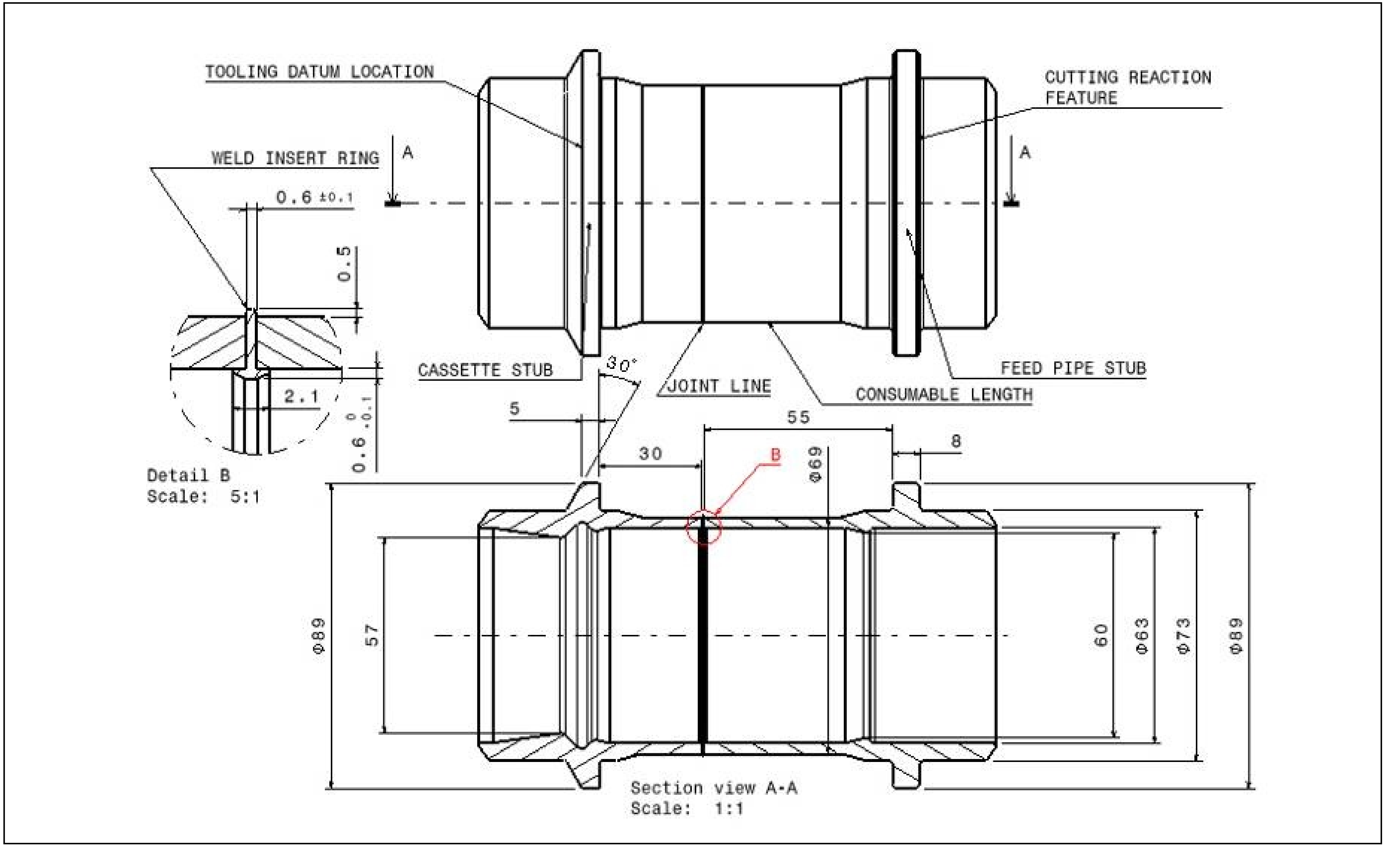


Figure 9.1 : Typical Butt Weld incorporating Remote Handling Features

9.2.6. Pipework Design Guidance

The quality of the pipe alignment is greatly enhanced by the use of a tee section insert ring (see figure 9.2). This ring locates the two pipe ends to be concentric and supports the joint during welding. The head of the T is located on the inside of the joint so that the quality of the joint fit-up can be viewed from the outside. The benefit for the alignment tooling is that once the ring is engaged, only the axial joint closure load has to be applied. The ring becomes fully fused in the weld and provides reinforcement to the joint. It can also be made of a material that improves the weld metallurgy. It is recommended that an insert ring is used for all butt welds. This joint can be made in any orientation of the pipe (i.e. horizontal or vertical). On the JET project where access was available outside of the pipe to view the joint the same ring was used for both orbital welds and bore welding operations. This inverted T shaped ring allowed the weld to be inspected visually from the outside in both cases.

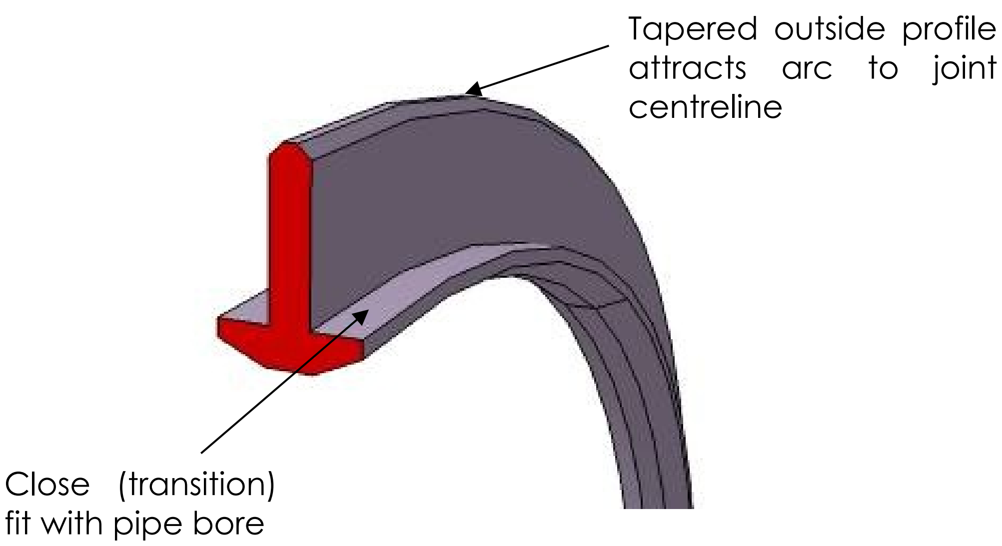


Figure 9.2 : Cross-Section of Weld Insert Ring

The pipe joint must be engineered to have sufficient compliance to allow the joint to be aligned. This compliance is usually provided by bellows sections in the pipe run. To be able to design the bellows it is necessary to known what the maximum alignment error can be. This is usually several millimetres since it is not practical to manufacture “precision” pipework. The errors will be a combination of lateral, axial and angular displacements. Designing bellows with sufficient flexibility is very demanding, especially if it is necessary to use thick wall or multi wall bellows because of the application duty. The bellows will be required to adopt an “S” shaped double bend to accommodate a parallel offset. The lateral force and the moment required to induce the double bend can be substantial. Figure 9.3 shows how these forces are applied. A length of rigid pipe between two short bellows sections will often be preferable as this limits the maximum angular distortion of each bellows and hence reduces the loads.

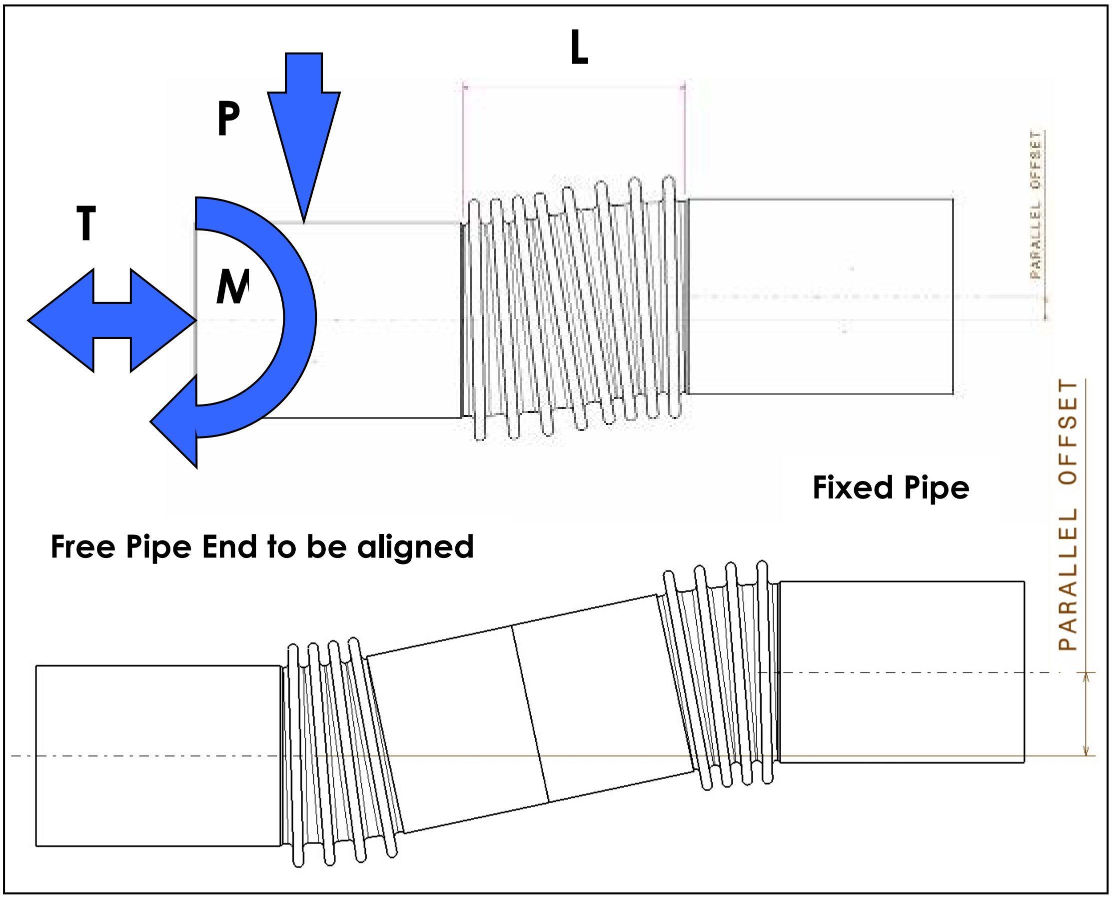


Figure 9.3 : Alignment Forces Applied to Bellows

For pipe wall thickness greater than 3mm it will be necessary to add filler wire to the weld. The joint will require 2 or more orbital weld passes with the first pass being an autogenous butt weld with an insert ring as discussed. The subsequent passes will add the filler. For this joint the ends of both pipes must be prepared with a J profile. This ensures that there is adequate tool access for the root pass and that the filler has a U shaped groove to follow in the subsequent passes.

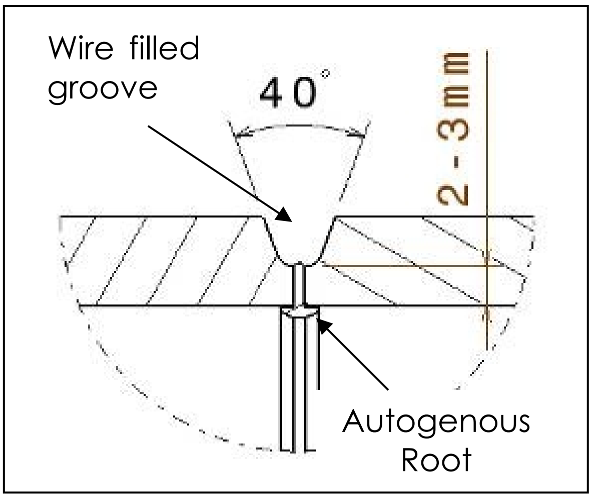


Figure 9.4 : J profile pipe preparation with insert ring

The addition of filler metal greatly increases the degree of difficulty to create an acceptable weld. The filler wire positioning and feed rate has to be precise to prevent it hitting the electrode, fusing to the pipe or melting it in globules that fail to reach the weld pool. The size envelope for the weld tool that is able to add filler wire will be substantially larger than for the autogenous joint. Hence, the addition of filler should be used only when there is no alternative.

Figure 9.5 : Bore Alignment Tool

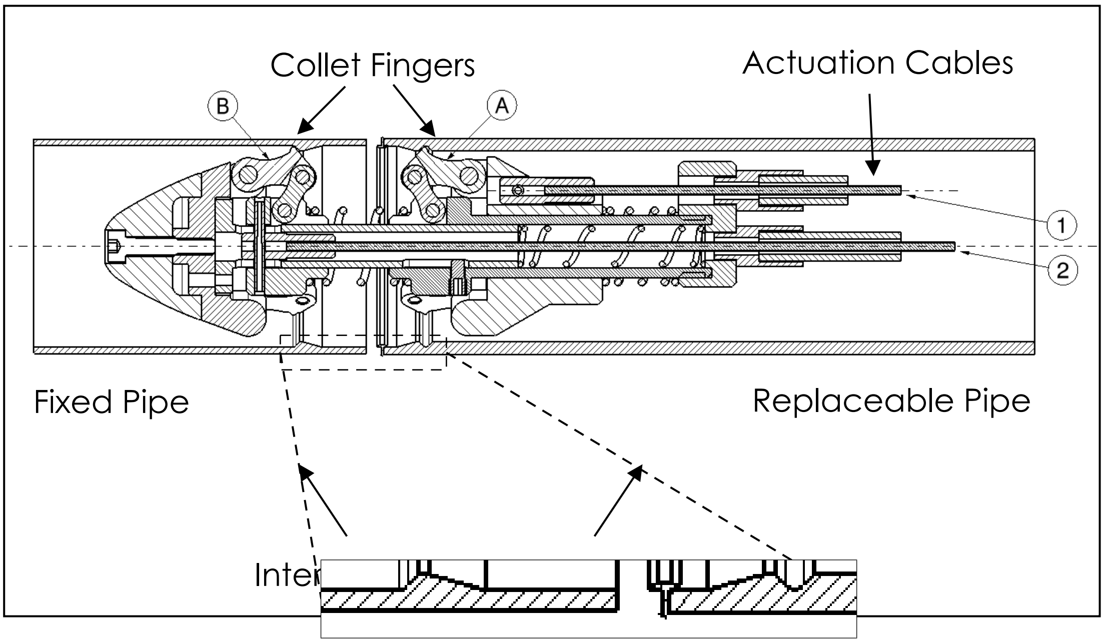


Figure 9.6 : Bore Alignment Tool - Functional Schematic

The collet style alignment tool shown in figure 9.6 is used to align pipes when internal access is available and external access is restricted. The tool requires features to be built into both pipes. An arrangement of three collet fingers locates the tool in the replaceable section of pipe. By pulling on actuation cable 1 (see figure 9.6) the collet fingers (labelled A) locate on the pipe features. This location operation can be performed before the pipe is moved into position. The tool is now axially aligned with the replaceable pipe and can be offered up to the fixed pipe. The specific shape of the nose cap of the tool is used to assist in this process. The nose cap is made from an acetal plastic to prevent damage to the pipes as it passes through them. Once the nose of the tool is inside the fixed pipe the second set of collet fingers (labelled B) can be operated by pulling on actuation cable 2. Once the collets have made contact with the features in the second pipe continued tension on actuation cable 2 will pull the two pipes (now axially aligned) together. The springs in the mechanism are biased in order to ensure that the collet fingers contact the fixed pipe wall and align the two pipes before the tool pulls the pipes together. The tool remains in place during the welding operation, keeping the join between the pipes rigid until they are fused together. The insert ring used in the welding process protects the tool from damage. Once the weld is complete the tension on both cables is removed and the tool is withdrawn through the pipe. Both sets of collet fingers are spring loaded into the closed position to ensure they retract completely and do not impede the motion of the tool through the pipe.

9.2.7.

Typical Assembly Process for Orbital Butt Welded Joint

The assembly sequence of a typical joint can be summarised as follows:

i. Perform inspection of the cut face quality and measurement of ovality and diameter of the fixed pipe end*. This is to establish the requirements for the preparation for assembly. Diameter is difficult to measure directly, especially if ovality is present. A better method is to measure the circumference with a tool with a follower roller and divide the result by Pi.

ii. Perform rounding by expanding the pipe end into a backing ring (which prevents over-expansion). A collet expansion tool is used to take the pipe end to just beyond its yield point. The careful selection of the bore of the backing ring will limit the expansion to the minimum necessary. The diameter must be re-measured after rounding.

iii. The new pipe end and the insert ring are then expanded to match the size of the fixed pipe end. For clean parts, this can be done in a manned facility. Otherwise it must be done in the hotcell. Note that the new pipe end has the datum location features for the joint.

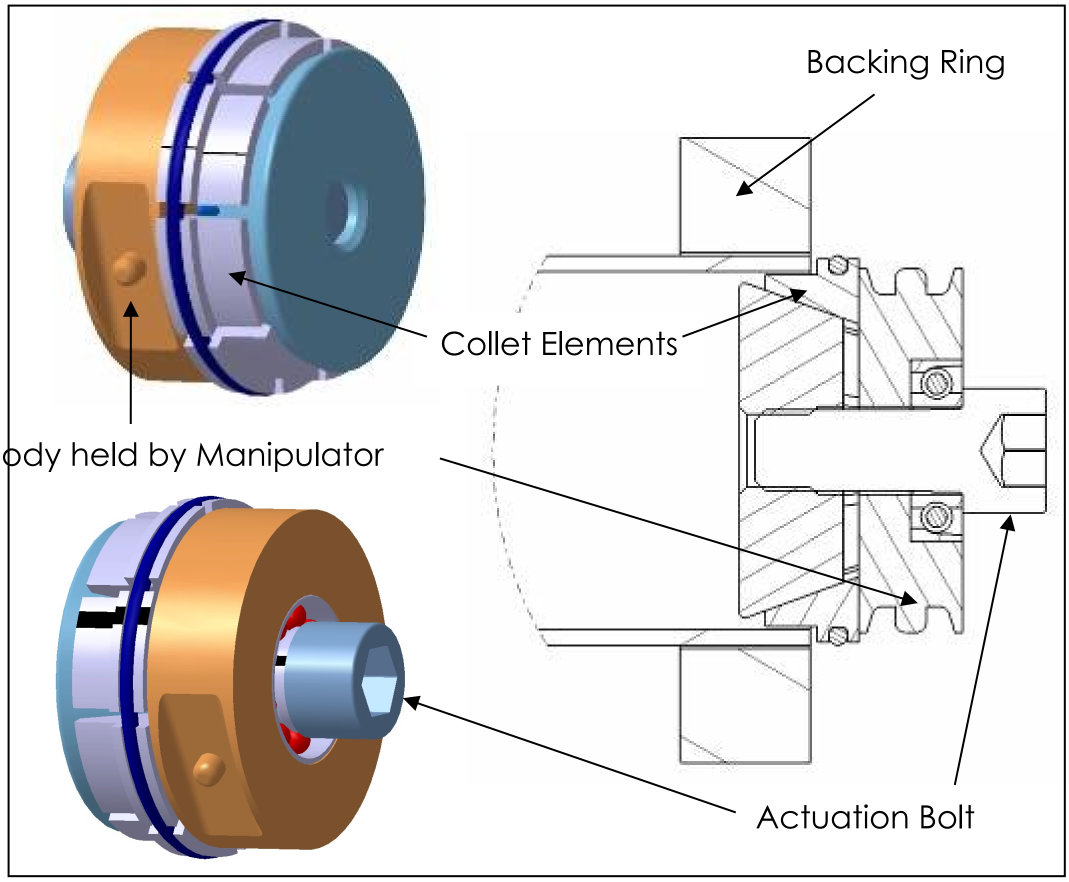


Figure 9.7 : Rounding and Expanding Tool

iv. The Insert ring must be tack welded into the new pipe end to ensure it is secure. As the ring is an interference fit in the pipe, only 3 tiny tacks are required.

v. The prepared ends of the pipes must be fitted with plugs that protect them from accidental damage and contamination. These protection plugs are removed immediately prior to the joint final assembly.

vi. The plant components must be assembled with a sensible clearance between the pipe ends. This will ensure that they do not get damaged during the assembly process and that the plugs can be removed. Pipe retraction tooling may be required to hold the pipe ends apart during assembly. There must be sufficient compliance in the pipework to allow this to be done with reasonable force, say less than 200N.

vii. Fit the pipe joint alignment tool and release the pipe retraction tooling. The alignment tooling may be located inside the pipe bore when feasible; otherwise it will be externally mounted such as the co-axial alignment tool in 9.8.

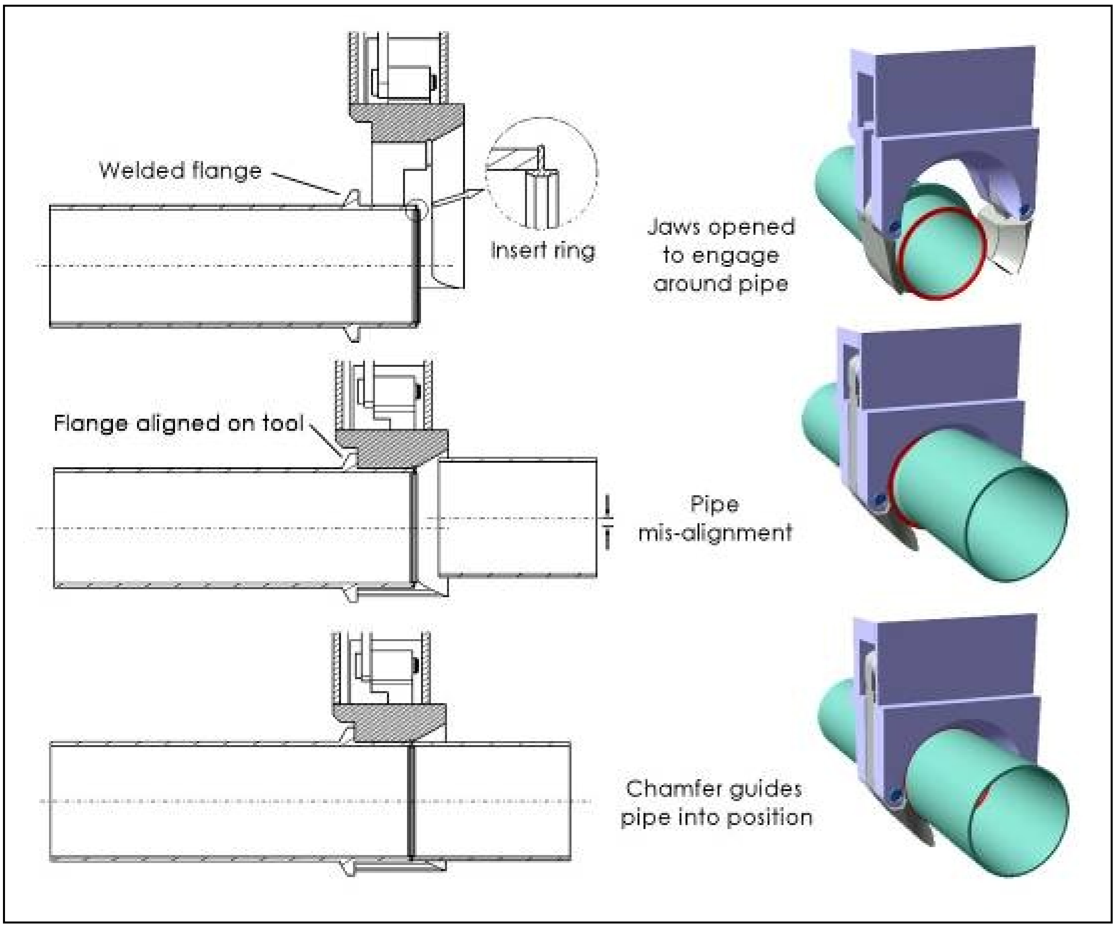


Figure 9.8 : Co-axial Alignment Tool Operation

viii. Make a trial closure of the joint. It will be necessary to use a guide tool to bring the pipe ends into coaxial alignment. This is important so that the insert ring engages correctly and is not damaged.

ix. Inspect the fit-up of the joint. Ensure the ring has engaged and that the butt has closed. The pipework compliance must be such that the joint can fully close around its entire circumference.

x. It may be necessary to re-machine the fixed pipe end so that it can be made to align with the new pipe end. (the new pipe end must not be re-machined because it incorporates the joint datum) The tooling to perform the re-machining must align the pipe ends so that the fixed pipe can be machined parallel to the new pipe end (by referencing the datum location). It is important that the machining does not create a burr on the pipe end as this may prevent the joint closure.

xi. Close and clamp the joint using the appropriate alignment tooling.

xii. Inspect the quality of the fit-up using a close-up inspection camera.

xiii. Purge the pipe bore with Argon inert gas. An oxygen level of less than 0.2% is required. Note that the whole pipe run must be completely free of water (or other contaminants) prior to welding. Ensure that the pipe is not subjected to internal pressure as this can blow a large hole in the weld.

xiv. Fit the weld tool to the joint. Ensure the weld gas is flushed. Perform the weld. Monitor the weld parameters and watch for irregular occurrence. Abort the weld if there is any suspicious event. It is easier to complete a part finished joint than to repair a damaged one.

xv. On completion, remove the weld tool.

xvi. Wire brush the weld clean and inspect visually using a close-up inspection camera.

xvii. Perform NDT such as Radiographic Inspection and Helium leak test.

xviii. Rework if necessary. The joint can be re-melted twice in an attempt to cure a fault such as lack of fusion. After that the joint must be cut out and refurbished from step i here.

* fixed pipe end means the joint half that is not required to be removed from the vessel or the plant.

Figure 9.9 shows some pipe alignment tools produced for a flexible bellows joint of 48mm diameter. They required a 2-armed manipulator for operation. The co-axial alignment tool was used in conjunction with the bellows compression tooling and the joint clamp. The joint clamp tool is designed with an aperture for the welding tool to operate.

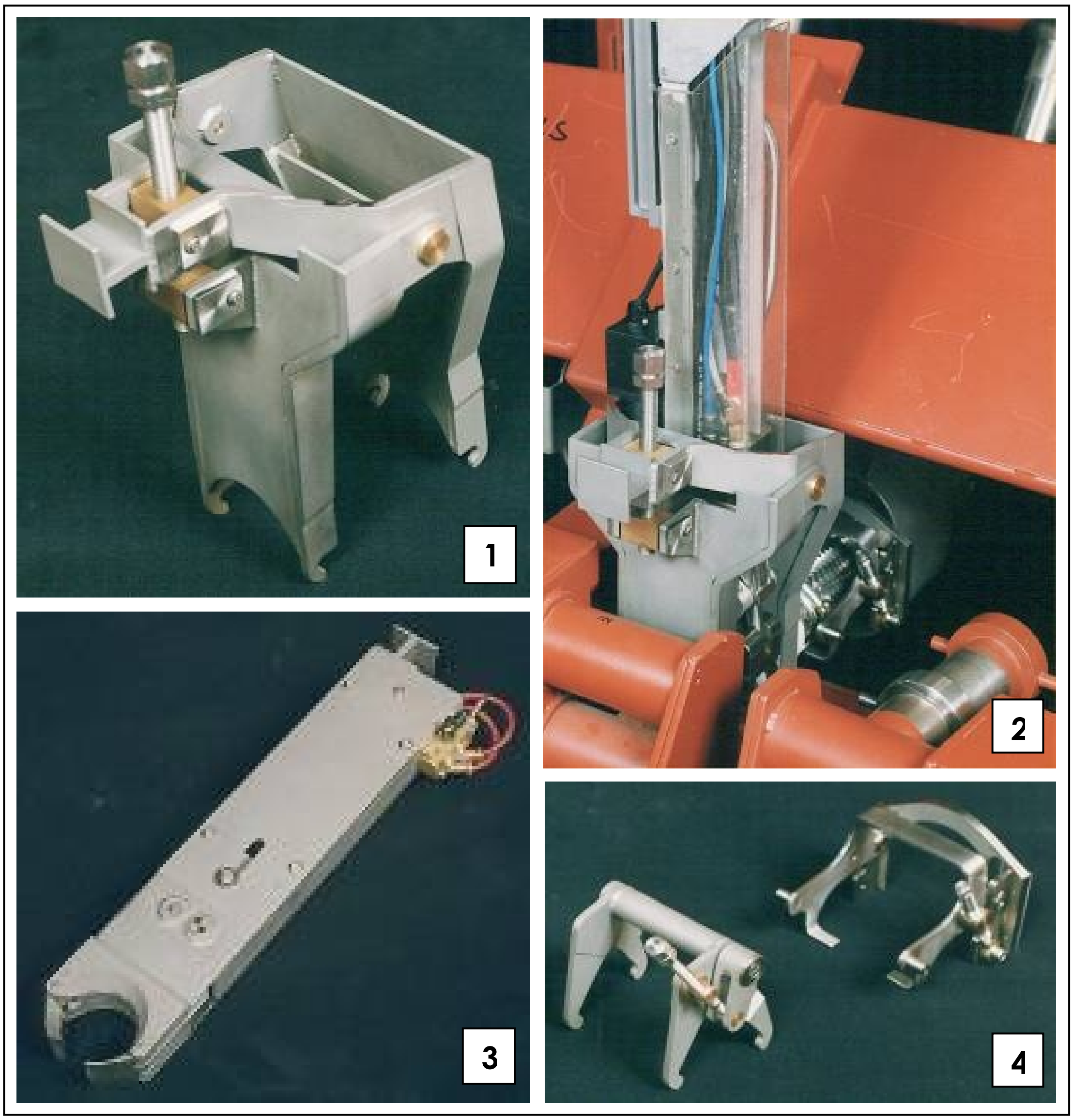


Figure 9.9 : Pipe Joint Alignment Tools

1. Joint Clamp Tool, 2. Weld Tool positioned within Joint Clamp Tool, 3. Co-axial Alignment Tool, 4. Bellows Compression Tooling.

9.2.8. Typical Disassembly Process for Orbital Butt Welded Joint

Cutting of the joint requires an orbital cutter. This is usually a lathe type tool with one or two single point cutting tool bits that orbit the pipe. Advancing the cut can be by simple spring pressure for thin pipes or by an incremental indexing mechanism. The swarf produced is contained and collected by a vacuum extraction unit.

At the point when the tool breaks into the bore, it is impossible to prevent some swarf entering the pipe. This can be controlled by fitting pipe bungs into the bore if there is access. Otherwise it will be necessary to recover the debris from the stub pipe before the joint is reassembled.

The cutting procedure is summarised as follows:-

i. The Pipework must be completely drained and dried.
ii. Fit a joint brace to block any movement of the pipe when it is cut and the residual strain in the joint is released.
iii. If there is access to the pipe bore then a pipe bung can be fitted at the joint to prevent swarf entering the pipe system. Any swarf inside the pipe will be contained close to the cut.
iv. Connect the cutting tool services. Locate and lock the cutting tool on the datum location ring on the pipe. The cut will be made on the fixed pipe side of the joint sufficiently far from the weld to remove the heat affected zone.
v. Connect the vacuum extraction to the cutting tool to remove the cutting debris.
vi. Begin the cutting operation. The tool wear can be judged by monitoring the cutting power. The cutter should be operated for a duration that has been determined by trials to be adequate to cut through.
vii. Remove the Cutting Tool. Inspect the joint to establish that the cut is complete.
viii. Remove the joint brace to relax the pipes. Fit the joint retracting tool to open the joint slightly.
ix. Use a vacuum extraction tool to remove any swarf inside the pipe ends.
x. Remove any bore plugs and fit pipe end protectors*.
xi. The plant can then be disassembled.

*Simple rubber bungs were used as pipe end protectors at JET. A device for ITER will need to be developed.

9.2.9. Orbital Butt Welding Tools - Horseshoe Type

Whilst proprietary Horseshoe type Orbital Butt Welding tools are available, the examples shown here of the remote handling compatible tools developed for JET are bespoke designs to satisfy very restricted access locations. The joint style can be a simple butt or located with an insert ring for total wall thicknesses up to 3mm. The tool design comprises two principal parts: a rotor housing a water cooled TIG weld torch which orbits the pipe and a stator which secures the tool, provides the motive power and manages the power cable loom.

The water cooled TIG torch is housed in a ceramic arm, which controls arc length by means of a follower maintaining contact with the tube. The torch is capable of weld current up to 150 amps. The torch incorporates a gas lens system to provide arc shield gas containment. The water cooled power cable, water return hose and shield gas supply hose are organized as a flat power cable loom which coils around the rotor as it turns. The rotor is driven by a pair of worm gears spaced to provide constant engagement with the horseshoe shaped rotor. The stator is located and locked onto a location ring on the tube by means of a water hydraulic clamp. Remote handling interface handles are incorporated in the chassis of the tool.

The typical space envelope required for orbital welding tools is as follows. Note that additional space allocation must be made for the joint alignment tooling. Where access is possible to the pipe bore, internal alignment tools may be a viable solution. Otherwise, externally mounted alignment bracing will be necessary. It is generally true that the cutting tools require more space and they react bigger loads onto the pipe. As a general rule the radial spacing between pipes and their nearest obstructions should be at least "½D+70mm" for proprietary tools and "½D+25" for bespoke horseshoe type tools. Note that for clamshell type tools shown here a gap of "1D+25" is required. Clear access is required from one side of the pipe for the placement of the tool. For joints of wall thickness greater than 3mm it is likely that additional weld filler metal will be necessary and the weld tool envelope space will be significantly larger:-

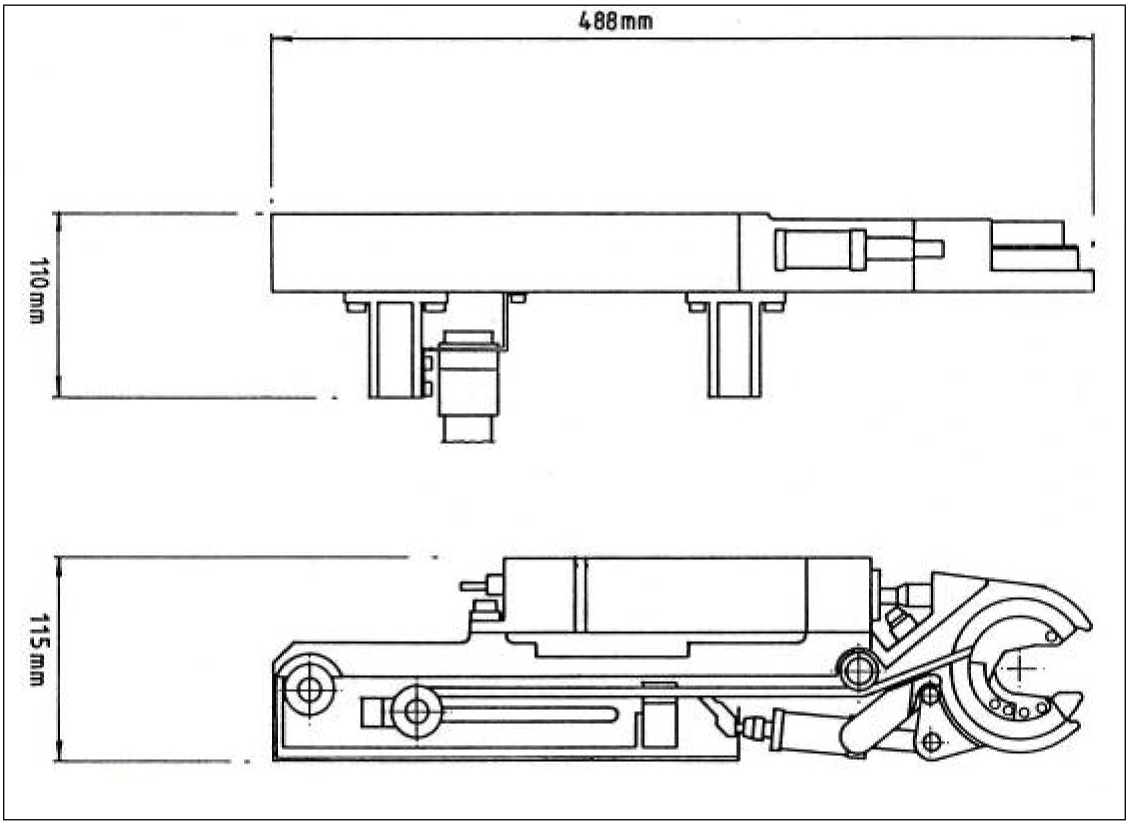


Figure 9.10 : Dia. 21mm to 27mm Orbital Butt Welder

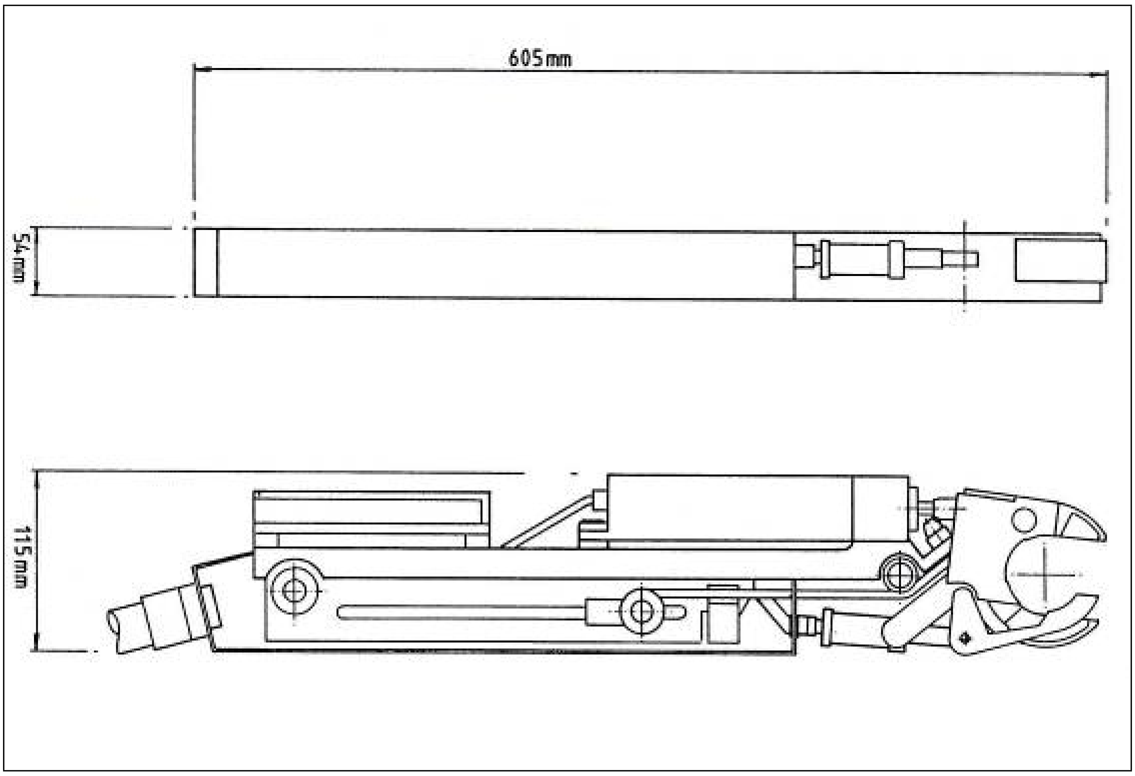


Figure 9.11 : Dia. 50mm Orbital Butt Welder

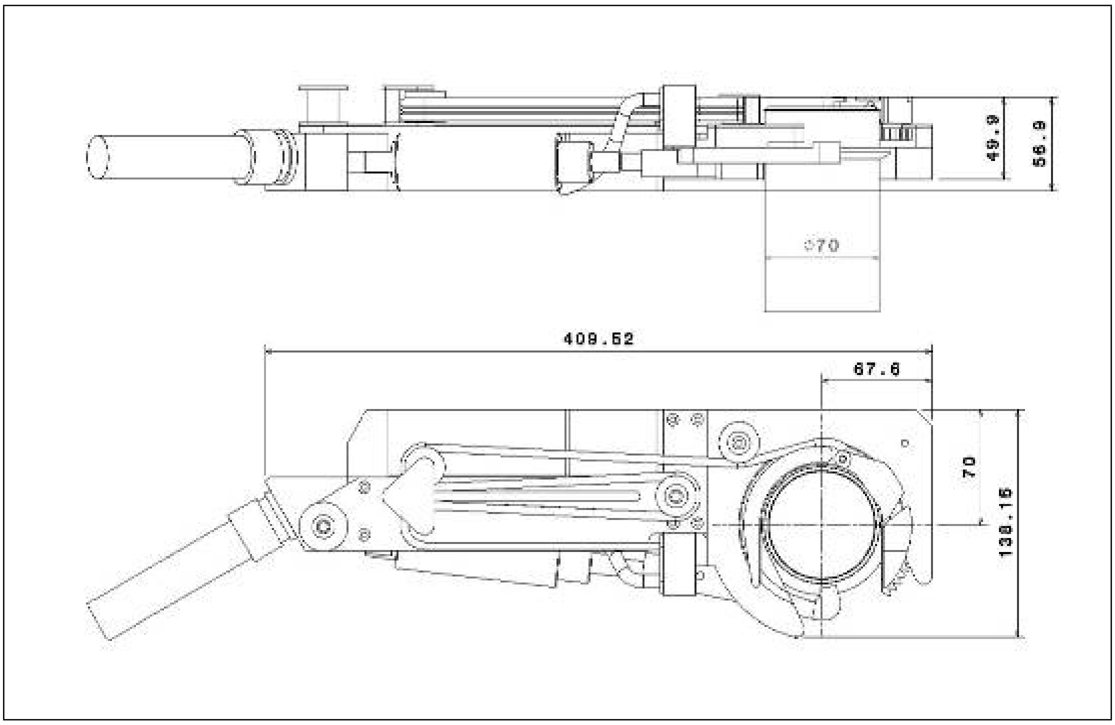


Figure 9.12 : Dia. 70mm Orbital Butt Welder

9.2.10.

Orbital Pipe Cutting Tools

The bespoke remote handling compatible Orbital Pipe Cutting tools developed for JET are orbital lathe type tools. The ones shown below are capable of cutting 48mm and 70mm tube in very restricted access locations. Forces in the tube must be supported during the cutting operation to prevent the cut closing and the tool bit jamming. Vacuum extraction is used to capture and remove the cutting debris from the tool. It is important that all cutting debris is captured and prevented from entering the pipework bore.

The tool design comprises two principal parts: a rotor housing a single point tool bit which orbits the pipe and a stator which secures the tool and provides the motive power. The lathe type parting tool bit is mounted in a hinged carrier arm. A cutting force is applied by a stack of disc springs. The tool carrier arm and actuating springs are mounted on a gear, which orbits the pipe concentrically. The orbital gear and bearings are slotted to enable the tool to be assembled onto the pipe. The swarf generated by the cutting process is chipped and drawn by a vacuum cleaner through the rotor and into an extractor pipe on the chassis.

In order to maintain continuous drive to the rotor, two input spur gears mesh with the orbital gear. These input gears are simultaneously driven by a single drive motor, via an epicyclic gearbox and a spur gear train. At the gearbox input a docking feature is provided to enable the drive motor to be remotely connected. The drive train is housed within the main chassis which is locked onto the pipe by means of two clamps. They engage on a location ring attached to the pipe which ensures the accurate location of the tool.

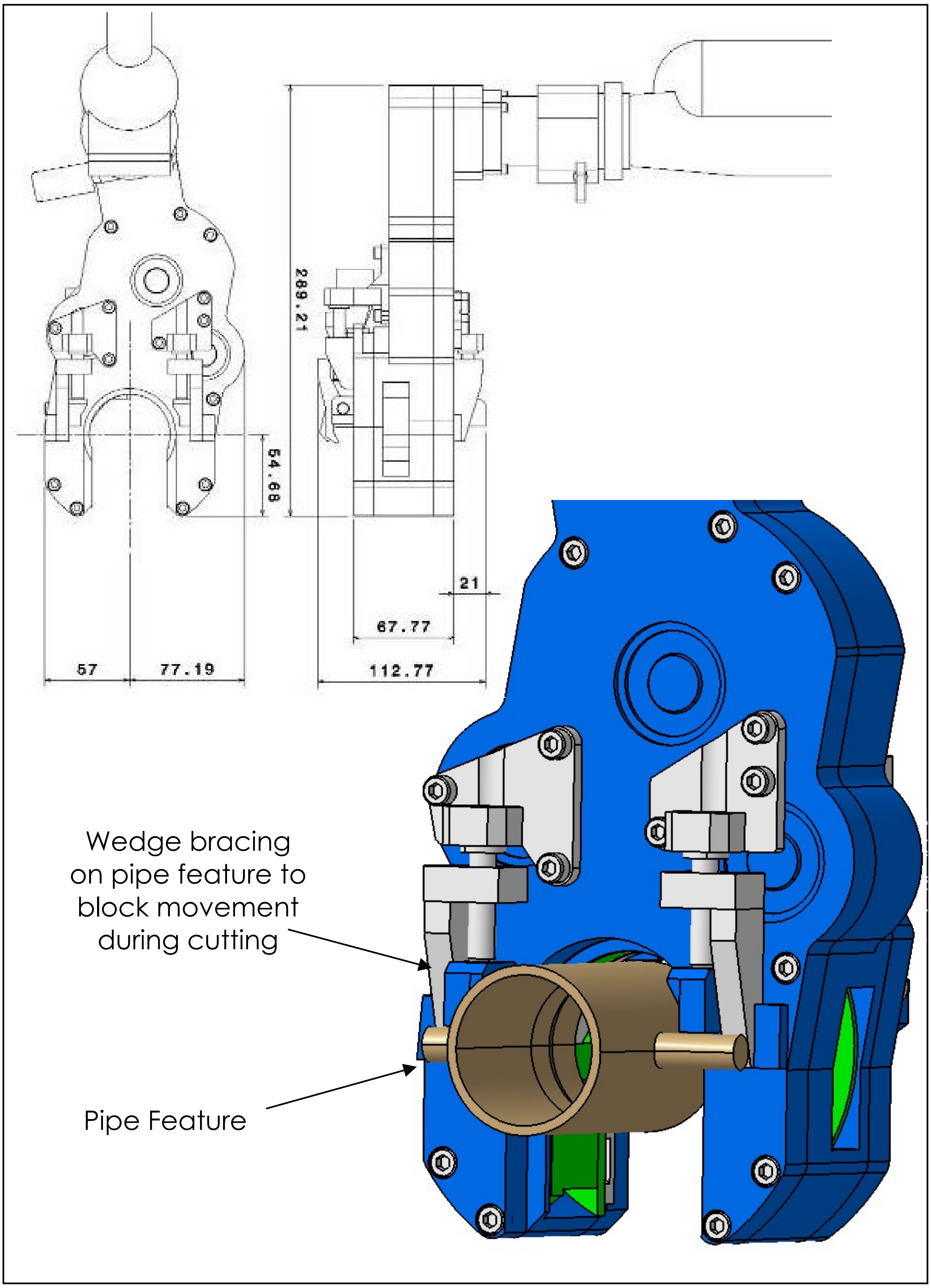


Figure 9.13 : Dia. 48mm Orbital Cutter

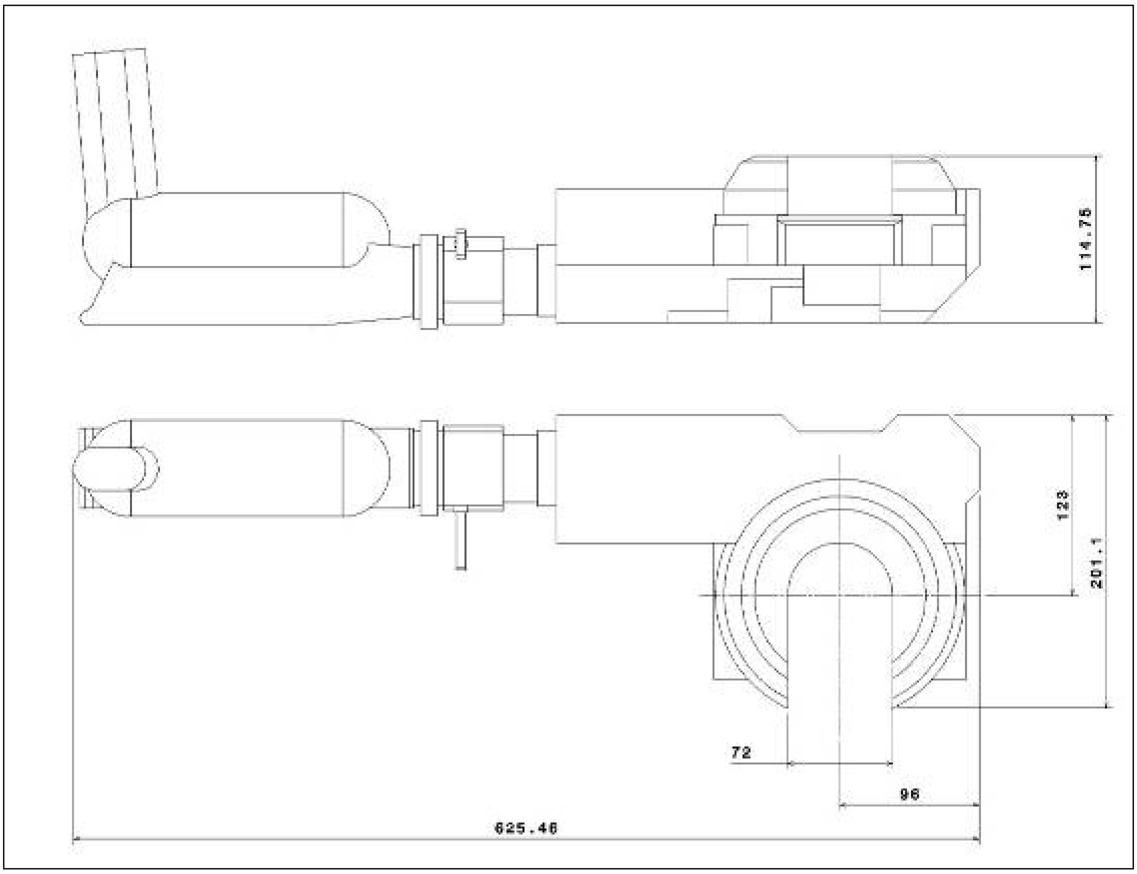


Figure 9.14 : Dia. 70mm Orbital Cutter

9.3. Bore Welded Pipe Joint

If external access to perform an orbital butt weld is impractical, it is possible to perform an autogenous weld from inside the pipe bore – known as Bore Welding. For this process there must be direct straight internal access to the joint. The joint must be self aligning such that only an axial load needs to be applied to ensure the required quality of fit-up. The smallest tube that can be bore welded is around 15mm bore. The depth of weld is limited only by the practicality of fitting the tooling and the robustness of the tool. A small pipe joint should be less than a metre from the pipe end. A large pipe joint could be 5 metres of more.

For bore welding it is necessary to provide an Argon shield around the outside of the joint. Generally, as access to the outside of the joint is impractical a permanent shroud with a gas feed pipe is required to be pre-attached to the joint.

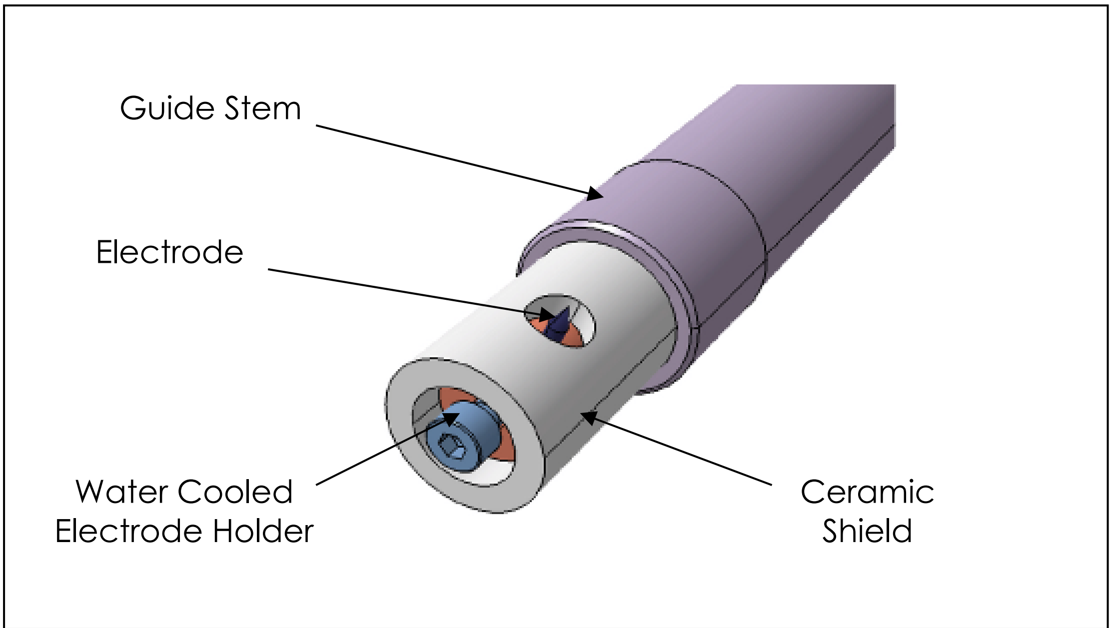


Figure 9.15 : Small Bore Welding Tool

9.3.1. Typical Assembly Process for Bore Welded Joint

The preparation of the pipe ends for bore welding are similar to the orbital butt weld joint. The difference is that because of the restricted access, it will be necessary to pass all tooling through the pipe bore. Access to the bore is generally through the new or replacement pipe.

The assembly procedure is summarised as follows:-

i. Before assembly, fit the bore weld tool to the new pipe and adjust the tool depth stop so that the electrode aligns with the joint.

ii. Fit the new pipe through and engage the insert ring. An internal alignment tool will aid this process and allow inspection by means of an integral camera.
iii. Apply the axial load to the new pipe to maintain the joint closed.
iv. Remove any bore alignment tooling and fit the bore welding tool.
v. Provide shield gas to the external pipe shroud to prevent oxidation of the joint.
vi. Perform the weld programme.
vii. Remove the weld tool and replace the camera inspection tool to view the weld quality.
viii. Perform a helium leak test.

9.3.2. Typical Disassembly Process for Bore Welded Joint

Internal bore cutting is performed using a slitting saw. A saw is used because it produces small swarf particles that can be easily collected by a vacuum extraction unit. The saw drive is mounted eccentrically in a feed shaft so that it can be moved radially outwards to cut through the pipe wall. The eccentricity required is dependant on the wall thickness of the tube and is limited by the space inside the bore diameter. Hence, small pipes must be thin. A general guide is that the bore must be more than 8 times the pipe thickness. ($D_i > 8t$). The saw must be able to extend not less than 0.5mm beyond the maximum wall thickness to accommodate the slight swelling that occurs on the outside of the pipe as it is cut through.

The length of the cutting tool is limited by the stiffness of the saw drive. If it is too flexible then there will be a lot of chatter and the saw will not cut properly. Typically, for small pipes the length of the tool should be less than 200mm for 15mm bore and less than 3000 for 30mm bore. For these pipe sizes, the saw blade diameter is typically 1mm smaller than the pipe bore.

For larger pipes a blade diameter of 50mm is sufficient for wall thicknesses up to 5mm (which is greater than that which can be bore welded). A blade width of 2-3mm is recommended.

Swarf can be extracted along the shaft of the tool where the pipe bores are greater than 25mm. The efficiency of the swarf removal is never 100% and provision must be made to clean the pipe bore once the cut is complete and the free pipe removed.

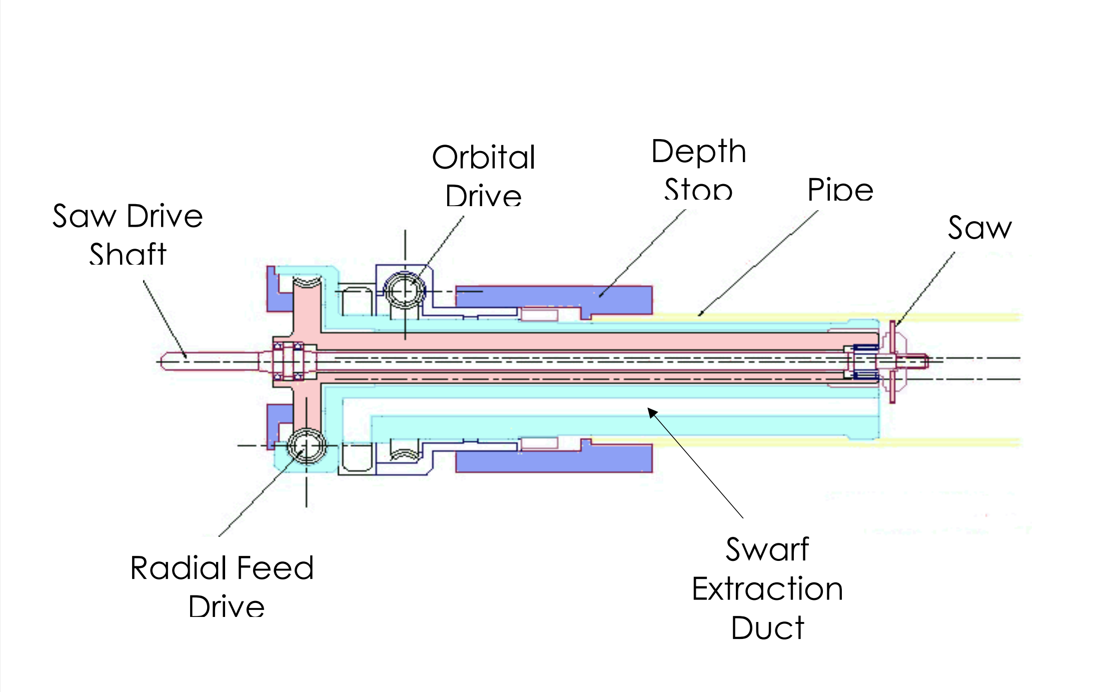


Figure 9.16 : Bore Cutter Schematic

The cutting procedure is summarised as follows:-

i. Adjust the depth of the cut so that the weld is removed including the heat affected zone.
ii. Install the tool and connect the vacuum swarf extraction.
iii. Ensure the pipe is restrained from moving during the cutting process. This may be inherent in the location of the pipe installation.
iv. Start the saw blade drive and index the eccentric shaft to give a depth of cut of 0.2-0.3mm. Then orbit the tool through 360°.
v. Repeat step 3 until the saw is at top-dead-centre and the joint is severed.
vi. Remove the cut pipe captive on the sawing tool.
vii. Vacuum clean and Deburr the cut pipe end.

9.3.3. Internal Butt Weld Tools developed for JET

Below is an example of a JET tool used for a bore size of 67mm (figure 9.17). Internal butt welds have the same joint configuration as the externally welded butt welds (**9.2**) including the use of the pipe weld insert (figure 9.2). This insert was used because the fit-up could be viewed externally. If this was not feasible, the ring profile could be inverted so the internal inspection of the fit is possible.

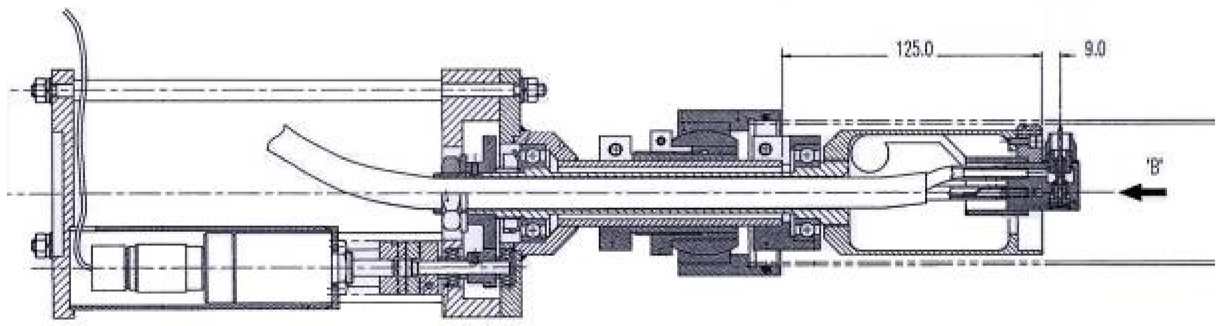


Figure 9.17 : Dia. 65mm Bore Welder

RH tooling related to internal butt welding is as follows:-

Tool Description	RH Ident. Number	Drawing Number
Dia. 45mm Bore Welding Tool	tbd	Contact RH Section
Dia. 67mm Bore Welding Tool	tbd	Contact RH Section
Dia. 45mm Bore Cutter	tbd	Contact RH Section
Dia. 67mm Bore Cutter	tbd	Contact RH Section

Table 9.2 : Internal Butt Welding Tools

The remote handling tool developed for JET is shown as an example. It is anticipated that its design and technology can be readily adapted for the specific needs of ITER (for instance the Divertor PFC pipework).

9.4. Sleeve Welded Joint

This weld style is most complex to perform remotely and it should only be used where a butt weld is not feasible i.e. when the joint must accommodate locations that have no axial compliance.

The sleeve weld can be used to join two coaxial pipes – see figure 9.18. The weld is between the end of the outer pipe and the outside diameter of the inner pipe. The weld requires the addition of filler metal to produce a fillet weld profile. It is necessary for the joint to have sufficient assembly clearance to allow easy assembly and to accommodate any ovality of the pipes. This results in a radial gap that varies around the joint.

It is not possible to devise a weld program that can cope with the range of possible assembly fits. Hence, it is necessary to adjust the arc position and power as the weld is in progress.

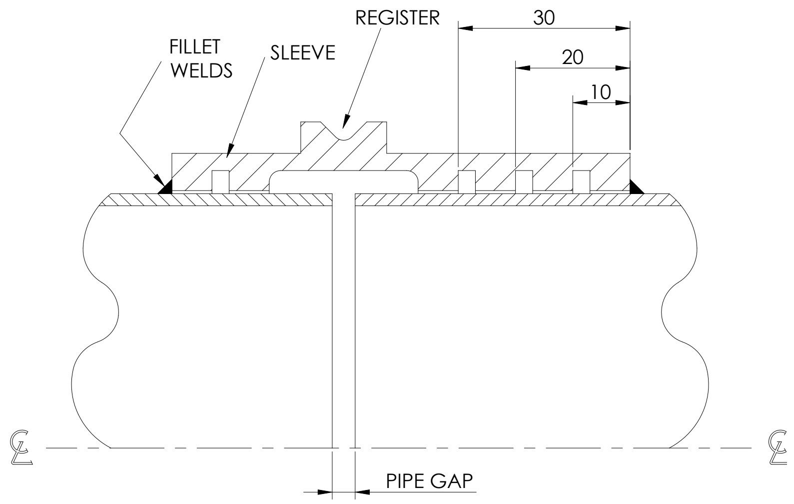


Figure 9.18 : Typical Sleeve Welded Joint

The sleeve weld design has been developed at JET for the joining of equal sized pipes where a small amount of axis misalignment needs to be accommodated (Figure 9.18 : Typical Sleeve Welded Joint). The sleeve incorporates a V-shaped register that is used to locate either the welding or cutting tools. The range of pipe sizes that can be sleeve welded are shown in Table 9.3.

The sleeve design is such that joint can be cut and re-made. Internal grooves within the sleeve are machined at fixed position to enable an external cutting tool to break through the sleeve and release one end of the connecting pipes (Figure 9.19). The cut leaves the sleeve end ready for re-welding and the joint is re-made with a new pipe. It can be seen from Figure 9.19 that the right-hand side of the joint can be re-made three times and the left-hand side once.

Size Ref.	O.D. Pipe x Wall Thk (mm)	Sleeve Material	Drawing Number
C	88.9 x 2.11	Stainless Steel 316L	Contact RH Section
C	101.6 x 2.11	Stainless Steel 316L	Contact RH Section

Table 9.3 : Pipe Sizes for Sleeve Welds

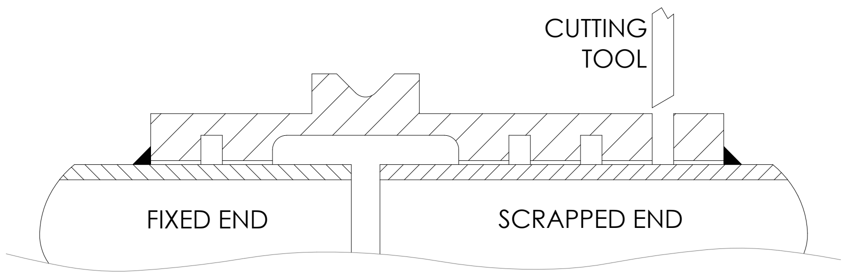


Figure 9.19 : Sleeve Cutting

As a general rule the radial spacing between pipes and nearest obstructions should be at least "1D+25" for clamshell type tools shown here with clear access from one side of the pipe.

9.4.1. Sleeve Welding Tool

The sleeve welding tool is a remote handling compatible orbital TIG welding tool designed to weld tubes from 85mm to 105mm in very restricted access locations. The radial height of the tool is only 55mm allowing it to be used in tight spaces. The tool produces a fillet welded socket joint.

The principal features of the tool are:

i. Water cooled TIG weld torch
ii. Arc voltage control
iii. Wire feed from an onboard spool
iv. CCD camera view of the weld pool
v. Cross-seam positioning axis
vi. Rotational velocity control

The design comprises two hinged sections which allow it to clamp around the socket. The tool locates in a groove in the component by means of three wheels. One of the three wheels provides the orbital motion by means of friction drive with sides of the groove. Another wheel provides the drive to a velocity feedback sensor.
A miniature colour CCD camera provides a view of the leading edge of the weld pool during the welding process. The water-cooled torch is capable of weld current up to 200 amps and incorporates a gas lens system to provide arc shield gas containment. The water cooled power cable, water return hose, shield gas supply hose and signal cables are organised as a flat power cable loom which coils around the tool as it turns. The torch is mounted on a linear slide axis parallel to the electrode to facilitate automatic arc length control. Another motorised axis parallel to the pipe is used for cross-seam positioning of the torch.

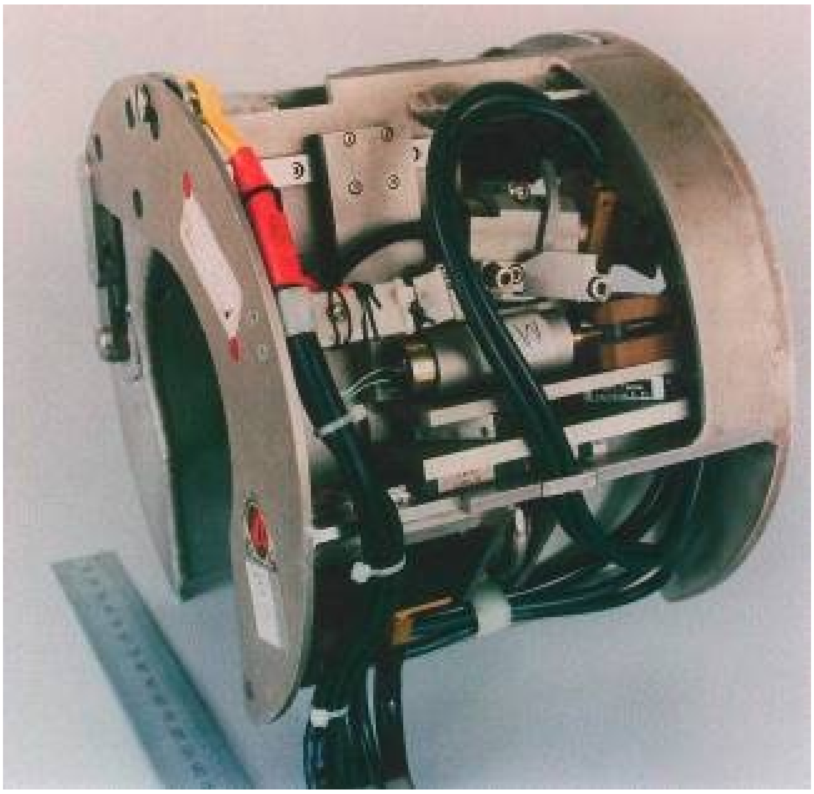


Figure 9.20 : Sleeve Welder – Size C

The welding tool envelope is as follows:-

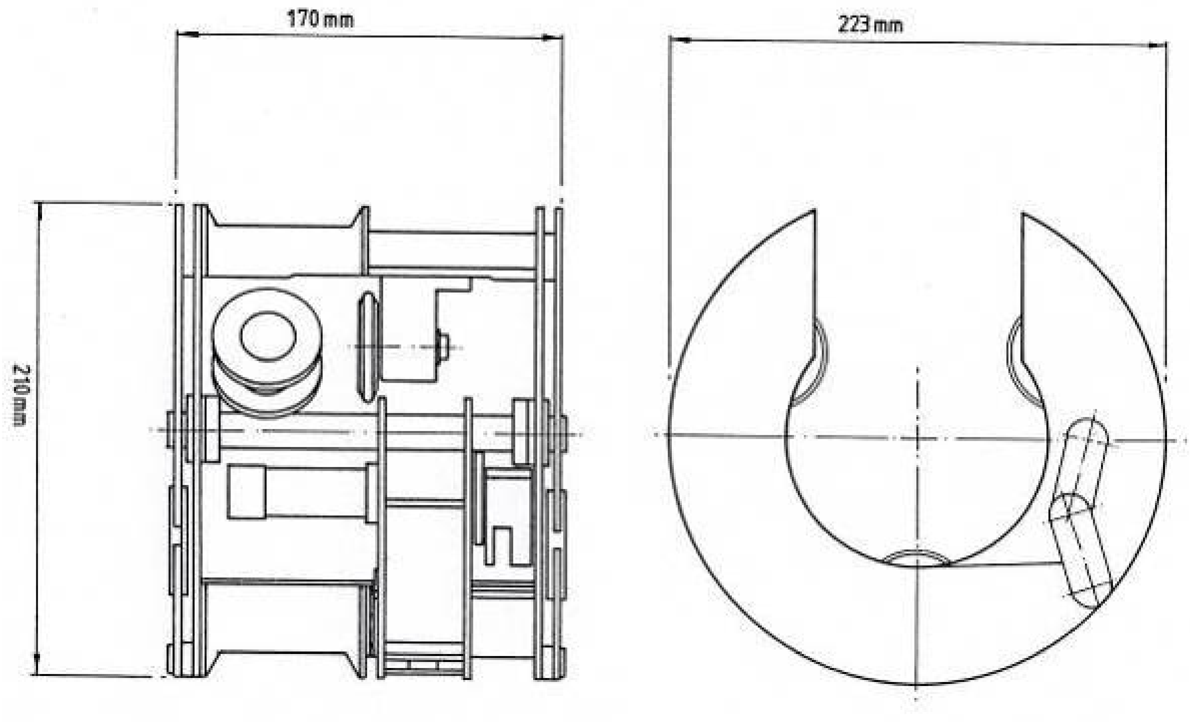


Figure 9.21 : Sleeve Welder – Size C

9.4.2. Orbital Clamshell Cutting Tool

The orbital clamshell type of cutting tool is similar to the orbital cutters described here except in the way that it attaches to the pipe. The clamshell tool design has a rotor assembly divided into two halves. Each half contains a single point (lathe) toolbit which orbits the pipe. The stator in which the rotor is located is also split into two halves. The stator secures the tool to the pipe and provides the motive power.

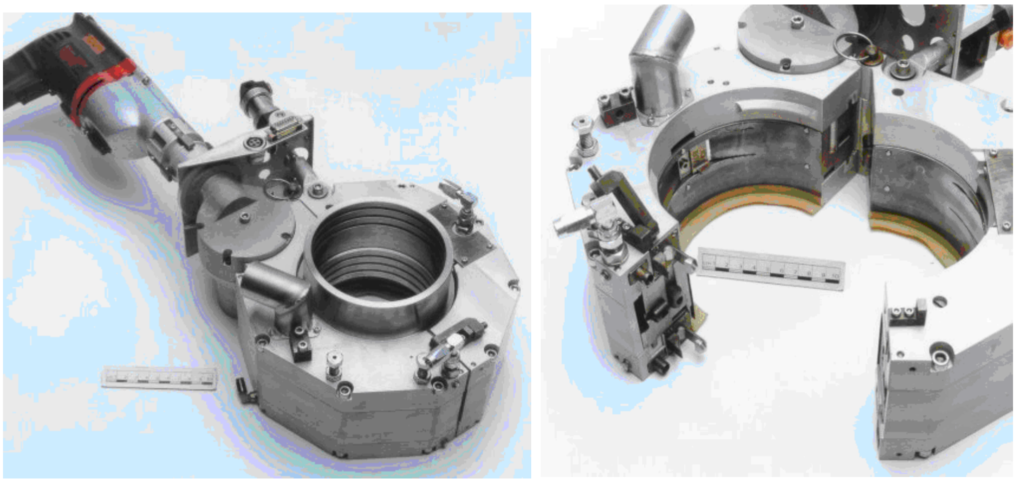


Figure 9.22 : Clamshell Orbital Lathe Cutter for Sleeve Joints

The two halves of the rotor each house a lathe type toolbit mounted on a radius arm. A single drive gear engages alternately with the rotor halves, the cutting forces being transmitted by their mating faces. Feed of the toolbit is provided by a leadscrew indexed by a star-wheel. A striker pin incrementally indexes the star-wheel each rotation of the rotor. This allows the tool to make deeper cuts than with the spring loaded toolbits of the Orbital Lathe mentioned above. The swarf generated by the cutting process is chipped and drawn by a vacuum cleaner through the rotor and into an extractor pipe on the chassis.

Between the halves of the stator is a hinge which allows the tool to be opened to fit it to the pipe. The hinge motion is pneumatically actuated and the halves are locked in the closed position by water hydraulic latches.

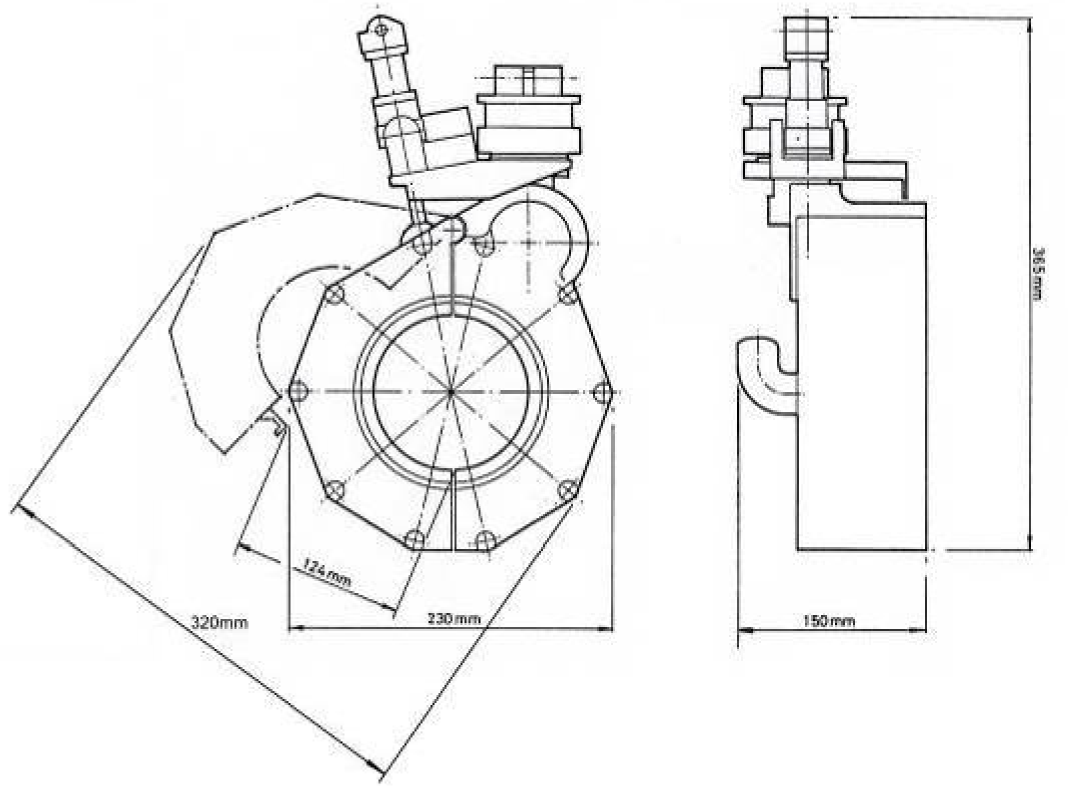


Figure 9.23 : Sleeve Cutting – Size C

9.5. Plug Welded Joint (Circular Port)

This joint style can be used to fit a plug to circular port tube. The plug requires internal features which provide a handling interface for the tooling. To fit the plug, its rim is expanded to provide a 0.2mm interference fit in the port. The plug has to be pressed into position with a jacking tool. This ensures that there is no gap in the joint. Also, the friction between the plug and the port ensures that the plug can support the tool for the welding operation.

In order to achieve the interference fit of the plug, it is necessary to accurately measure the port diameter and then expand the plug to a suitable size. When the plug is pressed into the port, the port becomes slightly flared at the rim. This means that subsequent plug replacements will need slightly bigger plug diameters.

To remove a plug, the port and plug are machined on the end face to reduce the port length by about 3mm. This cuts through the weld and allows the plug to be pulled out. The cut end of the port may need deburring, but is essentially ready for the plug replacement. However, after several replacements the port can become excessively flared. It is then necessary to machine more of the rim length to remove the flare.

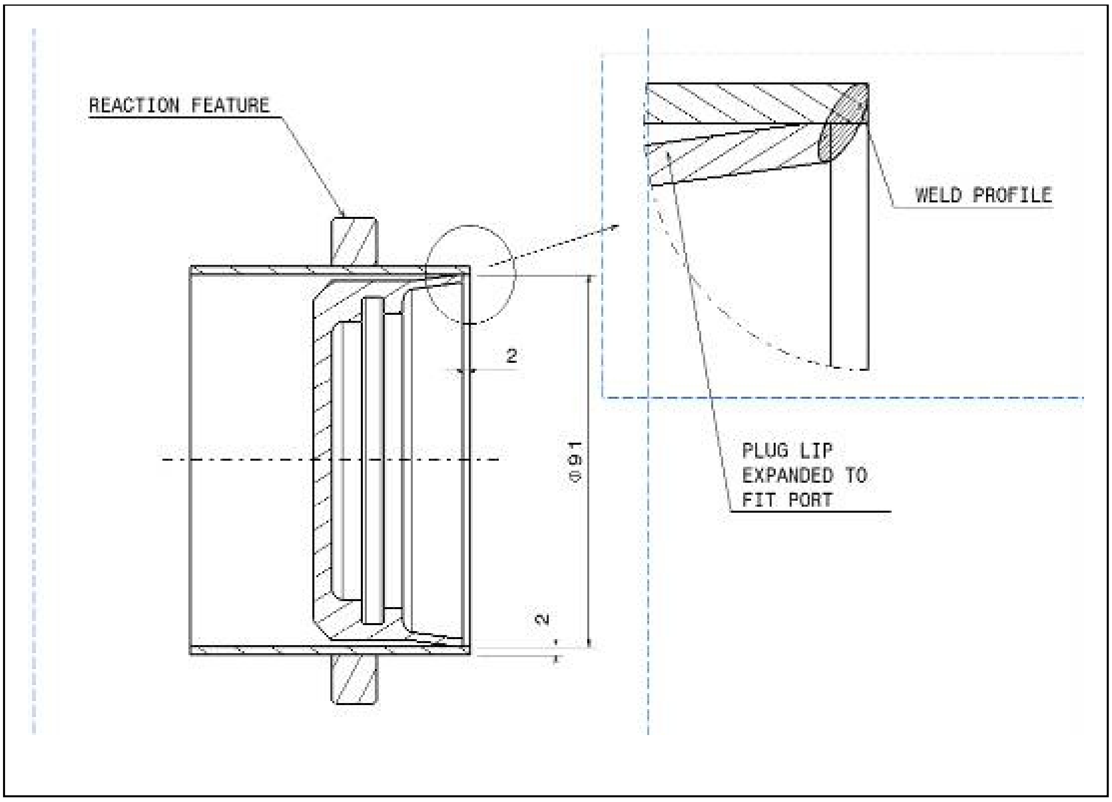


Figure 9.24 : Typical Plug Weld

For the plug jacking and pulling operations it is necessary to provide force reaction features on the outside of the port tube. These must be placed sufficiently along the tube to allow the required number of refitting operations.

9.5.1. Tooling Developed for JET

To ensure remote handling compatibility the preferred design for seal welded vacuum vessel circular ports and feedthroughs is shown in Figure 9.25

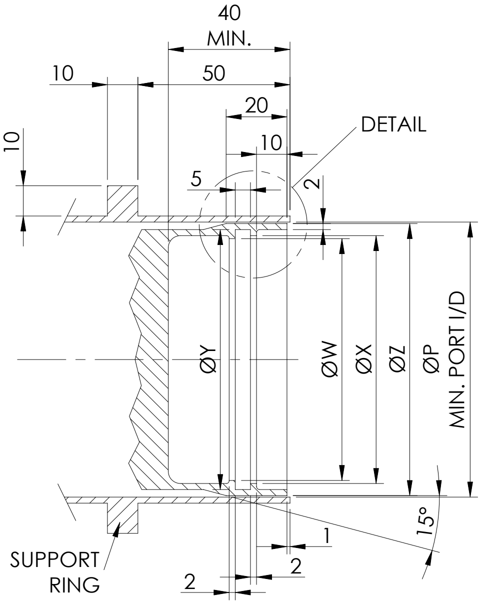


Figure 9.25 : Circular Port Weld Joint

Ports are standardised for a range of sizes from ‘A’ to ‘F’ with the following dimensions (with reference to Figure 9.25 : Circular Port Weld Joint):-

Size Ref.	∅ P	∅ W	∅ X	∅ Y	∅ Z
A	91.0 91.2	80.00 80.35	82.00 82.35	85.50 85.85	∅P-0.5 ∅P-0.7
B	103.0 106.6	91.00 91.35	93.00 93.35	96.50 96.85	∅P-0.5 ∅P-0.7
C	125.7 128.8	107.00 107.35	109.00 109.35	112.50 112.85	∅P-0.5 ∅P-0.7
D	154.8 155.0	135.00 135.35	137.00 137.35	140.50 140.85	∅P-0.5 ∅P-0.7
E	175.4	164.85 164.5	166.85 166.5	170.35 170.00	∅P-0.5 ∅P-0.7
F	187.4	175.85 175.5	177.85 177.5	181.20 181.00	∅P-0.5 ∅P-0.7

Table 9.4 : Standard Port Plug Sizes

Four circular port welding tools are configured to carry out all weld sizes (from 'A' to 'F') along with the associated pullers, expanders and cutting tools:-

Tool Description	RH Ident. Number	Drawing Number
Size A/B circular port welder	tbd	Contact RH Section
Size C/D circular port welder	tbd	Contact RH Section
Size E circular port welder	tbd	Contact RH Section
Size F circular port welder	tbd	Contact RH Section
Circular port welder collet – size A	tbd	Contact RH Section
Circular port welder collet – size B	tbd	Contact RH Section
Circular port welder collet – size C	tbd	Contact RH Section
Circular port welder collet – size D	tbd	Contact RH Section
Circular port welder collet – size E	tbd	Contact RH Section
Circular port welder collet – size F	tbd	Contact RH Section
Size C/D circular port cutter	tbd	Contact RH Section
90 deg angle drive for CT/03 or CT/04	tbd	Contact RH Section
Slim 91mm dia. circular port cutter	tbd	Contact RH Section
Size A/B circular port expander	tbd	Contact RH Section
Size C/D circular port expander	tbd	Contact RH Section
175mm dia. hydraulic expansion head	tbd	Contact RH Section
187mm dia. hydraulic expansion head	tbd	Contact RH Section
Size A/B circular port hydraulic puller	tbd	Contact RH Section
Size C/D circular port hydraulic puller	tbd	Contact RH Section
91mm dia. In-vessel circular port jacking tool	tbd	Contact RH Section
Size A,B & C Jacking and pulling tool	tbd	Contact RH Section
Size E & F Jacking and pulling tool	tbd	Contact RH Section
Blocking Ring	tbd	Contact RH Section

Table 9.5 : Circular Port Weld Tools

Figure 9.26 : Circular Port Welding Tool

The required space envelope for welding tools are as follows:-

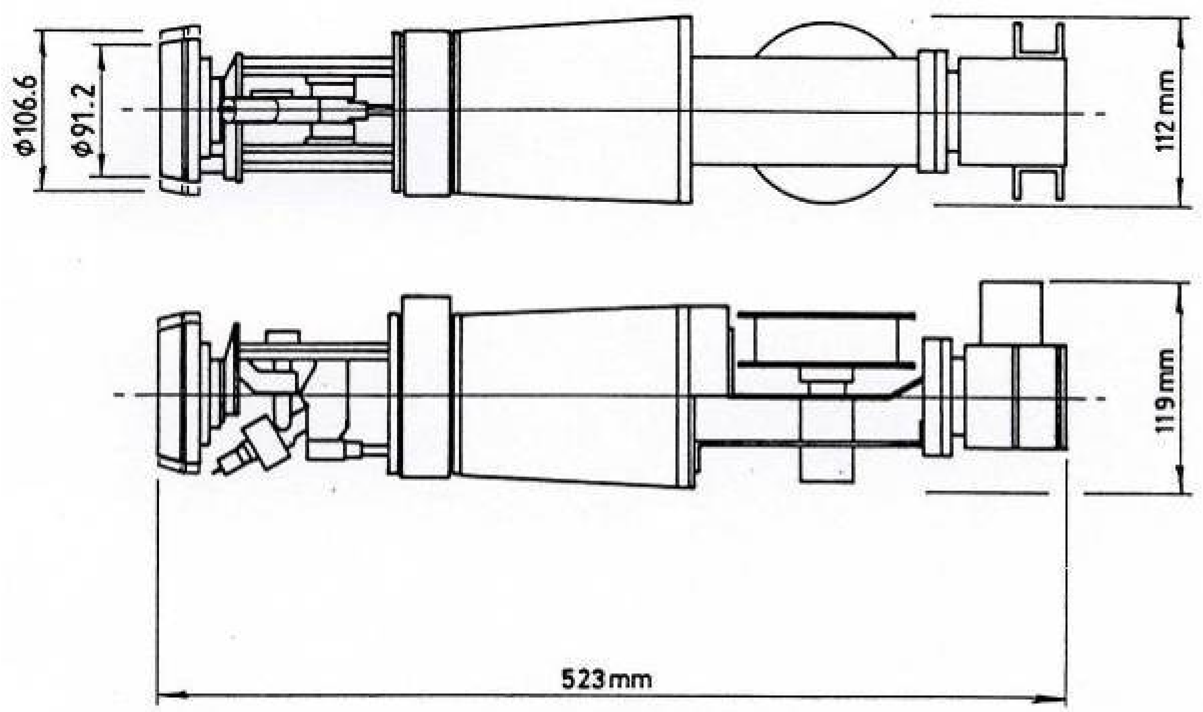


Figure 9.27 : Size A/B Circular Port Welding Tool

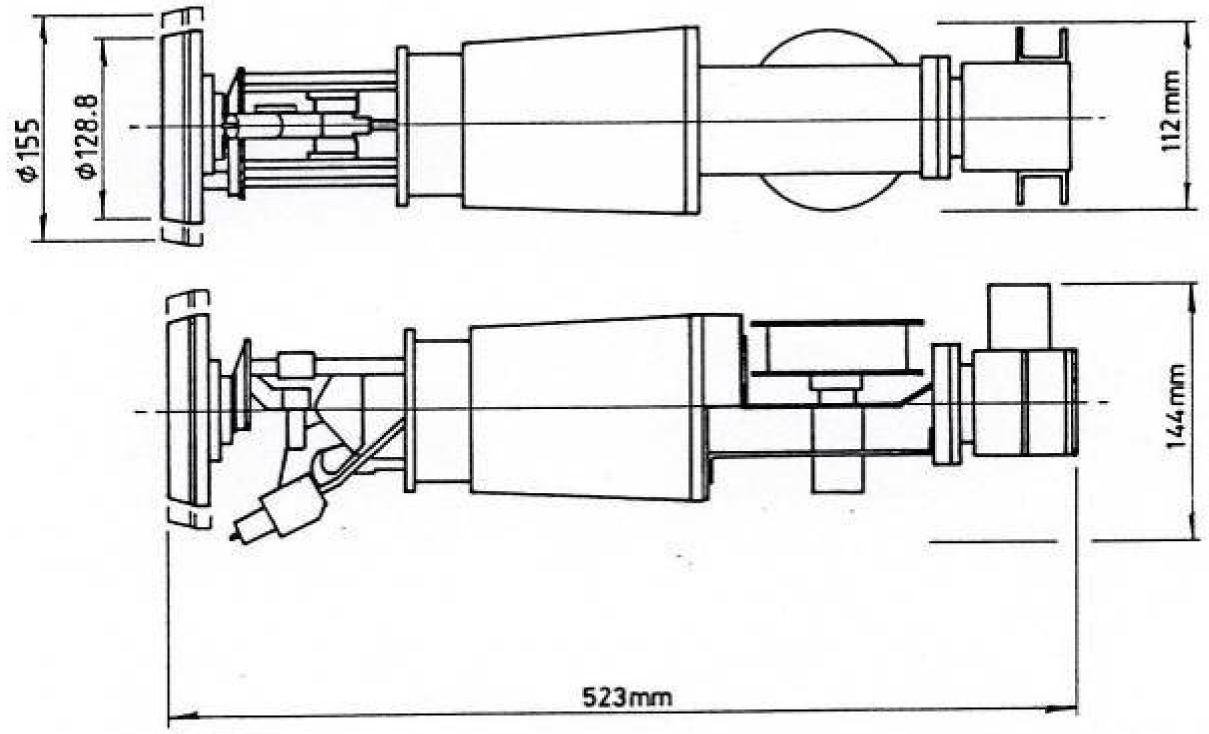


Figure 9.28 : Size C/D Circular Port Welding Tool

The required space envelope for cutting tools are as follows:-

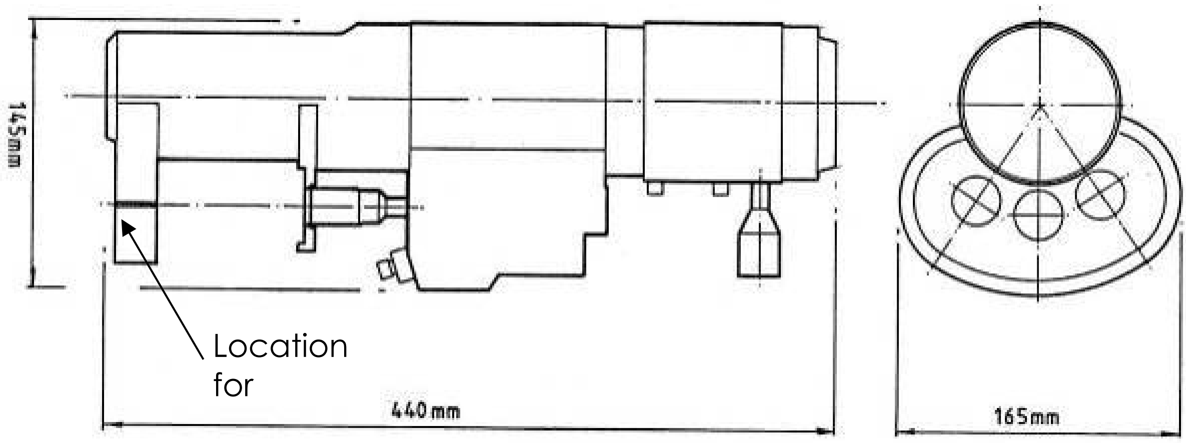


Figure 9.29 : Size A/B Circular Port Cutting Tool

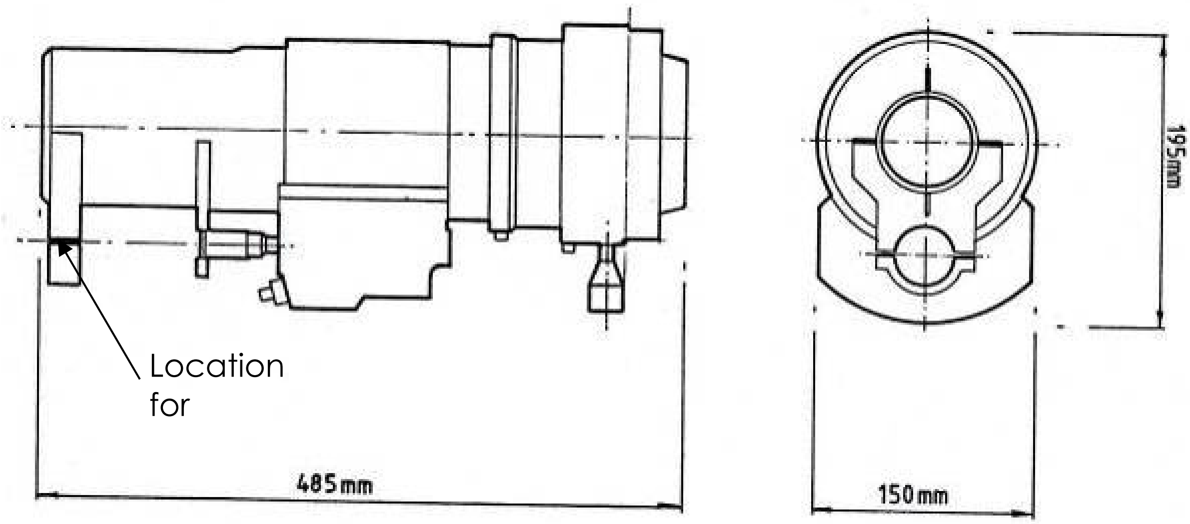


Figure 9.30 : Size C/D Circular Port Cutting Tool

The required space envelope for pulling tools are as follows:-

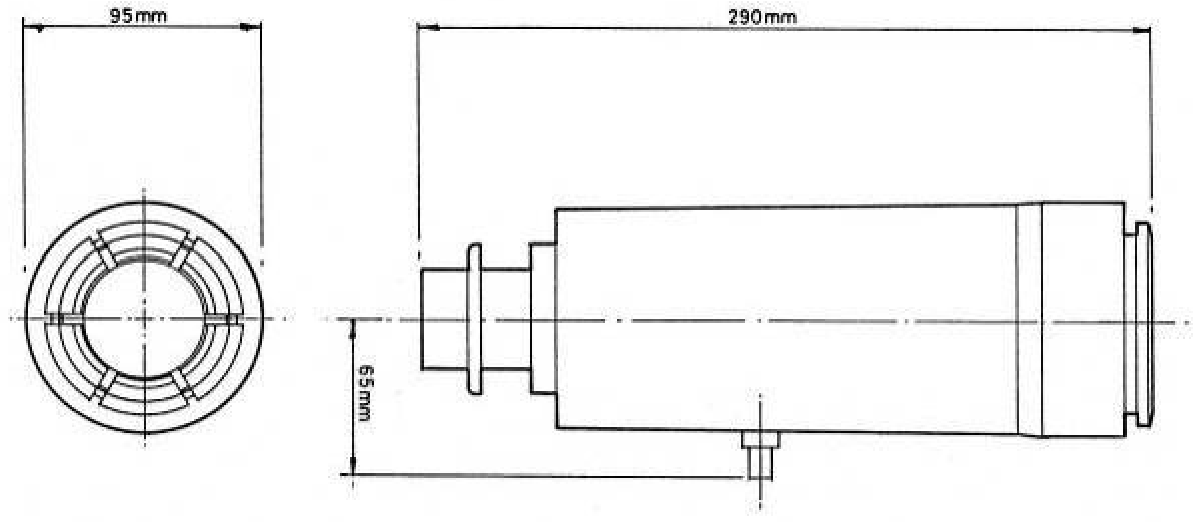


Figure 9.31 : Size A/B Circular Port Pulling Tool

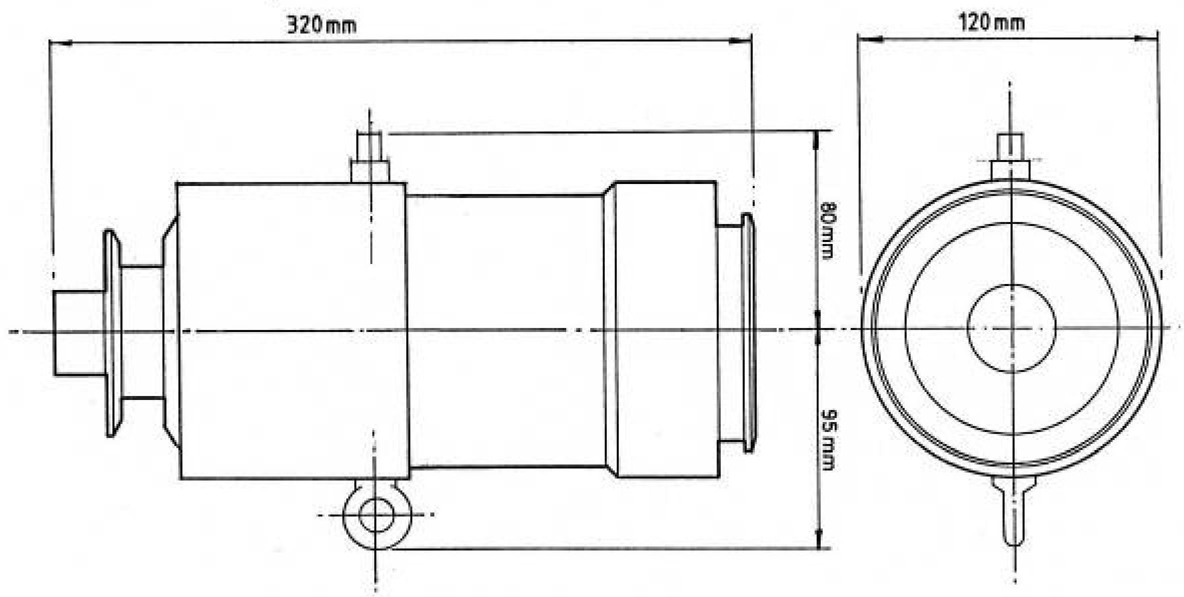


Figure 9.32 : Size C/D Circular Port Pulling Tool

The required space envelope for expansion tools are as follows:-

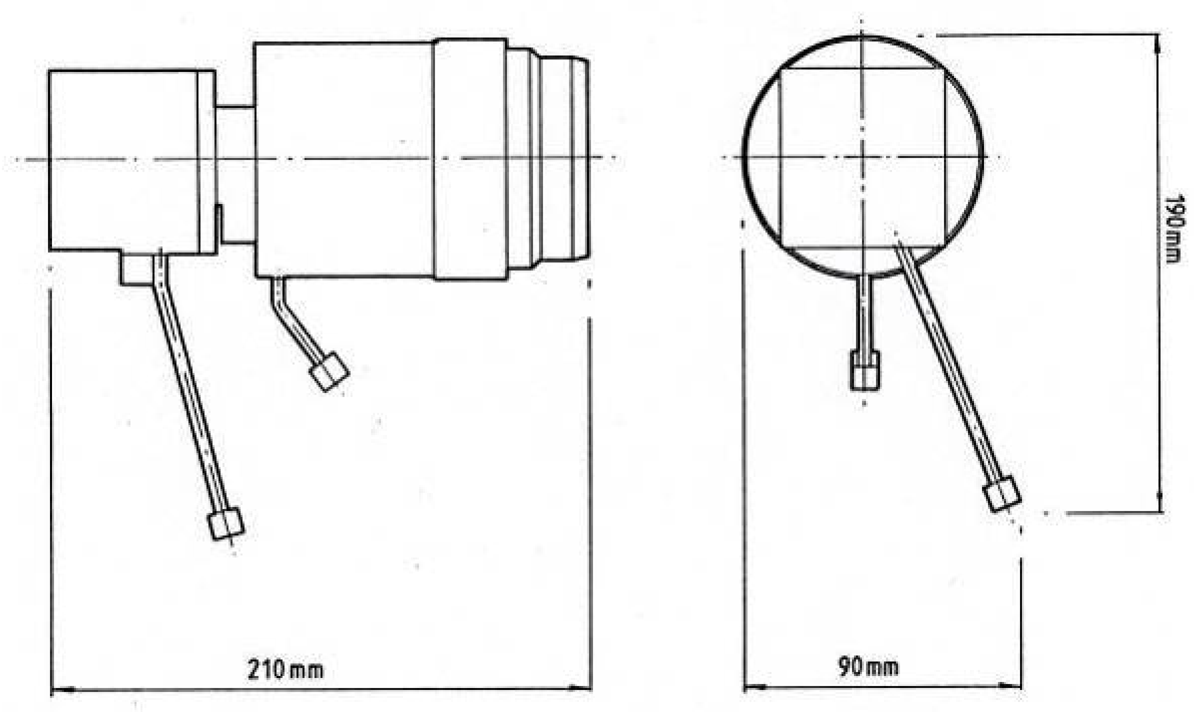


Figure 9.33 : Size A/B Circular Port Expansion Tool

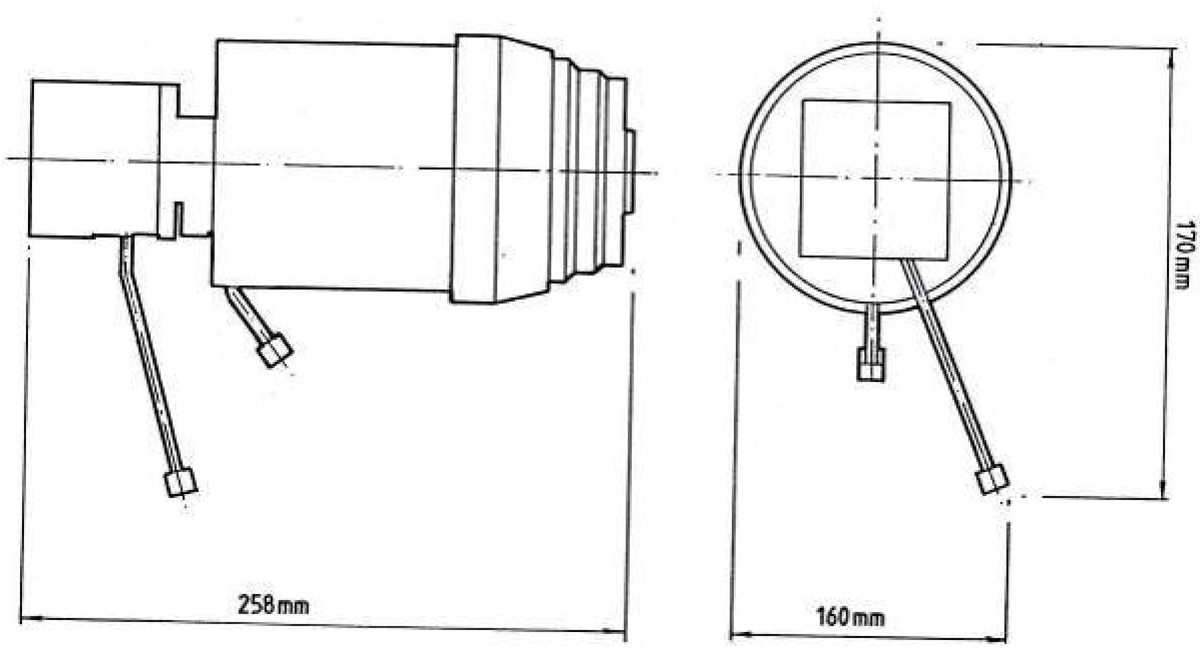


Figure 9.34 : Size C/D Circular Port Expansion Tool

Figure 9.35 : Port Jacking Tool (Typical configured for manual operation)

9.6. Lip Welded Joints

The lip welded joint comprises two 2 mm thick sheets placed face to face and welded along their edge. This joint is used as a closure weld for vacuum vessel lids. It does not support internal pressure and only minor mechanical loads. Generally, mechanical bracing support is required to bridge the joint when the welding has been completed. It is suggested that swing bolts are used so that they can be progressively removed and replaced as the lip joint tool proceeds.

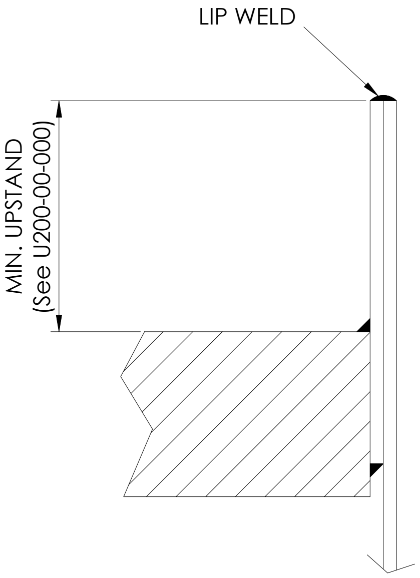


Figure 9.36 : Section through Lip Weld

It is important that the lip lengths are the same for the 2 lips. To ensure this, after assembly the longer lip is trimmed using the shorter lip as a template. This trimming still results in small differences between the lip lengths and this is overcome by making a light cut through both lips simultaneously. This results in near perfect alignment and hence optimum weld quality. The lip length consumed will be dependant on the degree of mismatch of the 2 lips, but 4mm typical for the two operations. The trimming and cutting operations are done with a hydraulic nibbling tool which makes overlapping scallop cuts.

The joint must be tightly fitting to achieve a successful autogenous edge weld. Lip distortions (which tend to become worse with each successive cut and weld operations) require that the joint is clamped and then tack welded to keep it closed. The necessary pitching of the tacks will depend on the degree of distortion, but 50-100mm is usually adequate. The tacks become fully re-fused when the lip weld is performed.

The joint is dismantled by nibbling about 3mm from the edge. This ensures that the lip is fully severed. Trying to be economical by cutting less deep can result in the need to make a second cut if the lip does not part. It can be difficult to locate the region that has not been cut. Pulling on the partly cut lip can lead to serious bending damage to the lips. This will result in even greater lip consumption.

All these factors must be taken into account when assessing the length of lip required to satisfy the number of remote disassembly operations that are to be accommodated.

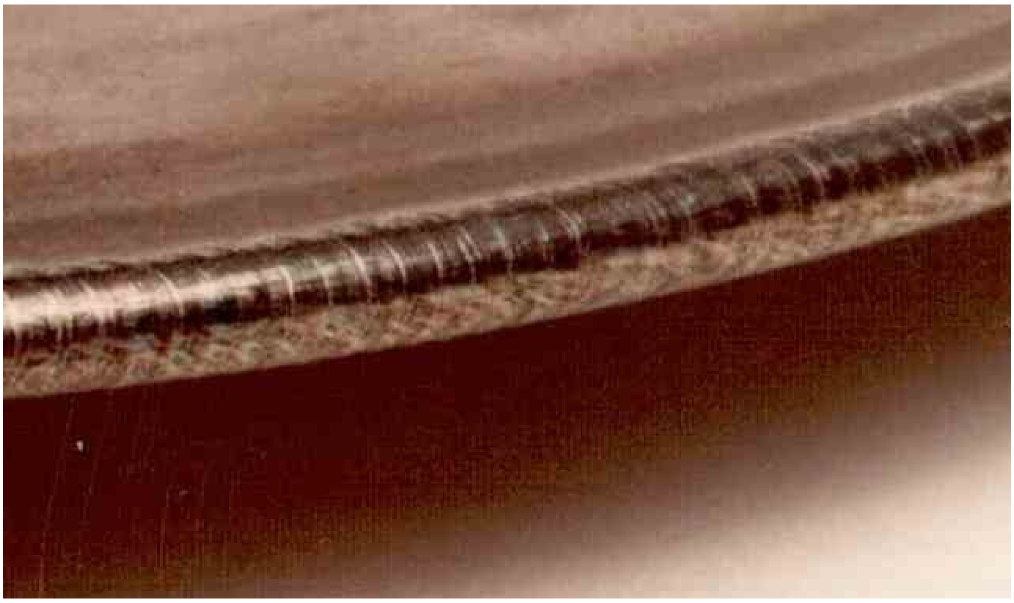


Figure 9.37 : Complete 2 x 2mm Lip Weld

Lip Joint Assembly Procedure:

The joint preparation prior to welding is critical in making a suitable joint. As a working guide the maximum mismatch in height between adjacent components allowable is:-

- ±0.5mm prior to welding
- ±6mm prior to trimming
-

When replacing a lip weld the following stages are required in preparation of the joint using the lip cutting trolley prior to re-welding:-

- Cut the existing weld and disassemble
- Assemble new adjoining lip flanges
- Trim the higher lip down to the level of the other lip
- Trim the two sides of the lip joint together to an equal height

Trimming the plates as described above guarantees the scallops made by the trimming tool are matched - this ensures that the welding arc does not "wander" from plate to plate as has been experienced when the crests of scallops are mismatched.
Approximately 2.5mm is lost per cut; therefore approx. 7.5mm of the lip is lost to re-make the joint.

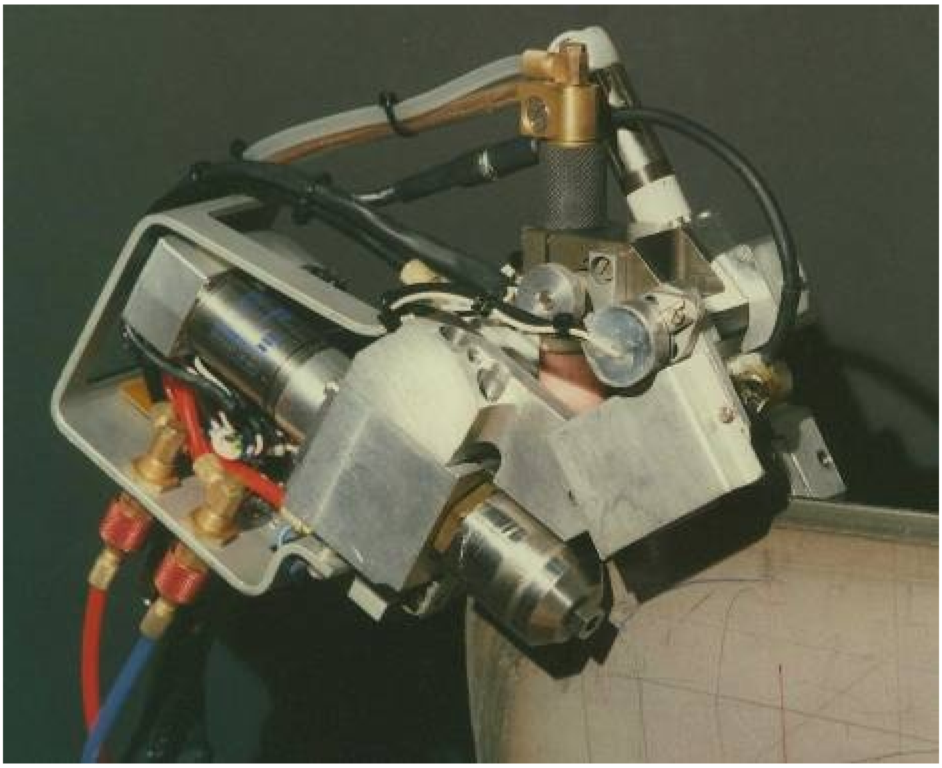


Figure 9.38 : Lip Welding Trolley

The required radial clearance for a clear path of the welding trolley is a minimum of 200mm from the edge of the plate. A greater clearance of 250mm is required for external bend profiles, see Figure 9.40**.**

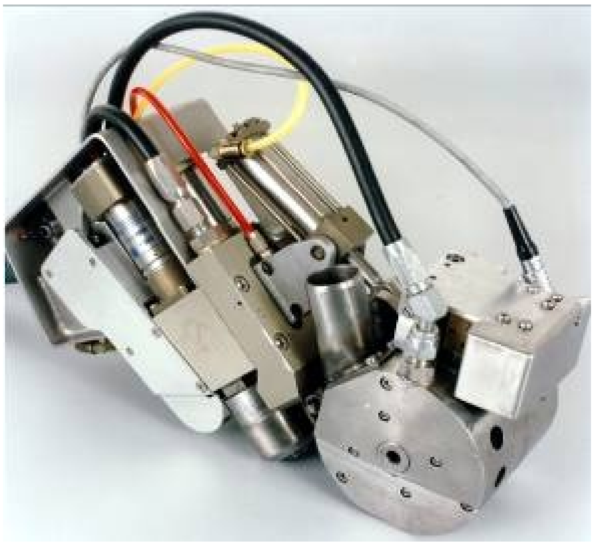


Figure 9.39 : Lip Cutting Trolley

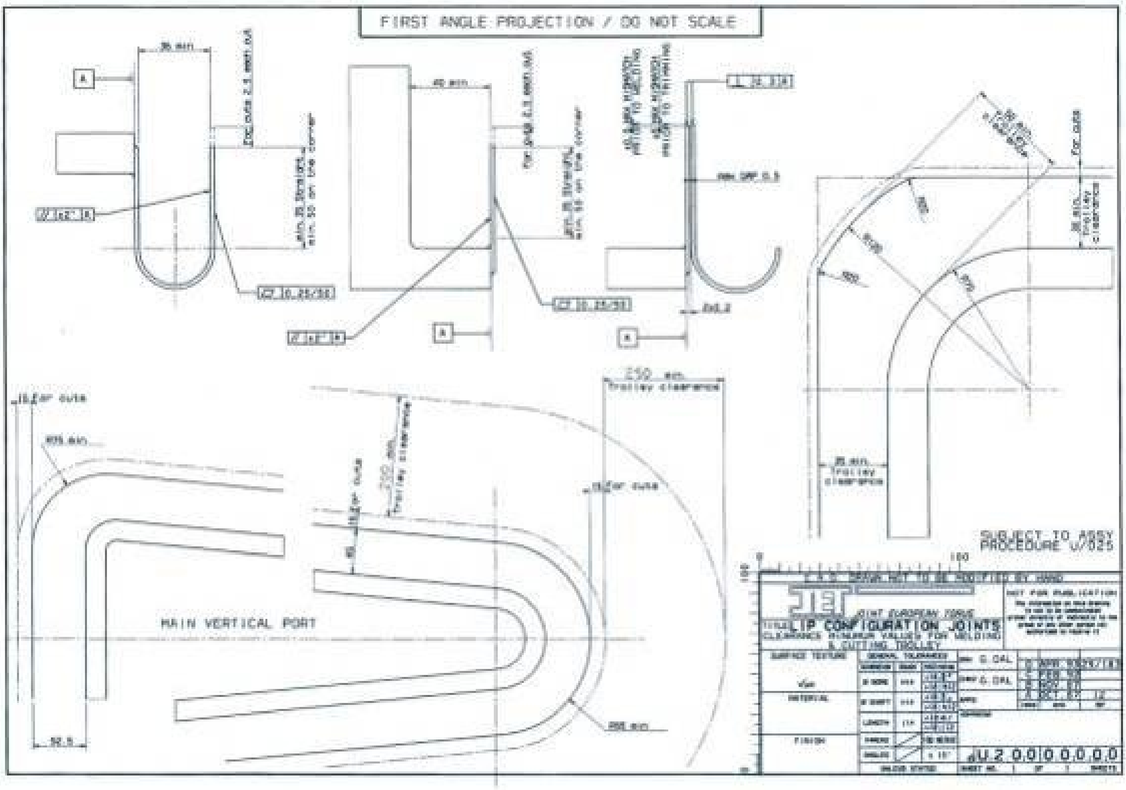


Figure 9.40 : JET Lip Joint Configurations

The required space envelope for welding and cutting tools is as follows:-

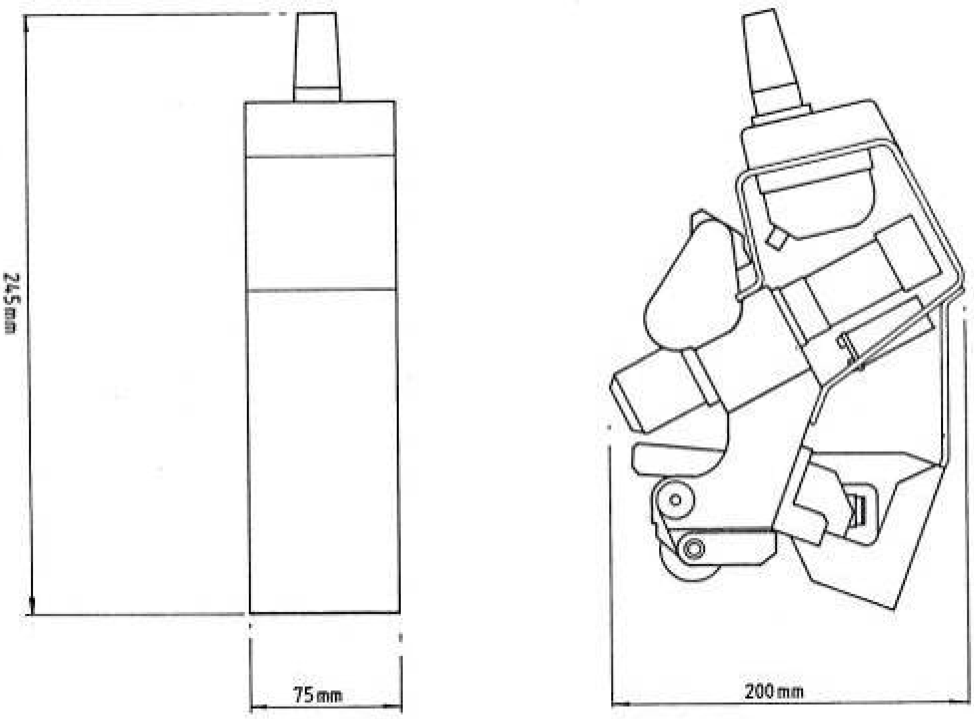


Figure 9.41 : Lip Welding Trolley

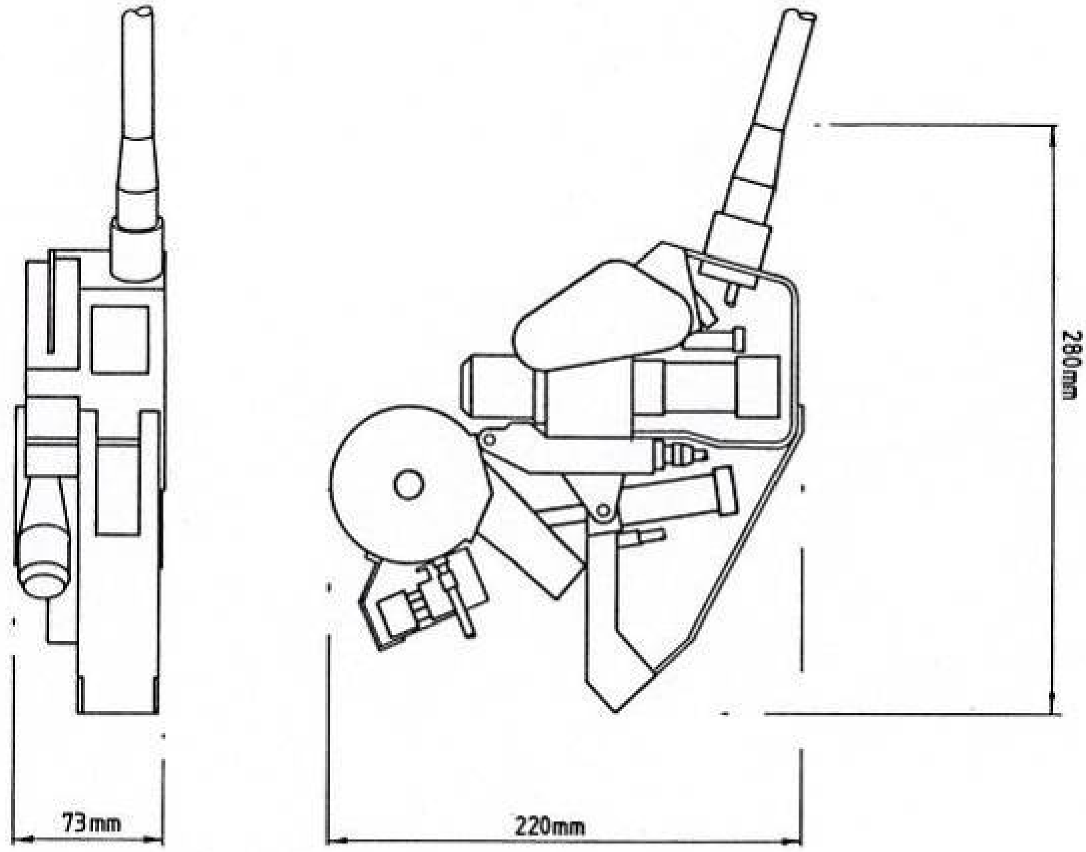


Figure 9.42 : Lip Cutting Trolley

9.7. Structural Joints

New installations of pipework and wiring conduit can be mounted on remotely installed support rails. These support rails may be remotely welded to torus vessel wall or other structural component. The rail design includes a V cross-section that ensures component alignment. The support rails incorporate two parallel flanged feet of 36mm length, which are attached to the structure by welding. The weld process is autogenous TIG which produces two fillet welds that incorporated the flanges of the feet as sacrificial filler material.

The welding is performed using a tool specifically designed for this installation technique. The tool design had to be compact so that it can be used for applications with tight access. The tool comprises two weld torches mounted on a linear traverse parallel to the rail axis. The torches are each inclined at 45° and aligned with the rail flanges. The welds are performed on alternate sides of the rail as a series of overlapping TIG spot welds. The spot positions are controlled by indexing along the linear traverse by using a manipulator to actuate a leadscrew. The weld spots are produced at 2mm increments which gives sufficient overlap to generate a continuous weld bead.

The spot welding technique eliminates the need for a powered torch traverse drive and its associated control system. The simplicity of the process contributes to achieving a compact tool design. The structure of the tool is cooled with helium gas, which is then vented. This avoids the use of cooling water and its associated risk of leakage. Weld power to each torch is supplied by two independent power sources. Argon with 2% Hydrogen is used as the weld shield gas to improve the penetration of the weld into the wall material. Gaps between components of up to 0.25mm can be tolerated without affecting the weld quality.

Before welding, the cleaning of the weld site to remove the oxide layer and contamination is necessary. This is done using a ratchet roller file designed specifically for this application. The roller is coated with tungsten carbide grit which has the advantage of presenting a new abrasive surface with each rolling stroke.

The rails are pre-assembled to the welding tool so that they can be handled remotely. Guides attached to the welding tool aid its positioning with reference to local features.

A digital photogrammetry camera adapted for remote use is used to capture an array of images of calibrated targets which are attached to each of the support rails. By computational analysis it is possible to generate the relative target positions in 6 degrees-of-freedom within 20μm. This enables corresponding installation component features to be matched to the precise locations of the support rails.

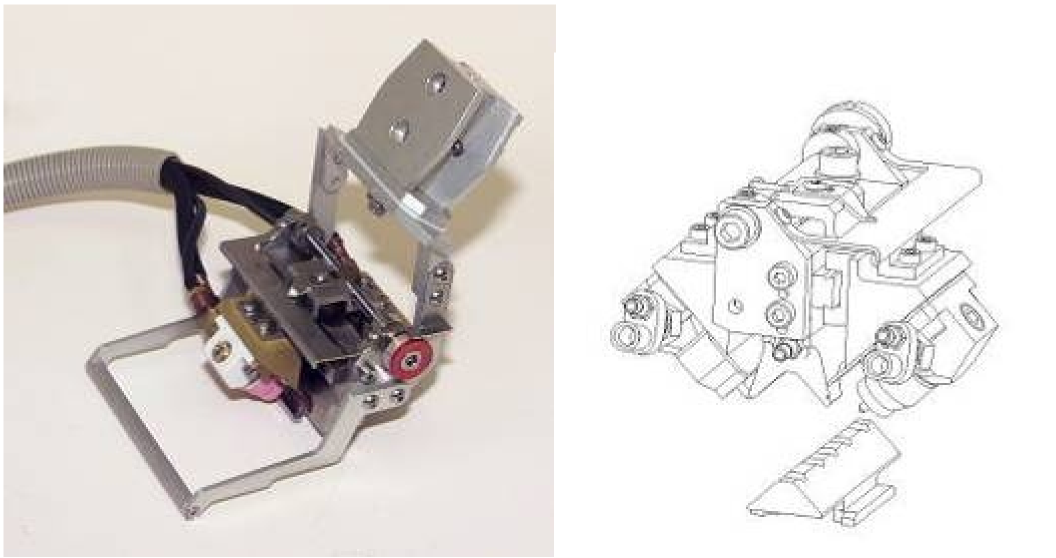


Figure 9.43 : Support Rail Welding Tool

Figure 9.44 : Support Rail

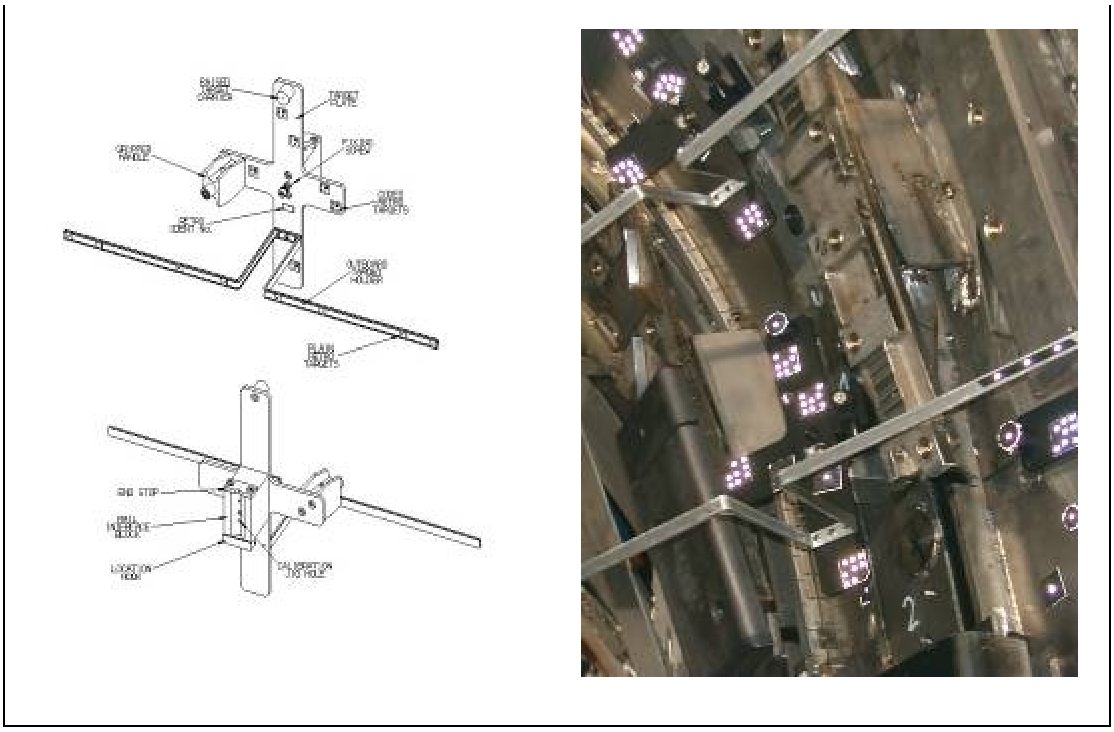


Figure 9.45 : Photogrammetry Targets

9.8. Tack Welds

A “pencil” TIG torch is used to provide autogenous tack welds whenever necessary. One main use of this weld process is to securely tack tab-washers between bolts and the vessel structure to ensure the bolts do not loosen. The ceramic shroud is used to hold down the tab whilst the tack weld is made. Cut-outs in the shroud end allow purging gas to flow over the weld area during operation.
This form of weld is designed for joints which do not require remote removal.

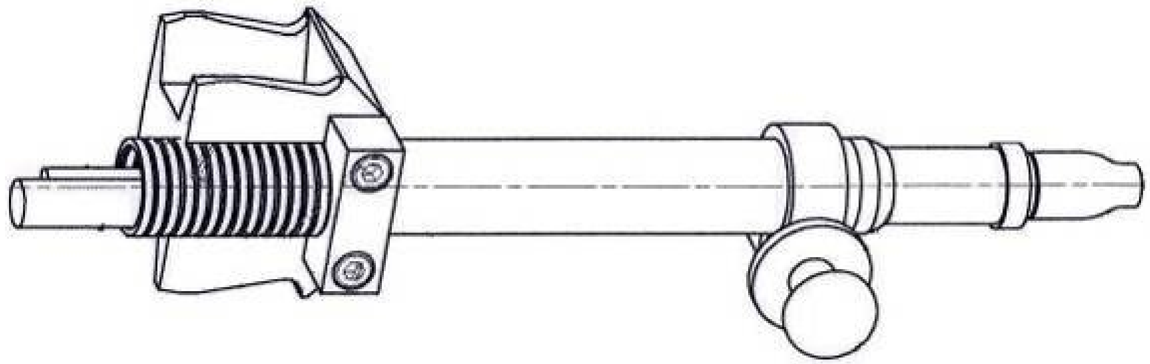


Figure 9.46 : Pencil Welding Torch

10. ITER remote handling standards for - Electrical Connectors

10.1. Electrical Connectors

Electrical connectors should be located in positions that do not interfere with the removal of the main components to avoid collision damage. They should be reliable, capable of being remotely engaged and disengaged, be accessible and easily manoeuvred by the servo-manipulator via extension tools where this is required by space or insertion forces.

The minimum space between connectors should be 40mm. This spacing allows the connector to be handled directly by the servo-manipulator.

To ensure remote handling compatibility the preferred type of electrical connectors are LEMO Series B and Standard Series connectors - listed below in table 10.1.

For detailed information about size and electrical characteristics for B-Series and Standard Series connectors refer to a current LEMO catalogue.

In addition to the commonly used B Series connectors LEMO produce a range of Remote Handling connectors (N-Series) that incorporate additional features which assist alignment and engagement whilst maintaining a standard LEMO pin interface (figure 10.1). For applications where the available engagement force is limited a lever and cam latching mechanism can be specified as an option. For details refer to a current LEMO catalogue.

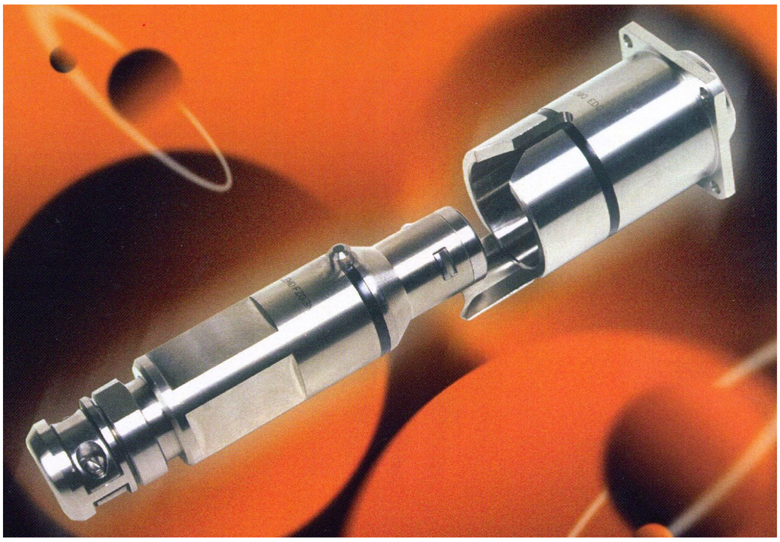


Figure 10.1 : LEMO N-Series Remote Handling Connector

All connectors used at ITER between equipment and jumper cables or jumper pipes should normally be mounted with their axis vertical (preferably downwards) but never at an angle greater than 30 degrees from the vertical. If this disposition is not possible an extra support is needed to avoid the bending of the cable or pipe at the connector.-

10.2. In-vessel RH Connectors

Remote handling compatible connectors for use inside the ITER vacuum vessel will inevitably be bespoke units and cannot be prescribed here. However as a good example of how remote handle-able connectors should be designed to incorporate many of the features described in earlier chapters, figure 10.2 shows the JET remote handling compatible 20 way in-vessel connector. The plug assembly incorporates standard remote pin and dowel features to provide the required level of control for installation into the socket. The plug assembly should have a socket head fixing bolt to match the surrounding tasks The protective wiring conduit attached to the plug is required to have the necessary compliance to enable the plug to be mated with the socket on installation.

The socket assembly is deployed remotely with integral conduit and is securely fastened prior to remote installation of the plug.

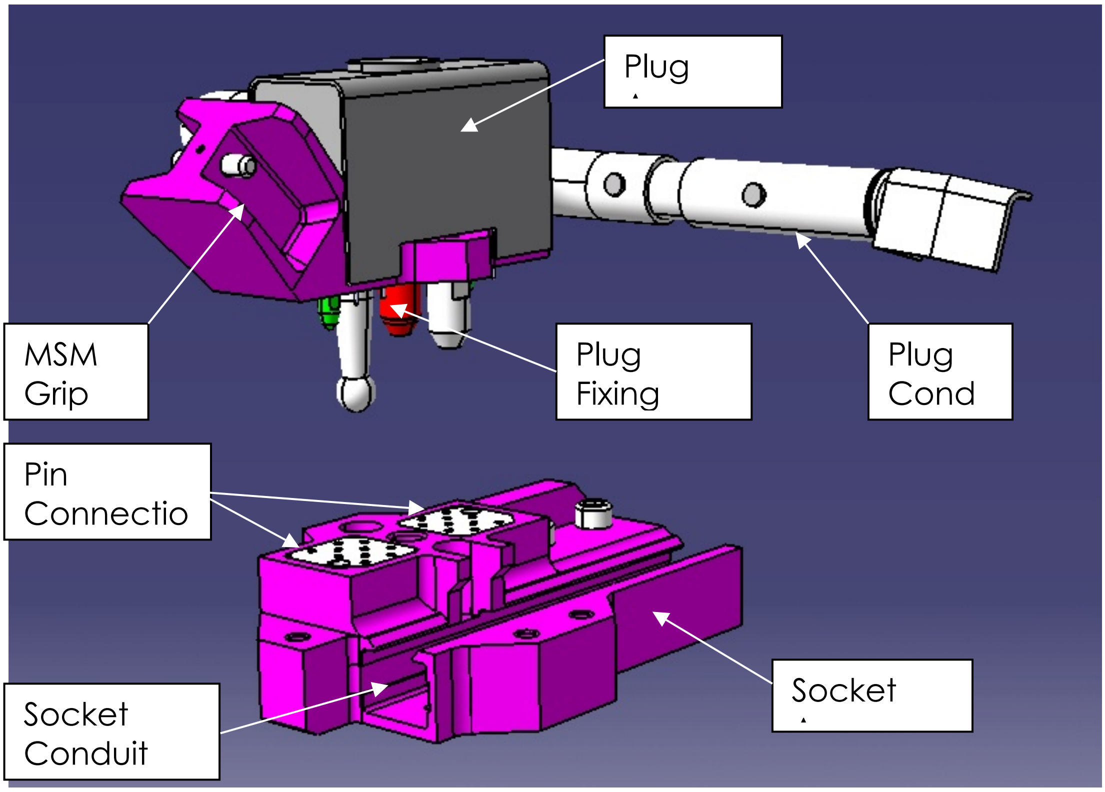


Figure 10.2 : 20-Way In-vessel Connector

Figure 10.3 shows the typical dowel and bolt lengths for the 20-way plug consistent with the kinematic constraint methodology defined in the specification for Location Devices. It must always be the case that pin lengths:-

$$L1 > L2 > L3 > L4 > L5$$

Dowel pins corresponding to L1 and L2 provide coarse alignment before the fixing bolt (L3) is engaged. Pins L4 provide final precision alignment of the electrical pin connectors (L5) as these require tighter clearances than the relatively loose clearances provided for L1 and L2.

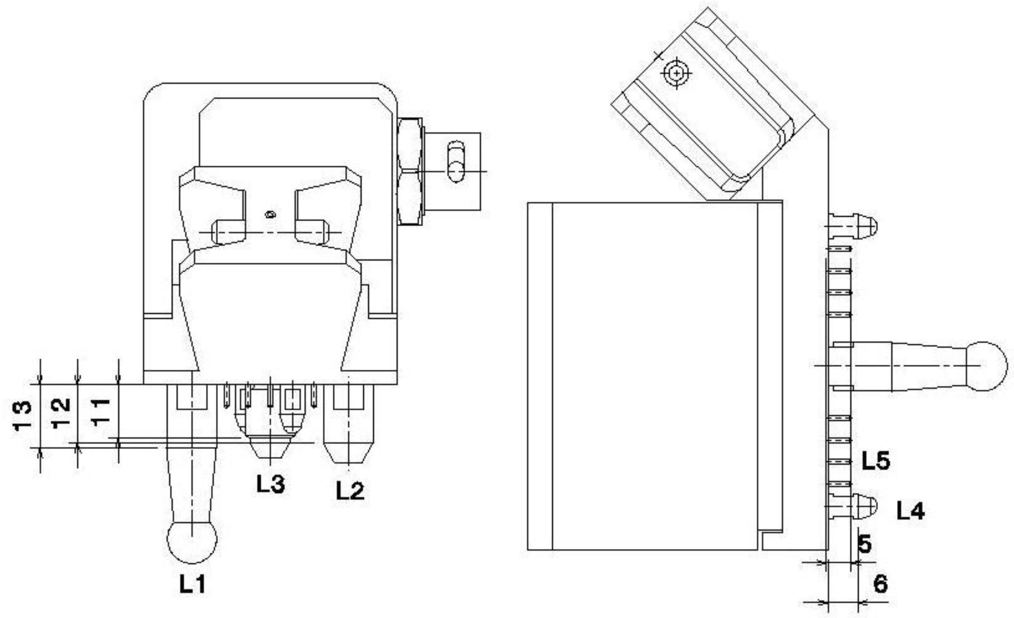


Figure 10.3 : 20-way Pin Lengths

10.3. ITER Divertor In-Vessel RH Connector Assembly

The maintenance of the ITER Divertor cassette modules requires their periodic removal from the Torus by remote handling means. The service connections to the instrumented cassettes, which include electrical connections, must be disengaged for this operation. The tooling required for the connector operation is limited to a bolt driver in order to simplify the deployment logistics.

10.3.1. Connector Modular Designs

A range of connector designs has been devised to meet the requirements for the instrumented cassettes providing connection of 80, 180 and 240 pin capacity. A connector pin spacing of 8mm centres has been adopted to be compatible with the termination of glass insulated braided cable. The connections have been organised in modules of either 40 or 60 pins (Figure 10.4). The modular construction makes manufacture and assembly easier and improves the reliability. It also allows for smaller or larger connectors to be readily developed if necessary.

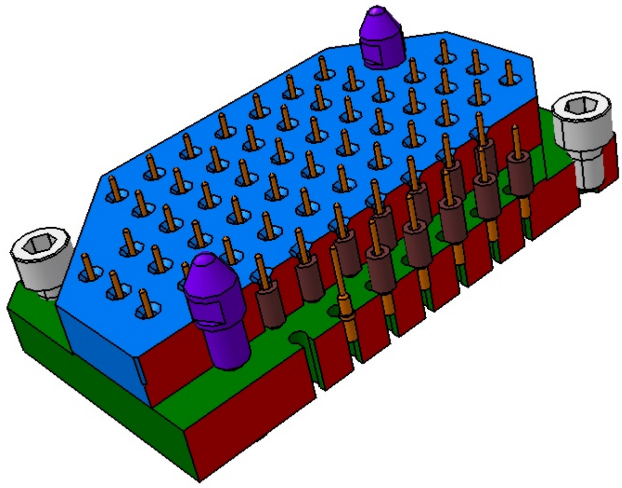


Figure 10.4 : Connector Pin Contact Module

10.3.2. 180 and 240 pin Connector

A 240 pin unit with 4 x 60 pin modules and a 180 pin compact version with 3 modules of 60 pins have been produced. For the larger connector, the socket is divided into 2 independent units of 120 ways each. This arrangement ensures that there is sufficient compliance to allow all of the pins to engage correctly.

The parts subjected to the highest risk of failure (flexing cables, mechanism parts, etc) have been located on the divertor cassette to facilitate maintenance when the cassettes are removed to the hot cell. A translation of the connector plug of 140mm is provided by the use of a “Sarrus” straight line mechanism that employs 2 pairs of wishbones hinged in orthogonal planes. This mechanism constrains the connector plug to move in a parallel linear motion. The linkage also provides a support for the flexing element of the cable loom (Figure 10.5 & Figure 10.6).

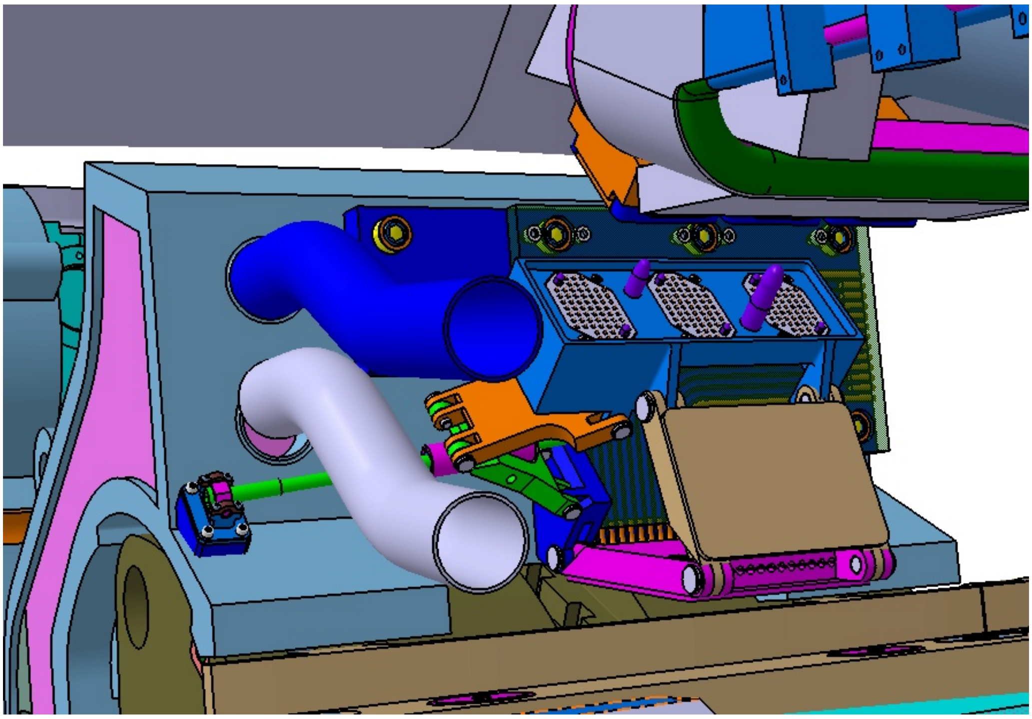


Figure 10.5 : Connector Assembly retracted

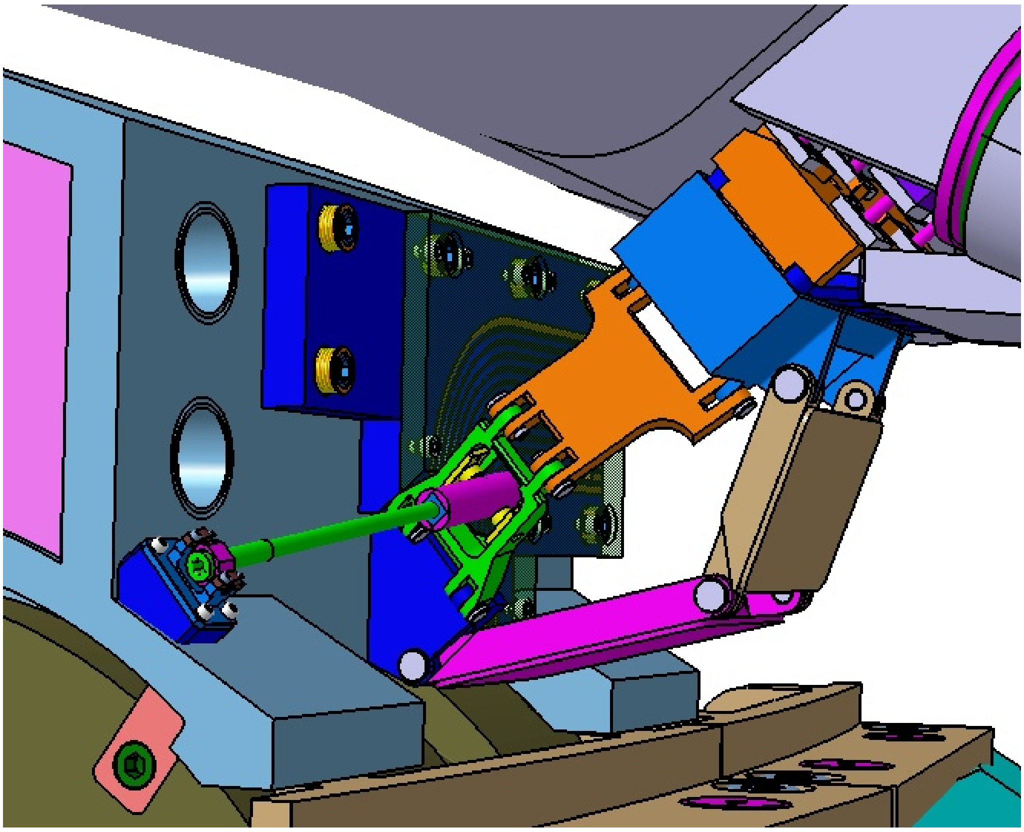


Figure 10.6 : Cassette Connector engaged (pipes not shown)

The translation of the plug is by means of a screw jack. The screw, which is operated with a manipulator using a bolt driver, has a 14mm A/F hexagon socket head at each end. This provides a degree of versatility which allows the connector to be operated from either side of the cassette. The jack incorporates a stack of disc springs which provide compliance in the Sarrus mechanism so that the connector can accommodate the potential disruption displacements of the cassette in the direction of the connector insertion. For this reason it is important that the links do not fully straighten but remain back-driveable.

The pair of guide pins provides a gradual phased alignment of the connector halves. They prevent the connector from becoming wedged or jammed. This is achieved by the pins being of different lengths, the longer one having a spherical nose and a tapered shank. By engaging this pin in a hole in the socket, 2 degrees of freedom of the plug are constrained by the spherical section. As the pin continues into the hole, the taper gradually brings the connector halves parallel to each other leaving only 2 degrees of freedom: translation and rotation about the pin. The shorter pin then begins to engage in a slot in the socket body. This removes the rotational freedom and permits only fully constrained translation of the plug body into the fully engaged position. This is consistent with the RHCOP guidelines here.

Further protection of the electrical pins is achieved by providing 2 dowels in the opposite corners of each plug module to further constrain the precision of engagement to better than 0.2mm. This arrangement ensures that the electrical pins cannot be damaged by misalignment of the connector halves.

The connector mechanism base plate is bolted to the cassette body by 6 x M16 RH captive pop-up bolts. This ensures that it is in good thermal contact with the water cooled cassette. The braided glass insulated cable pairs are grouped in bundles of 7 and are clamped in good thermal contact with the base plate in grooves that route the bundles to the side of the cassette.

10.3.3. 80 pin Connector

The connector design for the central cassettes has 80 pins. Up to 3 of these connectors can be fitted to a central cassette. The connector has 2 modules of 40 pins (Figure 10.7).

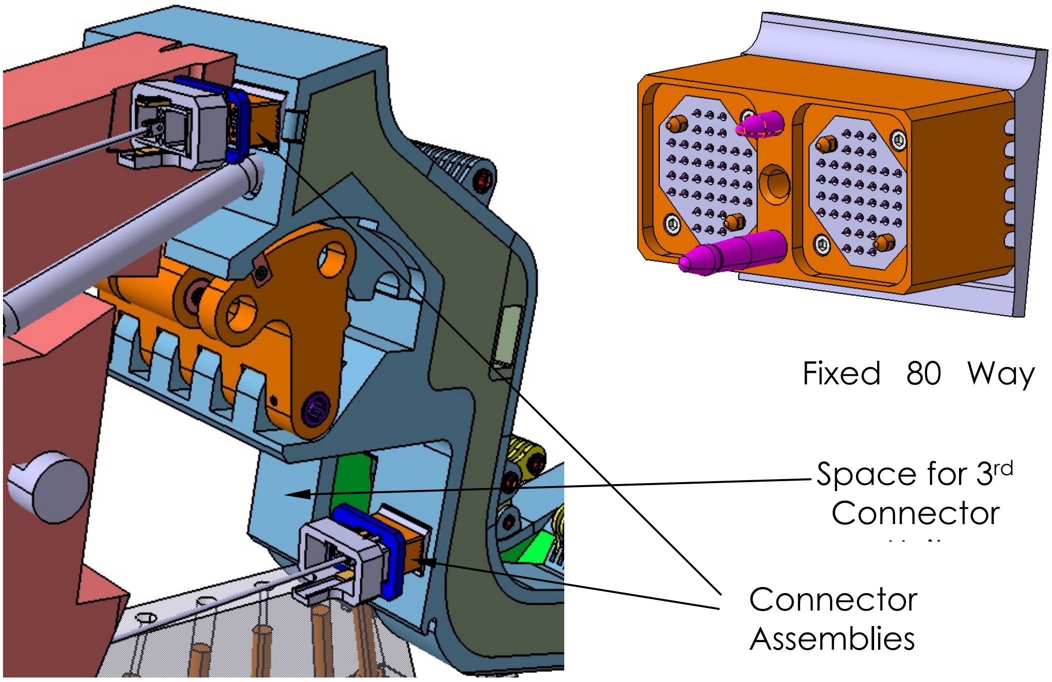


Figure 10.7 : Central Cassette Connectors

The 80 pin Plug Connectors are rigidly fixed to the cassette body. The corresponding sockets are guided on linear slides mounted on the diagnostic rack structure. The mountings incorporate compliant struts that allow the connector to withstand disruption displacements of up to 5mm in any direction (Figure 10.8).

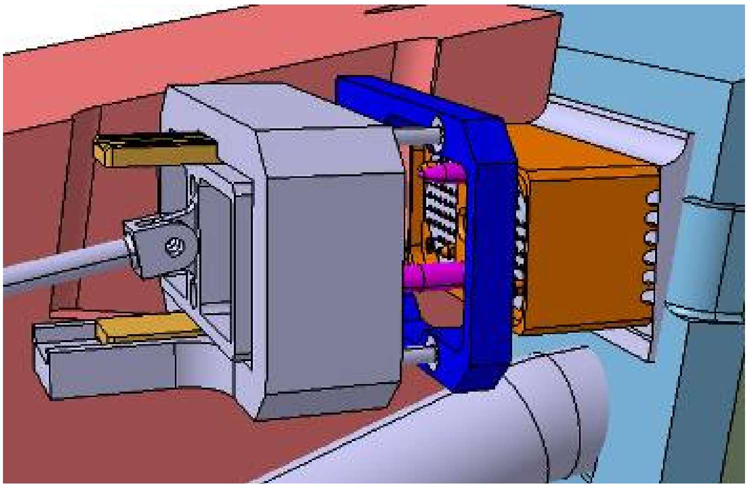


Figure 10.8 : Upper Central Cassette Connector

The sliding sockets are positioned by means of a pushrods and leadscrew drive connector. The leadscrews are located at the outboard end of the diagnostic rack and are accessible to the CMM manipulator which uses a bolt runner to make and break the connector. The pushrods translate the leadscrew motion to the sliding sockets. Locating the leadscrews at the outboard end of the diagnostic rack means that if the thread seizes it can be reached and maintained by the CMM manipulator. The connectors' pushrods are tightened to a torque which provides preload in a compression spring. This ensures that the connector will remain engaged during disruption displacements.

The axis of the linear slides is parallel to the direction of installation of the diagnostic rack at 8° to the horizontal. This means that if the connector cannot be uncoupled by normal means, the CMM is still able to remove the diagnostic rack. The pushrod transmissions have rocker links positioned to ensure the correct line of action of the pushrod on the connector.

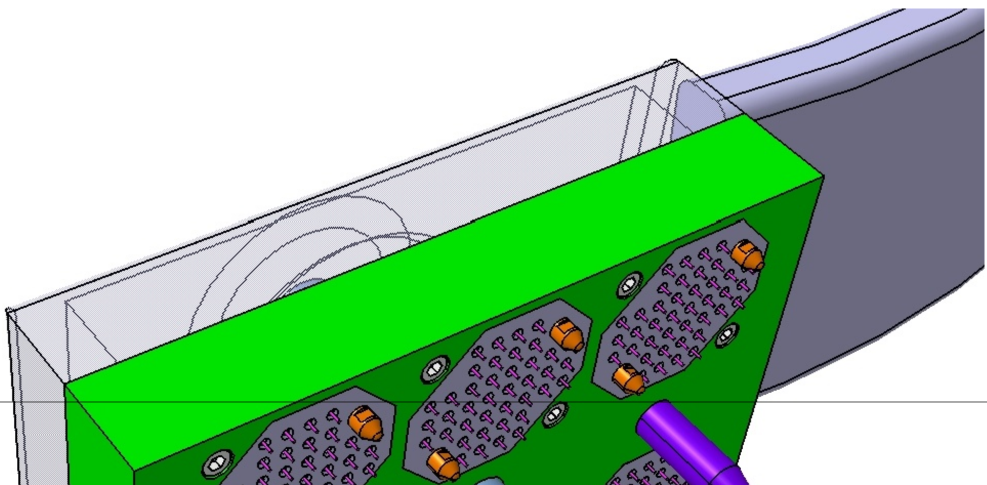
The connector halves are brought into alignment during the insertion by a pair of dowels similar to those used for the side cassette connectors. Each of the 2 connector modules within the plug has two short dowels to achieve the final alignment prior to the electrical pins engaging.

10.3.4. 240 pin Port Feedthrough and Loom RH Connectors

The sections of cables routed through the divertor ports are connected by means of a 240 way connector that incorporates 6 modules of 40 pins. This connector is designed to be handled directly by a manipulator. A central M20 bolt provides the connection and disconnection forces and maintains connection during operation.

A pair of guide pins provides a gradual phased alignment of the connector halves. They prevent the connector from becoming wedged or jammed. This is achieved by the pins being of different lengths, the longer one having a spherical nose and a tapered shank. By engaging this pin in a hole in the socket, 2 degrees of freedom of the plug are constrained by the spherical section. As the pin continues into the hole, the taper gradually brings the connector halves parallel to each other leaving only 2 degrees of freedom: translation and rotation about the pin. The shorter pin then begins to engage in a slot in the socket body. This removes the rotational freedom and permits only fully constrained translation of the plug body into the fully engaged position consistent with the RHCOP guidelines here.

Further protection of the electrical pins is achieved by providing 2 dowels in the opposite corners of each plug module to further constrain the precision of engagement to better than 0.2mm. This arrangement ensures that the electrical pins cannot be damaged by misalignment of the connector halves.



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11. ITER remote handling standards for – Fluid Couplings

11.1. Water Connectors

To ensure remote handling compatibility the preferred connector type for water circuits is the STÄUBLI quick release coupling for nuclear confinement cell applications – designated RBE. This is a stainless steel 316L connector which incorporates a raised button for disconnection using an Manipulator(figure 11.1).

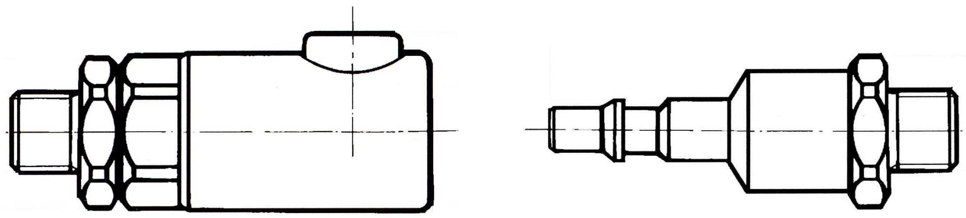

Figure 11.1 : STÄUBLI RBE Connector

STÄUBLI RBE connectors come in a range of sizes (table 11.1).

Connector Size	Nominal Diameter	Standard Pressure Rating	High Pressure Rating
RBE 03	3mm	50 bar	400 bar
RBE 06	5.5mm	50 bar	450 bar
RBE 08	8mm	50 bar	400 bar
RBE 011	11mm	50 bar	350 bar
RBE 19	19mm	50 bar	400 bar

Table 11.1 : STÄUBLI RBE connector range

Double shut-off couplings (plug and socket) must be specified.

For detailed information about RBE connectors, including dimensions and temperature ratings, refer to a current STÄUBLI catalogue .

The use of couplings with diameters larger than those specified in table 11.1 or a specifically designed coupling is only possible after obtaining approval from the ITER Remote Handling Section.

Connectors with nominal diameters up to 11mm can normally be handled directly by the servo-manipulator where access is available.

The minimum allowable clearance between maximum diameters of adjacent couplings is 40mm. This clearance allows connectors to be handled directly by the servo-manipulator.

To aid remote handling of connector and flexible hose assemblies a grasp feature with the standard servo-manipulator grasp profile can be incorporated (figure 11.2).

Male and female connectors can be configured as either the fixed or the removable part of the joint. Reversing connector gender is one method which can be used to avoid incorrect connection of supply lines.

Fixing the male connector has the advantage that releasing of the joint only requires one arm of the servo-manipulator – to simultaneously grasp the connector and depress the release button.

The hose connected to the female part is to be flexible enough to allow for an axial stroke sufficient to avoid damage to the cylindrical sealing surface of the male part.

Where possible O-ring seals are to be Nitrile (standard STÄUBLI supply), however, Flourocarbon (Viton) seals can be specified if required.

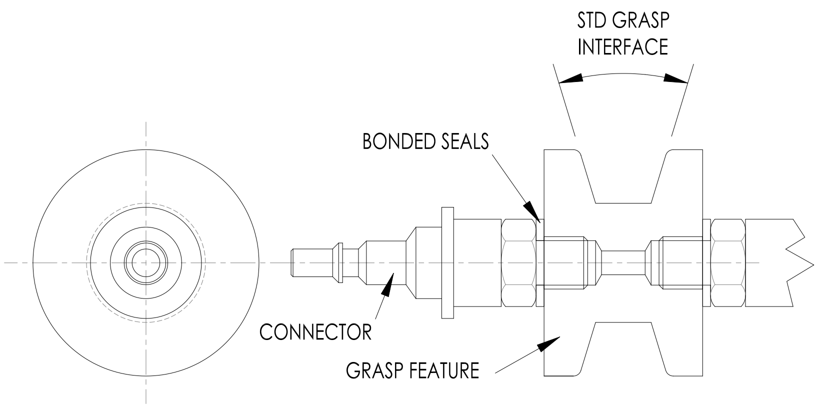

Figure 11.2 : Water Connector Grasp Feature

Each division responsible for the installation of the connectors must make sure that proper quality control is carried out before acceptance and after installation (including welding effects etc.).

A manual functional test of coupling and un-coupling should be carried out to ensure that the operation is correct and requires the expected force to be applied to make or break the connection.

All connectors between equipment and jumper cables or jumper pipes should normally be mounted with their axis vertical (preferably downwards) but never at an angle greater than 30 degrees to the vertical. If this disposition is not possible an extra support is needed to avoid the bending of the cable or pipe at the connector.

The standardised thread to be used on all water connectors is British Standard Pipe (BSP) – both parallel and tapered forms.

11.2. Pneumatic Connectors

To ensure remote handling compatibility the preferred connector type for pneumatic circuits is the STÄUBLI RBE connector.

The preferred nominal diameter for pneumatic connectors is 8mm, however, where air consumption or safety considerations determine a larger diameter 11mm nominal diameter is acceptable.

The design features adopted for pneumatic connectors are the same as for the water connectors.

All connectors between equipment and jumper cables or jumper pipes should normally be mounted with their axis vertical (preferably downwards) but never at an angle greater than 30 degrees to the vertical. If this disposition is not possible an extra support is needed to avoid the bending of the cable or pipe at the connector.

12. ITER remote handling standards for – Flanged Joints

For RH compatible bolted or clamped flanged joints relevant to ITER applications refer to the ITER Vacuum Handbook.

13. ITER remote handling standards for – Cryogenic compatible Couplings

New chapter to be included in a later Issue.

14. Design and Development of The ITER Remote Maintenance System Equipment

14.1. Baseline ITER Remote Maintenance System (IRMS)

The baseline IRMS, its operating regime and its configuration is given in the IRMMS chapter 10.

The IRMS operating regime is described in the IRMMS section 10.1.

The IRMS baseline for all areas except the Hot Cell is described_in the IRMMS section 10.2 .

The IRMS baseline for the Hot Cell is described in the IRMMS section 10.3 .

14.2. IRMS Equipment Life Cycle

A large proportion of the IRMS handling systems will be bespoke and prototypical in their nature. It is vital for the success of ITER that all of the IRMS and particularly the bespoke equipment will be subject to a rigorous and reliable design, development and qualification process.

The overall life cycle for IRMS equipment is described in the IRMMS section 10.4.1 .

14.3. Principles for the specification and selection of RH Equipment

All equipment to be supplied for the IRMS will be specified by the IO RH team.

The IRMS equipment covers a wide range of differing systems and will need to be integrated and supported in service by the IO team.

The specification process will take account of the following main aspects:-

- Equipment functional requirements
- Equipment performance requirements
- RH Human-Machine-Interface (HMI) requirements
- Acceptance / Qualification requirements for RH operations status
- Preventative maintenance in-service requirements
- Safety requirements
- 3rd party licensing and statutory requirements
- IO Quality requirements
- Recovery from failure requirements
- IRMS – Plant interface requirements
- In-service condition monitoring and fault identification requirements
- Operating area environment constraints (thermal, radiological etc)
- Rationalisation of equipment to ease support in service

- Standardisation of equipment to ensure cost effective spares policy
- Materials compatibility with the operating environment

14.4. Principles for the acceptance and proving of new IRMS equipment

New IRMS equipment will be delivered to IO site and acceptance tested against the relevant Procurement Technical Specification (PTS).

After satisfactory completion of the acceptance processes all new IRMS equipment will be subject to a further period of proving trials in order to become qualified for fully remote operations.

The proving trials will be organised and run by the IO RH team and will take the form of mixed mock-up operations activities and stand-alone test operations. The proving trials will address the following aspects:-

- Reliability
- Failure mode behaviour
- Feasibility of rescue after failure
- Ease of fault location and maintainability
- Ease of use

The proving trials will occupy almost 20% of the total life cycle time and will invariably result in identification of design changes – both urgent and longer term.

At the successful end of the proving trials the IRMS equipment will be considered as qualified for remote operation use and a Statement of Readiness form must be raised and approved.

14.5. Principles for the support of IRMS equipment during RH operations

The IRMS equipment in operational service will be supported by a team of IO maintenance engineers supported by specialists with detailed knowledge of each equipment and sub-system.

The support activities required during equipment operation will include:-

- Preventative Maintenance
  - Periodic replacement of consumables & short life parts
  - On-line condition monitoring
  - Periodic visual inspection
  - Periodic functional and performance testing
- Response to failures in service
  - First line call-out procedures
  - Fault isolation and diagnosis methodologies
  - Rescue procedures and activities
- Fault Reporting and Corrective Action System
- Tracking of IRMS equipment location and radiological status
- Control and management of spares and maintenance/service manuals

A more detailed explanation of the IRMS equipment support in service functions is provided in the IRMMS.

14.6. Principles for the design of new IRMS RH equipment

The principles for specification of IRMS equipment will be influenced by the general and constraints described and defined in the IRMMS.

The following sections here provide guidance on methods for implementation of the principles.

14.6.1. General constraints

14.6.1.1. Modularity

> "All IRMS equipment must be designed to be modular for ease of assembly, fault location and repair. Modules should take the form of Line-Replaceable-Units with simple interfaces to facilitate their removal and replacement"

Line Replaceable Units (LRU's) will comprise single integrated units with the characteristic of being readily removable from its in-situ-location without significant removal of other items.

For IRMS equipment which will operate within the active areas then the LRU's must designed to be easily disconnected and handled by personnel who will be working in full pressurised air-line fed suits with double (or triple) layer rubber gloves on their hands. The personnel will be working for limited periods inside a controlled area and will have the support of craneage and dedicated support jigs and fixtures.

IRMS equipment which will be located in clean and accessible areas during operation, e.g control system cubicles, then the LRU's need to be designed for ease of replacement by personnel in normal laboratory clothing. These LRU's must be designed to facilitate the fault location and repair processes and will typically be at electronic board level.

14.6.1.2. Recovery after failure

> "All IRMS equipment (which operates within the active areas) must be designed to ensure remote rescue after failure."

Recovery after failure can be achieved in one of two ways. Either the IRMS equipment will have on-board capabilities incorporated to ensure that there is sufficient redundancy of actuation and sensing so that the equipment remains operational and can be driven out of the active area. Or, there will be a separate rescue system which can be deployed with the primary aim of detaching the failed equipment from its location and moving it to a suitable maintenance area.

The preferred method for recovery after failure is to implement a rescue using a separate and dedicated ‘rescue’ system. In this case the IRMS equipment must incorporate suitable mechanical latches and decoupling devices suitable for the rescue system to engage with the failed equipment, to release the failed equipment from its locked position and to then remove the failed equipment out of the active area and transport it to a maintenance/repair area. These rescue activities will require incorporation of many specific features into the IRMS equipment to enable the grappling of it by the rescue system and the mechanical release of joint actuators.

In some cases where access will be impossible or very difficult to adopt the rescue approach then the IRMS equipment must be designed and proven for a ‘fail operational’ mode. The IRMS equipment will incorporate sufficient redundancy of actuator and sensor to allow the system to remain working albeit at a degraded level of performance. This approach requires considerable analysis of failure mode and effects in order to identify the suite of credible failures which will lead to incorporation of redundancy. The resulting IRMS equipment will be complex and will require more than normal proving of function and reliability.

14.6.1.3. Fail safe

> “All IRMS equipment must be designed to ensure ‘safe’ conditions after any failure “

For a manipulation system this shall be fail to a stopped condition, for RH tooling this shall mean fail to stopped condition and with all appropriate power and services switched off, for viewing and similar sensing equipment this shall mean fail to a stopped condition but with camera/sensor signals remaining available if possible.

Failure modes will vary depending on the equipment and it is impossible to provide design standards for every possibility. However as a matter of principle all actuators on the IRMS manipulation systems should have brakes which apply braking at all times that their power is off. Similarly all system controllers must have at the lowest level a ‘watch dog’ timers to ensure their operational integrity and in the event of a failure to respond will automatically switch off all power to actuators.

14.6.1.4. Adaptability

"All IRMS manipulation equipment must be designed to accommodate extensions and adaptations for new tasks over the medium to long term"

Adaptability is required for the IRMS equipment in three timeframes:-

- Short term adaptability – day/week timescales
- Medium term adaptability – month/year timescales
- Long term adaptability – IO programme timescales

Best practise guidance:-

- Short term adaptability is required to be able to deal with unexpected changes in task requirements which become apparent only during remote handling operations. Typically, the components being handled are discovered to be different or damaged. Short term adaptability of IRMS equipment which is used within the active areas requires the ability to integrate very quickly new types of tooling or adjustments to the plant interface elements. These changes will be implemented by manual intervention within the suited hands-on controlled areas and a modular design of IRMS equipment is essential to be able to respond quickly. Short term adaptability of IRMS equipment which does not enter the active areas is no less demanding as unexpected events during remote handling operations will also create demands for immediate changes to software and sensor interfaces. These are also facilitated with modular design and implementation of the IRMS software and control system hardware.

- Medium term adaptability is required to be able to respond to new RH task requirements in the inter-shutdown time frame. The IO operations programme will generate changes to IO plant with the consequent knock-on effect to RH. It will be required to handle IO plant of a significantly modified form and also new IO plant. The modular nature of the ITER machine and the use of standard interfaces to the tokamak help to minimise the impact on RH but the repair and refurbishment of modified and new plant will have a potentially significant impact on the IRMS Hot Cell systems. The time and cost involved in creation and proving of new IRMS equipment is significantly longer than the time available between plant modification and the IO shutdowns and so all IRMS systems will need to be adaptable to these plant changes by extension and modification rather than by replacement. Medium term adaptability in IRMS equipment will be facilitated by its modularity and also, where possible, by the adoption of a Transporter/End-effector/Tools (TET)configuration. In terms of relative impacts the design and development of a new tool system compares to that of an end-effector system and a transporter system in the ratio of 1 : 5 : 100. With IRMS equipment configured in this way then short term adaptability will be provided by relatively low cost/impact changes to tools whilst medium term adaptability will be provided by changes to medium cost/impact end-effectors. Changing of transporters is out of the question for short and medium term adaptability.

- Long term adaptability is required to be able to respond to long term changes with the overall IO programme. If major changes are proposed to the IO plant, e.g the introduction of a completely new divertor concept, magnetic diagnostics, fuelling or blanket system then the IRMS equipment must be able to respond to these changes without a major replacement and development of the basic infrastructure, equipment and methodologies. Similarly as the IO programme develops then many of the IRMS equipment technologies will become out of date and will need replacement or refurbishment. The ability to respond to equipment 'life' type of changes is facilitated if the IRMS system is modular. The ability to adapt to major changes of the IO machine is facilitated both by the TET configuration but also if the IRMS equipment avoids major mechanical interfaces to the IO plant.

14.6.1.5. Facilities to deal with on-board fire

"All IRMS equipment must be designed to detect and extinguish on-board fires"

Best practise guidance:-

- Fire risk inventory on IRMS equipment should be minimised
- High voltage cables and connectors should be segregated and screened
- Smoke detectors to be installed on the IRMS with feedback to the control room
- Provision to purge the IRMS with a Tokamak compatible fire extinguishing medium

14.6.1.6. Elimination of Common-Mode Failures

"All IRMS equipment must be designed so ensure that no common mode failures can occur. Particular care must be taken to separate and protect key power and signal lines from each other and from any possible contamination by hydraulic fluid after failure."

Best practise guidance for the avoidance of common mode failures situations :-

- Segregate primary and redundant power/signal lines from each other
- Avoid using a common voltage supply &/or return rail for all sensors
- Shroud all hydraulic connectors from electrical connectors – assume that hydraulics will fail in the form of a spray mist

14.6.1.7. Minimisation of preventative maintenance activities

"All IRMS equipment must be designed with the aim of zero routine/preventative maintenance. The ITER policy for IRMS equipment is to maintain on failure and to require the incorporation of facilities to enable remote monitoring of the condition of the equipment and to provide advanced warning of impending failure. "

Best practise guidance for minimisation of preventative maintenance :-

- Use large design margins for candidate components e.g bearings and actuators
- Remote condition monitoring will require the incorporation of sensors into key components
- Avoid the use of cables (tendons) & ribbons for mechanical transmission

14.6.1.8. Control of contamination

"All IRMS equipment must have provision for control of contamination by means of (in order of preference):-

- Design features to prevent ingress of contamination to the inside of the equipment
- Design construction to facilitate post operation decontamination from particulate by swabbing and disassembly followed by aggressive cleaning of component parts
- Design of features to install a protective, removable, layer of working area compatible flexible material "

Best practise guidance:-

- Where possible and consistent with other requirements then use fully sealed units
- Shroud (gaiter) IRMS equipment with removable flexible (Tokamak compatible) material
- Use a low pressure gas to purge gaiters
- Use materials and sub-components which are compatible with the ITER Hot Cell decontamination processes

14.6.2. Mechanical constraints

"Whenever possible IRMS equipment actuation systems should be electrically based. Hydraulic power systems should only be used on IRMS equipment when there is no practical electrical alternative."

"IRMS Equipment must not contain any materials which are known to be incompatible with the working environment. In particular inside the ITER torus and related vacuum systems."

"All IRMS equipment must be manufactured and assembled to ITER QA standards and relevant statutory lifting/robotic safety standards."

Best practise guidance:-

- Materials which are unacceptable for use on IRMS equipment can be found in the ITER Vacuum Handbook.
- The relevant QA and Statutory standards are given in the ITER Quality Assurance Manual.
- The appropriate design and proof load safety factors are given in the ITER Quality Assurance Manual.

14.6.3. Control System and HMI constraints

"All IRMS equipment should include provisions to ease fault location including:-

- Built-In-Test
- Control sensor connection points
- Diagnostic sensors
- Cabling/connector specific fault isolation facilities "

Best practise guidance:-

- All guidelines for the design, build and operation of the ITER RH control systems and the Human Machine Interfaces will be described in the ITER Remote Handling Control System Handbook (to be issued).

15. Preparation and Implementation of Remote Handling Operations

15.1. Overview

The implementation of ITER Remote Handling operations will be achieved through the successful integration of people, procedures and systems.

Remote operations will be performed under a man-in-the-loop philosophy with computer assistance by trained operators performing tasks according to a pre-defined set of procedures.

The operations will be commanded and monitored from purpose built control rooms.

It will be essential for efficient operations that detailed preparations are made in advance for planned tasks but not forgetting the need to accommodate unplanned tasks which will occur only after the remote operations campaign has started.

The overall organisation and management of remote operations is described in the IRMMS.

15.2. ITER Remote Operations Life Cycle

The processes required for preparation, implementation and continuous improvement of the ITER remote operations are described in the form of the through life cycle as shown in the IRMMS (fig 11.1.1).

15.3. Management Controls for ITER Remote Operations

The management controls and processes involved in remote operations are defined in the IRMMS.

Templates for the remote operations management control documents can be found as follows:-

- Operations Sequence Description — OSD form
- Mock-up requirements Specification — tbd
- Virtual Reality Requirements Specification — tbd
- RH Operations Documentation Release Form — DRF form

15.4. Preparation for Remote Operations

The RH operations preparation phase comprises the following steps:-

- Planning and definition of an ITER shutdown leading to RH task requirements
- Characterisation of the RH tasks in terms of their novelty and challenge to RH operations capabilities
- Development of a manipulation/handling methodology
- Negotiating and obtaining agreement from all stakeholders of the overall handling methodology
- Development and validation of the necessary RH operations detailed procedure(s)
- Training and qualification of RH operations staff

15.4.1. Task Characterisation and Assessment

Remote handling task characterisation and assessment will be performed at an early stage by a remote handling engineer. The assessment will be made using the Remote Handling Compatibility Checklist given in annexe -1.

15.4.2. Operations Documentation

The ITER Remote Handling Operations Documentation System (IRHODS) is described generally in the IRMMS.

The detailed methodology for creation, validation and issue of RH operations documentation can be found in the IRMMS.

15.4.3. Mock-ups

Mock-ups and bench test rigs are a key part of the process for remote operations development and task validation. Virtual mock-ups are used for task procedure development by default, physical mock-ups are used for testing and validation where the tasks are either novel and challenging or involve physics characteristics which cannot be reliably represented in a Virtual mock-up.

The physical mock-ups for ITER tasks are:-
Divertor Test Platform

- Blanket Test Facility
- Test Stand

15.4.4. Training of operations staff

The general approach to training ITER remote handling operations staff is described in the IRMMS.

15.5.

Implementation of Remote Operations

All RH operations will be conducted under the IO Safe System of Working rules and regulations.

ITER remote operations will be conducted by multiple teams of operators and engineers organised and managed to ensure round the clock operations.
Each team will comprise:-

- IRMS equipment operators
- RH Operations Engineers
- RH Operations Support Engineers

Each of the roles and the requisite qualifications is described in the IRMMS.

During remote operations activities and in addition to performing the tasks according to remote handling operations documentation the RH operations team will be responsible for the following:-

- Daily update of operating schedules
- Implement pre-task operator refresher training
- Control shift handover
- Prepare operations shift pattern
- Update plant "as-built" information
- Perform routine (daily) checks on support facilities
- Report progress
- Adjust procedures and record non-normal events
- Record task activities "as implemented"
- Record all IMS equipment faults
- Check and Comply with all IRMS operational constraints

16. References

[1] ITER Remote Maintenance Management System (IRMMS) (ITER_D_2FMAJY V1.6)
[2] ITER Vacuum Handbook (ITER_D2EZ9UM)

17. Annexe – 1

Remote Handling Compatibility Checklist

* indicates the stage at which checklist is applicable.

SN	Specification	Conceptual Design Review Checklist **CDR**	Preliminary Design Review Checklist **PDR**	Final Design Review Checklist **FDR**
1	**GENERAL ASPECTS**			
1.1	Provision for space needed by plant and IMS equipment together during the complete handling trajectory ?	*		
1.2	Inspection access facility for plant items to be inspected provided ?	*		
1.3	Self alignment guides with wide capture range and staged capture provided?	*		
1.4	Non-vertical load transfer length sufficiently long and gradual ?	*		
1.5	Plant together with handling system complies with port size, shape and load limits?		*	
1.6	Modules for handling are within the lifting capacity of the relevant IMS equipment?		*	
1.7	Plant with RH equipment attached to it fit within the cask and less than its maximum carrying capacity?		*	
1.8	Redundant lifting attachment points provided ?		*	
1.9	All precision grappling features suitably protected during plant operation ?		*	
1.10	Appropriate provision for measurement / Inspection /calibration after installation ?		*	
1.11	All lifting features / attachment are of RH Section approved design ?			*
1.12	No double(multiple) handling ?			*

1.13	Suitable attachment points for target and datum references for plant items that require meteorology inspection provided?			*
1.14	Clear identification of plant items provided ?			*
1.15	Clear identification of IMS provided ?			*
1.16	Visual cues for gross alignment motions before capture provided ?			*
1.17	Highly reflective surfaces avoided for viewing ?			*
1.18	Design care to ensure no leakage of fluids from plant onto the IMS equipment during handling ?			*
1.19	Provision to ensure no electrical or thermal impact from plant onto the IMS equipment during handling ?			*
1.20	All essential visual cues suitably protected during plant operation ?			*
1.21	All flying leads are short or able to be stowed safely during handling ?			*
1.22	All welded joints accommodate the required number of refurbishment operations ?			*
1.23	No dexterous handling actions within the torus or port cells?			*
1.24	All grappling features are secure even after power failure ?			*
1.25	Disengagement of plant from in-situ only possible after grappling safely secure ?			*
1.26	Provision for handling after credible damage scenarios considered ?			*

2	**FASTENERS**			
2.1	Minimal no. of bolts considered to minimise RH operations ?	*		
2.2	Space envelope required for fastener RH tooling considered?	*		
2.3	Pop-up bolts for installation considered?	*		
2.4	Captive nut considered?	*		
2.5	Lead-in cone with integral shoulder on hexagonal bolt head / Bi-hex bolt head considered?		*	
2.6	All female (nut) side of bolted fasteners are remotely replaceable?		*	
2.7	Spiralok type thread for self locking considered?		*	
2.8	Feathered thread ends shown in the drawing ?			*
2.9	Bolt nose for RH compatibility designed ?			*
2.10	Locking washers for non pop-up fastener considered?			*
2.11	Do all the threads conform to metric thread from BS 3643-1:1981 considered ?			*
2.12	Class of fit for thread joint “8g” in accordance with BS 3643:1981 considered?			*
2.13	ISO metric plain socket heads conform to BS EN ISO 4762:1998 used ?			*
2.14	Hexagonal nut conform to BS 3692:2001. The class of fit “7H”in accordance with BS 3643:1981 mentioned in the drawing ?			*
2.15	Fastener material for RH compatibility considered?			*

2.16	Pilot hole to drill-out in-vessel bolt in case of seizure considered?			*
2.17	Method of replacement of In-vessel insert in the event of damage considered?			*
2.18	Method of recovery of fastener from seizure considered ?			*
2.19	All fasteners are of RH Section approved design?			*
2.20	Design care to ensure that plant fixings do not become loose during operation considered ?			*

3	**PIPES**			
3.1	Celifac type V-flange considered for RH compatibility ?	*		
3.2	Space requirement around the flange to facilitate RH tool considered ?	*		
3.3	Radial spacing around the pipe for joint alignment and orbital butt welding tool provided?	*		
3.4	Radial clearance for circular path of welding trolley for remote replacement of lip joint considered?	*		
3.5	Space envelope for circular port cutting, pulling, expansion and welding tools considered?	*		
3.6	Port size standardised as per IRHCOP ?	*		
3.7	Circular port weld for RH Compatibility considered ?		*	
3.8	Provision for insert ring and welding tool guide for remote orbital butt welding considered?		*	
3.9	Provision to capture all the cutting debris considered?			*
3.10	All pipe sizes and flanges are RH Section approved design?			*

4	**CONNECTORS**			
4.1	Provision for leak detection equipment (e.g helium spraying/sniffing) considered ?	*		
4.2	Provision for remote attachment or placement of visual inspection devices for connectors considered?	*		
4.3	RH compatibility of dowels for electrical connectors provided?	*		
4.4	All connectors mounted vertical ?		*	
4.5	Non – vertical connectors angle less than 30° checked?		*	
4.6	Minimal spacing between connectors about (40mm) for RH by manipulator considered?		*	
4.7	Location of electrical connectors do not interfere with the removal of main component checked?		*	
4.8	Provision for fault isolation before removal from in-situ or repair considered ?		*	
4.9	All electrical connectors are of RH approved design?			*
4.10	Water & pneumatic connectors – STAUBLI RBE quick release couplings considered ?			*
4.11	All cryogenic couplings are of RH Section approved design ?			*
4.12	BSP thread for water connectors considered ?			*
4.13	Minimal cable looms with multiple terminations considered?			*
4.14	All location devices for connectors are of RH Section approved design that progressively reduces the no. of D.o.F available to the handled item?			*

5	**SPECIFIC PROVISIONS FOR REMOTELY WELDED JOINTS**			
5.1	**(a) DURING CUTTING**			
5.1.1	Provision for attachment and alignment of a cutting tool considered ?	*		
5.1.2	Provision for the space required to deploy the tooling and the associated local vacuum cleaner ?	*		
5.1.3	Provision for restraining the two halves of the joint during cutting (accommodation of the joint strain energy) ?	*		
5.1.4	V-shaped register provided for sleeve to locate cutting or welding tool considered ?		*	
5.15	Provision to view/sense the depth and completeness of the cut with the cutting tool in-situ ?		*	
5.16	Feasibility of cutting to a sufficiently high quality for welding ?			*
5.2	**(b) DURING WELDING**			
5.2.1	Provision to remotely prepare the in-situ joint remnants for welding (flattening, rounding, trimming etc) ?	*		
5.2.2	Suitable design feature to accommodate the loss of material when the joint is cut provided ?	*		
5.2.3	Provision of suitable compliance to facilitate the alignment of the two halves of the new joint ?	*		
5.2.4	Provision for applying sufficient holding force to the joint during alignment and also during welding ?	*		
5.2.5	Provision for attachment of the weld tool ?	*		
5.2.6	Provision for the space required to deploy the tooling and the associated local wire feed system (if required) considered?	*		

5.2.7	Provision for a full visual inspection before and after welding ?	*		
5.2.8	Provision (where required by the Welding Quality Control) for Ultrasonic inspection ?	*		
5.2.9	Provision (where required by the Welding Quality Control) for a Radiographic inspection ?	*		
5.2.10	Provision for Helium spraying / sniffing for leak detection / vacuum leak testing after welding ?	*		
5.2.11	Provision for remote cleaning of the completed welded joint ?	*		
5.2.12	Suitable provision for refurbishment of stub remnants after multiple cutting and re-welding ?	*		
5.2.13	Provision of space and interface features for weld inspection ?	*		
5.2.14	Multi-pass wire fillet joints avoided?		*	
5.2.15	Provision for weld purge gas supply and measurement ?		*	
5.1.16	Provision for shroud gas supply and measurement ?		*	
5.1.17	All welded joints are of RH Section approved design ?			*
5.1.18	Weld quality standards have been established ?			*

6	Interfacing agents approval			
6.1	ITER Plant Definition form (PDF) prepared?	*		
6.2	Task Definition form (TDF) prepared ?	*		
6.3	System requirement document (SRD)reviewed ?	*		
6.4	ITER Remote Handling Compatibility assessment form (RH-CA) prepared ?	*		
6.5	RH sub-system analysis approval obtained from RH section RO ?	*		
6.6	System Interface Control Document (S-ICD) reviewed ?		*	
6.7	For class-1 & class-2 components Mock-up facility requirements defined ?		*	
6.8	CMM of plant component approved by TIDH ?			*