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Specifica tecnica per la realizzazione dell'avvolgimento della bobina di JT-60SA

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SPECIFICA TECNICA PER LA REALIZZAZIONE DELL'AVVOLGIMENTO DELLA BOBINA DI JT-60SA

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This technical specification defines the detailed technical requirements for winding pack manufacture, winding pack integration into the casing structure, and final machining requirements of the casing for 9 JT-60SA Toroidal Field Coils in charge of ENEA.

This document is issued for the execution of the Agreement of Collaboration between Fusion for Energy, CEA and ENEA for the joint implementation of the procurement arrangement for the design and manufacture of the toroidal field magnet for the Satellite Tokamak Programme.

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§ 1 Introduction

§ 1.1 Background Information on the JT-60SA TF Magnet

The mission of the JT-60SA project is to contribute to the early realisation of fusion energy by addressing key physics issues for ITER and DEMO. JT-60SA is characterised by 18 toroidal field, 4 central solenoid and 6 equilibrium field coils. All of these coils are superconducting, cooled by supercritical helium at 4.4 K and thermally protected in a cryostat.

The mechanical interfaces for the TF magnet include: the gravity support, which is attached to the lower outboard side of the coil; the lateral bearing support pads, which are located on the sides of the TF coil casing and support any lateral loads on the TF coil in normal operation; the adjacent TF coil, through the inner intercoil structure bolted joint; and the helium inlets and outlets, which are located in the joint region of the coil and provide a flow of supercritical helium at 4.4 K through the conductor and casing. The electrical interfaces for the TF magnet include: the connection to the JT-60SA power supplies; and the instrumentation connection to the control system.

The nominal operating current for the TF coil is 25.7 kA providing a peak field of 5.65 T on the TF conductor during machine operation.

The requirements and data described herein may be changed following the change procedure agreed by the parties.

§ 1.2 Scope of the Document

The subject of this specification is the manufacture and integration of the 9 TF coil winding pack into the TF coil casing, including subsequent machining operations on the casing structure, packaging and transport to cold test facility. The technical specification defines the detailed technical requirements for winding pack manufacture, winding pack integration into the casing structure, and final machining requirements of the casing.

Since the casing components and the conductor will be free issued to the Contractor, technical details of these components are specifically excluded from this technical specification.

§ 1.3 Design and Manufacturing Validation Test Program

There are a number of aspects of the design and manufacture for the JT-60SA TF coil that require validation prior to their adoption.

Since the validation is linked to the manufacturing process, this validation shall be proposed and carried out by the Contractor. In general, this validation could be carried out using any of the following means:

- Manufacture and testing of one or more partial mock-ups which is representative of the final design geometry using the proposed manufacturing processes, or

- By review of similar manufacturing processes which have been carried out previously in the same facility, and have demonstrated success in a similar operating environment.

The Contractor shall propose a Validation Program including validation of all items as requested by the technical specification. The Validation Program will form part of the Control Plan as required by the Management Specification. The actual requirements for items which require validation are included in the body of the document.

The Contractor shall present a list of all processes that they deem necessary to be included in the validation program to ENEA. This list is to include a justification of all validation steps. As a minimum, the validation of the following manufacturing processes is suggested prior to the commencement of coil manufacture:

- Bending and forming conductor using the production procedure
- A 3 x 3 grid demonstrating the shear capacity of the insulation after impregnation.
- Transverse and closure plate welding test on a significative coil cross section
- Repairing procedure on defect of welded coil casing
- One double pancake prototype manufactured with the superconducting dummy conductor.
- The helium inlets, including the installation of insulation on a representative sample of this area of the coil.
- Internal full size joint. Tests at cryogenic temperature shall be performed by ENEA.
- Terminal full size joint sample if a different design than internal joints. Tests at cryogenic temperature shall be performed by ENEA.
- Impregnation process on a beam that simulates a part of the casing.
- Embedding process, which could be carried out on the same beam as described above.

It remains the responsibility of the Contractor to ensure that the processes adopted for final manufacture provides an electrically and mechanically sound product which meets all requirements of the technical specification. The Contractor shall submit a list of any additional materials they require to carry out the validation program to ENEA.

§ 1.4 Detailed Procedures

The Contractor is responsible for establishing procedures, each being referred to as a Detailed Procedure, for submission to ENEA for endorsement prior to the commencement of the manufacturing process. Since ENEA relies on the experience of the Contractor to define the process in these cases, the responsibility of the outcome after following the procedure remains with the Contractor.

For each manufacturing process:

- The Contractor shall be responsible for the preparation of the Detailed Procedure covering the actual process;

- At least two calendar months prior to the proposed commencement of the process, the Detailed Procedure shall be submitted to ENEA and ENEA shall provide comments where appropriate on the procedure within two weeks;
- The Detailed Procedure is considered to be a deliverable of the current winding pack contract;

A brief description of the key items requiring a Detailed Procedure is listed in Table 1.1.

Detailed Procedure Number	Related To	Detailed Procedure Descriptions
1	§ 6.2, Conductor Preparation	- Incoming acceptance tests - Straightening, cleaning and sandblasting the conductor prior to any manufacturing operations
2	§ 6.3, Helium Inlet	- Machining of helium inlet - Welding of helium inlet - Weld integrity checks for the helium inlet
3	§ 6.4, Conductor Winding	- Wrapping of insulation - Winding of the conductor - Preparation and protection of the conductor ends after pancake winding, but prior to installation of the joints - Geometrical measurement of the double pancake after winding.
4	§ 7.1, Double Pancake Stacking	- Proposed method for stacking of the double pancakes. - Geometrical and electrical measurements during stacking of the double pancakes.
5	§ 7.2, Internal Joints and terminals	- Design, manufacture, installation and testing of internal joints and terminals
6	**Errore. L'origine riferimento non è stata trovata.**, Fillers	- Installation of the fillers of the DP and mounting of the joint region filler.
7	§ 7.5, Ground Insulation	- The method for wrapping of the ground insulation around the complete winding pack - The method for wrapping of the ground insulation around the joint region, including the

Detailed Procedure Number	Related To	Detailed Procedure Descriptions
		internal joints - The method for wrapping of the ground insulation around the helium inlet region
8	§ 7.6, Winding Pack Impregnation	- Process for each winding pack impregnation including the curing process prior to installation of the winding pack into the casing structure.
9	§ 8.2, Winding Pack Installation into Casing	- Insertion method, including orientation of structures, manipulation of spacers, and proposal for control of the winding pack centreline - Method for measuring and externally marking of the winding pack centreline.
10	§ 8.3, Casing Assembly and Welding	- Control of spacers on inboard side of casing - Installation of inboard cover plates including, support for winding pack and closure plates - Completion of components assembly and transverse welds, including distortion control during completion of welds - Inspection of all assembly and transverse welds - Completion of closure welds, including distortion control - Inspection of welds
11	§ 8.4, Winding Pack Final in-case Impregnation and Cure	- Winding pack final in-case impregnation and cure
12	§ 9.1, Joints Support and Protection	- Design, manufacture and installation of internal joint support - Design, manufacture and installation of internal joint protection - Electrical grounding tests of the joint support
13	§ 9.2, Casing Interface Machining	- Machining process, including proposed support method and orientation for coil, and control of winding pack centreline

Detailed Procedure Number	Related To	Detailed Procedure Descriptions
		- Measuring process of coil after machining
14	§ 9.3, Helium Cooling Pipes	- Design, manufacture and installation of helium cooling pipes - Insulation of helium pipes - Support of helium pipes - Description of the tests, including leak test and pressure drop measurement
15	§ 5, Handling Operations	- Procedure for all handling and craning operations which are considered necessary for the completion of manufacture

Table 1.1 - List of Detailed Procedures

§ 1.5 Workshop Cleanliness

All manufacturing operations shall be performed under clean conditions. Particular care must be taken to ensure the following:

- The area in which any operation is being carried out is generally clean and free from debris which may contaminate the process or contribute to damage any of the TF coil components under manufacture.
- Any other non related processes which may be carried out in the vicinity of manufacture of the TF coil will not adversely affect the manufacture of the TF coil.
- All coil components shall be protected such that they do not come into contact with unpainted ferritic steel.
- ENEA will inspect the contractor facility prior to the commencement of manufacture.
- During any operations on any component associated with the coil, care shall be taken to prevent the ingress of debris into the winding pack.
- The work area shall be identified, closed and protected.

§ 1.6 Workshop Personnel

All workshop personnel of the Contractor involved in any manufacturing operation shall be informed of the special requirements of the work associated with the TF coil manufacture. In particular:

- It is essential that workshop personnel do not deviate in any way from the design, or make repairs to resolve any manufacturing issue, without ENEA involvement. As such, there must be an open channel of communication between technical responsible officer and ENEA.

- Conductor cleanliness is a key issue. During all operations involving the conductor, any openings, such as the conductor terminations and helium inlets, shall be protected against damage and the ingress of any particulate or liquid material.
- All personnel entering the area of the TF coil manufacture shall be informed of the importance of the points as noted in § 1.5..

In relation to the above points, ENEA must be present while workshop personnel are informed of these requirements.

§ 1.7 Contractor Quality Documentation

§ 1.7.1 Procedure Data Package

On delivery of each coil, a Procedure Data Package shall be compiled including:

- All of the Detailed procedure and tests that were performed,
- Evidence by signature of the technical responsible officer,
- Details of any modifications made to the Detailed Procedure including a description of why the modifications were required, and
- Each modification implies the issue of a notification of the change to ENEA.

§ 1.7.2 Works Acceptance Data Package

For each TF coil, quality documentation is required and will form part of the Acceptance Data Package for the complete coil. This must be delivered with the coil to the cold test facility. Unless otherwise stated in the relevant section of the Technical Specification, the following records shall be provided after completion of manufacture:

- The complete Acceptance Data Package as received by the Contractor for:
  - the casing components, and
  - each unit length of conductor.
- Records detailing the outcome of all acceptance testing. In all cases, where visual inspection is specified, a series of photographs documenting the acceptance testing is required.
- Records associated with non conformities, including the following information:
  - detail of the non conformity,
  - agreement reached with ENEA, Fusion for Energy and, where appropriate, JAEA, for the resolution of the non conformity, and
  - evidence of the resolution for the non conformity including supporting analysis.

- Records detailing any design changes which have been incorporated in the actual manufacturing process. Where design changes have been carried out, the following shall be included:
    - o the technical details of the design change,
    - o the implications of the design change on the manufacturing process, and
    - o agreement reached with ENEA for the design change.
- Results of all measurements carried out during manufacture.
- Material certificates for all raw materials, including welding materials, used during the manufacturing process.
- Detailed Record (or As-Built) Drawings (showing known as built representation of the coil), including a bill of materials identifying all sub-components in the assembly, for the complete TF coil.
- Traveller of all the operations carried out during manufacture of the coil. The Traveller shall include:
    - o reference numbers for all of the sub-components of the coil, including reference numbers for the:
        - conductor,
        - electrical breakers, and
        - casing components.
    - o acceptance report for the glass tape,
    - o for each operation, a reference number, including the version used, of the Detailed Procedure followed,
    - o identification of the machines and test equipment used,
    - o records detailing the outcome of all testing,
    - o date of completion for each operation, including the name and signature of the technical responsible officer,
    - o name and signature of the workshop supervisor during completion of the manufacturing operations
- Original material certificates for the casing, and all the components parts of the helium system, including the:
    - o conductor jacket (delivered with each conductor unit length),
    - o helium inlet components,
    - o components associated with the joints,
    - o helium pipes, and
    - o helium manifolds.

- Copy of welder qualification records where required.
- Copy of the third party pressure test inspections where required.

All of the above documentation shall be included in the Works Acceptance Data Package for the TF coil.

Associated with acceptance testing, ENEA shall be invited to witness all tests.

The presence of ENEA inspector should be agreed according to the control plan. ENEA will be informed 5 working days in advance. ENEA will notify the presence during the test.

The contractor shall add a cover page for each acceptance data package. The cover page shall include a list of documents included in the ADP, and shall be signed by the supplier technical responsible officer and by the supplier quality representative.

The ADP will not be considered complete until the final cold testing has been carried out and the associated documentation included. It remains the responsibility of the Cold Test Facility to complete the final documentation associated with cold testing.

§ 1.8 Codes and Standards

During execution of the work the following codes and standards in their current revision shall be applied. In particular the following standards shall be applied:

- The ASME BPV CODE in general for welding and for welding inspection
- The ASME BPV CODE: SECTION IX , PART QW for welding qualification
- The ASME BPV CODE: SECTION IX for welded coupons inspection
- The ASME BPV CODE: SECTION II Part C for welding filler material
- The ASME BPV CODE: SECTION VIII for pressure vessel
- ASTM E45, Method A for inclusion measurement
- JIS Z3119 for analysing ferrite content in raw material

§ 1.9 Scope of Supply

The scope of the supply is the manufacture of 9 TF coil winding pack, integration into coil casing, packaging and transport to cold test facility. The items as shown in Table 1.2 are included in the scope of supply for one complete toroidal field coil. The items described in § 2 will be free issued to the Contractor.

Item	Description	Quantity
1	Complete coil composed of 6 double pancakes, associated joints and instrumentation, integrated into the casing	1
2	Procedure Data Package	1
3	Acceptance Data Package	1
4	Transportation Frame	1
5	Full set of packaging for the complete TF coil suitable for shipment to the cold test facility in Europe, followed by maritime shipment to Naka, Japan	1

Table 1.2 - Scope of supply for one complete TF coil

§ 1.10 Abbreviations and Acronyms

CICC - Cable In Conduit Conductor
CQMS - Common Quality Management System
DMS - JT-60SA Document Management System
DP - Double Pancake
EUHT - European Union Home Team
F4E - Fusion for Energy (European Implementing Agency for JT-60SA)
JAEA - Japan Atomic Energy Agency
JT-60SA - JAEA Tokamak 60 Super Advanced
NCR - Non Conformance Report
NDT - Non Destructive Testing
OIS - Outer Intercoil Structure
PED - Pressure Equipment Directive
PID - Plant Integration Document
TF - Toroidal Field
TFC - Toroidal Field Coil

§ 2 Free Issue Components

§ 2.1 Conductor

§ 2.1.1 Description of the Conductor

The TF conductor is a Cable in Conduit Conductor, composed of twisted multifilament NbTi and Cu copper strands. The strands are compressed inside a stainless steel jacket, the cross section dimensions of which are as shown in Figure 2.1.

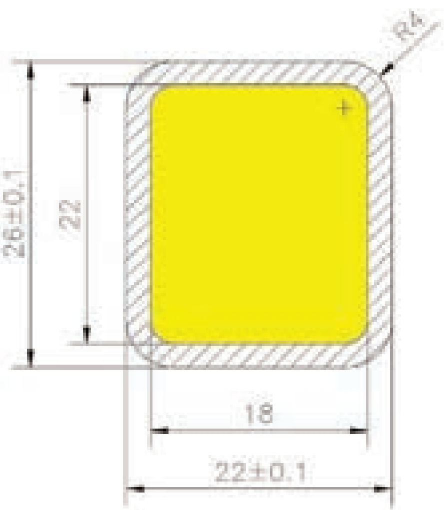

Figure 2.1 - Cross section of the as delivered conductor (dimensions in mm)

The conductor jacket is manufactured from 316L stainless steel.

§ 2.1.2 Condition of Supply of the Conductor

- Six unit lengths, each 240 m long, will be delivered for the coil. There is approximately 12 m of extra length of real conductor per unit length with an additional 10 m of empty jacket at each end of the conductor to assist the winding process.
- Each unit length will be delivered stress free wound and clamped with steel bands as a single layer solenoid with a minimum diameter of 2.3 m. Details of the conductor layout in the as delivered state will be made available to the Contractor such that the winding line can be designed to suit. The direction of spooling is defined as right hand helix.
- The conductor shall be spooled on its widest side (i.e. the long edge) well aligned to the drum without any visible twisting.
- The conductor will be equipped with connecting pipes and a pressure gauge. For reference, a conceptual layout of these components is shown in Figure 2.2.

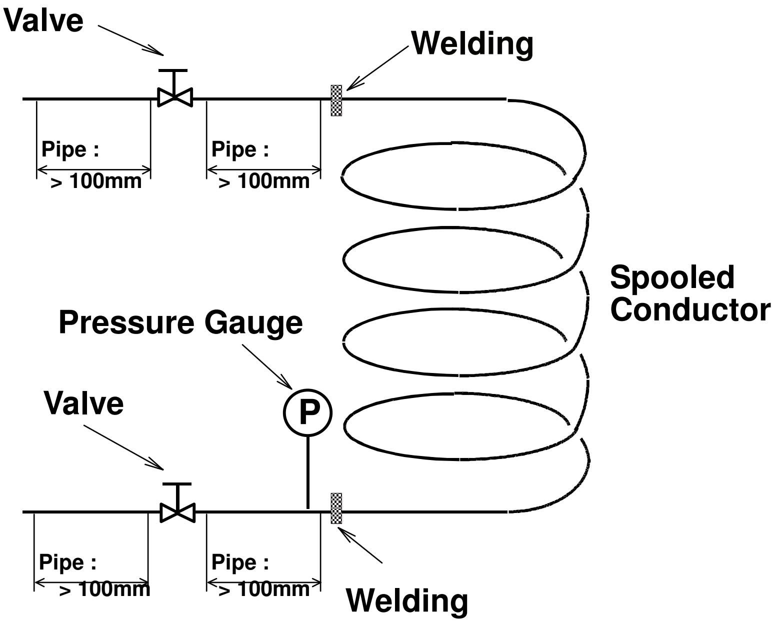

Figure 2.2 - Conceptual schematic for TF conductor in its "as delivered" state

- The conductor will be enclosed in an evacuated bag containing non-halide salt drying agents, and packed in a separate wooden box. The packaging is designed to protect against dust, humidity and mechanical damage. The following items will be printed on the surface of the box:
  - Identification code of the conductor unit length
  - Name of the conductor supplier
  - Measured length of the conductor
  - Gross weight
  - Dimensions of package
  - Date of fabrication (date of packing list completion)
  - Points at which lifting and handling cables may be attached
- It will be sealed and pressurised with inert gas prior to shipment, with the value of pressurisation being recorded prior to delivery.
- Each unit length will be instrumented with 4 x 5 g and 4 x 10 g accelerometers.
- The conductor will be cleaned, free of dust, dirt, moisture, oil, grease or organic component.
- A series of acceptance tests will be performed on each conductor length prior to shipment from the manufacturer's facility. A report describing the results of the tests, the Acceptance Data Package, will be made available to the Contractor.

§ 2.1.3 Design, Manufacture and Supply of Conductor

The conductor manufacturer is responsible for the design of the shipping arrangement of the conductor. The details of the as shipped conductor geometry, including the clamping devices, will be provided at the commencement of contract activities. The conductor delivery shall be agreed between the conductor manufacturer, the coil manufacturer and ENEA and shall be consistent with the manufacturing schedule. The acceptance of the final conductor will be given according to the results of the work tests performed by the contractor. The manufacturer remain responsible of the conductor superconductor performance.

§ 2.1.4 Reference Drawings for the Conductor

Detail of the geometrical layout of the conductor can be found in the following drawings:

- 010202-503110 - Conductor Cross Section, Parameters

§ 2.2 TF Coil Casing Components

§ 2.2.1 Description of the Casing Components

The TF coil casing includes all of the prefabricated structures associated with the TF coil casing, as shown in drawing number 010301-500987. These structures will be finally welded by the Contractor to form a complete TF coil case after the insertion of the winding pack.

The components shall be manufactured with austenitic stainless steel. The chemical composition of the chosen material will be provided to the Contractor prior to the qualification activity reported in § 1.2.

§ 2.2.2 Condition of Supply of the Casing Components

- The casing components will be delivered as welded components prepared for winding pack insertion.
- The casing components shall have the weld preparations machined according the geometry defined by the Contractor.
- To confirm that the fabrications are within specification, a series of acceptance tests are made during manufacture. A report detailing the results of the acceptance tests will be made available to the Contractor. The acceptance tests include:
    - Non destructive testing of all welds;
    - Conformity check on all material certificates;
    - Detailed measurement of key dimensions as shown in drawing numbers 010301-500988, 010301-500989, 010301-500990, 010301-500991, 010301-500992 and 010301-500992 .
- The components will be free from burrs and sharp edges.

- The components will be cleaned and free from oil or other debris.
- The components will be uniquely labelled
- The packaging is designed to ensure there are no permanent deformations in the structures during road transport. The packaging is designed to allow the components to be stored outside.
- The material of construction of the casing components will be 300 series stainless steel.
- As described in § 8.3, the casing components will be delivered with additional material to allow final machining operations.

§ 3 Operational Conditions of the TF Coil

§ 3.1 Number of Loading Transitions

The following number of loading transitions shall be considered for the design:

- TF Coil energisations: 3000
- Magnet cool-down / warm-up from ambient temperature: 100
- Fast discharges: 200

§ 3.2 TF Coil Energisation

One TF coil energisation cycle is defined as an increase of current from 0 to 25.7 kA, followed by a decrease to 0 kA.

§ 3.3 Cool-down and Warm-up

The cool-down of the magnet from 300 K to 4 K shall be achieved within 10 days. The cool-down phase will be determined by the maximum tolerable temperature difference between the helium inlet and the case. The maximum differential temperature between any two positions on the coil shall not exceed 40 K throughout the cool-down phase. The cooling rate shall be limited to:

- 2 $K \cdot h^{-1}$ for temperatures above 100 K;
- 4 $K \cdot h^{-1}$ for temperatures in the range between 50 K and 100 K; and
- 10 $K \cdot h^{-1}$ for temperatures below 50K.

The warm-up phase will be similarly determined by the maximum tolerable temperature difference between the helium inlet and the case. This implies that the maximum differential temperature between any two positions on the coil shall not exceed 40 K, and the heating rates are identical to the cooling rates within the same temperature range.

§ 4 Paschen Testing

§ 4.1 Definition of Paschen Proof

The electrical breakdown voltage of a gas is a function of gas pressure times the distance between the high voltage and the closest ground potential. This function shows a characteristic minimum voltage for each gas. While the minimum breakdown field strength of air at ambient conditions is approximately 3.3 $kV \cdot mm^{-1}$, the minimum breakdown field strength of helium at a pressure of 100 Pa is only 160 $V \cdot mm^{-1}$.

A Paschen proof arrangement is defined as one in which the insulation around all conducting components is sufficient to ensure that the field strength in the surrounding gas does not exceed the breakdown conditions.

§ 4.2 Requirement for Paschen Testing

During a fast discharge of the TF coils voltages of up to 1.9 kV will be induced. In order to avoid arcing between the TF coil system and ground due to the minimum breakdown voltage being reached, all parts of the TF coil which may be subject to high voltage must be appropriately insulated using a dielectric material. Since discharges may develop even along very narrow channels the insulating dielectric must basically form a vacuum tight enclosure around the conducting surface.

§ 4.3 Example Simplified Paschen Test Procedure

A simplified Paschen test can be carried out by introducing low pressure helium at ambient temperature around the coil, increasing the static voltage in the winding, and ensuring that no discharge occurs.

The test procedure shall be as follows:

- Install the test object in a vacuum chamber and connect it to a high voltage source. The high voltage source must be adjustable and have a current limiter at 5 μA.
- Evacuate chamber to a level of 0.1 Pa.
- Ramp-up voltage to 3.8 kV at a rate of less than 150 $V \cdot s^{-1}$, and maintain this voltage for 1 minute and check for any discharge current.
- Ramp-down voltage to 0 kV in 1 minute.
- Increase pressure in the vacuum chamber to 10 Pa by injecting helium gas and repeat the high voltage test at each pressure.
- Increase the pressure in steps to 100, 10^3 and 10^4 Pa and repeat the high voltage test at each pressure.

Purge the vacuum chamber and dismount the component.

Since the Contractor is responsible for implementing simplified Paschen tests on the coil at ambient temperature, a Detailed Procedure is required describing the proposed simplified Paschen testing for the coil. As a minimum, this Detailed Procedure shall include:

- Proposed pressure steps and voltages under which the tests are carried out,
- The time during the manufacturing process when the test(s) are proposed, and
- Technical details of the equipment proposed to carry out the tests.

§ 5 Handling Requirements

During the manufacture of the TF coil, many handling operations are required. In order to minimise the risk of damage to any components due to handling operations being carried out, it is expected that the Contractor will pay close attention to all expected handling operations prior to commencement of the operation.

With reference to, and meeting the requirements of, § 1.4,, the Contractor shall submit a Detailed Procedure for all of the handling operations which are expected to be carried out during the manufacturing process. In developing the Detailed Procedures, the Contractor will consider the complete manufacturing process, and will:

- Attempt to carry out all manufacturing processes with a minimum number of intermediate handling operations;
- Install suitable supports around the components to be handled to ensure that the components do not undergo plastic deformation;
- Ensure that the helium connections are closed to prevent the ingress of particulate or liquid material;
- Ensure that the internal joints and terminal joints, including the voltage taps, are supported and protected;
- Ensure that all pipes are protected from mechanical damage;
- Ensure that there are no loads directly applied to the helium pipes, the internal joints or the cable terminations;
- Ensure that the conductor ends are protected from the ingress of particulate or liquid material;
- Not weld any lifting equipment to any component of the TF coil;
- Ensure that there is no direct contact between unpainted ferritic steel and any of the winding pack or casing components;
- Design and manufacture appropriate jigs and fixtures for all handling processes;

The list of Detailed Procedures depends on the chosen manufacturing process(es), however, it is expected that a Detailed Procedure will be submitted for the following handling procedures as a minimum:

- Lifting of a double pancake in all orientations;
- Turning of a double pancake;
- Lifting of the complete winding pack prior to and after impregnation in all orientations;
- Lifting of the complete winding pack for installation of ground insulation;
- Turning of the complete winding pack prior to and after impregnation;
- Lifting of all casing components;

- Insertion of the winding pack into the casing structure;
- Handling during closure welding;
- Lifting of the complete coil;
- Turning of the complete coil;

Where the Contractor's chosen manufacturing process specifically excludes the possibility of one of the above operations being carried out, it is accepted that a Detailed Procedure is not required. However, in this case, it must be demonstrated that the handling procedure will not be required during manufacture.

§ 6 Double Pancakes

§ 6.1 Double Pancake Design Overview

Each double pancake consists of a 240 m length of cable in conduit conductor wound by a suitable bending device to the final shape. Due to the orientation of the joints each double pancake will be slightly different to the adjacent double pancake. As such, a separate drawing exists for each double pancake, as described in Table 6.1.

Drawing number	Description
010202-503101	Double Pancake Number 1
010202-503102	Double Pancake Number 2
010202-503103	Double Pancake Number 3
010202-503104	Double Pancake Number 4
010202-503105	Double Pancake Number 5
010202-503106	Double Pancake Number 6

Table 6.1 - Double Pancake Drawing Numbers

Prior to winding, the conductor must be cleaned and prepared to allow for the wrapping of the turn insulation. The preparation shall include a sand blasting process prior to wrapping with 1 mm thick glass fibre insulation.

The terminations of the double pancake will be prepared to accept the internal joints and terminals. Since this could be done after winding of the complete winding pack, it remains at the discretion of the Contractor to define when this work will be carried out.

The helium inlets are placed in the region of the transition from the first to the second pancake. This region is on the inner circumference of the winding at the midpoint of the double pancake. Detail of the helium inlets can be found in the double pancake drawing. It remains at the discretion of the Contractor to define when this work will be carried out.

During all manufacturing operations, it is important to consider the requirement that the coils be Paschen proof. As such, when considering design and manufacturing validation and final component testing, Paschen testing at room temperature shall be included.

The manufacture of the double pancakes includes:

- Preparation of conductor.
- Wrapping of turn insulation on conductor.
- Manufacture of helium inlet, including insulation of joint and check of weld integrity.

- Winding of conductor, including manufacture and installation of interpancake insulation.
- Preparation of conductor terminations.

§ 6.2 Conductor Preparation

§ 6.2.1 Scope of Work

Preparation of the conductor includes:

- Receipt of the conductor spool.
- Incoming conductor acceptance inspection.
- In line unspooling of the conductor.
- In line cleaning and sand blasting of the conductor.

§ 6.2.2 Technical Requirements

- The conductor technical specification also describes details of the acceptance tests which will be carried out on the conductor prior to shipment. In the straight condition, the conductor section shall meet the tolerances as specified in drawing number 010202-503110
- The Contractor shall perform incoming acceptance tests as soon as possible after receipt of each conductor length, including, but not limited to:
  - Visual inspection of packaging to check for any signs of damage during transport;
  - Visual inspection of the conductor for signs of damage such as cracks or scratches and confirmation of cleanliness while it is still spooled;
  - Nitrogen flow test and helium leak tests;
  - Review of accelerometers to ensure that the conductor has not seen an acceleration greater than 5 g;
  - Review of the internal pressure to ensure that this has remained constant during transport; and
  - Review of the Acceptance Data Package of the conductor.

  Any non conformance to the above items or claims for damage shall be submitted to ENEA within 15 calendar days of receipt of the conductor.
- The Contractor shall unspool, clean and sandblast the conductor in preparation for wrapping of the turn insulation. The purposes of cleaning and sandblasting are:
  - to minimise the chance of electrical short through any burrs or sharp edges which may exist on the conductor length, and

  - to provide a suitable surface roughness on the conductor surface to ensure sufficient adhesion of the turn insulation such that it has the required minimum shear capacity as quoted below.

  It remains the responsibility of the Contractor to choose the process, including the material, to be used to provide the appropriate surface roughness to guarantee sufficient adhesion between the turn insulation and the conductor to meet the mechanical shear requirement as stated below. Note that only a non ferrous material may be used.

- The turn insulation must not be damaged during winding or any other subsequent operations. In order to prevent insulation damage this could be carried out after bending of the conductor to suit the manufacturer's chosen process. As such particular care must be taken to the overlapping of the turn insulation. It shall be demonstrated that the process for installation of the turn insulation provides an electrically and mechanically sound finish in a repeatable fashion. Demonstration of the process could be achieved:
  - through the use of mock-ups, or
  - by review of similar manufacturing processes which have been carried out previously in the same facility, and have demonstrated success.

  Documentation associated with the above meeting the requirements of § 1.3 shall be forwarded to ENEA for review and acceptance prior to the commencement of manufacturing operations.

- During all operations involving the conductor, any openings; such as the conductor terminations and helium inlets; shall be protected against damage and the ingress of any particulate or liquid material.

§ 6.2.3 Tooling Requirements

In order to satisfactorily prepare the conductor, the following is required:

- Suitable lifting equipment to handle the delivery spool.
- Suitable supports for unwinding of the conductor.
- In line straightening equipment suitable for preparing the conductor for commencement of winding.
- In line cleaning equipment to remove any oil, grease, dirt or other debris from the conductor.
- In line sandblasting or other equipment to prepare the conductor for wrapping of the turn insulation.
- Protective covers to be installed after the valving has been removed from the as delivered conductor.

§ 6.2.4 Testing / Other Measurements

- Visual inspection shall be carried out on the conductor after sandblasting to ensure the conductor is in a suitable condition to bond to the turn insulation.
- Visual inspection shall be carried out on the turn insulation.

§ 6.2.5 Quality Control and Documentation Requirements

The following documents are required prior to the commencement of the conductor preparation process and shall form part of the Procedure Data Package:

- Documented evidence demonstrating that the turn insulation will comply with the shear capacity requirement after impregnation.
- A document which describes the proposed method for cleaning, sand blasting and installation of the turn insulation.

§ 6.3 Helium Inlets

§ 6.3.1 Scope of Work

The helium inlets include:

- Machining of the conductor jacket to accommodate the helium inlet.
- Removal of the cable wrapping.
- The manufacture and welding of the helium inlets.
- Non destructive examination of the welded interface to confirm the integrity of the weld.
- Pressure testing of the welded interface.
- Leak testing of the welded interface.
- The installation of appropriate insulation in the area of the inlets.
- Installation of protection to the helium inlet for subsequent operations.

§ 6.3.2 Technical Requirements

The design and manufacture of the helium inlet is critical for a number of reasons:

- After final assembly of the TF coil it will be completely inaccessible on the machine, hence repairs will not be possible.
- The pressure drop through the helium inlet will be large, so the design must be carefully considered to minimise this pressure drop.
- The associated helium inlet pipework is vulnerable and could easily be damaged if it is not carefully protected.
- The strands inside the conductor are vulnerable during the manufacturing processes.

There are a number of critical points to consider in the manufacture of the helium inlets. These include:

- The helium inlets are located on the inner circumference of each double pancake in the upper area of the winding pack, as shown in the drawing which describes the double pancake (refer to Table 6.1 for more information). The helium inlets shall be welded on a straight part of the conductor, i.e. in a location where there will be no bending during the winding process after the helium inlet has been welded.
- During the machining process for the conductor jacket, it is critical that the strands are not damaged inside the conductor, hence good control is required over the process for cutting the conductor jacket. As stated in § 1.6, care must be taken to ensure that any openings in the conductor are well protected against the ingress of any particulate or liquid material during this process.
- For any hot work which is required on the conductor, the maximum temperature of the inner surface of the conductor should be minimised. The overall thermal load on the strand must not exceed 500 °C for 30 seconds. The Contractor is responsible for developing a suitable Detailed Procedure describing the proposed weld procedure and all controls included during welding to ensure this requirement is met.
- The welding process must be carried out using a process which eliminates the likelihood of leaks during operation. It shall be demonstrated that the process for welding of the helium inlets provides a good quality repeatable weld. Demonstration of this weld quality could be achieved through the use of mock-ups. It is expected that at least one fully welded sample is:
    - Subject to 3 thermal shock cycles using liquid nitrogen, and subsequently examined to confirm the integrity of the welded joint.
    - Both non destructively and destructively tested to confirm that there is no weld defect greater than 0.4 mm in size throughout the weld.

  Documentation associated with the above meeting the requirements of § 1.3 shall be forwarded to ENEA for review and acceptance prior to the commencement of manufacturing operations.
- The process for welding shall begin and end in the weld region of lowest stress, parallel to the side of the conductor, as shown in Figure 6.1.

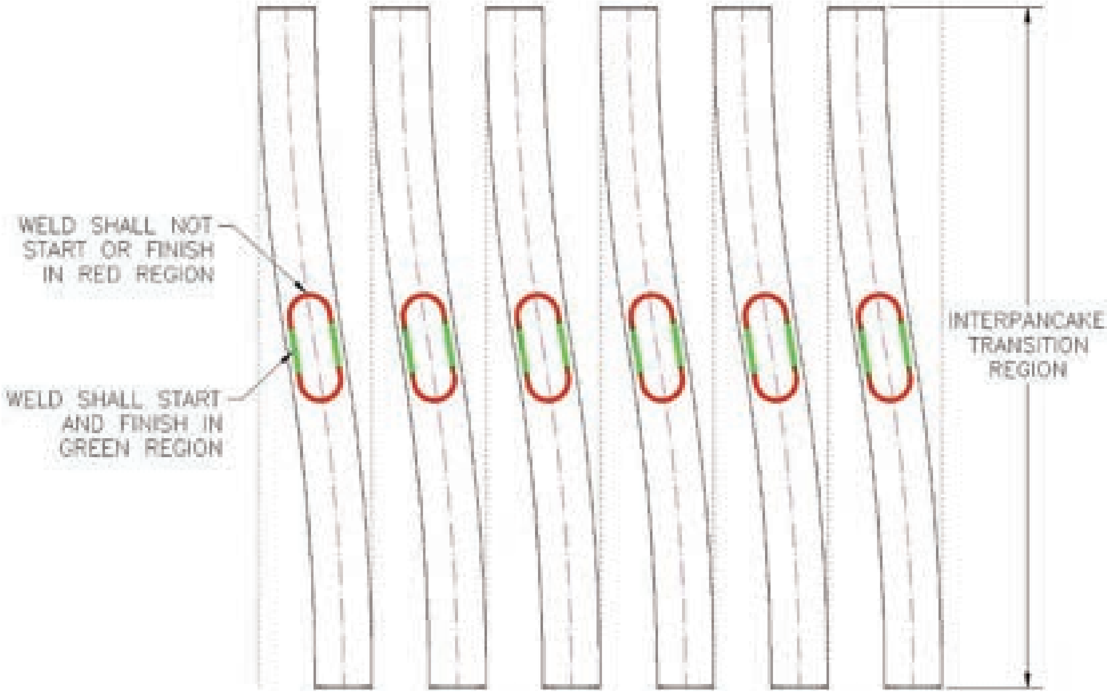

Figure 6.1 – Allowable welding region for helium inlets

- In order to confirm the integrity of the welds during manufacture, the Contractor shall carry out non destructive testing on each helium inlet. The purpose of the non destructive testing is to provide confidence in the welded joint.

  As a minimum, pressure testing and leak testing of the welded joint shall be carried out to confirm weld integrity. Other NDT methods shall be investigated during the qualification tests. Where a suitable test is found, this shall be applied during manufacture.
- The extension of the helium inlet pipe from the conductor must be sufficient to:
  - allow welding of the external helium line to the pancake after installation in the casing, and
  - allow the installation of sufficient insulation such that the winding pack embedding process will also embed this insulation, and the continuation of the insulation of the helium inlet pipe.
- The protection installed to the helium inlet shall be sufficient to:
  - protect the helium inlet against any mechanical damage and
  - prevent the ingress of any particulate or liquid material into the conductor during subsequent manufacturing operations.

§ 6.3.3 Tooling Requirements

The tooling required to manufacture the helium inlets includes:

- Cutting tools to remove conductor jacket and cable wrapping in the area of inlet. It is essential that there is a high level of control of the cutting process to ensure there is no chance of damage to the strands inside the conductor during machining.
- Welding tools.
- Non destructive weld testing equipment.
- Pressure testing equipment.
- Leak test equipment.

§ 6.3.4 Acceptance Testing / Other Measurements

During fitment of the helium inlet the following inspections are required:

- Prior to welding to the conductor jacket, visual inspection of the prepared helium inlet shall be carried out:
    - to ensure that the conductor strands have not been damaged,
    - to confirm that the area is free from debris, and
    - to confirm that all burrs and sharp edges have been removed from the conductor jacket.
- After welding, the following checks shall be carried out:
    - Non destructive weld testing to confirm the integrity of the weld,
    - Pressure test at 2.5 MPa for one hour using nitrogen or helium, and
    - Local leak test at $\leq 10^{-8}$ $Pa \cdot m^3 \cdot s^{-1}$ with an internal pressure of 2.5 MPa helium.

  The pressure test shall be witnessed by a European certified body. It may be possible to perform the pressure test and leak test concurrently.

§ 6.3.5 Quality Control and Documentation Requirements

The following documents shall be provided prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- Documented evidence that the helium inlet weld will provide suitable containment.
- A document which describes the proposed method for preparation and welding of helium inlet.
- A document describing the proposed testing methods and procedure to be followed.
- In order to qualify the welding procedure, a sample weld shall be performed. The weld shall be pressure tested, leak tested and examined using non destructive techniques. Additionally, the sample shall be cut such that an internal visual inspection can be carried out. Where required by the Pressure Equipment Directive the different tests will be witnessed by a qualified third party. The records of the procedures followed, the tests and the inspection shall be provided to ENEA for administrative purposes.

§ 6.4 Conductor Winding

§ 6.4.1 Scope of Work

The conductor winding includes the manufacture of:

- One double pancake,
- One helium inlet at the midpoint of the double pancake, as described in § 6.3, and
- Two conductor terminations.

The process required for winding the conductor consists of the following:

- Bend the conductor to form the first pancake, consisting of six complete turns as defined by drawing number 010202-503101, supporting the pancake on a suitable flat surface.
- In line wrapping of the complete conductor length with insulation, which meets the requirements detailed in § 6.4.2.
- Bend the conductor transition from first to second pancake as shown in drawing number 010202-503101.
- Bend the conductor to form the second pancake, consisting of six complete turns as defined by drawing number 010202-503101on top of the previous pancake.
- Bend the conductor at the end of each pancake to the correct position for mounting of the internal joints.
- Prepare suitable conductor ends for fitment of conductor terminations and internal joints, and install suitable protection to conductor ends.
- Apply Double Pancake insulation (thickness 0.5 mm) by wrapping with glass fibre tape.

§ 6.4.2 Technical Requirements

The following points shall be adhered to during the winding of the conductor.

- In the as built condition, the turn insulation for the conductor shall comply with the following requirements in all locations:
  - 1 mm thickness with a minimum of two layers of wrapping in all locations,
  - minimum glass fibre content of 60 % by volume,
  - must be suitable to insulate against a nominal voltage of 80 V in air at room temperature
  - minimum shear capacity after impregnation of 55 MPa at 4 K, corresponding to 40 MPa at 300 K,
  - minimum shear capacity after 36000 cycles of 20 MPa at 300 K.
  - must maintain material properties after 20 kGy.

- The above mechanical properties shall be demonstrated through mechanical testing at 4 K. A sample of nine conductors, laid out in a 3 x 3 grid, shall have the centre conductor cyclically loaded, as shown in drawing number 010202-503112. The conductor's central conductor i.e. the loaded conductor, should be supported laterally such that the shear loading is applied directly to the insulation and does not simply damage the loaded end of the conductor jacket. In order to ensure this requirement, the central conductor could be a solid piece of steel which is geometrically similar in cross section to the real conductor. The radiation resistance can be demonstrated through prior documentation associated with the impregnation system.
- During all handling operations of the conductor, including the winding process, the conductor shall not be bent to an inner radius less than 200 mm.
- The centreline of the conductor winding is defined in drawing number 010202-503112. This shape shall be obtained using a controlled bending process, placing the formed conductor on a suitable flat surface to support the conductor during winding.
- Depending on which double pancake is being manufactured, the conductor termination must be bent to the appropriate angle as shown in the drawing of the double pancake. Refer to Table 6.1 for the reference drawing numbers. It is essential that the location of the termination matches the previously wound double pancake termination such that the internal joints can be fitted.
- During winding, care must be taken with the cleanliness of the work area to ensure that no burrs or other debris will be introduced between conductor turns.
- The helium inlet is located at the midpoint of the double pancake, as shown in the drawing of the double pancake. Refer to Table 6.1 for the reference drawing numbers.
- The protection installed to the conductor ends shall be sufficient to:
    - protect the conductor against any mechanical damage and
    - prevent the ingress of any particulate or liquid material into the conductor

  during subsequent manufacturing operations.
- The interpancake insulation could be introduced as:
    - A dedicated layer of additional material or
    - An additional wrapping of insulation around the complete double pancake.
- The interpancake insulation is suggested to:
    - protect the turn insulation from damage during subsequent operations, and
    - accommodate a stack up of tolerance error.
- Since a Double pancake insulation is introduced, it shall comply with the following mechanical requirements in the as built condition:
    - 6 mm total maximum thickness i.e. through the complete thickness of the winding pack a total allowance of 6 mm of DP insulation is available,
    - the material properties to be the same as for the turn insulation.

§ 6.4.3 Tooling Requirements

The tooling required to wind the double pancakes includes:

- A bending device capable of forming the conductor to the specified shape.
- In line equipment to wind the turn insulation on the conductor.
- A suitable flat surface, or winding table, to support the conductor during winding. This flat surface must be free from burrs and sharp edges, and cleaned such that the conductor is not damaged during the winding process.
- A set of movable supports for DP insulation application.
- Measurement device suitable for locating the geometric centreline of the double pancake.

§ 6.4.4 Acceptance Testing / Other Measurements

Each double pancake shall be measured to confirm that it meets the requirements of its drawing. Refer to Table 6.1 for the double pancake reference drawing numbers. A Detailed Procedure is required describing the proposed acceptance testing of a double pancake. As a minimum, this Detailed Procedure shall include:

- Measurement of the thickness and visual inspection of each pancake to allow choice of an insulation compensation thickness, and
- Check of the electrical integrity of the turn insulation using a appropriate testing.
- Geometrical measurement of the centreline for the double pancake.

§ 6.4.5 Quality Control and Documentation Requirements

The following documents shall be provided prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- detail of the proposed material for the insulation , and
- documented evidence that the chosen DP insulation will comply with the shear capacity requirement after impregnation.

§ 7 Winding Pack Design Overview

Six double pancakes are stacked on top of each other to form a complete winding pack. It is suggested that each double pancake is wrapped with DP glass fibre insulation to avoid any damage to the turn insulation and to minimise the effect of a stack up of tolerance error.

Low resistance internal joints are required to electrically connect adjacent double pancakes. These joints could be installed during the winding process or after completion of the winding pack. The timing of joint fitment remains at the discretion of the Contractor.

Filler material must be fitted in the voids between adjacent double pancakes in the joints area and the transition area between adjacent pancakes. These fillers must provide mechanical support and allow for the subsequent flow of impregnation material around the winding pack.

In order to insulate the complete winding pack against electrical short, a total 3 mm layer of ground insulation must be installed around the complete winding pack.

To ensure that the winding pack is not damaged during handling and to facilitate the inspection of the ground insulation impregnation, a winding pack impregnation must be carried out. It is the responsibility of the Contractor to choose when the impregnation(s) are carried out.

It is essential that the centreline of the inner leg of the winding pack is well defined after the winding pack is complete. As such, a series of measurements shall be made during the process to locate and mark this centreline. It must be possible to identify the location of the winding pack centreline when the winding pack is inserted into the casing.

The complete process of winding pack manufacture includes:

- Stacking of the double pancakes.
- Installation of instrumentation equipment.
- Installation of the internal joint between adjacent double pancakes.
- Manufacture and installation of filler material where required i.e. in area of the helium inlet and the joints.
- Installation of Paschen proof ground insulation to complete winding pack, including the joint area.
- Performance of a pressure test and helium leak test to allow for repairs to be made prior to impregnation of the winding pack.
- Impregnation(s) of the winding pack.
- A geometrical survey of the winding pack, paying close attention to the location of the centreline of the inner leg.
- Painting of the complete winding pack with conductive paint, if required.
- Wrapping of the impregnated winding pack with anti-adhesive tape.

§ 7.1 Double Pancake Stacking

§ 7.1.1 Scope of Work

Stacking of the double pancakes includes:

- Placement of the first double pancake, wrapped with 0.5 mm insulation, in the correct orientation on the winding table.
- For the second to sixth double pancake, placement of the following double pancake on top of the preceding double pancake, ensuring:
    - the correct orientation of the joints and helium inlets with respect to the previous double pancake,
    - the geometrical centreline for the inner leg matches the previous double pancake, and
    - the turn insulation is not damaged during the stacking process.
- Identification of the geometrical centreline for the complete winding pack.

§ 7.1.2 Technical Requirements

The stacking of the double pancakes must be carried out on a suitable flat surface. The definition of this flat surface is at the discretion of the Contractor.

The orientation of the conductor terminations and helium inlets shall be as described in drawing number 010202-503107. In order to fit the internal joints, care must be taken to ensure that the conductor terminations and helium inlets are in the correct location with respect to the preceding double pancake. While the final tolerance on the location of the internal joints is not critical, it is essential that the filler material in the area of the joint be manufactured to suit the available space to ensure that the area is completely filled with filler material, and no resin rich areas or voids are created.

Care must be taken to ensure that when the final stack of double pancakes is complete, there will be sufficient allowance for ground insulation prior to winding pack impregnation.

It remains the responsibility of the Contractor to define the process to be followed for stacking of the double pancakes.

§ 7.1.3 Tooling Requirements

- For stacking of the double pancakes, since the tooling requirements depend on the chosen process, the detailed requirements are to be determined by contractor
- Suitable calibrated metrology equipment is required to identify and mark the location of the centreline of the inner leg of the winding pack with the specified accuracy.

§ 7.1.4 Acceptance Testing / Other Measurements

Each winding pack shall be measured to confirm that it meets the requirements of drawing numbers:

- 010202-503111for the winding pack centreline, and

- 010202-503107for the winding pack cross section.

A Detailed Procedure associated with acceptance testing of the complete winding pack is required. As a minimum, this Detailed Procedure shall include:

- Cross section measurements,
- Measurements defining the location of the centreline of the inner leg of the winding pack, and
- Check of electrical integrity of insulation between turns in the pancakes

§ 7.1.5 Quality Control and Documentation Requirements

The following documents are required prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- A Detailed Procedure describing the process of stacking of the pancakes.
- A Detailed Procedure describing the geometrical and electrical measurements to be made during stacking of the pancakes.

§ 7.2 Internal Joints

§ 7.2.1 Scope of Work

The internal joints include:

- Manufacture of the joints to suit the conductor terminations.
- Installation of the joints between adjacent double pancakes.

§ 7.2.2 Technical Requirements

- The complete TF coil excluding terminal joints shall have a resistance less than 10 nΩ as measured at the normal operating current of 25.7 kA at 4.4 K. In addition to this, no internal joint shall have a resistance greater than 5 nΩ.
- Prior to commencement of manufacturing operations, a detailed design file describing the mechanical design of the joints shall be submitted to ENEA. This file shall include the following detail:
  - o Calculation report defining the design. The calculations should be carried out according to the ASME code.
  - o Detail associated with a sample which has been manufactured for testing.
  - o Detail of the testing carried out on the test sample, including all results. As a minimum, the welds shall be mechanically tested at room temperature.

  While ENEA remains responsible for ensuring the appropriate certification of the design is carried out, the Contractor is responsible for:

  - o carrying out the design work,
  - o completing the testing, and

  - compiling a test report for submission.

- The joints must withstand an internal pressure of 2.0 MPa, and, as such, shall be designed and manufactured as a pressure vessel in accordance with the PED requirements. As a minimum, the following is required:
  - Original materials certificates for all materials used during manufacture,
  - A sample manufactured to the final design specification is to be tested,
  - All welds are to be performed by qualified welders, with a copy of the qualification licence included in the documentation,
  - All welds shall be qualified with a third parties involved according to ASME IX Code.
  - Helium leak test, with internal pressure at 2.5 MPa for one hour. Under these conditions, the maximum leak rate shall be < 10^{-9} $Pa.m^3.s^{-1}$.

  The pressure test shall be carried out with an EU certified witness, according to the requirements of the PED.

- The final arrangement of the joints must fit within the space defined in each double pancake drawing. Refer to Table 6.1 for the reference double pancake drawing numbers.

  Since the choice of the joint design is at the discretion of the Contractor, the Contractor shall demonstrate that the chosen joint will meet the above electrical and geometric requirements. Demonstration of the geometrical requirements, of both the joint and the tooling required to fit the joint, shall be carried out using three dimensional modelling techniques. Demonstration of the electrical requirements should be achieved through the use of mock-ups and appropriate cryogenic temperature testing.

- The joint must be insulated in such a way that the final arrangement remains Paschen proof as defined in § 4.1. As such, simplified Paschen testing will be required as described in § 4.3.

§ 7.2.3 Tooling Requirements

- Since the joint design must be defined by the Contractor after suitable studies, as described above, have been performed, the Contractor remains responsible for defining the appropriate equipment required to manufacture the joint.

§ 7.2.4 Acceptance Testing / Other Measurements

- After completion of manufacture a geometrical survey of the arrangement shall be carried out to confirm that the components lie within the required area.
- Leak test and pressure test of completed joint meeting the requirements stated above.
- Pressure test and leak of the winding pack including the joints as described above.
- Simplified Paschen testing for the joints as described in § 4.3.

§ 7.2.5 Quality Control and Documentation Requirements

The following documents are required prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- Report containing details of the proposed joint. The report shall provide sufficient information to demonstrate confidence in the chosen joint. As a minimum, the report shall include:
    - the design features of the chosen joint,
    - the testing that has been carried out to demonstrate the mechanical and electrical integrity of the joint,
    - any information regarding ongoing operation of the joint, and
    - records associated with both weld and welder qualification.
- Report containing the geometric details and the assembly process for the proposed joint. As a minimum, the report shall include:
    - the geometrical features of the joint demonstrating that it will not occupy more than the currently allocated space,
    - any additional geometric requirements to fit the required tooling for joint installation, and
    - details of the assembly, disassembly and repair process for the joint in case of failure during testing.

§ 7.3 Terminal Joints

§ 7.3.1 Scope of Work

The terminal joints include:

- Manufacture and installation of the coil side of the terminal joint.

The manufacture processes shall be performed on the base of the final design specification.

§ 7.3.2 Technical Requirements

In order to interface correctly with the electrical supply, the terminal joints shall be of the twin box type. The final design will be provided by ENEA on the base of design made available by cold test facility. The following technical points apply:

- The terminal joints shall have a resistance less than 5 nΩ as measured at the normal operating current of 25.7 kA at 4.4 K. The manufacturing procedure for termination will be qualified during the qualification activity. In any case, if the manufacture of the joint is done according to the approved procedure, the Contractor is not responsible for the final connection performances.

- The joints must withstand an internal pressure of 2.0 MPa, and, as such, shall be designed and manufactured as a pressure vessel, in accordance with the PED requirements. As a minimum, the following is required:
  - o Original materials certificates for all materials used during manufacture,
  - o A sample manufactured to the final design specification is to be tested,
  - o All welds are to be performed by qualified welders, with a copy of the qualification licence included in the documentation,
  - o All welds shall be qualified with a third party involved according to ASME IX Code.
  - o Helium leak test, with internal pressure at 2.5 MPa for one hour. Under these conditions the maximum leak rate shall be < 10-9 Pa.m3.s-.

  The pressure test shall be carried out with an EU certified witness, in accordance with the PED requirements.
- The joint must be insulated in such a way that simplified Paschen testing described in § 4.3 can be performed. The final insulation of the terminal joint shall be carried out during the installation of the machine and is responsibility of JAEA.

§ 7.3.3 Tooling Requirements

- Suitable equipment to install and test the joint as defined in the Technical Requirements.

§ 7.3.4 Acceptance Testing / Other Measurements

- After completion of manufacture a geometrical survey of the arrangement shall be carried out to confirm that the components lie within the required area.
- Leak test and pressure test of completed joint meeting the requirements stated above.
- Pressure test and leak of the winding pack including the joints as described above.
- Simplified Paschen testing for the joints as described in § 4.3.

§ 7.3.5 Quality Control and Documentation Requirements

- No additional documentation to that defined in § 1.7.

§ 7.4 Fillers

§ 7.4.1 Scope of Work

Installation of the fillers includes:

- Design, manufacture and installation of the filler material in the joint area and the helium inlet area to suit the Contractor's process.

§ 7.4.2 Technical Requirements

The time during the manufacturing process when the filler material is fitted is at the discretion of the Contractor. However it is suggested that:

- the fillers in the helium inlet area and in the area between the body of the winding and the underside of the conductor termination are fitted during winding,
- the fillers in the termination area outside the winding are fitted after stacking of the double pancakes.

Since the coils must be Paschen proof, as defined in § 4.1, the area of the joints and helium inlets must be considered carefully. Due to the critical nature of this area, the process shall be studied in detail by the Contractor. The study shall fulfil the requirements of § 1.3 prior to the commencement of manufacture for the filler material. In addition, the area shall be Paschen tested after manufacture in accordance with the requirements of § 4.3.

The key points associated with the design and installation of the fillers are:

- The filler material in the joint area should be G10. Other materials may be considered, however the use of different filler material must be proposed and approved with ENEA prior to commencement of manufacture. Regardless, in the as built condition, the fillers shall comply with the same requirements as for the turn insulation.
- It is expected that there will be two stages of installation of filler material – one before, the other after, the installation of ground insulation.
- It must be possible to wrap the ground insulation around the winding pack, including any fillers which are already installed, without damage being sustained to the ground insulation in the process i.e. there must be no features; such as corners, burrs or sharp edges; associated with the filler material which could damage the ground insulation.
- The size and shape of the fillers must be designed such that a minimum of epoxy is required to fill the remaining space.
- The flow of resin around the winding pack and fillers shall be considered in detail to eliminate the possibility of void spaces in the completed winding pack.
- It is suggested that no conductive components are used in the installation of the fillers. However, if conductive components are used, these shall be attached to an electrical ground.
- To protect the turn insulation, it is suggested that all fillers are wrapped in fibre glass insulation material prior to installation.

§ 7.4.3 Tooling Requirements

- Appropriate manufacturing equipment for manipulation of the filler material to the correct size and shape to fill the voids in the winding pack. As stated above, in order to define the design and the manufacturing process, it is expected that the Contractor will perform preliminary design and manufacturing validation work for this area. During this process it is expected that any specific tooling requirements will be defined.

§ 7.4.4 Acceptance Testing / Other Measurements

- The Contractor shall demonstrate that the process used for manufacture and installation of the filler material allows the flow of the impregnation material to seal the winding pack and prevents the formation of bubbles in all areas, paying particular attention to the area of the joints.

§ 7.4.5 Quality Control and Documentation Requirements

The following documents are required prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- A drawing of the proposed and actual layout of the filler material in the joint area, and
- A procedure describing the fitment of the filler material.

§ 7.5 Ground Insulation

§ 7.5.1 Scope of Work

- Wrapping of glass tape ground insulation around complete winding pack.
- Identification of the winding pack centreline using fixed datum points after the ground insulation is complete.

§ 7.5.2 Technical Requirements

- In the as built condition, the ground insulation for the winding pack shall comply with the following requirements:
    - nominal 3 mm thickness as shown on drawing number010202-503100 ,
    - must be suitable to insulate against a voltage of 1.4 kV for normal operation,
    - must be suitable to insulate against a voltage of 3.8 kV for testing purposes,
    - All other properties to be similar to those for the turn insulation as defined in § 6.4.2.
- The ground insulation must not be damaged during winding or installation of the winding pack into the casing or during cyclic operation at cryogenic temperatures. As such particular care must be taken to the overlapping of the ground insulation and the way in which the ground insulation is applied in the joint area. It shall be demonstrated that the process for installation of the ground insulation provides an electrically and mechanically sound finish in a repeatable fashion. Demonstration of the process could be achieved:
    - through the use of mock-ups, or
    - by review of similar manufacturing processes which have been carried out previously in the same facility, and have demonstrated success.

Documentation associated with the above meeting the requirements of § 1.3 shall be forwarded to ENEA for review and acceptance prior to the commencement of manufacturing operations.

- With reference to, and meeting the requirements of, § 1.4, the Contractor shall submit a Detailed Procedure for wrapping of the ground insulation around the conductor to ENEA. The Detailed Procedure shall be considered in three parts:
  - the joint region,
  - the region of the helium inlets, and
  - the remaining uniform section of the winding pack.
- It is critical to know the location of the centreline of the inner leg of the winding pack, hence a procedure must be developed which allows control of this after ground insulation has been fitted.

§ 7.5.3 Tooling Requirements

- Appropriate equipment for installation of the ground insulation. Since the process must be defined by the Contractor after suitable studies, as described above, have been performed, the Contractor remains responsible for defining the appropriate equipment required.

§ 7.5.4 Acceptance Testing / Other Measurements

- Visual inspection of the ground insulation to check for any obvious signs of defect.
- Confirmation of the integrity of the electrical insulation to operate with the specified voltages.

§ 7.5.5 Quality Control and Documentation Requirements

The following documents are required prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- Documented evidence demonstrating that the ground insulation will comply with the both the electrical requirement and shear capacity requirement after impregnation.

§ 7.6 Winding Pack Impregnation(s)

§ 7.6.1 Scope of Work

The winding pack impregnation includes:

- Insertion of the winding pack into a suitable rigid mould.
- Vacuum pressure impregnation of the winding pack in the mould.
- Detailed measurement of resultant shape to confirm that the final shape is suitable prior to proceeding to the next step in the manufacturing process.

§ 7.6.2 Technical Requirements

The Contractor is responsible choosing how many, and when, the impregnations are carried out. However, one impregnation must be carried out after the winding pack ground insulation has been installed and before placement of the coil into the casing. This impregnation is required to protect the ground insulation and winding pack during the process of installing the winding pack into the casing.

The key consideration of the impregnations is that they must be done in such a way that no void spaces exist in the winding pack after the impregnation is complete.

Before the impregnation process, the following tests shall be carried out on the complete winding pack:

- Pressure test at 2.5 MPa for one hour using nitrogen.
- Nitrogen flow test.
- Helium leak test, with a maximum leak rate of 10^{-8} Pa.m^3.s^{-1}.

After the impregnation process, the following tests shall be carried out on the complete winding pack:

- Pressure test at 2.5 MPa for one hour using nitrogen.
- Nitrogen flow test to compare with the results obtained before the impregnation process.
- Helium leak test, with a maximum leak rate of 10^{-8} Pa.m^3.s^{-1}.

Note that the helium leak test and pressure test could be carried out concurrently, using a vacuum vessel to perform a global leak test with the conductor filled with 2.5 MPa helium.

The Contractor shall demonstrate that the process for impregnation of the winding pack provides an electrically and mechanically sound finish in a repeatable fashion. Demonstration of the impregnation process could be achieved through the use of mock-ups. Documentation associated with the winding pack impregnation process(es) meeting the requirements of § 1.3 shall be forwarded to ENEA for review and acceptance prior to the commencement of manufacturing operations.

Prior to insertion in the casing, it is essential to confirm that the winding pack will fit into the casing structure. In order to do this, the winding pack must be geometrically surveyed to ensure that it fits within the bounds defined by drawing number 010202-503111. Documented evidence of the outcome of the geometrical survey shall be included in the documentation associated with the winding pack manufacture.

After confirmation of the geometrical accuracy of the complete winding pack, a number of reference points must be attached to the outside of the winding pack. The key points about the reference points are:

- They must be indelibly marked such that they can be seen clearly from the outside of the impregnated winding pack.

- The location and quantity of the reference points will be as shown in drawing number 010202-503100. The final detail of the mounting locations will be defined at a later date.
- The location of the reference points must be well understood with reference to the three dimensioning reference planes defining the winding pack geometrical centreline. The three dimensioning reference planes are as shown in Figure 7.1.
- The reference point markings will be used after insertion of the winding pack into the casing to complete the final machining of the casing with direct reference to the winding pack.
- In the location of the inner leg, it must be possible to identify the winding pack centreline with an accuracy of ±1.0 mm after installation of the complete winding pack in the TF coil casing.

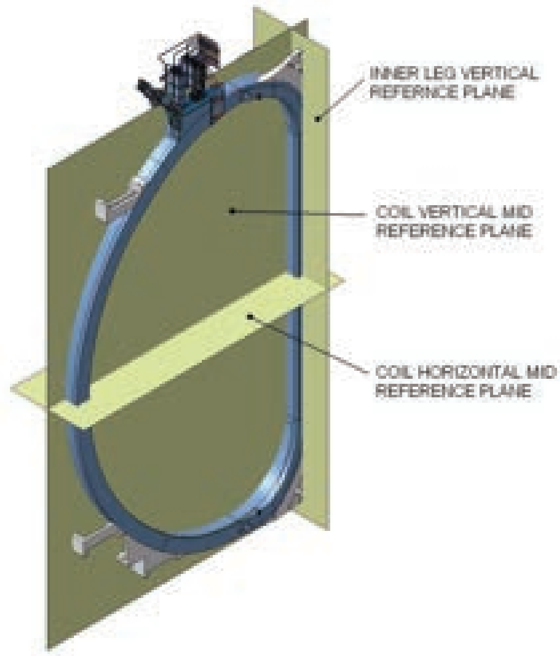

Figure 7.1 – Reference planes for dimensioning

§ 7.6.3 Tooling Requirements

- The mould(s) must be designed and manufactured for the impregnations. Depending on the number of impregnations chosen which describes the final shape of the winding pack.
- Vacuum pressure impregnation equipment with enough capacity to fill all the voids in the winding pack impregnation.
- Suitable equipment to install reference markers on the surface of the winding pack.
- Suitable metrology equipment is required to identify the location of the centreline of the inner leg of the winding pack with reference to the installed reference markers which are attached to the surface of the winding pack.

§ 7.6.4 Acceptance Testing / Other Measurements

The following acceptance tests shall be carried out prior to continuing to the next step in the manufacturing process:

- Local helium leak and pressure test of the complete winding pack prior to impregnation as described above.
- Testing to confirm that the flows between pancakes are similar within 20%.
- Visual inspection of the impregnation to confirm there are no obvious areas of incomplete impregnation.
- Check of the electrical integrity of the ground insulation using appropriate measurements.
- Geometrical check of the shape of the winding pack.

After completion of the final impregnation prior to integration of the winding pack into the casing, ENEA shall be invited to witness the acceptance testing.

§ 7.6.5 Quality Control and Documentation Requirements

The following documents are required prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- Documented evidence demonstrating that, in conjunction with the insulation, the impregnation will comply with the both the electrical and mechanical requirements for the insulation.

§ 7.7 Instrumentation

§ 7.7.1 Scope of Work

The instrumentation requirements include:

- The installation of two redundant (i.e. four in total) voltage taps to be fitted at each terminal joint.
- The installation of 3 cryogenic temperature sensors, Cernox or equivalent, on the casing structure.
- The installation of 10 voltage taps at the internal joints, one on each conductor associated with each joint. The manufacturer is not responsible for removing these 10 V-taps after cold test. An agreed procedure shall be defined with the CTF.

§ 7.7.2 Technical Requirements

An electrical layout of the instrumentation for the TF coil is shown in Figure 7.2. It is the responsibility of the Contractor to procure and install all of the instrumentation defined in this figure.

For the instrumentation associated with normal operation of the JT-60SA tokamak, the following points apply:

- The instrumentation required includes:
    - The two redundant voltage taps associated with the terminal joints, and
    - The three cryogenic temperature sensors mounted on the casing structure.
- The location of the cryogenic temperature sensors shall be as follow: one will be located near the helium inlet, one will be located near the helium outlet and one will be located at the opposite side of the coil.
- The connector specification for the wires associated with the voltage taps and temperature sensors will be provided by JAEA.
- The voltage taps shall provide an accuracy of ± 0.5 %.
- The temperature sensors should be Cernox or equivalent and shall provide the following accuracies when measuring temperatures in a magnetic field of up to 10 T:
    - ± 20 mK for 2 K < T < 10 K
    - ± 0.3 K for 10 K < T < 80 K
    - ± 1.0 K for 80 K < T < 330 K
- A calibration sheet shall be provided for each temperature sensor.
- For each voltage tap, a 10 m long high voltage cable shall be fitted which is suitable for electrical connection at the cold test facility, i.e. it must be suitable for use in cryogenic vacuum conditions in a high magnetic field.

The cold test facility remains responsible for the removal or isolation and insulation of the V-tap according to a procedure agreed with the contractor.

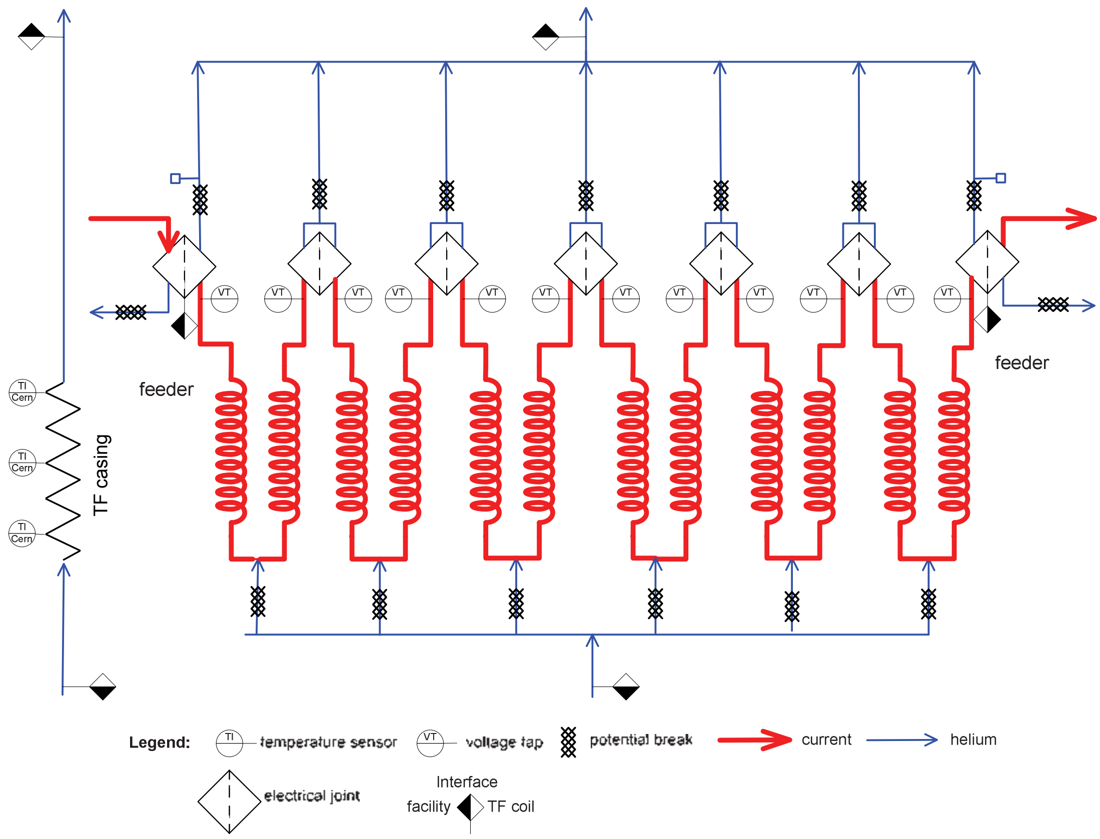

Figure 7.2 – Gauge layout for complete TF coil for test facility

§ 7.7.3 Tooling Requirements

- Appropriate equipment for the installation of the instrumentation.
- Equipment to insulate all of the cabling and connections associated with the instrumentation in a Paschen proof fashion.

§ 7.7.4 Acceptance Testing / Other Measurements

- Visual inspection of the instrumentation to check for any obvious signs of defect.
- Confirmation of the integrity of the electrical insulation to operate with the specified voltages, with particular attention to those operating at high voltage.

§ 7.7.5 Quality Control and Documentation Requirements

The following documents are required prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- A Detailed Procedure describing the process for installation of all instrumentation, with particular attention to the insulation in the case of instrumentation operating at high voltage.
- Procedure to be agreed with the Cold test facility to remove the temporary V-Taps

§ 7.8 Winding Pack Grounding

§ 7.8.1 Scope of Work

The winding pack grounding includes:

- The installation of a layer of conductive material to the outside of the complete winding pack.
- The installation of a fixed connection between the conductive material and the ground potential of the coil casing.
- Application of an anti-adhesive tape on all the winding pack surface .

§ 7.8.2 Technical Requirements

An equipotential layer is required to homogenise the electrical field distribution on the surfaces of the winding pack. This equipotential layer could be in the form of:

- A conductive paint applied to the outer surface of the complete winding pack or
- Any kind of conductive foil which is wrapped in an overlapped fashion around the outer surface of the complete winding pack.

The Contractor remains responsible for choosing the material for manufacture of the equipotential layer. The key points about the chosen material are that:

- It must remain conductive at 4 K. This requirement shall be demonstrated through testing of a sample in cryogenic conditions.
- If a paint is chosen it must not be possible for the paint to penetrate the ground insulation and impregnation material. In part, this depends on the quality of the impregnation.

With reference to, and meeting the requirements of, § 1.4, the Contractor shall submit a Detailed Procedure for applying the equipotential layer to the surface of the winding pack.

It is expected that this conducting surface will need to be electrically attached to the coil casing. The requirements for this interface will be confirmed after consultation with JAEA.

§ 7.8.3 Tooling Requirements

Depending on the process chosen by the Contractor, suitable equipment to:

- wrap the conducting material, or
- paint the conducting material

around the outside of the complete winding pack in a homogeneous fashion.

§ 7.8.4 Acceptance Testing / Other Measurements

- Visual inspection of the equipotential layer confirming that it is constitutes a continuous layer.
- Electrical check confirming the continuity of the conductive layer.

§ 7.8.5 Quality Control and Documentation Requirements

The following documents are required prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- Documented evidence demonstrating that the material chosen for the equipotential layer will remain conductive in cryogenic conditions.
- A Detailed Procedure describing the process for installation of the conducting material.

§ 8 Winding Pack Integration to Casing

The complete winding pack must be inserted into the coil casing. Since the location of the centreline of the current in the region of the inboard vertical leg is highly critical, particular attention must be paid to this area.

After insertion and wedging of the winding into the casing, the lateral and longitudinal welding of the closure plates to complete the casing structure must be completed. In order to ensure that the winding pack is secure inside the casing, a final impregnation is envisaged to fill any void spaces.

The complete process of winding pack integration includes:

- Preparation of the casing components.
- Installation of the complete winding pack assembly into the casing.
- Installation closure plates on the inside of the casing.
- Final closure welding including geometrical check on the structure after welding.
- Embedding of the winding pack in the casing.

§ 8.1 Casing Components Preparation

§ 8.1.1 Scope of Work

Preparation of the casing components includes:

- Receipt of the casing components.
- Incoming acceptance inspection of the casing components.
- Cleaning of the casing components.
- Design of the weld preparations and associated protection plates to suit the manufacturer's process.

§ 8.1.2 Technical Requirements

The casing will be delivered to the Contractor as a number of separate prefabricated components. These components are defined as shown in drawing number 010202-503204 .

The purpose of casing components preparation is to confirm that all components are in an acceptable condition to carry out proceeding operations.

The Contractor shall carry out incoming acceptance tests as soon as possible after receipt of the casing components, including, but not limited to:

- Visual inspection of packaging to check for any signs of damage during transport;
- Visual inspection of the casing components for signs of damage such as cracks or scratches and confirmation of cleanliness;
- Review of the Acceptance Data Package of the casing components to confirm the geometry and the material composition of the components.

Any non conformance to the above items or claims for damage shall be submitted to ENEA within 15 calendar days of receipt of the casing components.

It is expected that the Contractor will choose a weld process, for all of the interfaces between casing components i.e. all of the welds as shown in drawing number010202-503204, which suits their specific manufacturing capabilities. Hence, it is the responsibility of the Contractor to:

- Define the weld process to be applied at the interfaces between the casing components; and
- Design during the qualification process the weld preparations to suit their chosen welding processes.

As shown in drawing number 010202-503204, the welding of the inner closure plate follows the contour of the casing side plates on both sides of the casing. In the region of the inner leg, the weld shall be typically 15 mm, while in the outer leg, the weld shall be typically 20 mm.

In order to define the welding process to be followed, it is expected that the Contractor will work closely with the casing components manufacturer, who retains the responsibility for machining the required weld preparations. When the weld process has been defined, the Contractor shall inform both the casing components manufacturer and ENEA in writing of the required weld preparations.

Associated with the welding of the casing components, protection will be required for the winding pack during the welding process. This will be required in all cases where there is a direct line of sight between the welding head and the winding pack. Protection could be achieved by:

- installing a protective plate between the weld and the winding pack, or
- machining a recess into the casing component to remove the direct line of sight between the welding head and the winding pack.

With reference to, and meeting the requirements of, § 1.4, the Contractor shall submit a Detailed Procedure for all of the welds to be carried out on the casing components. The Detailed Procedure shall consider the following points:

- The chosen weld process(es),
- The required shape of the weld preparation,
- Manufacture and installation of appropriate mechanical protection between the weld and the winding pack,
- The completion of the weld, and
- Subsequent testing of the weld to confirm the structural integrity of the joint.

§ 8.1.3 Tooling Requirements

- Appropriate measuring equipment will be required, such as laser tracker or similar, to carry out the detailed measurements of the casing components.
- Welding equipment to install the weld protection plates where necessary.

§ 8.1.4 Acceptance Testing / Other Measurements

The Contractor shall perform incoming acceptance tests to ensure that no component has been damaged during transport. The incoming acceptance tests shall include as a minimum:

A visual inspection of the packaging and the casing components to confirm that:

- o there are no obvious signs of damage sustained during transport and handling, and
- o they are free from debris and are in an acceptable condition for coil insertion.

- Review of the casing component’s material certificates to ensure that the appropriate materials and procedures are used when the casing closure welds are completed.
- Any non conformances to the above items or claims for damage must be submitted to ENEA within 15 calendar days of receipt of the casing components and associated documents.

The Contractor may choose to carry out additional tests at their own discretion.

§ 8.1.5 Quality Control and Documentation Requirements

In addition to the standard documents as described in § 1.7, a series of photographs are required documenting the state of the components with relation to their specification in the as delivered state.

§ 8.2 Winding Pack Installation in Casing

§ 8.2.1 Scope of Work

The installation of the winding pack into the casing includes:

- Detailed measurements of the inside dimensions of the casing structure,
- Design, manufacture and installation of spacers in the inner vertical leg region of the coil,
- Installation of the winding pack to the inboard region of the casing,
- Measure relationship between outboard region of winding pack and outboard region of casing to define the required size of the spacers in the outboard region.
- Manufacture and installation of spacer material for outer leg region,
- Installation of the outboard region of the casing around the winding pack,
- Installation and welding of the joint vertical port and associated plates as shown in drawing number 010202-503204 , and
- Completion of the transverse weld joining the outer region to the inner region of the winding pack.

§ 8.2.2 Technical Requirements

The location of the centreline of the inner vertical leg of the winding pack with respect to the casing is critical. In order to control the centreline location, the relationship between the internal dimensions of the as built casing structure and the as built winding pack must be understood. The centreline of the winding pack was previously identified (refer to § 7.6.2 for more information), and the internal dimensions of the casing must be accurately measured.

The required spacer thicknesses are in all directions as shown in drawing number 010202-503203. It is necessary to measure the geometry for the as built casing and winding pack prior to defining the actual thicknesses for the spacers.

During installation of the winding pack to the casing structure, care must be taken to ensure the ground insulation is not mechanically damaged. Adequate space must be available between the winding pack and any components associated with the casing such that the ground insulation will not be damaged during subsequent operations of the coil.

With respect to the terminal joints, sufficient space must be available to ensure that no part associated with the joints will come into contact with the casing structure.

During completion of both the transverse welds and those associated with the upper joint port, some distortion of the casing structure is expected. During the welding process this distortion must be controlled such that the complete coil will meet the required final dimensions for interface to adjacent components. The key point is the relationship between the outboard region and the inner leg vertical region, as shown in Figure 8.1, which must be maintained within ±5 mm.

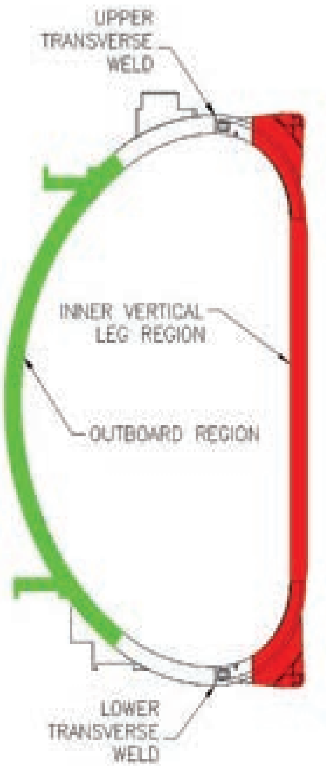

Figure 8.1 - Location of transverse welds

§ 8.2.3 Tooling Requirements

- Suitable metrology equipment to define the required spacer thicknesses.
- Suitable welding equipment to complete both the transverse welds and those associated with the joint port.
- Suitable lifting and handling equipment to lift and control both the casing components and the winding pack during installation. This includes appropriate equipment to stop the winding pack and casing components from sagging during installation operations.
- Depending on the method chosen for installation of the outer leg, there may be a requirement to apply a nominal pressure to the inside of the winding pack 'D' shape such that the winding pack position can be defined. Additional purpose built tooling would be required to perform this function.
- Suitable metrology equipment is required to identify and mark the location of the centreline of the inner leg of the winding pack with the specified accuracy.

§ 8.2.4 Acceptance Testing / Other Measurements

- 100 % non destructive testing of the integrity of all welds, through the thickness of the weld. The maximum defect size allowable in the welds is 5 mm^2.
- Geometrical check of the casing after welding.
- Geometrical measurement confirming that the location of the terminals and helium inlets is within specification.

§ 8.2.5 Quality Control and Documentation Requirements

The following documents shall be provided prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- Detailed Procedure describing the proposed method for measuring and marking the centreline of the inner leg of the winding pack.
- Detailed Procedure describing the proposed method for controlling the thickness of the spacers in the outboard region of the winding pack.

§ 8.3 Casing Assembly and Welding

§ 8.3.1 Scope of Work

Casing assembly includes:

- Installation of suitable filler material between the side of the winding pack and the casing structure.
- Detailed measurements of the dimensions of the winding pack with reference to the casing structure,
- Design, manufacture and installation of spacers between the winding pack and the inboard closure plates,

- Installation of the closure plates to the casing with particular care in the area of the helium inlets, and
- Completion of the final closure welds on the casing.
- Measurement of fabricated coil casing shape.

§ 8.3.2 Technical Requirements

As shown in Figure 8.2, there are two areas in which filler material is required; between the sides of the winding pack and the casing; and between the inner surface of the winding pack and the cover plates. Due to the different requirements of the two different locations, it may be appropriate to use two different materials.

For the filler material in both locations, the following points are important:

- The filler material should be impregnable, such that during final embedding, there will be a relatively free flow of embedding material inside the casing structure. Exception can be made for the positioning wedges and spacers which are used to guarantee the final position of the winding pack.
- The flow of embedding material around the winding pack and fillers shall be considered in detail to eliminate the possibility of void spaces existing in the completed winding pack.
- No conductive components can be used in the installation of the fillers.

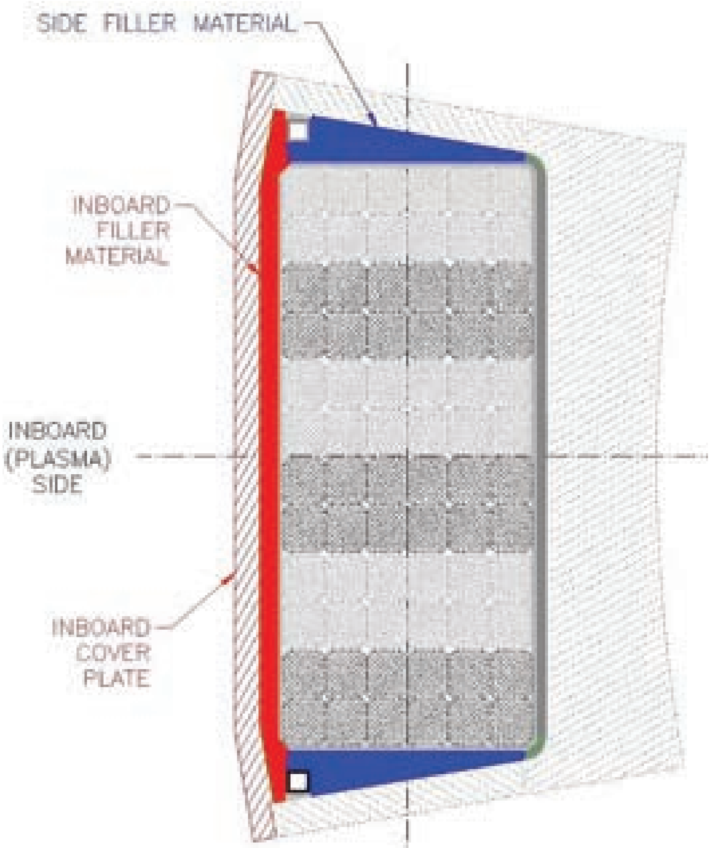

Figure 8.2 - TF coil inner vertical leg cross section showing the inboard and side filler material

- In the as built condition, the fillers shall comply with the same requirements as those for the turn insulation.

In addition, the side filler material shall provide sufficient lateral support for the winding pack such that the winding pack will not move relative to the casing during the processes of final closure welding and final embedding.

Additional points associated with the design and installation of the fillers in the inboard region are:

- The filler material should be compressible such that during installation of the inner plate, there will be contact between the filler material and both the winding pack and the inner cover plate.
- In order to identify the required thickness of the filler material between the inboard closure plates and the winding pack, detailed measurements are required of both the as built casing components and the as built winding pack. After understanding the relationship between the two components it will be possible to choose an appropriate thickness for the filler material.

The Contractor remains responsible for the choice of the filler material(s) for use in both locations, however the material(s) must be proposed and approved with ENEA prior to commencement of manufacture.

The Manufacturer shall minimise the displacements of the coils before final impregnation in order to avoid relative displacements of the winding pack and the casing.

As stated in § 8.1.2, the Contractor is responsible for defining the weld procedure to be followed for all closure welds. Due to the size of the welds, it is anticipated that there may be some distortion of the plates during the welding process. As such, the Contractor shall demonstrate that the process for welding provides a well controlled geometrical finish in a repeatable fashion. Demonstration of the process could be achieved:

- through the use of mock-ups, or
- by review of similar manufacturing processes which have been carried out previously in the same facility, and have demonstrated success.

Documentation associated with the above meeting the requirements of § 1.4 shall be forwarded to ENEA for review and acceptance prior to the commencement of manufacturing operations.

§ 8.3.3 Tooling Requirements

- Appropriate welding equipment for completion of the casing closure welds. Since the welding process must be defined by the Contractor after suitable studies, as described above, have been performed, the Contractor remains responsible for defining the appropriate welding and ancillary equipment required.
- Appropriate jigs and fixtures for supporting the winding pack during installation and welding of the inner plates.

§ 8.3.4 Acceptance Testing / Other Measurements

- 100 % ultrasonic test of the integrity of all welds. The weld shall be inspected to the requirements of ASME VIII, div III.
- Complete geometrical check of the casing after welding.

§ 8.3.5 Quality Control and Documentation Requirements

The following documents shall be provided prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- All details of the filler materials to be used in both the side region and the inboard region of the casing.

§ 8.4 Winding Pack In-case Impregnation and Curing

§ 8.4.1 Scope of Work

Winding pack in-case impregnation and curing includes:

- Installation of temporary closure plates for sealing of all holes in the casing structure.
- Vacuum pressure impregnation of the casing.
- Removal of the temporary closure plates.

§ 8.4.2 Technical Requirements

Temporary closure plates must be fitted over any openings, including the internal casing cooling pipes, in the casing structure such that:

- They provide a suitable seal during the embedding process.
- They can be easily removed after embedding, without the possibility of damaging the embedding material in the process.

In order to minimise the likelihood that void spaces occur, a series of distribution tubes could be installed inside the casing structure to facilitate the distribution of resin throughout the complete casing.

Since it will not be possible to visually inspect the final embedding after it has been completed, it is important that the process is well understood and well controlled. The Contractor remains responsible for defining the process to be followed for the final embedding. It shall be demonstrated that the chosen process provides an electrically and mechanically sound finish in a repeatable fashion. Demonstration of the process could be achieved:

- through the use of mock-ups, or
- by review of similar manufacturing processes which have been carried out previously in the same facility, and have demonstrated success.

Documentation associated with the above meeting the requirements of § 1.3 shall be forwarded to ENEA for review and acceptance prior to the commencement of manufacturing operations.

A Detailed Procedure is required describing the final embedding of the winding pack. In addition to describing the embedding process, the Detailed Procedure shall describe a proposed method for confirming the integrity of the embedding.

§ 8.4.3 Tooling Requirements

- Appropriate embedding equipment for impregnating the complete winding pack. Since the manufacturing process must be defined by the Contractor after suitable studies, as described above, have been performed, the Contractor remains responsible for defining the appropriate equipment required.

§ 8.4.4 Acceptance Testing / Other Measurements

- Check of the volume of embedding material inserted into the structure to provide an indication of the quality of the embedding.
- A minimum of 5 resin samples which have been cured at the same time as the final impregnation to be used for testing to confirm the glass transition temperature of the cured resin. The Contractor is responsible for defining the method used for confirming the glass transition temperature.

§ 8.4.5 Quality Control and Documentation Requirements

The following documents shall be provided prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- Documented evidence demonstrating that, in conjunction with the filler material, the embedding material will comply with the mechanical requirements.
- A document describing the proposed process for the final embedding process.

§ 9 Final Coil Preparation

Once the complete TF coil has been assembled into the casing, some machining is required on the final structure to ensure the correct relationship between the winding pack, the crown plates, and the interface to the OIS and EF and gravity supports. Due to the size of the TF coil and level of accuracy required, it is suggested that a large machine centre is used for the task such that a minimum of different set ups are required to complete the machining.

Due to the vulnerability of components in the joint area, these must be well protected prior to carrying out the machining processes. The same applies to the helium cooling pipes which are routed around the inboard side of the outer leg.

The complete process of final coil preparation includes:

- Carry out all casing interface machining, including, but not limited to:
  - The crown plate region,
  - The interface to the lateral bearing pads on the OIS,
  - The complete inner leg wedge region,
  - The EF/CS support regions, and
  - The connection to the gravity support region.
- Connect helium lines and cooling for curved leg, manifolds and potential breaks.
- Install supports for joints.
- Install protection for all vulnerable components, such as the helium inlets and internal electrical joints.
- Measure final coil configuration including all key interface points such as the helium inlets / outlets, the terminal locations and the crown region interface.

§ 9.1 Joints Supports and Protection

§ 9.1.1 Scope of Work

There are two distinct aspects of work associated with

Joints support includes:

- Installation of permanent supports for the internal joints.
- Provide additional support for the terminal joint.

Joint protection includes:

- Installation of additional temporary supports which are suitable for allowing the completion of machining processes.
- Cover the complete joint area.

§ 9.1.2 Technical Requirements

Since the supports and protection for the joints depend on the chosen joint design, the Contractor remains responsible for the design and manufacture of the supports and protection.

The key points associated with the internal joint *supports* are:

- They shall be suitable to support the joints and prevent mechanical damage to the insulation and conductor:
    - after installation and during normal operation on the machine,
    - during final assembly of the coil,
    - during testing operations, both in the Contractor's workshop and in the cold test facility, and
    - during handling operations.
- They shall be designed and manufactured such that, during subsequent processes, the conductor will be protected against damage and the ingress of any particulate or liquid material.
- They should not occupy more space than that shown as the "Internal Joint Space Allocation" area of drawing number 010202-503107. This may vary depending on the chosen joint design, however, regardless of the chosen joint, they shall not occupy space outside that defined by the "Space Reservation" area of the same drawing, number 010202-503107.
- The proposed layout for the supports in the joints area is shown in Figure 9.1.

In addition, for the terminal joints:

- These supports must be easily removable such that the joint can be assembled and disassembled for testing.

The key points associated with the joints *protection* are:

- It shall be easily removable, and hence should be of bolted or pinned construction,
- In conjunction with the final packaging, it shall provide sufficient protection for shipment to Naka,
- It should be used to provide additional protection to the area during the machining operations as described in § 9.2,
- A proposed layout is shown in drawing number 010202-5032020-500245.

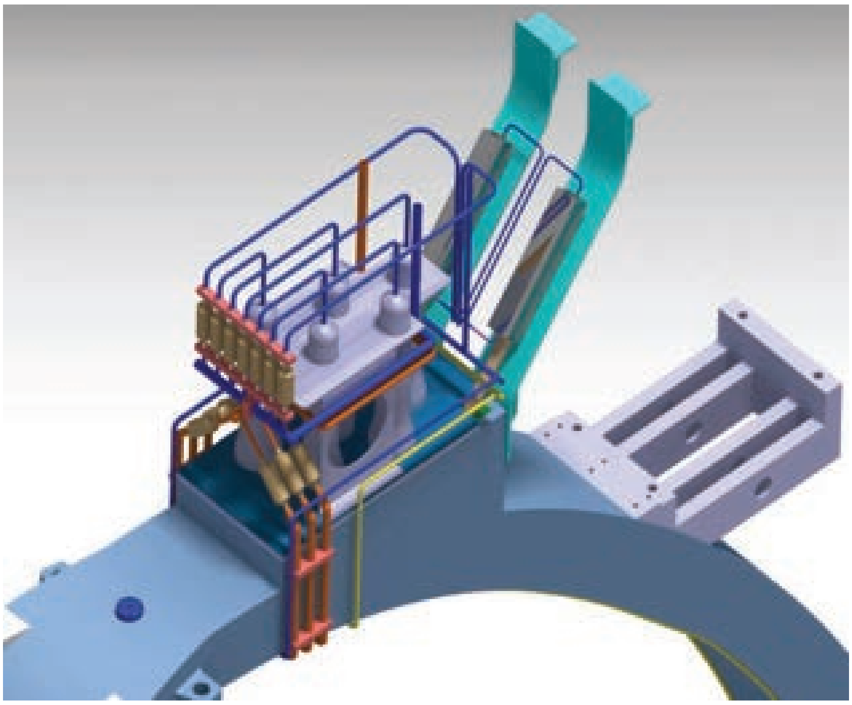

Figure 9.1 – Proposal for supports for the internal joint

§ 9.1.3 Tooling Requirements

- Since the design of the joint remains the responsibility of the Contractor, the Contractor retains responsibility for defining the appropriate equipment required to manufacture and install the joint supports and protection.

§ 9.1.4 Acceptance Testing / Other Measurements

- Geometrical conformance check of the joint supports to ensure they do not occupy more space than that shown in drawing number 010202-503107
- High voltage check on the joints. Note that this testing could be carried out during final acceptance testing.

§ 9.1.5 Quality Control and Documentation Requirements

The following documents are required prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- For the joint *supports* a report containing:
  - Geometric features of the supports demonstrating that they do not occupy more than the available space.
  - An assembly / disassembly procedure.
- For the joints *protection* a report containing sufficient information to demonstrate confidence in the chosen arrangement for the proposed joints protection. As a minimum, the report shall include geometric features of the protection and an assembly / disassembly procedure.

§ 9.2 Casing Interface Machining

§ 9.2.1 Scope of Work

The casing interface machining includes all machining referred to on drawing number 010202-503200. This includes:

- The interface to the OIS through the lateral support pads.
- The crown region interface.
- The temporary mounting holes for the OIS interface.
- The interface for all EF/CS coil mounting interfaces.
- The gravity support stand interface.
- Final geometrical check of the machining with respect to the winding pack centreline placed on the casing.

§ 9.2.2 Technical Requirements

The areas, with their associated tolerances, which require machining are shown in drawing number 010202-5032000-500384 . These include but is not limited to:

- The inner leg interface machining. This includes the complete length of the inner leg region, including the crown region interface at both the top and the bottom of the coil.
- The crown region pinned joint detail, comprising the ten bolt clearance holes and the two larger bush holes in four locations, one on each crown plate.
- The outer leg interface machining. There are five areas of the curved leg which must be machined to interface correctly with the OIS.
- The witness marks on the top and bottom of the crown plates identifying the winding pack centreline.

The machining shall be carried out with direct reference to the winding pack centreline as defined by the reference markers which were attached to the winding pack as described in § 7.6.2. In this way the interface machining can be achieved with a high level of accuracy for the final assembly of the TF coil in the JT-60SA device.

The machining shall be carried out with a minimum number of setups. While this will depend on the chosen machine centre, two setups are expected as follows:

- The TF coil is placed in the horizontal position such that all of the machining for one side of the coil can be completed.
- The coil is then reoriented to carry out the machining on the opposite side of the casing, again in one setup.

A Detailed Procedure is required describing the complete machining process. As a minimum, the following points shall be covered in the Detailed Procedure:

- Details of the chosen machine centre such as size, capacity and number of degrees of freedom of the cutting tool.

- The proposed orientation of the coil for each setup.

§ 9.2.3 Tooling Requirements

- A suitable machine centre to be able to complete all of the required machining with the required accuracy with a minimum of set ups for the TF coil structure.
- Suitable metrology equipment is required to confirm the final dimensions of the casing meet the geometrical requirements.

§ 9.2.4 Acceptance Testing / Other Measurements

- Geometrical and surface roughness check of the key machined areas, including the:
    - crown region,
    - OIS interface,
    - inner leg, and
    - temporary mounting fixtures.
- Geometrical check of all machined holes.

§ 9.2.5 Quality Control and Documentation Requirements

The following documents shall be provided prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- Detailed Procedure describing the proposed machining processes.

§ 9.3 Helium Cooling Pipes

§ 9.3.1 Scope of Work

The connection of the helium cooling pipes includes:

- Manufacture and installation of the:
    - casing cooling pipes except the inner pipe of the inner leg already mounted by casing manufacturer,
    - inlet cooling pipes, and
    - outlet cooling pipes.
- Manufacture and installation of insulation to the conductor inlet and outlet of the cooling pipes to the location of the potential breaks.
- Manufacture and installation of manifolds and potential breaks where required. A suggested design for the potential breaks is shown in drawing number010202-503302.
- Installation of a suitable support structure for all components associated with the helium cooling system.

§ 9.3.2 Technical Requirements

The main supply and return lines for the helium are located near the joints. Local piping is required to route the helium from this location to the conductor exits, with:

- The inlet to each conductor being on the inboard side of the outer leg of the casing, as described in § 6.3.
- The outlet from each conductor is located in the joint. The inlet and outlet for the casing cooling is similarly located in the joint region.

Common points associated with the design of the helium pipes, including the potential breaks, are:

- The sizes and approximate required lengths shall be as indicated in drawing number 010202-5033030-600383.
- It shall be manufactured from 304L or 316L stainless steel.
- The design pressure is 2.0 MPa, with a test pressure of 2.5 MPa using nitrogen gas for 30 minute.
- The helium lines shall be manufactured and tested in accordance with ASME VIII.

The proposed layout for the helium pipes is shown in Figure 9.2 and Figure 9.3, with the following colour scheme:

- Orange – components associated with the helium supply to the conductor,
- Blue – components associated with the helium return from the conductor, and
- Red – components associated with the casing cooling.

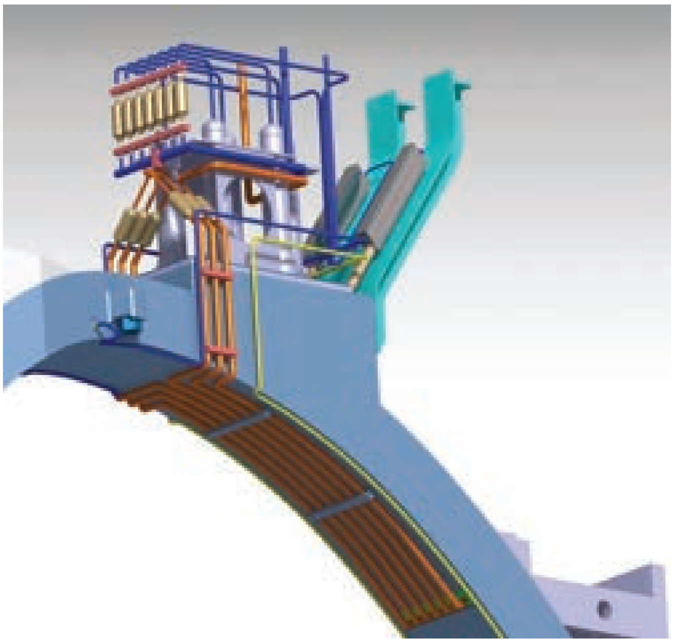

Figure 9.2 – Underside of joint region showing helium inlet piping in orange and helium outlet piping in blue

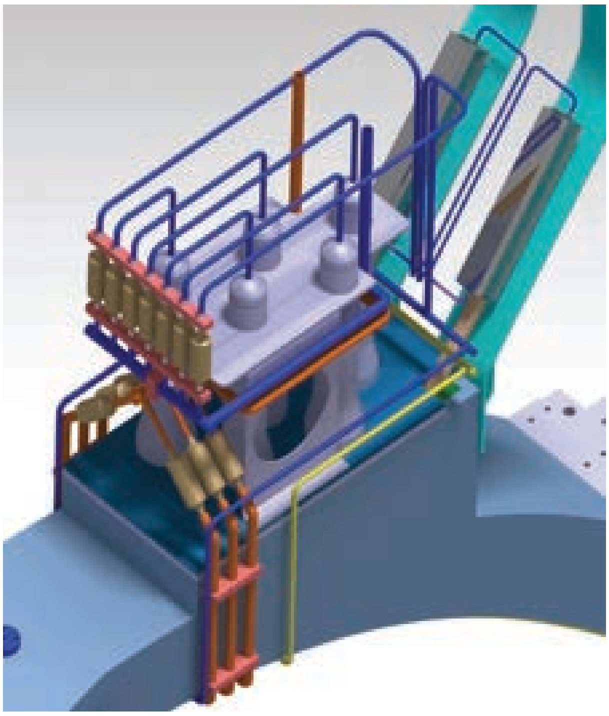

Figure 9.3 – Top of joint region showing helium inlet piping in orange and helium outlet piping in blue

The items required for the helium supply include:

- A manifold, which converts a single feed, with a flow of 48 $g \cdot s^{-1}$, into six individual feeds, each with a flow of 8 $g \cdot s^{-1}$, suitable for delivery to each double pancake.
- A potential break connected to each individual pipe to decouple it from ground potential in the case of rapid shutdown.
- Interconnecting pipework between all of the inline components.
- A set of supports providing mechanical support to the pipes. The mounting point shall be electrically insulated where the supports are at a ground potential and the pipe may reach high voltage e.g. for all supports to the casing between the conductor inlets and the potential breaks an insulated joint shall be fitted.

For the potential breaks, the Contractor remains responsible for the choosing the design. However, the following testing shall be carried out on a test sample:

- Five cooling cycles to liquid nitrogen temperature;
- After the temperature cycling they shall be subject to a 3.8 kV high voltage test;
- Pressure test at 3 MPa at room temperature;
- Local leak test at 10^{-9} $Pa \cdot m^3 \cdot s^{-1}$ with an internal pressure of 2.5 MPa helium.

Documentation associated with the above meeting the requirements of § 1.3 shall be forwarded to ENEA for review and acceptance prior to the commencement of manufacturing operations.

The same items are required for the return pipes, with the exception that, since the first and last joint will be completed in Naka, the final connection is not required for the first and last double pancakes.

Where a flow restriction device is required to balance the flows in the double pancakes it should be fitted in the external pipework prior to the manifold connection. After installation of the flow restriction device the flows should be balanced within ±20%. This must be performed in agreement with ENEA.

The supply and return for the casing cooling is similarly located in the joint region. Key points associated with the casing cooling are:

- For the outer leg of the casing, the helium pipe shall be continuously welded to the inside of the casing structure.
- For the inner leg, the helium pipe is welded to the inside of the casing by the structures manufacturer. The external piping, including the connection to the casing, shall be completed by the Contractor, with the pipe being continuously welded to the outside of the casing structure.
- The crossover from the outside to the inside of the casing is located adjacent to the transverse weld at both the top and the bottom of the TF coil.
- The connection to the crossover is made by an internal fillet weld, as shown in drawing number010202-503300.
- The normal operating flow for each of the parallel cooling circuits of the casing will be 5 $g \cdot s^{-1}$, at 4.5 K.

The proposed layout for the casing cooling pipes is shown in Figure 9.4, with the pipes shown in red.

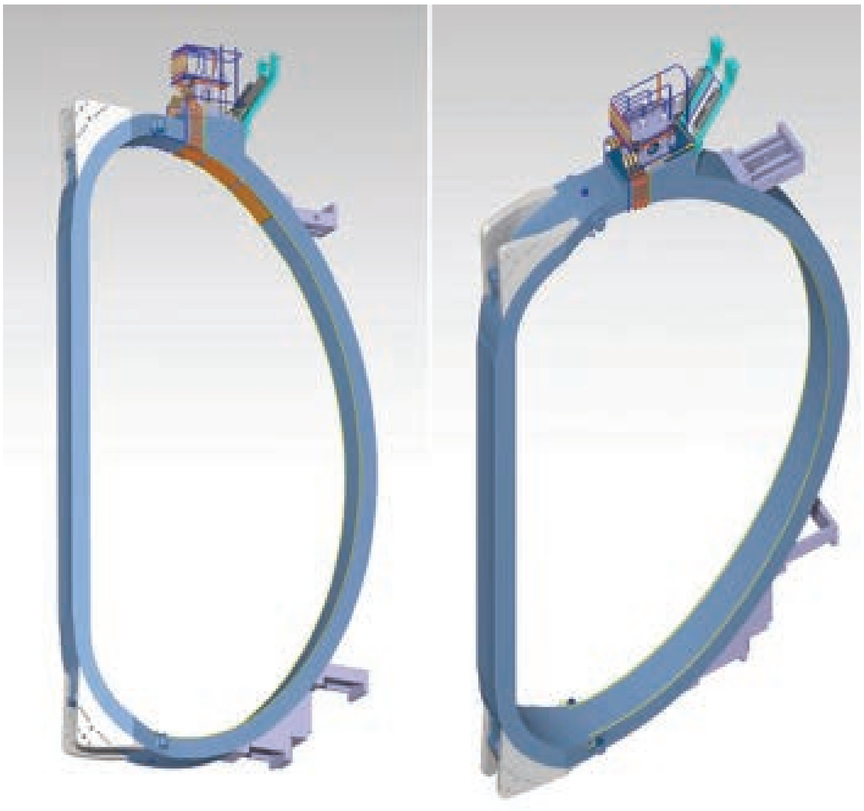

Figure 9.4 – Casing cooling helium pipes

§ 9.3.3 Tooling Requirements

The following tooling will be required:

- Suitable tube bending and forming equipment to shape the tubes to the desired shape prior to installation.
- Suitable welding equipment to seal the piping in close proximity to the casing.
- Suitable welding equipment to continuously weld the casing cooling tube to the casing.
- Suitable equipment to carry out pressure and leak test on the helium pipes after installation.

§ 9.3.4 Acceptance Testing / Other Measurements

- 100 % NDT of the integrity of all welds. The welds shall be inspected to the requirements of ASME VIII, div III.
- Pressure test, flow test and leak test of the complete helium system.

§ 9.3.5 Quality Control and Documentation Requirements

- No additional documentation to that defined in § 1.7.

§ 10 Intercoil Insulation Plates

§ 10.1 Scope of Work

The intercoil insulation plates include:

- The design and manufacture of the intercoil insulation plates.

§ 10.2 Technical Requirements

- The geometric requirements are as shown in drawing number 010202-503201. In total nine separate plates are required for the coil.
- The plates shall be manufactured from austenitic stainless steel with an insulating layer fitted to one side of the insulation plates. The insulating layer could be in the form of:
    - A layer of G10 or similar with a maximum thickness of 1.5 mm OR
    - A plasma spray using a material which has suitable insulating properties.
- The plates must be suitable to insulate against a voltage of about 200 V through their thickness.
- The average pressure applied to the insulation plates will be 170 MPa, with a local maximum pressure of 250 MPa
- The maximum shear stress in the insulating plates is about 30 MPa.
- On the opposite side of the plate to the insulating layer, the plate will be machined to its final thickness. This machining will be carried out after final assembly of the machine in Japan. The responsibility for this machining remains with Fusion for Energy.
- The total radiation is 20 kGray for the all life of the Tokamak
- It is expected that the Contractor develop a method for fixing the insulating layer to the coil casing.

§ 10.3 Tooling Requirements

- Appropriate machining equipment to provide a suitable surface over which the plasma spray can be applied.
- Plasma spray equipment.

§ 10.4 Acceptance Testing / Other Measurements

- Geometric check of the components confirming that they meet the requirements of drawing number 010202-503201.
- Visual inspection of the equipotential layer confirming that it is constitutes a continuous layer.
- Electrical check confirming the continuity of the conductive layer.

§ 10.5 Quality Control and Documentation Requirements

The following documents are required prior to the commencement of manufacturing operations and shall form part of the Procedure Data Package:

- A Detailed Procedure describing the process for installation of the insulation layer on the complete TF coil.
- Documented evidence demonstrating that the ground insulation will comply with the both the electrical requirement and compressive capacity requirements in cryogenic

§ 11 Labelling, Delivery and Storage Requirements

§ 11.1 Scope of Work

The delivery requirements include:

- Clearly labelling all JAEA and cold test facility interfaces;
- The design and manufacture of a transportation frame;
- Pressurising all the helium circuits with 0.2 MPa nitrogen and sealing them with VCR plugs.
- Rigidly fixing the complete TF coil to the transportation frame;
- Wrapping the TF coil in plastic foil and enclosing moisture absorbing bags;
- Attaching labels to the outside of the packaging identifying the components; and
- Noting any requirements for handling of the complete package during transport operations.

§ 11.2 Technical Requirements

The Contractor is responsible for:

- Delivery of the coil to the cold test facility at a location in Europe, and
- Supply to Fusion for Energy all the documents related to the coil manufacture which are also required for the subsequent transportation to Japan.

All interfaces of the coil, including:

- Instrumentation cables,
- Helium connections, and
- Terminal joints

shall be clearly marked and labelled to allow connection of the coil in both the cold test facility and during final assembly in Japan. The identification number on the label and the identification of the interfaces shall also be shown in the corresponding drawings of the component.

Associated with the design and manufacture of the transport frame, the following points shall be considered:

- The frame must be suitable for rigidly supporting the coil during transport.
- The preliminary design of the frame will be provided by Fusion for Energy.
- A proposed layout showing the approximate overall dimensions for the transportation frame can be found in drawing number 010000-500422.

The Contractor shall propose a design for the transport frame to ENEA and Fusion for Energy for approval prior to the commencement of manufacturing operations.

Associated with the packaging requirements for the coil, including the transport frame, the following points shall be considered:

- The coil must be packaged in a suitable fashion for road transport to the cold test facility in Europe, followed by sea transport to Naka, Japan.
- The coil shall be fitted with suitably located accelerometers to confirm that it has not undergone accelerations greater than 5 g during transport.
- Since the lifting equipment at the Cold Test Facility does not allow for turning of the coil, the orientation of the coil will be as shown in **Errore. L'origine riferimento non è stata trovata.** within the packaging.
- The packaging must be easily dismountable such that it can be re-used after cold testing has been carried out for shipment to Japan.
- It shall be noted that the orientation of the shipped component is critical.
- Appropriate lugs for lifting shall be included in the packaging.
- The Contractor is responsible for ensuring that the packaging is suitable for transportation to the Cold Test Facility. Additionally, for transport within Japan, the maximum transport dimensions of the packaging are 7 m long x 5 m wide x 4 m high, and the maximum weight is 70 tons.
- Each package shall be clearly marked on five sides with a label stating:
    - Contributor's name;
    - Destination for the package;
    - Reference number of the coil;
    - Manufacturing month and year;
    - Weight of complete package;
    - Centre of gravity of the package;
    - Correct orientation of the package;
    - Lifting instructions; and
    - Reference to the associated coil manufacturing documentation.
- Storage of the components may be required prior to cold testing being carried out. As such, the following should be considered when designing the packaging:
    - The possible temperature range is 263 K – 313 K;
    - The outside pressure is atmospheric;
    - The possible relative humidity is 100%; and
    - All circuits must be closed and filled with inert gas for storage.

During transport of the TF coil from the Contractor's Works to the Cold Test Facility site, the shipping company shall be forbidden from unloading and reloading the coil at any time.

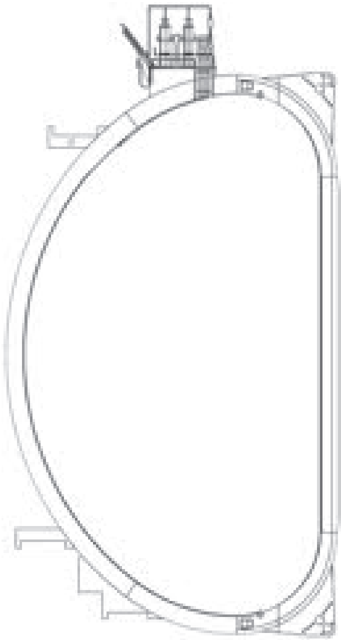

Figure 11.1 – Orientation of Coil for Shipping (Top view)

§ 11.3 Tooling Requirements

- Suitable handling equipment to manipulate the coil for installation in the packaging, including wrapping of the plastic foil.

§ 11.4 Acceptance Testing / Other Measurements

Visual inspection of the packaging to confirm that it meets the design requirements as defined by the Contractor.

§ 11.5 Quality Control and Documentation Requirements

As stated in the management plan, a complete set of documentation for all aspects of the coil design and manufacture shall be included with the final shipment of the coil. This includes all documentation in both the Procedure Data Package and Acceptance Data Package.

§ 12 Acceptance Criteria

§ 12.1 Works Acceptance Tests

The following tests shall be carried out prior to shipment of the TF Coil from the Contractor's works. The coil shall not be shipped prior to successful completion of these tests

- A series of visual checks are required to verify the integrity of the coil. They shall comprise as a minimum:
    - Check of the identification of the coil;
    - Check for proper labelling of all sensors;
    - Check of the integrity of the gas sealing of the conductor terminals; and
    - The integrity of the wiring for the temperature sensors shall be confirmed.
- The final machined coil shall be geometrically surveyed to confirm that it meets the requirements of drawing number010202-503200 . A document detailing all of the as measured dimensions of the coil will be provided.
- The coil resistance shall be measured at a maximum DC current of 10 A.
- The voltage tap wire connections shall be checked by measuring the voltage drops at the voltage taps.
- The insulation resistance shall be checked by carrying out a high voltage DC test.
- The turn to turn insulation shall be checked to confirm that there are no short circuits in the coil using appropriate electrical testing.
- Simplified Paschen testing at room temperature shall be carried out for the complete coil, meeting the requirements of § 4.
- A pressure test shall be carried out using dry nitrogen at 2.5 MPa with third party EU certified witness.
- A helium leak test of the coil shall be carried out at a helium pressure of 2.5 MPa for 30 minutes against vacuum. The test shall be carried out on all helium volumes in the coil, and an integral leak rate of $<10^{-8}$ $Pa \cdot m^3 \cdot s^{-1}$ shall be achieved.
- The flow rates and pressure drops of both the winding pack and the casing cooling pipes shall be measured simultaneously at the inlet or outlet pipes of the coil.

§ 12.2 Cryogenic Acceptance Tests

Final acceptance will be completed following the tests carried out in cryogenic conditions in the cold test facility. While the tests to be carried out at the cold test facility do not form part of the final acceptance of the coil, the following tests are required to be completed in a satisfactory fashion prior to the final acceptance. The Contractor is responsible for carrying out any repair or modification required as a result of not meeting any of the Acceptance Criteria where the failure is directly attributable to the Contractor's manufacturing process(es). All other cases, such as those relating to conductor performance, will be treated on a case by case basis. Where requested, the Contractor shall be responsible for demonstrating that any failure is not a result of their manufacturing process(es).

The cryogenic acceptance tests shall be carried out with the parameters as defined in Table 12.1, and the cool-down and warm-up cycles will be as described in § 3.3.

Mass flow rate through winding pack	approx. 24 $g \cdot s^{-1}$
Mass flow rate of case loop	0 $g \cdot s^{-1}$ (if possible)
Inlet temperature	5 - 7 K
inlet pressure	approximately 0.5 MPa
outlet pressure	>0.4 MPa

Table 12.1 – Parameters for cryogenic testing on coil

- The following tests will be performed at constant temperatures < 5 K:
  - The global pressure drop of the winding pack will be measured.
  - The pressure drop of the case cooling loop will be measured.
- Prior to the nominal current test a check of the quench detection system shall be performed by triggering a fast discharge from a current of approximately 1 kA.
- A continuous current test shall be carried out as follows:
  - Ramp-up speed of the current shall be in accordance with the available voltage of the power supply.
  - The continuous current test and the check of the safety margin are combined in one test, i.e. the continuous current test is done at the temperature TT defined for the safety margin check.
  - The current I_{CT} for the continuous current test amounts to 25.7 kA (nominal current).
- The total resistance of each internal joint shall be measured.
- The total resistance of the complete coil including all internal joints shall be measured. The determination of the terminal joint resistance can be based on voltage-current measurements or on caloric measurements. In case the total resistance of a coil exceeds the specified value, the origin of the high resistance shall be determined by evaluating the individual joint resistances between the pancakes.
- The ground insulation resistance shall be tested.
- The turn to turn insulation resistance shall be tested.

- The leak rate is measured a second time after the current test..

§ 12.3 Final Tests

Final acceptance of the coil after completion of the following tests which are carried out after cold testing of the coil:

- The coil resistance test shall be repeated at a maximum DC current of 10 A.
- The insulation resistance test shall be repeated by carrying out a high voltage DC test.

§ 12.4 Acceptance Criteria

For all of the tests described above, the acceptance criteria as shown in Table 12.2 are adopted.

Tests at Room Temperature		
Test	**Acceptance Criteria**	**Documentation required**
Visual checks: - Coil identified - Interface labelling - Integrity of gas sealing of the hydraulic circuit - Integrity of wiring	- Items as described exist	Report summarising condition of coil, including photos of labelling, wiring, insulation, and interfaces
Geometrical survey	- All dimensions fall within the defined tolerances.	Report detailing outcome of all measurements, including marked up drawing showing the as measured dimensions.
Electrical tests - Coil resistance at room temperature - Voltage tap wire connections - High voltage DC test to check insulation - Turn to turn insulation test	- Record coil resistance - Record voltage across voltage taps - Insulation resistance shall be greater than 500 MΩ - No shorts acceptable between turns	Report detailing test results
Simplified Paschen tests	- Zero Paschen breakdowns	Report detailing test results

Pressure test	- Zero degradation of pressure during test	Report detailing test results, including details of certified inspector who was present during the testing
Leak test	- Detected leak rate less than 10^{-8} Pa·m^3·s^{-1}	Report detailing test results, including details of certified inspector who was present during the testing
Pressure drop test	- With an inlet pressure of 1.5 MPa, and an outlet pressure of 0.1 MPa, the minimum nitrogen flow rate shall be typically 2.4 g·s^{-1} per winding pack. - Record pressure drop through winding pack and case cooling loop	Report detailing test results
Tests at Cryogenic Temperature		
Hydraulic tests - Winding pack pressure drop - Case cooling loop pressure drop	- With an inlet pressure of 0.5 MPa, and an outlet pressure of 0.4 MPa, the minimum required flow rate shall be 24 g·s^{-1} per winding pack - Record pressure drop through winding pack and case cooling loop	Report detailing test results
Current tests - Quench detection test - Continuous current test	- I_{CT} for the continuous current test amounts to 25.7 kA	Report detailing test results
Evaluation of joint resistance	- Maximum individual internal joint resistance shall be less than 5 nΩ - Total maximum joint resistance for complete coil shall be less than 10 nΩ	Report detailing test results
Leak tests after current tests	- The leak rate after the current tests shall be similar	Report detailing test results

	or lower than the leak rate recorded prior to the current tests	
Tests after Warm-Up		
Electrical tests - Coil resistance at room temperature - High voltage DC test to check insulation resistance	- Record coil resistance - Insulation resistance shall be greater than 500 MΩ	Report detailing test results

Table 12.2 – Acceptance criteria for TF coil

§ 12.5 Quality Documentation

Prior to the works acceptance of the toroidal field coil, the Contractor shall provide documentary evidence of all items requested for the:

- Procedure Data Packages, and
- Acceptance Data Packages.

Where it is not explicitly defined in the above data packages, the following shall also be supplied with the TF coil.

- Items associated with design validation mock-ups and testing prior to commencement of manufacture:
  - Test plan of design validation mock-ups.
  - Records of design validation program, including the results of all testing carried out.
- Items associated with quality control:
  - Quality Plan.
  - List of Suppliers and sub-contractors.
  - List of non conformities.
  - Non conformity reports.
  - Deviation reports.
  - Design change reports.
  - Completed quality documentation, as described in the Management Specification.
  - Supplier release note.

- Items associated with welding:
  - Weld inspection records.
  - Material certificates for all materials that have been supplied by the Contractor.
  - Non-destructive inspection records.
  - Qualification procedures for the welding and the welders
  - Welding plan.
- Items associated with metrology and the final configuration of the coil:
  - Metrology plan.
  - Record drawings.
  - Dimensional control report.
  - Final CAD models.

§ 12.6 Cold Test Facility Documentation

In addition to the above documentation, there are a number of specific requirements for the Cold Test Facility. The following documents shall accompany the toroidal field coil in a designated package to facilitate cold testing of the coils:

- Geometrical measuring data of the winding package and the interface areas on the casing and of the exact position of the joints and the helium pipes.
- Measurement results concerning the current carrying capability of the used strands as provided by the conductor manufacturer.
- Certificates for the high voltage (DC and AC) insulation tests against ground (winding and instrumentation).
- Certificate of pressure test at a test pressure of 2.5 MPa.
- Certificate of the integral leak rate of the winding and casing cooling loop.
- Calibration curves of the temperature sensors.
- Details of any deviations from required values and properties.
- Measurement results of the nitrogen gas flow measurements at room temperature with verification that the flow rates through the different pancakes are similar.
- Protocols of proper function of all installed sensors.