JADA-55342TS0106-1
ITER_D_696KB9

Technical Specification of PoPola Mirror Modules in Equatorial Port Plug 10

ITER Project Japan Domestic Agency

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Change log

Brunch no. (date) (IDM version)	Change description	Author
- (5 Nov 2021) (696KB9 v1.0)	The first version.	R. Imazawa
1 (21 Dec 2021) (696KB9 v1.1)	Table 5 “Chemical composition of SS316L(N)-IG (wt.%)” was added.	R. Imazawa

Table of contents

1. Purpose

This document provides all specifications that a manufacturer will need to comply with when they fabricate the mirror module in equatorial port plug of PoPola.

2. Definition

The definitions of abbreviations in this document are given in Table 1.

Table 1 the abbreviations in this document

EPP	Equatrial Port Plug
EMM	EPP Mirror Module
UEMM	Upper EMM
LEMM	Lower EMM
IVH	ITER Vacuum Handbook
JIS	Japanese Industrial Standards
MPH	ITER Material Property Handbook
OD	Outer Diameter
PoPola	PBS.55.C6 Poloidal Polarimeter
RT	Radiographic Test
SDC-IC	Structural design criteria - In-vessel Components
UT	Ultrasonic Test

3. References

[1] Technical Description of PoPola Mirror Modules in Equatorial Port Plug 10, ITER_D_696XRM (or JADA-55342DE0101)
[2] Structural design criteria - In-vessel Components (SDC-IC), ITER_D_222RHC
[3] ITER Vacuum Handbook (IVH), ITER_D_2EZ9UM
[4] ITER Material Properties Handbook (MPH), ITER_D_2226FR
[5] Drawing of Mirror Modules in EPP10: ITER_D_5R3R6W
[6] ITER Vacuum Handbook Attachment 1 Welding, ITER_D_2FMM4B
[7] ITER Vacuum Handbook Appendix 3 Materials, ITER_D_27Y4QC
[8] CAD Manual 12-2 Piping Design, ITER_D_33WL3N
[9] Optical Analysis and Design of PBS.55.C6 PoPola, ITER_D_RC2LB5 (or JADA-55332TS0022)
[10] Chit resolution report for PoPola CDR Chit #17 "Effect of potential bending of the flat plasma-facing mirrors" , ITER_D_UVR9CH
[11] Factory qualification test plan, ITER_D_69765M (or JADA-55342PL0101)
[12] ITER Vacuum Handbook Appendix 15 Vacuum Baking, ITER_D_2DU65F (ver.1.3)
[13] ITER Vacuum Handbook Appendix 2 Environmental Cleanliness, ITER_D_2EL9Y6 (ver.1.4)
[14] ITER Vacuum Handbook Appendix 13 Guide to cleaning and cleanliness, ITER_D_2ELUQH (ver.1.2)
[15] ITER Vacuum Handbook Appendix 4 Accepted Fluids, ITER_D_2ELN8N (ver.1.5)
[16] 55 C6 Manufacturing Assessment of PoPola Mirror Modules in Equatorial Port Plug 10, ITER_D_696RYF (or JADA-55342TS0102)

4. System Description

The primary aim of the PoPola is to measure the change of polarization of injected far-infrared (FIR) laser light in order to identify the profile of plasma current, or equivalently safety factor. There are thirteen PoPola measurement channels to accomplish this measurement task. Each channel is comprised of a set of optical components that launch a laser beam from Equatorial Port Plug 10 (EPP10) or Upper Port Plug 10 (UPP10) across the plasma to a retroreflector. Figure 1 and Figure 2 show an overview of the PoPola viewing chords and the PoPola in-vessel components, respectively. Especially, components in the scope of this documents are the mirror module in EPP10. It is called EMM (EPP Mirror Module) and consists of two parts. The upper part is called UEMM (Upper EMM) and the lower one is called LEMM (Lower EMM). Figure 3 and Figure 4 shows the overview of UEMM and LEMM.

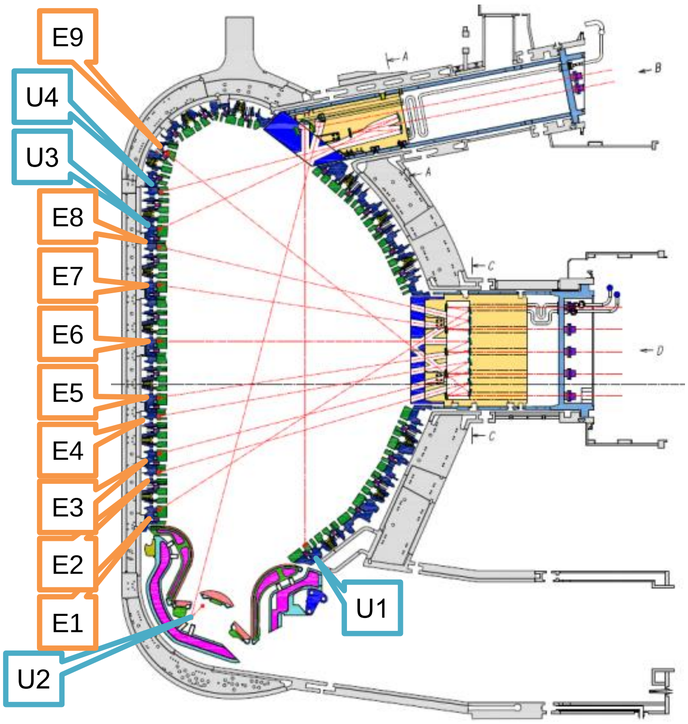


Figure 1 Overview of PoPola viewing chords

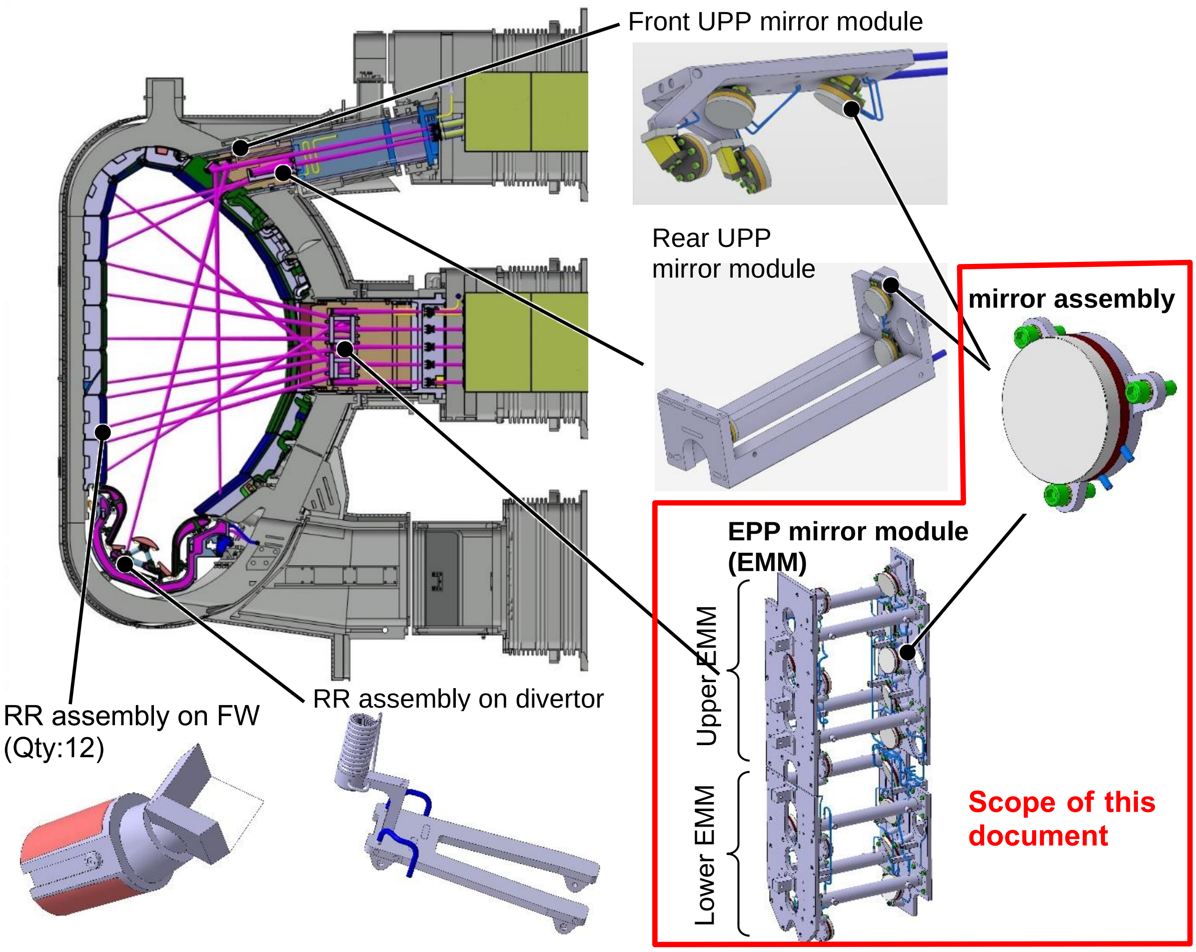


Figure 2 PoPola in-vessel components

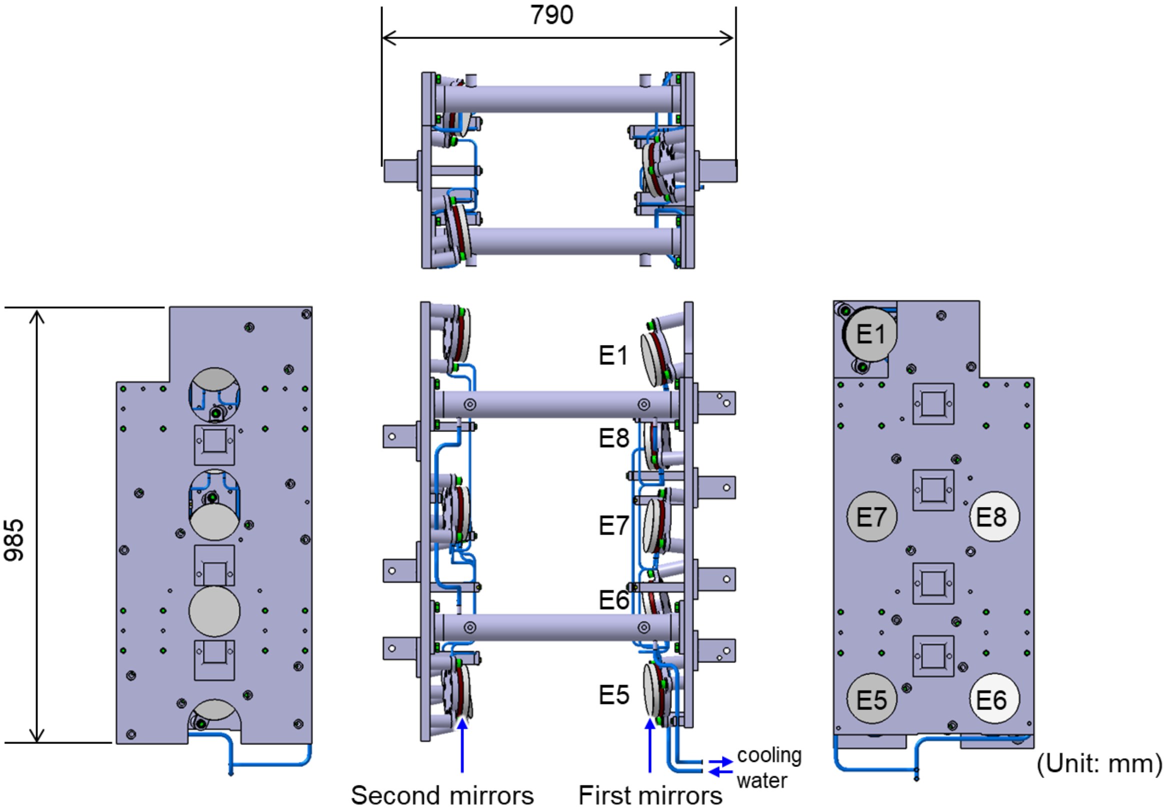


Figure 3 UEMM (Upper part of EP Mirror Module)

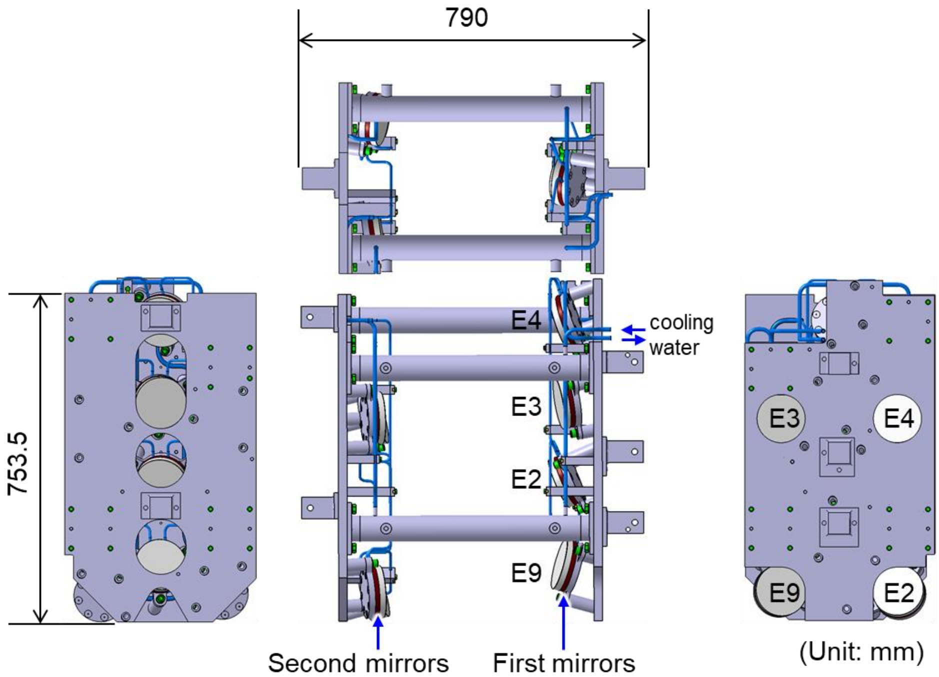


Figure 4 LEMM (Lower part of EP Mirror Module)

Both of UEMM and LEMM consist of the same components such as mirror assemblies, connecting rods, baseplates, and pipes. Figure 5 and Figure 6 show overview of components and assemblies. Technical description [1] provides the detailed explanation about each component.

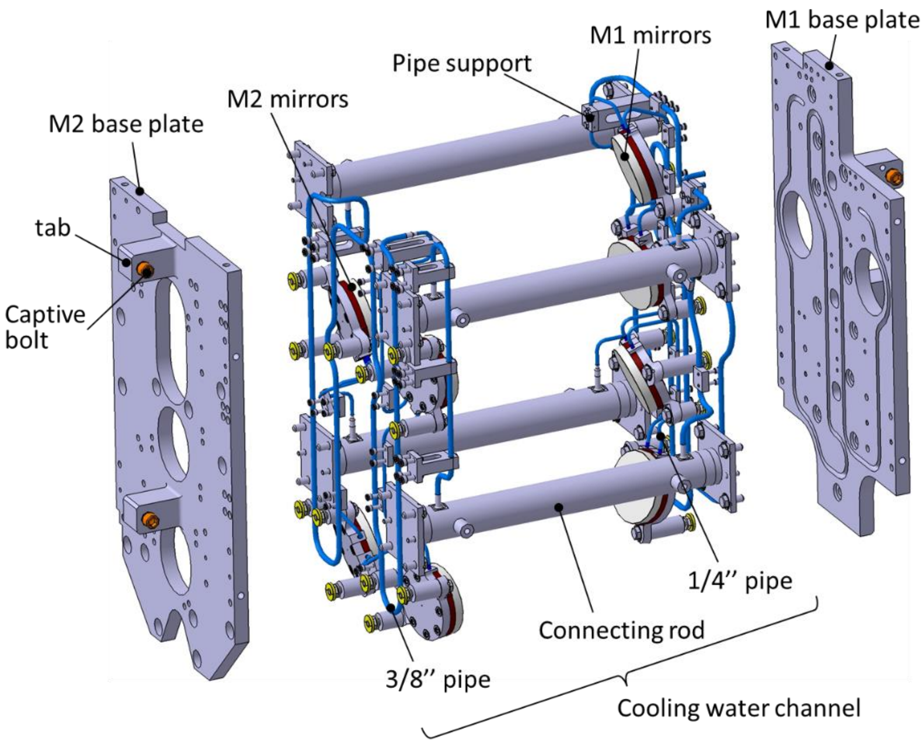


Figure 5. Components of EMM

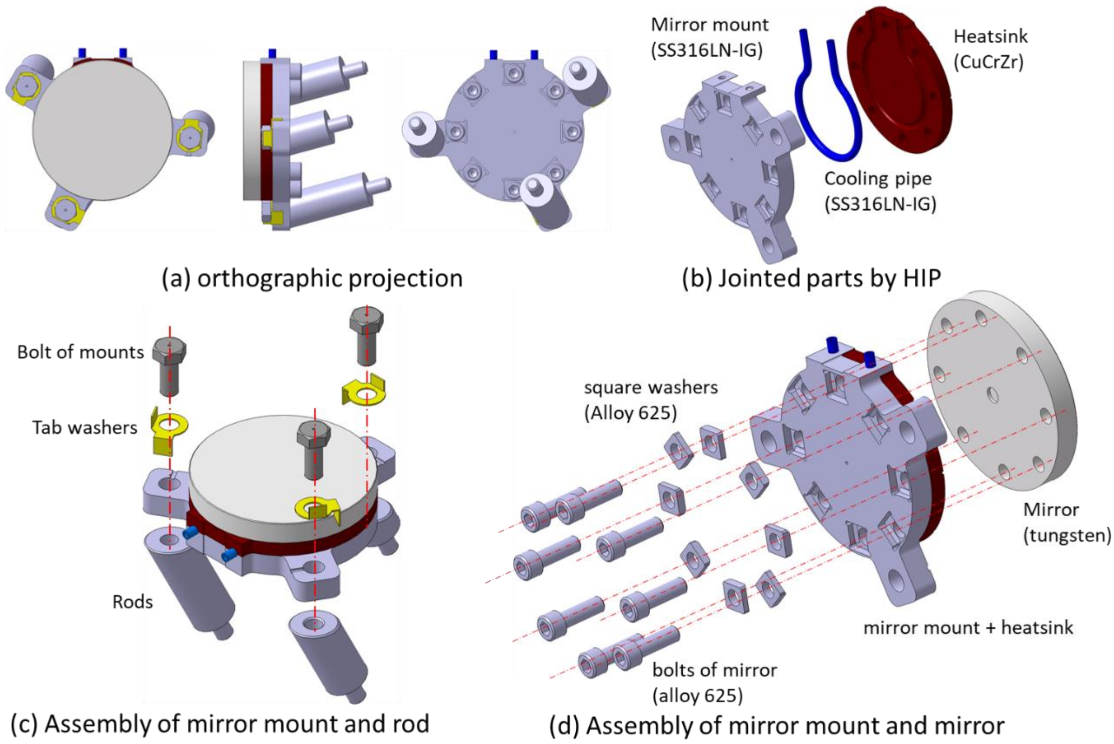


Figure 6. Components associated with mirror mount.

5. Technical Specification

5.1. Functional Specifications

Optical function

– To transmit the FIR laser of wavelength of 118.8 μm.

Mechanical function

– To cool the mirrors and the supports so that thermal deformations are less than (or equal to) the allowable tolerances based on the optical design requirements specified in Section 5.3 (6).

– To maintain the structural integrity under the expected loads so that no cooling water leaks into the vacuum vessel.

5.2. Environmental Specifications

Plasma discharge

The thermal conditions for EMM during plasma discharge are given in Table 2.

Table 2 Thermal load condition for EMM

Item	Value
Radiation heat load to mirror	694 W/m^2
Nuclear heat load to mirror	1.0 MW/m^2
Mass flow	0.18 kg/s (total) (0.09 kg/s for UEMM) (0.09 kg/s for LEMM)
Temperature of coolant water	70 °C
Inlet pressure of coolant water	4.8 MPa

Baking

During baking, the cooling water temperature is 240°C, and the pressure of cooling water is 4.8 MPa.

5.3. Design Specifications

(1) Equipment Class

The classifications of EMM components are shown in Table 3. PoPola's in-vessel components, including the EMM, are non-SIC equipment.

Table 3 Classifications of EMM

Safety Class	Safety Fanction	Seismic Class	Quality Class	Vacuum Class	RH Class	ESP/ESPN
Non-SIC	N	SC2	QC1	VQC-1A	non-RH	N3 Cat 0

(2) Applicable codes and standards
- (a) ESP/ESPN
- (b) The International Organization for Standardization (ISO).
- (c) RCC-MRx 2015 for manufacturing
- (d) SDC-IC for design [2]
- (e) ITER Vacuum Handbook [3]
- (f) ITER Material Properties Handbook [4]

(3) Dimensions

See the drawing [5].

(4) Parts and materials

The drawing [5] specifies materials and weights. Table 4 shows the summary of the material list.

Table 4 Material list of EMM

No.	Material	Component name
1	SS316LN-IG	─ Mirror mounts ─ Rods ─ Baseplates ─ Connecting rod ─ 1/4’ cooling pipes ─ 3/8’ cooling pipes ─ Reducers ─ Pipe supports ─ Bolts ─ Washers ─ Nuts
2	Pure Tungsten	Mirrors
3	CuCrZr	Heatsink
4	Alloy 625	Bolts

The materials in Table 4 shall comply with the ITER Material Properties Handbook (MPH) [4]. It is necessary for manufacturer to prepare traceable documents such as mill test certificate and inspection documents complying with EN10204 type 3.1.

Special requirements related to material specifications are as follows:

Requirement on SS316L(N)-IG

─ The chemical composition of SS316L(N)-IG shall be Table 5 that is copied from MPH [4].

─ Following the specification on heat treatment conditions described in MPH [2], steel products that have been exposed to temperatures of 1050 °C to 1150 °C then rapidly cooled using solution heat treatment shall be used.

─ A manufacturer shall prepare technical requirements specified in a purchase order in compliance with RCC-MRx RM 011-1. When employing RM 011-1.1 “General case”, the manufacturer can select either one of RM 032, RM 332-1, RM 332-2, RM 332-4 or RM 332-5. Mechanical tests of material depend on the selection. Whichever the manufacturer selects, the chmical composition of SS316L(N)-IG in MPH [4] shall be satisfied.

─ Section 5.3 of IVH [3] shall be complied.

- When the final thickness is less than 5 mm, the material needs to be made from cross-forged material which is Electro-Slag Remelted (ESR) or Vacuum Arc Remelted (VAR). The rate of inclusions in such steels shall be checked in accordance with ASTM E-45 Method D (or equivalent) to be within the following inclusion limits: Inclusion Type A-C ≤ 1.0 and Inclusion Type D ≤ 1.5.
- When the final thickness between 5 mm and 25 mm, products shall be manufactured from approved steel (listed in IVH Appendix 3 [7]), in the form of stock which has been cross-forged (upset forged).
- When the final thickness is more than 25 mm, no requirements are specified in Section 5.3 of IVH [3]

Table 5. Chemical composition of SS316L(N)-IG (wt.%)

	316L(N)-IG ITER grade
	max or range
C	0.030
Mn	1.60-2.00
Si	0.50
P	0.025
S	0.010
Cr	17.00 - 18.00
Ni	12.00 - 12.50
Mo	2.30 - 2.70
N	0.060 - 0.080
Cu	0.30
B	0.0020
Co	0.05
Nb	0.01
Ta	0.01
Ti	0.10

Requirements on Pipe

EMM uses two kinds of pipes; OD1/4″ and OD3/8″. The first pipe is the outer diameter is 1/4″ (=6.35) mm, and the thickness is 1 mm. The second pipe is the outer diameter is 3/8″ (=9.35) mm, and the thickness is 1 mm. The dimensions comply with “CAD Manual 12-2 Piping Design” [8]. The thickness of the both pipes comply with requirements on the thickness defined in RCC-MRx RB 3632. The both pipes need to be inspected complying with NF EN 10216-5 that is referred by RCC-MRx.

According to Section 12.1 of IVH [3], the pipe shall be seamless one. Figure 7 shows the requirements of pipe material copied from Section 12.1 of IVH [3].

A manufacturer shall prepare technical requirements specified in a purchase order in compliance with RCC-MRx RM 011-1. When employing RM 011-1.1 “General case”, the manufacturer can select either one of RM 034, RM 334-1, or RM 334-2. Mechanical tests of material depend on the selection. Whichever the manufacturer selects, the chmical composition of SS316L(N)-IG in MPH [4] shall be satisfied

For VQC 1A and VQC 2A, & VQC 4A (process to insulation vacuum) pipework of wall thickness less than 2.0 mm designed to contain helium, Electro-Slag Remelted (ESR) or Vacuum Arc Remelted (VAR) material shall be used for the pre-extruded material and the inclusion limits of Section 5.3 adhered to.

Figure 7. Requirements of pipe material copied from Section 12.1 of IVH [3]

Requirements on tungsten

The chemical composition of pure sintered tungsten shall be 99.96% W. The chemical composition ratios in MPH [4] shall be satisfied.

Requirements on CuCrZr

The CuCrZr shall comply with UNC C18150 standard CuCrZr as described in the IVH Appendix 3 [7] or, CuCrZr specified as ITER Grade having a chemical composition of 0.6% to 0.9% Cr, and 0.07% to 0.15% Zr as described in MPH [4].

(5) Surface profile

Regarding laser reflective surfaces, surface roughness (Ra) needs to be 10 nm or less and flatness needs to be 5,940 nm or less (less than 1/20 of the laser wavelength of 118.8 μm). Taking into account the acheivement of the prototype manufacturing, the specification of the flatness of the product is 1 μm or less.

Regarding all other surface finishes, the maximum average surface roughness (Ra) shall be 6.3 μm or less according to the requirements for VQC 1 components in Section 8.1 “Surface Roughness" of IVH [3]. An extract of the relevant maximum average surface roughness requirements for VQC 1 components copied from IVH [3] is shown in Figure 4.

8 Surface Finish

8.1 Surface Roughness

Metallic components for different VQC shall be supplied with the maximum average surface roughness listed in Table 8-1. Surface roughness is defined in accordance with ISO 4287: 2000.

Classification	Maximum average Surface Roughness Ra (μm)	Measurement Technique
VQC 1	6.3	Electric stylus
VQC 2	12.5†	Electric stylus
VQC 3	12.5	Electric stylus
VQC 4	12.5	Electric stylus

† Where to satisfy this surface roughness requirement additional machining would be required a rougher surface is accepted provided the surface is easily cleanable and can be shown not to catch fibres when wiped with a lint free cloth.

Figure 4. Requirements of surface roughness copied from IVH [3]

(6) Mirror angles of EMM

- Tolerance of relative mirror angle between the first mirror and the second mirror is ±0.16° [9].
- The out-of-plane deformation of the mirror shall be 10 μm or less [10].

(7) Welded Joints

The welded joints of the EMM are shown in Figure 8, and the specifications of each joint are given in Table 6. The manufacturer shall comply with requirements that both IVH and RCC-MRx specify.

Requirements from IVH

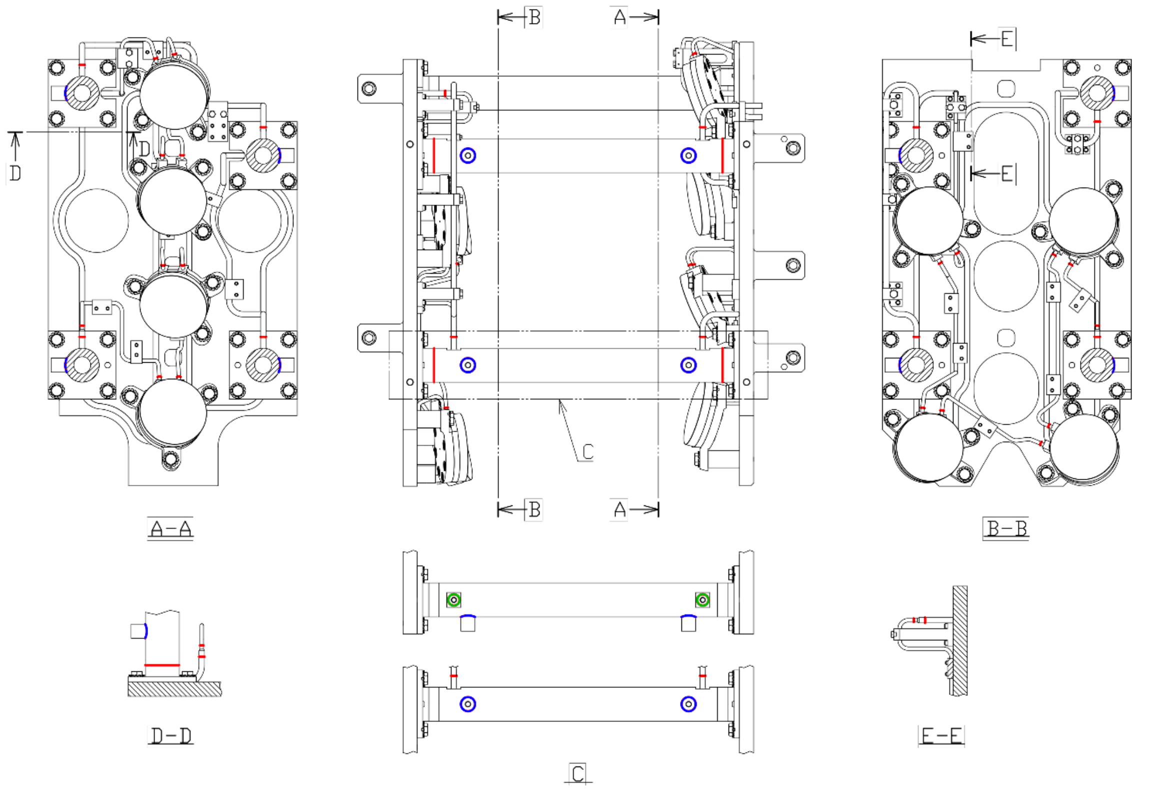
The manufacturer shall carry out qualification and welding in accordance with IVH Attachment 1 [6], which is based on the international standards ISO 9606, ISO 15614 and ISO 15609. Figure 9 shows the applicable standards regarding welding.

Because the vacuum equipment class of EMM is VQC1A, 100% volumetric inspection (RT or UT) shall be performed for the pressure-retaining joints that form the cooling water boundary (red lines in Figure 8) in accordance with Section 7.1.4 “Inspection and Testing of Production Welded Joints" of IVH [3] (see Figure 10). The standards for the welding procedures and post-weld inspections are given in Figure 9.

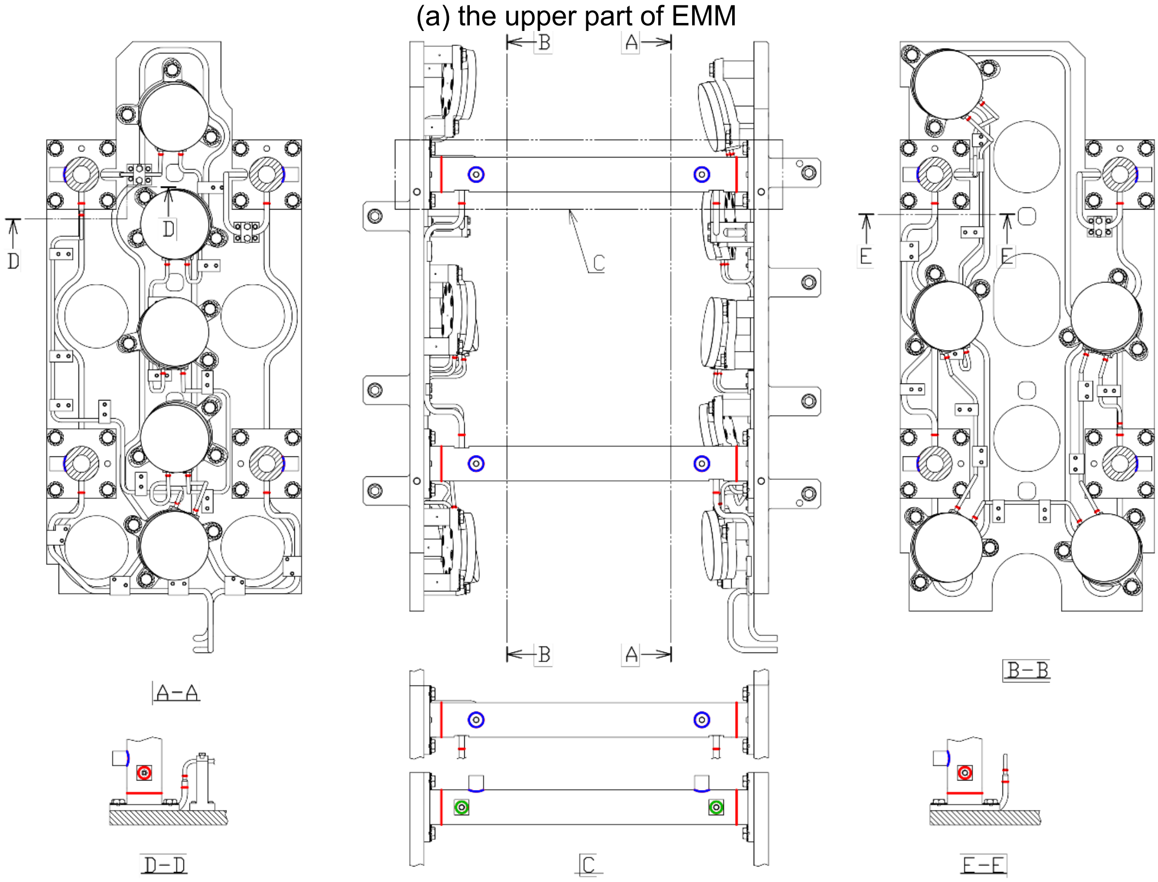
If conducting penetrant testing for surface inspections, the PT shall be carried out in accordance with the procedures approved by the ITER Organization, including removal of the testing liquid.

Helium leak tests shall also be performed in accordance with "7.1.6. Helium Leak Testing of Production Welds" (see Figure 10). Leak test procedure manuals shall be prepared in advance and approved by ITER Organization. In case of leak test failure, mutual agreement concerning corrective measures is necessary prior to re-executing the leak tests.

The manufacturer shall comply with the reuiqrements regarding tests such as acceptance levels and the total number of tests are specified by IVH Attachment 1 [6]. For example, Figure 11 shows the acceptance levels specified in IVH Attachment 1.



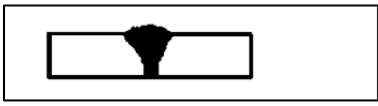
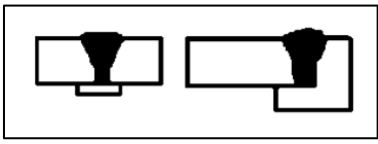
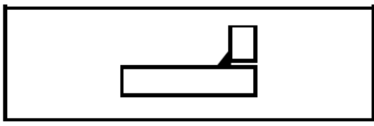
(a) the upper part of EMM



(b) the lower part of EMM

Figure 8. Welded joints of EMM

Table 6. Specification of types of welded joint

Color code	Pressure-containing member [1]	Type of welded joint [2]
Red	Yes	 II.1
Green	Yes	 II.2
Blue	No (Welded joints at a threaded boss that is used just for assembly)	 VII

[1] According to ASME PTC 23 defition, pressure containg member means a component which is exposed to and contains pressure, and pressure retaining member means a component which holds one of more pressure containing members together but is not exposed to the pressure.

[2] Types of welded joint is defined in Table IC 4012-1 of SDC-IC.

ISO 15607	Specification for the qualification of welding procedures for metallic materials – general rules
ISO 15614	Specification and qualification of welding procedures for metallic materials-welding procedure test
ISO 15609	Specification and qualification of welding procedures for metallic materials – Welding procedure specification
ISO 17637	Non-destructive examination of fusion welds. Visual examination.
ISO 4063	Welding and allied processes – Nomenclature of processes and reference numbers.
ISO 3452	Non-destructive testing. Penetrant testing.
ISO 17638, ISO 9934	Non-destructive examination of welds. Magnetic particle examination of welds
ISO 17636	Non-destructive examination of welds. Radiographic examination of welds.
ISO 17640	Non-destructive examination of welds. Ultrasonic Examination.
ISO 9606-1	Qualification test of welders – Fusion welding – Part 1: steels.
ISO 9606	Qualification test of welders – Fusion welding – Part 2: aluminium and aluminium alloys.
ISO 14344	Welding and allied processes – Flux and gas shielded electrical welding processes – Procurement guidelines for consumables.
ISO 5817	Fusion welded joints in steel, nickel, titanium and their alloys (beam welding excluded) – Quality levels for imperfections.
ISO 14732	Welding personnel. Approval testing of welding operators
ISO 9712	Non-destructive testing - Qualification and certification of NDT personnel
ISO 22825	Non-destructive testing of welds - Ultrasonic testing - Testing of welds in austenitic steels and nickel-based alloys
ISO 10380	Corrugated metal hoses and hose assemblies

Table 4-1 Standards relating to welding

Figure 9. Standards relating to welding copied from IVH Attachment 1 [6].

7.1.4 Inspection and Testing of Production Welded Joints

All such inspection and testing shall be carried out using approved procedures in accordance with Attachment 1.

For all VQC 1A, VQC 2A water boundaries and vacuum boundary welds which become inaccessible, 100% volumetric examination of production welds shall be performed, unless a method of pre-production proof sampling is approved.

7.1.6 Helium Leak Testing of Production Welds

All vacuum sealing welds in each VQC shall be subject to helium leak testing in accordance with the procedures of Section 25.

Where multi-pass welding is required in the production of components of VQC 1A and VQC 2A, it is recommended that leak testing of the root weld pass shall be performed with only this pass completed. However, for multi-pass welding that takes place on the ITER site, this requirement is mandatory.

Figure 10. Reference about welded joints in IVH [3]

Defect Type		Permitted maximum
Planar Defects	Cracks or lamellar tears Lack of root fusion Lack of side fusion Lack of inter-run fusion Lack of root penetration	Not permitted
Solid inclusions	Slag inclusions - individual	20% of t or 2 mm, which ever is smaller
	Slag inclusions - Group	Aggregate length not to exceed t in a length of 12 t, except when the distance between successive indications exceeds 6L where L is the longest indication in the group
	Inclusions – ***Tungsten*** or Copper	Not permitted
Cavities	Isolated pores - round	Diameter <20% t or 2 mm, whichever is smaller
	Gas pore uniformly distributed porosity	1% for single layer (2% for multi-layer) by area where the area of the radiograph to be considered is the length of the weld affected by the porosity times the maximum thickness of the weld
	Elongated pores - wormholes	***Not permitted***
	Linear Porosity	***Not permitted***
Profile defects	***Under cut***	***Some intermittent undercut permitted. Depth not to exceed 0.5 mm for t > 3 mm or 10% for t < 3 mm. Under cut to blend smoothly with the parent material.***
	Incompletely filled groove, sagging. Root concavity, shrinkage groove	0.05 t or 0.5 mm, which ever is smaller. Weld thickness shall not be less than the parent plate thickness
	Excess penetration - pipe	Not greater than 5% of the pipe internal diameter up to 2 mm max.
	Excess penetration – plate	t = 0.5 to 3 mm: , h ≤1 mm+10% b t > 3mm: h ≤1 mm+20% b max 3mm.
		h=height of excess penetration on backside of plate and b the width
	Excess weld material	Not greater than 10% weld width
	Misalignment	***Not greater than 10% of the parent material thickness***
	Fillet leg length (asymmetry)	Unequal leg length should not exceed 20% of the fillet throat thickness
	Burn through	Not permitted
Other	Root oxidation	Not permitted where a backing purge gas is specified in the WPS

Table 6-6 Acceptance levels

Figure 11 Acceptance levels of welding copied from IVH Attachment 1 [6].

Requirements from RCC-MRx

The manufacturer shall comply with the requirements that RCC-MRx specifies for Class N3 components. For instance, RCC-MRx Table RS 7462 (Figure 12) is applicable to the welding of the connecting rod, and RCC MRx RF 4351 (Figure 13) is applicable to the welding of 1/4-inch cooling pipes.

Table RS 7462: class $N3_{Rx}$ – maximum permitted reinforcements for arc-welded butt welds (electrons and laser beam exclude) – steels, nickel, titanium

	Maximum permitted reinforcements on the front side	**Maximum permitted reinforcements on the back side**
Welds with backing run	(502) 1/10 of the bead width + 2 mm **with a maximum of 5 mm**	(502) 1/10 of the bead width + 2 mm
Welds without backing run	(502) 1/10 of the bead width + 2 mm **with a maximum of 5 mm**	e/10 + 1 with a max of 3 mm (**1**)

(502 – 504): Excess weld metal – Excessive penetration. Cassification given in *NF EN ISO 6520-1* standard

(1) For butt welds on class $N3_{Rx}$ pipes, the permitted reinforcement on the back side (504) is increased to:
2 mm for e ≤ 5 mm 2.5 mm for 5 < e ≤ 10 mm 3 mm for e > 10 mm

- e : nominal thickness of the pipe

Figure 12. Example of requirements specified in RCC-MRx (maximum permitted reinforcement)

RF 4350 ALIGNMENT TOLERANCES FOR PIPES AND PIPING

RF 4351 Steels, nickel and its alloys

a. When the inside surfaces of butt welded counterbored pipe components are inaccessible, the inside diameters of the components shall be offset in accordance with the method given in **RF 4330**. In these cases, the maximum misalignment at any point around the joint shall not exceed 1.5 mm.
b. In order to butt weld welded steel pipe and fittings whose thickness-to-diameter ratio is such that the pipe cannot be counterbored and may be subject to deformation, the Manufacturer shall calibrate the end sections of the joint, when necessary, to meet the tolerance requirements given in a. above.
c. For longitudinal joints of welded pipe, the internal offset shall not exceed:
   - 1 mm for e ≤ 20 mm
   - e/20 (in mm) for 20 mm < e ≤ 40 mm
   - 2 mm for e > 40 mm.

   For small schedule pipes welded longitudinally using the TIG process, it is recommended that these values be reduced.
d. For large pipes manufactured from rolled and longitudinally welded heavy steel plate, the tolerance requirements given in **RF 4320** and **RF 4330** shall apply.

Figure 13. Example of requirements specified in RCC-MRx (alignment tolerances for pipes)

(8) Brazed joints

The 1/4'' pipes are brazed to the M1 and the M2 base plate. Filler material is Au-18%Ni (W32X33) that is approved in the material database (N3SVRJ). In accordance with Section 7.2.3 “Inspection and Testing of Brazed Joints" of IVH [3], to ensure that there are no voids or blowholes, the surface of the brazing filler metal shall be visually inspected to ensure that there are no visible signs of inclusions and that the braze has filled the joints without overspreading.

In order to qualify the brazing procedure, a factory qualification test [11] will be carried out. Test samples shall be made, and then tests such as visual inspections and outgassing tests shall be made. The brazing procedure qualified by the factory qualification test shall be applied to the production equipment. Should brazing corrective measures be required, mutual agreement among the contractor, JADA and IO-CT is necessary prior to re-brazing.

Figure 14 shows the relevant references that are specified in IVH [3].

7.2.3 Inspection and Testing of Brazed Joints

Brazed joints shall be subject to qualification to ensure the vacuum integrity of the joint.

All brazed joints shall be inspected visually to ensure that the vacuum exposed braze regions are clean, flush and free from voids, blowholes, etc., that there is no visible evidence of inclusions and that the braze material has filled the joint without excessive over-run.

Where practicable, radiography of an agreed percentage sample of brazed joints shall be carried out. Where this is not practicable, then samples shall be produced for sectioning and microscopic examination.

The use of liquid dye penetrant or magnetic particle techniques shall not be permitted for the inspection of brazed joints or in the inspection of joint preparations.

All brazed joints which form part of a vacuum boundary shall be subject to 100% helium leak testing.

No braze shall be re-run for rectification of any sort without prior agreement.

Figure 14. Reference about brazed joints in IVH [3]

(9) Summaryu of Testing and Inspection
Table 7 shows the tests and inspections to be performed on production of EMM.

Table 7 Inspection and testing for CBRR

Test item		Reference standard	Remarks
Visual inspection		—	—
Dimensional inspection		—	Use calibrated instruments to measure component dimensions.
Surface inspection (roughness and flatness) of mirrors		—	See 5.3 (5)
Inspection of mirror angle		—	See 5.3 (6) and 5.4 Process C
Welding inspection	Visual inspection	ISO 17637	—
	Penetrant testing (PT)	ISO 3452	—
	Radiographic testing (RT)	ISO 17636	—
	Ultrasonic testing (UT)	ISO 17640	—
	Pressure tests	RCC-MRx RB 5200	—
	Helium leak tests	RCC-MRx RMC 7400 (ITER Vacuum Handbook 25. And Appendix12)	—
Destructive test of HIP joint		—	See 5.4 Process B
Thermal cycling tests		—	Unwitnessed inspection to check for initial defects (assuming three cycles at temperatures of 50°C/h or more))
Flow test		—	Unwitnessed inspection to confirm that there are no problems such as pressure loss due to blockage of the flow path.

(10) Outgassing requirements

Outgassing tests are required for all in-vessel components, according to IVH [3]. The allowable amount of gas release is defined in Section 5.4 “Outgassing" of IVH [3] according to its vacuum equipment class. The EMM is class VQC1A, which specifies maximum steady-state gas emissions of 1×10^{-7} Pa m^3 s^{-1} m^{-2} for hydrogen isotopes and 1×10^{-9} Pa m^3 s^{-1} m^{-2} for impurities.

Outgassing measurements are not performed on production equipment, instead, the satisfactionof the outgassing requirements are verified by the factory qualification. The manufacturing process of the procuts shall be identical with what is verified by the factory qualification.

(11) Baking requirements

The components and parts comprising the EMM shall be baked in accordance with the baking reference temperatures and baking times (Table 8) in IVH Appendix 15 [12].

Table 8 Standard temperatures and durations for vacuum baking

Vacuum Classification	Temperature (°C)	Time (hr)	Comment
VQC 1	240	24	
VQC 1*	350	24	Stainless steel and beryllium
	450 - 2000	24	Carbon composites (see Appendix 16)
	250	24	Precipitation-hardened copper alloys
	350	24	Tungsten

* For vacuum items in line vicinity of plasma

(12) Cleanliness requirements

After surface finishing, components are to be degreased using a solvent or alkaline detergent, then washed using desalinated water, then dried, in compliance with IVH Appendix 2 [13]. For washing/cleaning procedures, refer to IVH Appendix 13 [14]. Only use cleaning and degreasing procedures approved by the ITER Organization on production equipment.

For the area after final washing, the number of suspended particles shall be monitored to ensure that particles larger than 0.5 µm do not exceed $5 \times 10^6/m^3$, in accordance with the requirements for VQC1 equipment in IVH Appendix 2 [13]. All other products after final washing are to be handled under the environment shown in Table 9.

Table 9 Environmental cleanliness pertaining to VQC copied from IVH Appendix 2 [13].

VQC	Cleanliness requirements	Personnel	Area Cleanliness	Monitoring
1	Segregated clean area. Limited Access to authorised personnel. Authorised equipment operated to approved procedures. Management of equipment (e.g. no vacuum pumps exhausting into clean area)	Trained personnel. Protective hair nets. Powder free latex or nitrile outer gloves. Clean white overalls. Overshoes. Clean job specific footwear	Daily Cleaning of area including floors and surfaces. Sticky mats at area entry	Daily air quality checks. Results stored in component document package. Weekly cleanliness test of area with results stored in component document package
2	Authorised equipment operated to approved procedures. Management of equipment (e.g. no vacuum pumps exhausting into clean area)	Trained personnel Powder free latex or nitrile outer gloves for the handling of clean equipment	Daily Cleaning of work area including floors and surfaces.	
3&4	House Keeping	Trained personnel. Powder free latex or nitrile outer gloves for the handling of clean equipment	Daily cleaning of area.	

(13) Packaging specifications

For the packaging of equipment after manufacture, refer to Section 29 “Packaging and Handling of Vacuum Equipment” of IVH [3]. The packaging conditions shall, in principle, be as follows.

– All packages shall be enclosed in polyethylene containers filled with dry air having a moisture content of less than 4000 ppm, the outside of which shall be clearly labeled as VQC equipment in English.

– Ensure pipe interfaces are protected.

– If using tape for protection and packaging of austenitic stainless steels, use tape(s) that satisfies the leaching limits for chlorides (15ppm) and fluorides (10ppm).

– After any tape has been removed, acetone or a similar solvent shall be used to remove all traces of the adhesive.

– Packing workers shall wear clean, powder-free latex or nitrile gloves and clean white overalls.

5.4. Specification of manufacturing process

Figure 15 to Figure 21 show a plan of the manufacturing process of EMM, and processes A to C in these figures are the special processes. The explanations of the special processes are given below. In principle, the machining oils and cleaning solutions described in IVH Appendix 4 [15] shall be used in the manufacturing processes.

Process A: Welding

The type of welding of cooling pipes is a butt welding, and an automatic welding machine will be used. The non-destructive inspection for the welding part must meet the criteria specified in ISO 5817 quality level B (defect size $d \leq 0.2s$, max 2 mm (s: throat thickness of butt weld), etc.).

Process B: HIP (Hot Isostatic Pressing)

HIP process is applied to manufacture mirror mount assembly in order to bond a heatsink, a cooling pipe and a mirror mount. Nineteen mirror mount assemblies are manufactured in the same batch, and one of them is a sample that is used for destructive inspection.

Process C: Adjustment of mirror angle

Targets for laser position are used in order to adjust the mirror angles. The targets are set at the position of the vacuum windows and the retroreflectors. Mirror angles are adjusted so that the laser light beam passes through the center of the target. Shims are inserted between the mirror mount and the rods to adjust the mirror angle.

Figure 15 to Figure 21 are schematics of the manufacturing process, and detailed explanation is given by Reference [16]. The manufacturer can propose another manufacturing process by the manufacturing readiness review.

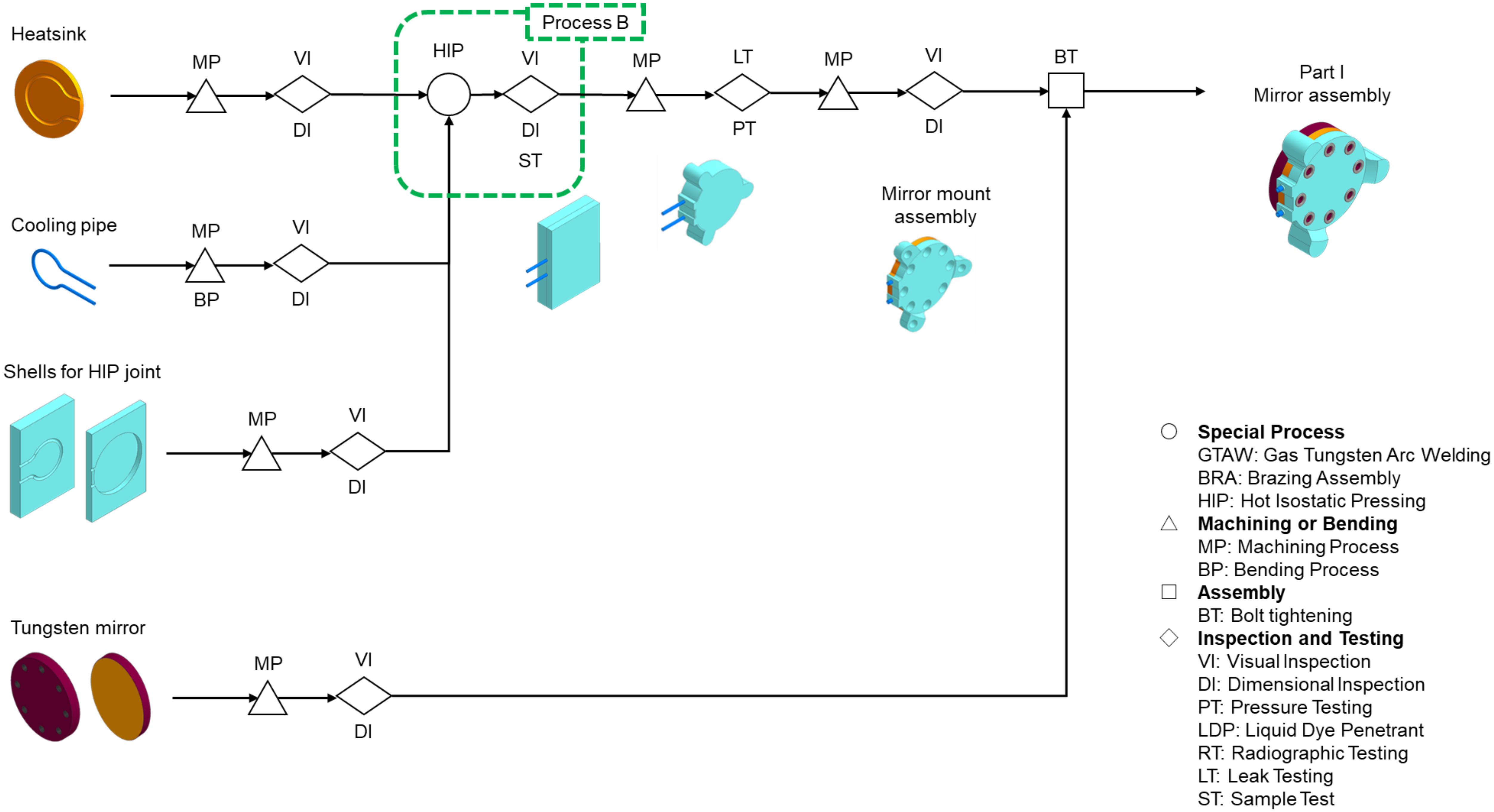


Figure 15 Manufacturing process of EMM (1/7)

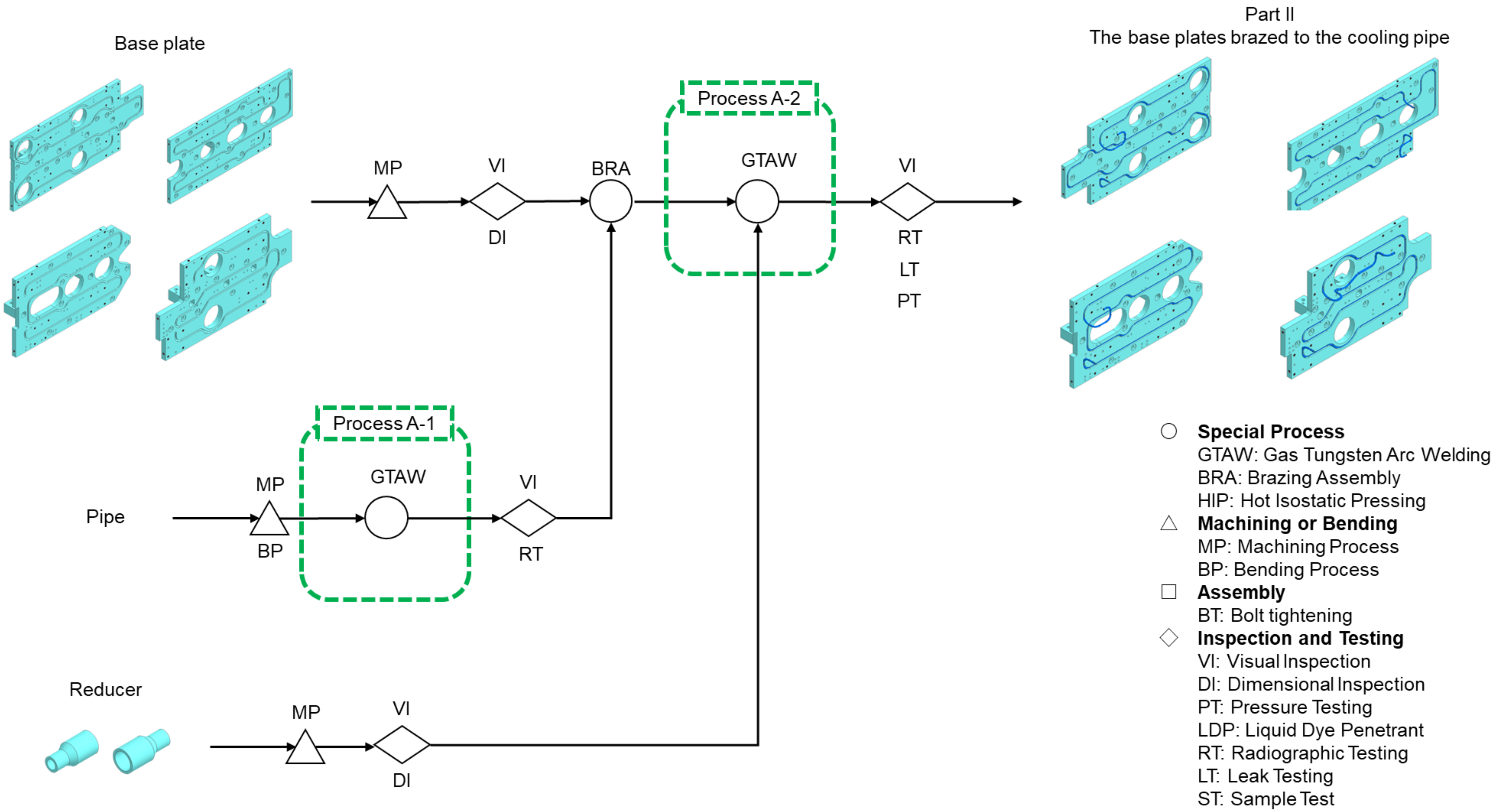


Figure 16 Manufacturing process of EMM (2/7)

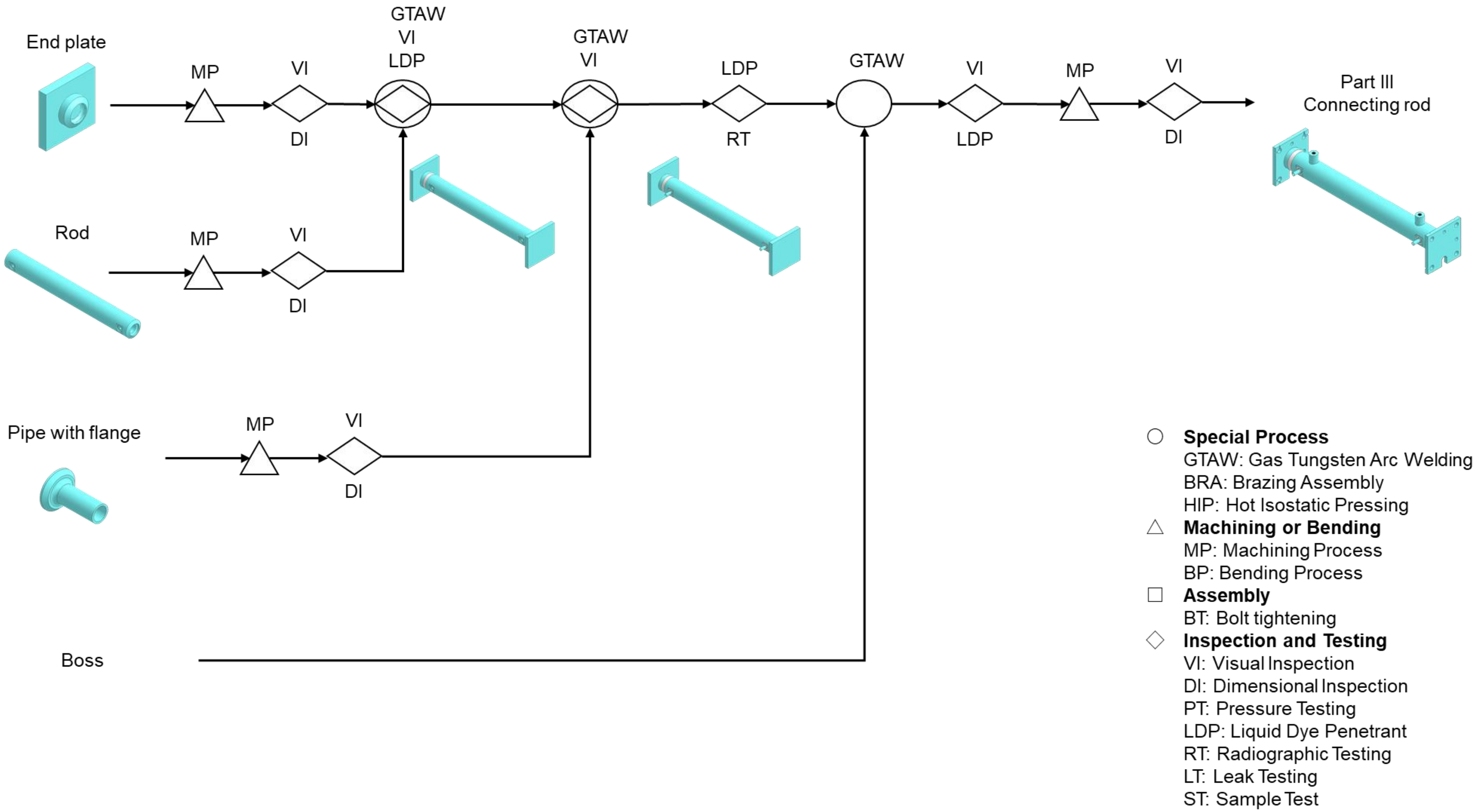


Figure 17 Manufacturing process of EMM (3/7)

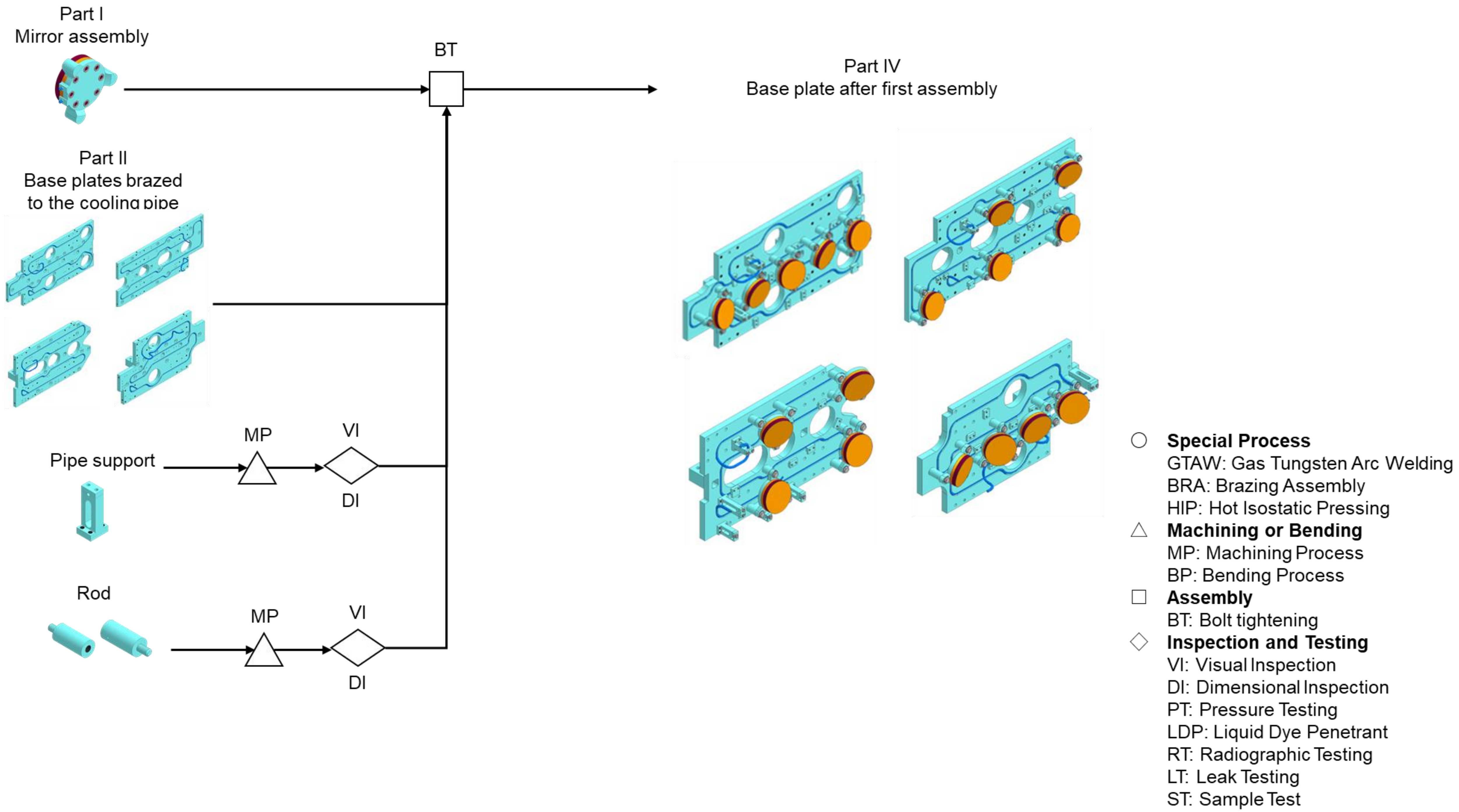


Figure 18 Manufacturing process of EMM (4/7)

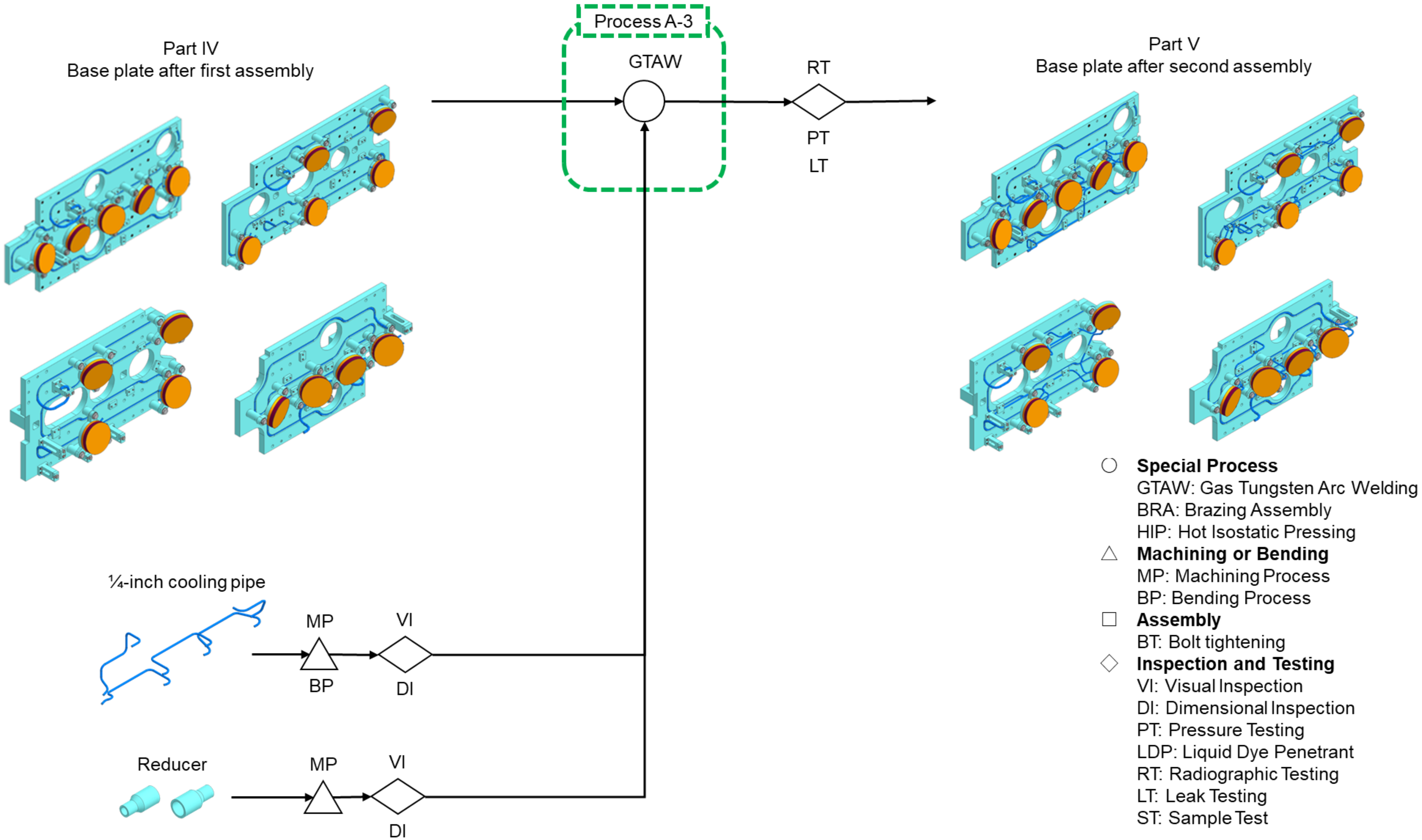


Figure 19 Manufacturing process of EMM (5/7)

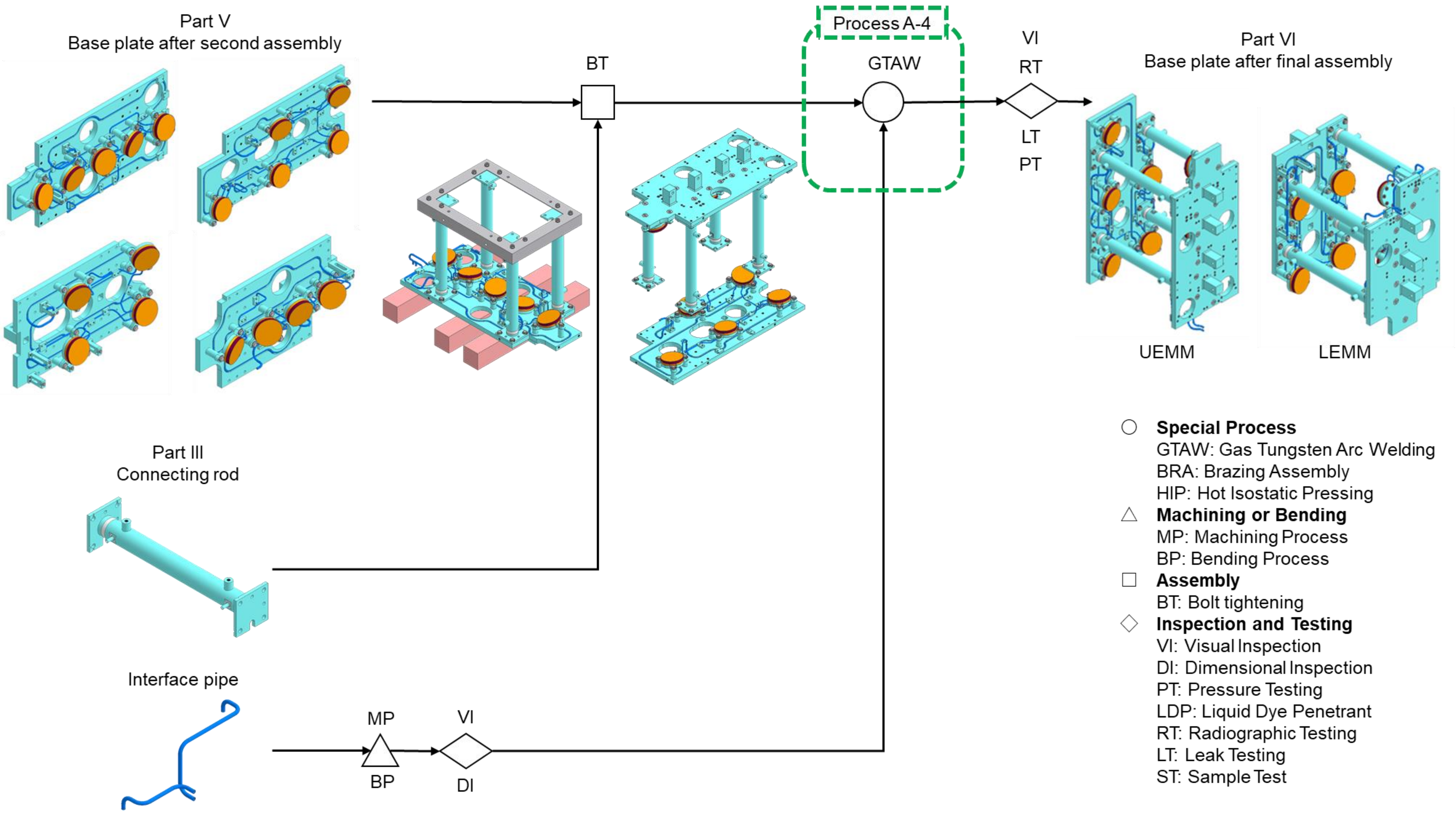


Figure 20 Manufacturing process of EMM (6/7)

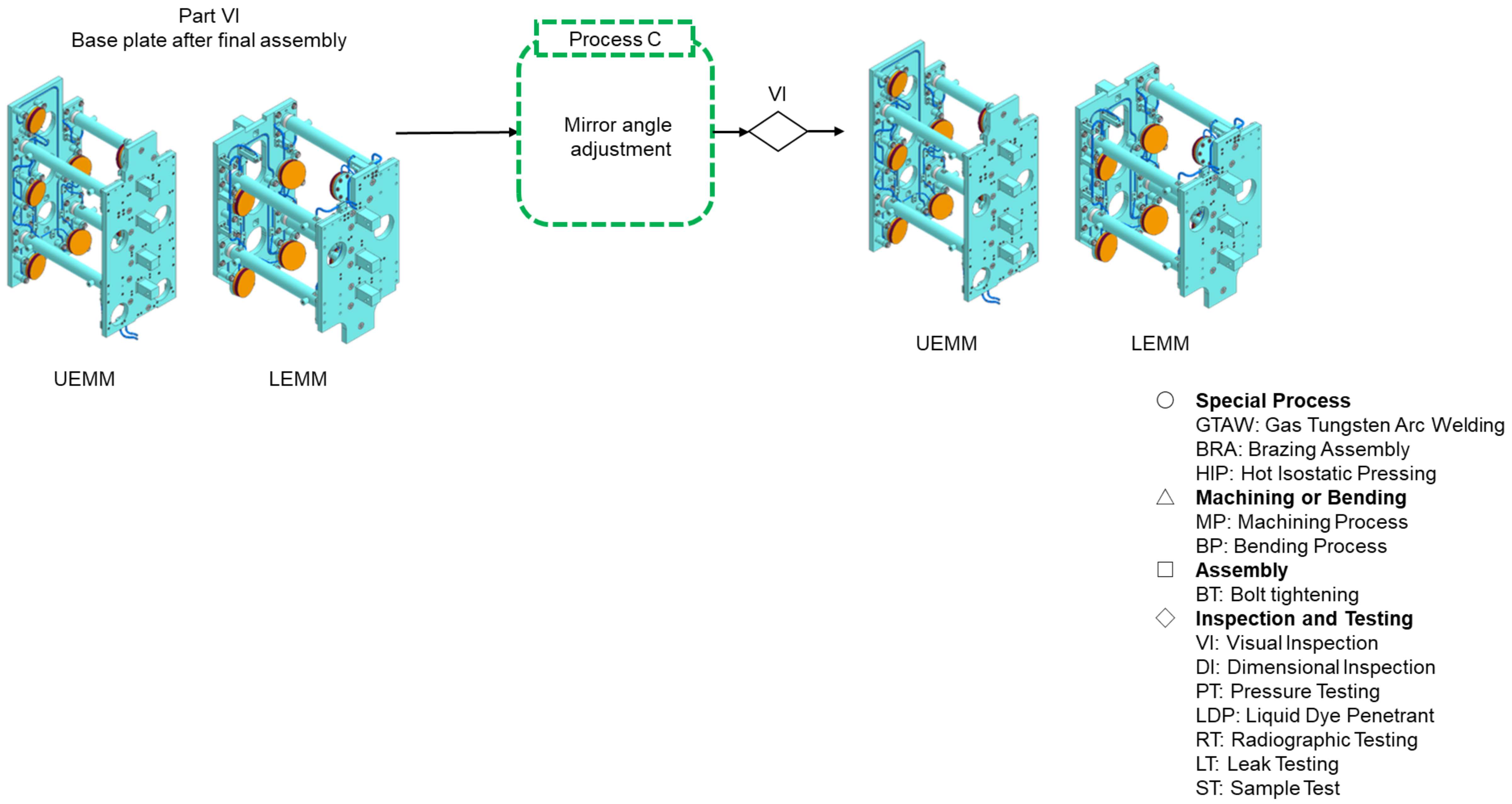


Figure 21 Manufacturing process of EMM (7/7)

JADA-55342DE0101-1
ITER_D_696XRM

Technical Description of PoPola Mirror Modules in Equatorial Port Plug 10

ITER Project Japan Domestic Agency

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Change log

Brunch no. (date) (IDM version)	Change description
- (20 Oct 2021) (696XRM v1.0)	First version
1 (19 Jan 2022) (696XRM v1.1)	– Explanation about RH operation in the hot cell facility are added to Section 9.
	–

Table of Contents

Abbreviations:

See ITER_D_2MU6W5 for abbreviations that are standard in ITER. Other special abbreviations are given below.

- EMM: EPP Mirror Module
- EPP: Equatorial Port Plug
- ESP: French regulation for Pressure Equipment
- ESPN: French regulation for Nuclear Pressure Equipment
- FIR: Far Infrared Ray
- HIP: Hot Isostatic Pressing
- LEMM: Lower EMM
- PoPola: PBS.55.C6 Poloidal Polarimeter
- StIR: Structural integrity report
- UEMM: Upper EMM

Reference:

[1] sub-SRD-55.C6, ITER_D_WYPRU9
[2] Technical Specification, ITER_D_696KB9 (or JADA-55342TS0106)
[3] Interface sheet with EPP10, ITER_D_UDPYGC
[4] SDC-IC, ITER_D_222RHC
[5] Load specifications, ITER_D_QWUFY2
[6] ITER Vacuum Handbook, ITER_D_2EZ9UM
[7] Components Classification BOM, ITER_D_RBZBEQ
[8] Optical Analysis and Design of PBS.55.C6 PoPola, ITER_D_RC2LB5 (or JADA-55332TS0022-1)
[9] Drawing of Mirror Modules in EPP10: ITER_D_5R3R6W
[10] Assembly drawing: to be uploaded to SMDD
[11] Structural Integrity Report, ITER_D_3DYHEQ
[12] Chit resolution report for PoPola CDR Chit #17 “Effect of potential bending of the flat plasma-facing mirrors”, ITER_D_UVR9CH
[13] Factory qualification test plan, ITER_D_69765M (or JADA-55342PL0101)
[14] 55.C6- Test Plan in PPTF for EP10 system ITER_D_WSSRAR (or JADA-55342TS0013)
[15] Maintenance and inspection plan, ITER_D_RTP6D8 (or JADA-55342TS0035)
[16] Remote Handling Compatibility Assessment of PBS.55.C6 PoPola, ITER_D_RRNUR9 (or JADA-55332TS0029)
[17] Decommissioning plan, ITER_D_RU2C32 (or JADA-55332TS0039)
[18] 55 C6 Manufacturing Assessment of PoPola Mirror Modules in Equatorial Port Plug 10, ITER_D_696RYF (or JADA-55342TS0102)

1 Introduction

The primary aim of the PoPola is to measure the change of polarization of injected far-infrared (FIR) laser light in order to identify the profile of plasma current, or equivalently safety factor. There are thirteen PoPola measurement channels to accomplish this measurement task. Each channel is comprised of a set of optical components that launch a laser beam from Equatorial Port Plug 10 (EPP10) or Upper Port Plug 10 (UPP10) across the plasma to a retroreflector. Figure 1 and Figure 2 show an overview of the PoPola viewing chords and the PoPola in-vessel components, respectively. Especially, components in the scope of this documents are the mirror module in EPP10. It is called EMM (EPP Mirror Module) and consists of two parts. The upper part is called UEMM (Upper EMM), and the lower one is called LEMM (Lower EMM).

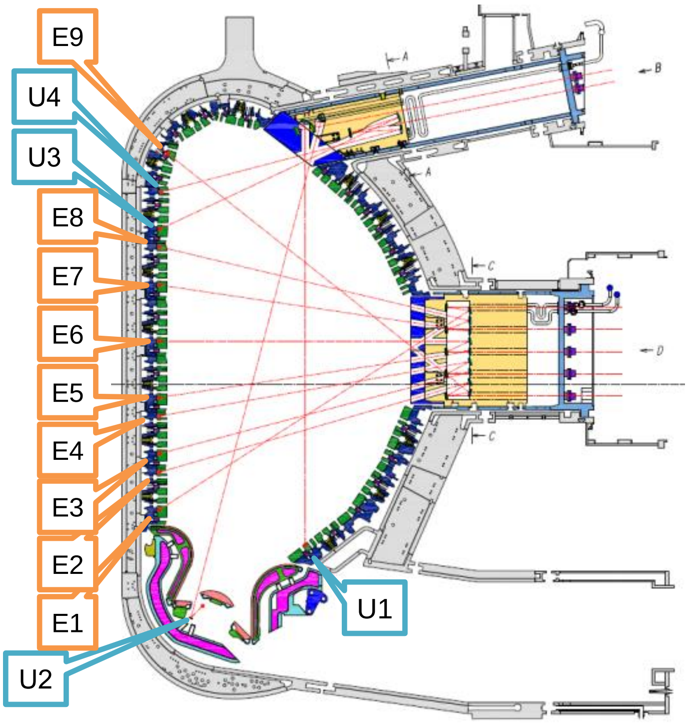


Figure 1 Overview of PoPola viewing chords

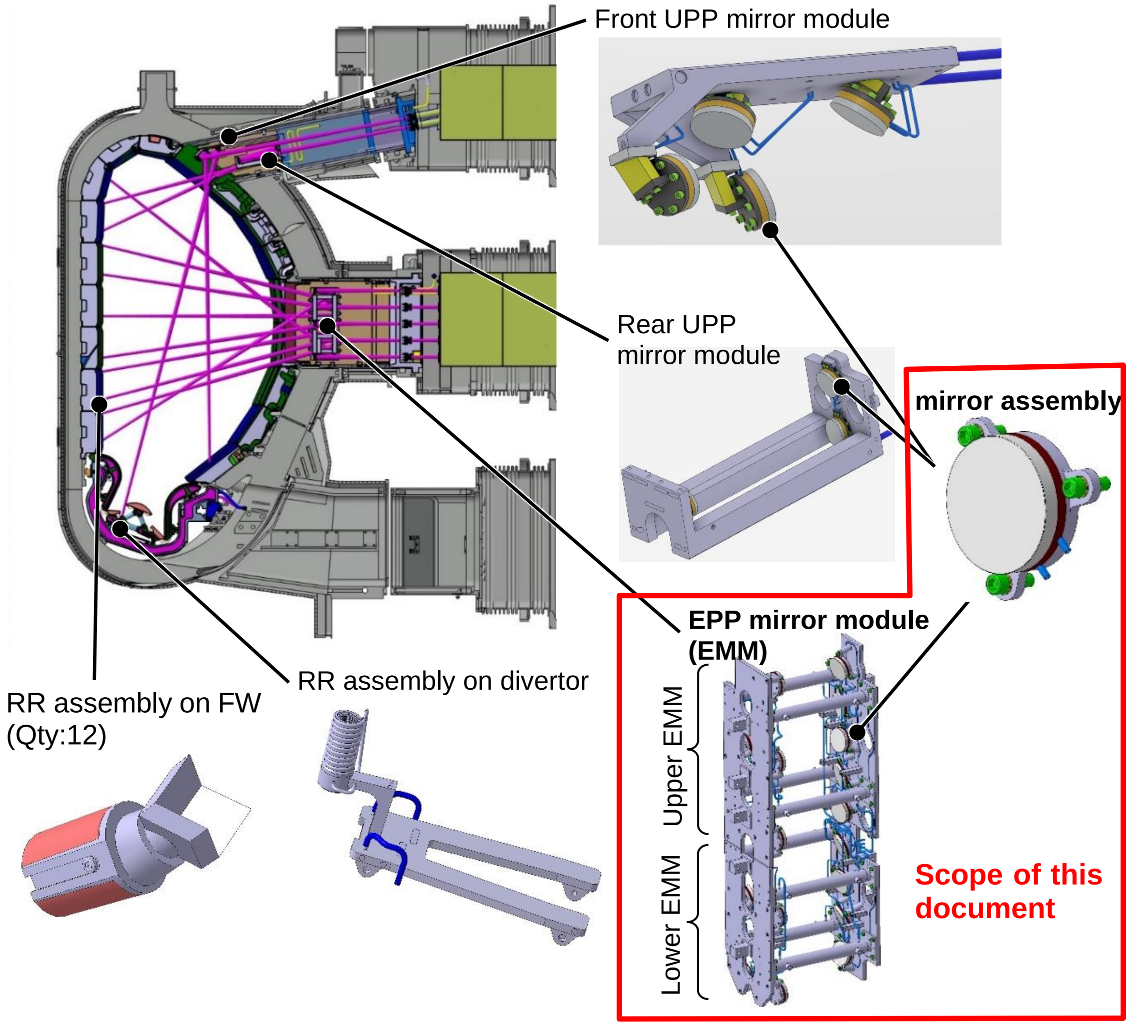


Figure 2 PoPola in-vessel components

2 Purpose

The purpose of this document is to provide design description of UEMM and LEMM.

3 Scope

As explained in Section 1, the components in the scope of this documents are UEMM and LEMM. Figure 3 and Figure 4 show the CAD images of them. Section 5 provides detailed explanation on the component design.

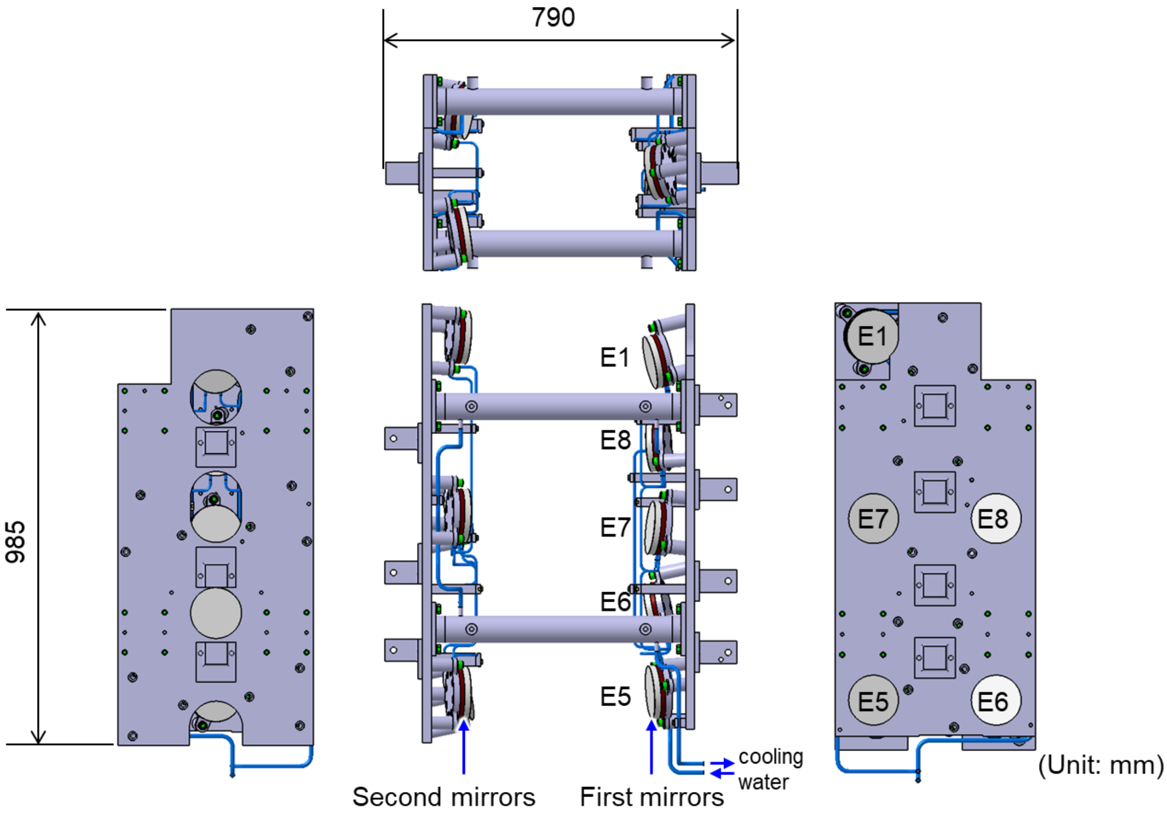


Figure 3 UEMM (Upper part of EPP Mirror Module).

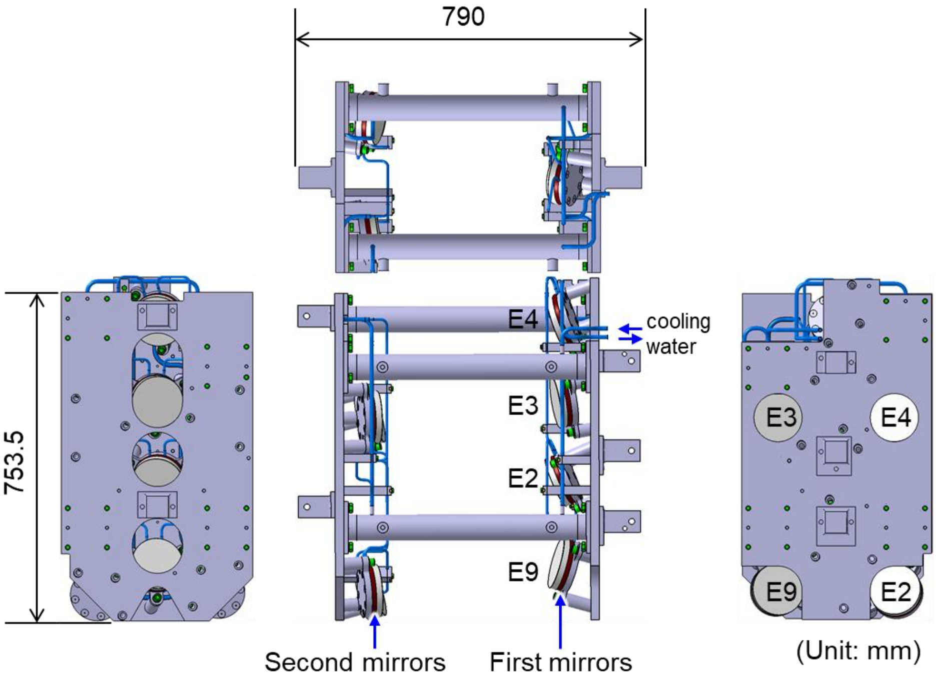


Figure 4. LEMM (Lower part of EPP Mirror Module).

4 Requirements

Applicable documents regarding the requirements are as follows.

- sub-SRD-55.C6 [1]
- Technical Specification of PoPola Mirror Module in Equatorial Port Plug 10 [2]
- Interface with EPP10 [3]
- SDC-IC (for design) [4]
- RCC-MRx 2012 (for manufacturing)
- ITER Vacuum Handbook [6]
- Load specifications [5]

The EMM's functions are as follows.

- To transmit the FIR laser beam.
- To transport the nuclear and radiation heat loads from EMM to cooling water.
- To ensure the confinement of the cooling water.
- To achieve low outgassing rate described in ITER Vacuum Handbook [6].

The document, "Technical specifications of PoPola Mirror Module in Equatorial Port Plug 10" [2], provides detailed specifications necessary for achieving the functions above.

Requirements given by ITER guidelines such as ITER Vacuum Handbook depend on the classification of the component. "Components Classification BOM" [7] provides the component classification, which are shown in Table 1.

Table 1 Classification table of UEMM and LEMM (Copy from BOM [7])

Safety Class	Safety Function	Seismic Class	Quality Class	Vacuum Class	RH Class	ESP/ESPN
Non-SIC	N	NSC	QC2	VQC-1A	RH-3	Cat 0

5 Design Description

Nine viewing chords pass through EPP10. Each viewing chord is transmitted by using two fixed mirrors called as M1 (or first mirror) and M2 (or second mirror). Thus, 18 mirrors are mounted in EPP10 in total. Mirrors of E1, E5, E6, E7 and E8 are included in UEMM, and those of E2, E3, E4 and E9 are included in LEMM. Clear aperture of M1 and M2 are 120 mm. M1 is a flat mirror, while M2 is a concave spherical mirror. Detailed data and justification can be found in "Optical Analysis and Design of PBS.55.C6 PoPola" [8].

5.1 Mechanical components

Both of UEMM and LEMM consist of the same components such as mirror assemblies, connecting rods, baseplates, and pipes. Figure 5, Figure 6 and Figure 7 show overview of components and assemblies. Table 2, Table 3, Table 4 and Table 5 provide the explanation about these components.

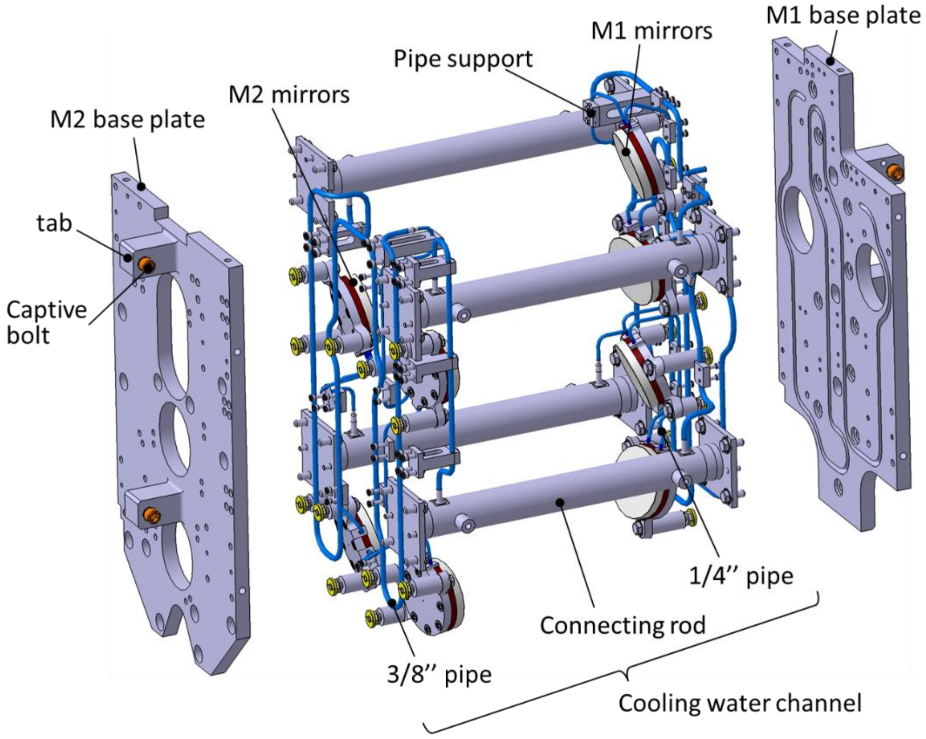
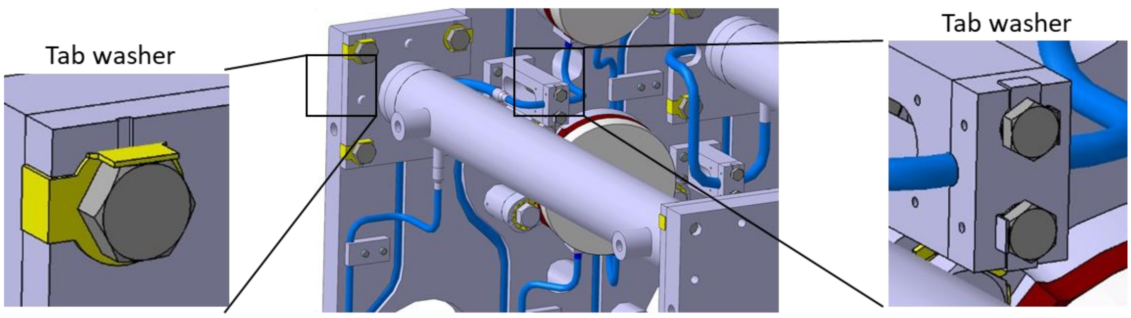
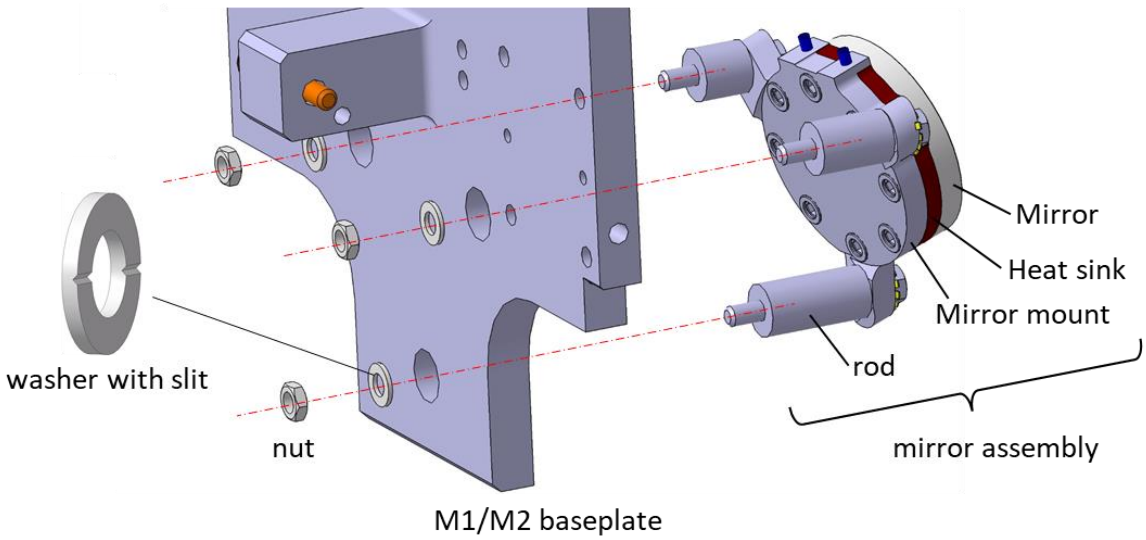


Figure 5. Components of EMM



(a) Fixation of connecting rod and 1/4'' cooling pipe



(b) Fixation mirror assembly

Figure 6. Fixation of components to M1/M2 baseplate.

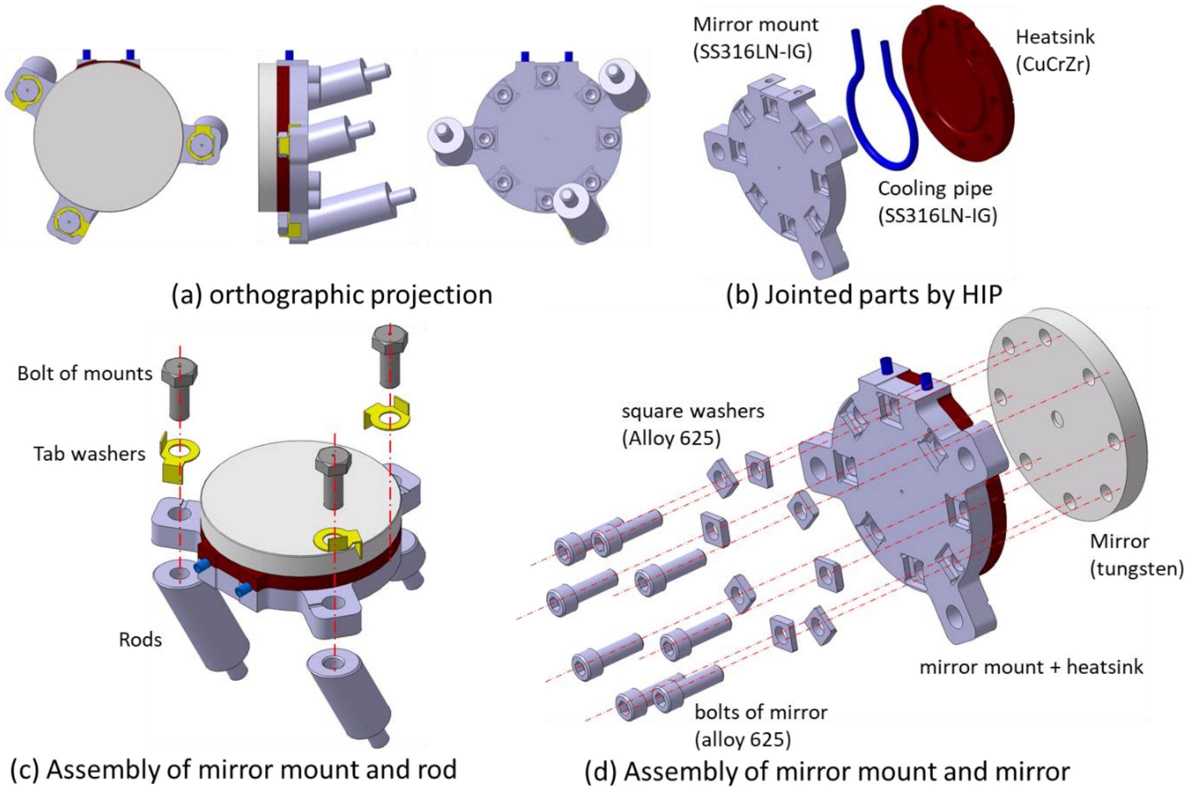


Figure 7. Components of mirror assembly.

Table 2 Connecting rods, M1 base plate and M2 base plate

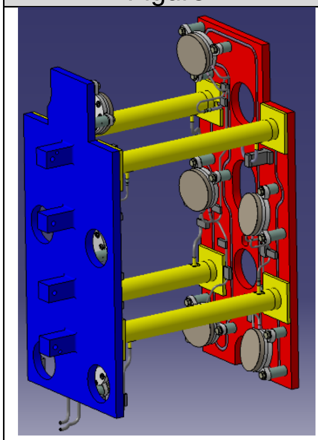
Figure	Colour code	Name	Description	Material
	_yellow_	Connecting rods	– Connected to M1 base plate and M2 base plate with bolting. – To transport cooling water through the inside of the rods.	SS316L(N)-IG
	blue	M1 base plate	– Connected to DSM with bolting. – Connected to first mirror assemblies with bolting	SS316L(N)-IG
	red	M2 base plate	– Connected to DSM with bolting. – Connected to second mirror assemblies with bolting	SS316L(N)-IG

Table 3 Mirror, heatsink, cooling pipe, mirror mount, rod and bolts

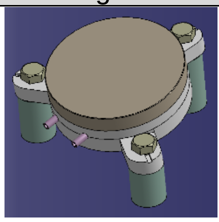
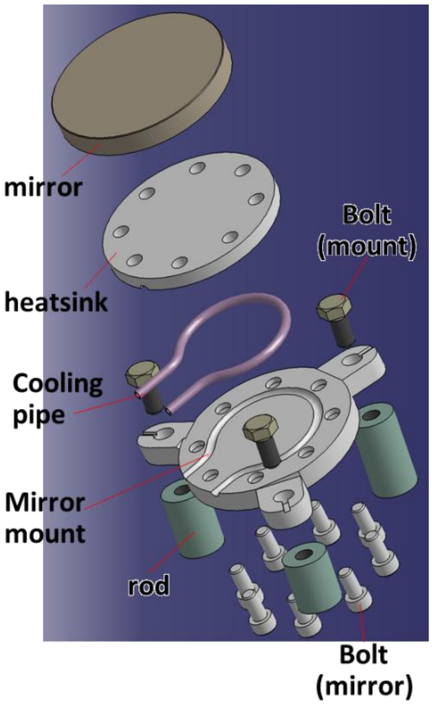
Figure	Name	Description	Material
 	Mirror	– To reflect laser beam. – The mirror is pressed toward the heat sink with a contact pressure of 3.5 MPa by bolting. – The mirror can slide on the heatsink within the clearance between a through hole of heatsink and a bolt.	Pure tungsten
	Heatsink	– Jointed to both the cooling pipe and the mirror mount by HIP. – Holes are through holes for “bolt (mirror)”.	CuCrZr
	Cooling pipe	– 1/4 inch pipe. – Jointed to both the heatsink and the mirror mount by HIP.	SS316L(N)-IG
	Mirror mount	– Jointed to both the cooling pipe and the mirror mount by HIP. – All holes are through holes for both “bolt (mirror)” and “bolt (mount)”.	SS316L(N)-IG
	Rod	– Connected to mirror mounts and M1/M2 base plate by bolting.	SS316L(N)-IG
	Bolt (mount)	– To connect the mirror mount and the rods. – Pretention: 12.5 kN – Tab washers are omitted in the left figure.	Alloy 625
	Bolt (mirror)	– To connect the mirror mount and the mirror. – Pretention: 5 kN – Square washers are omitted in the left figure.	Alloy 625

Table 4 Cooling pipes

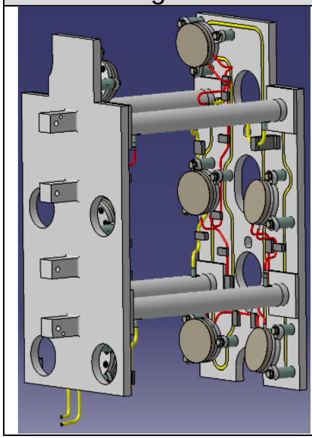
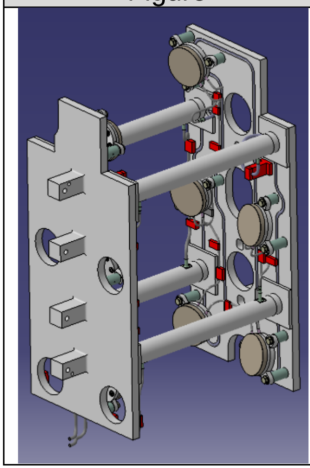
Figure	Colour code	Name	Description	Material
	_yellow_	Cooling pipe	– 3/8-inch pipe. – Blazed to M1/M2 base plate	SS316L(N)-IG
	red	Cooling pipe	– 1/4-inch pipe.	SS316L(N)-IG

Table 5 Pipe support

Figure	Colour code	Name	Description	Material
	_red_	Pipe support	– To support cooling pipes. – Fixed to M1/M2 base plate by bolting. – Bolts and lock washer are omitted in the analysis model.	SS316L(N)-IG

5.2 Interfaces

UEMM and LEMM have interface with EPP10, which is defined in the interface sheet [3].

<u>*Mechanical interface*</u>

EMM is fixed to DSM by bolting (see Section 8). The positions of the bolt fixation are labelled as IF01 to IF12. Figure 8 shows the definition of the IF01 to IF12. The bold size is M12, while the diameter of the through hole of the tab of EMM is 16 mm. Clearance between bolt and hole is 2 mm. The clearance of 2 mm can lead the misalignment of ± 0.2°. The optical analysis [8] shows that the misalignment of ± 0.2° is acceptable.

During plasma operation, the interfacing points moves because of thermal expansion of DSM. According to the interface sheet [3], the horizontal gap and the vertical gap between IF04 and IF12 become wider by 1.67 mm and 1.72 mm, respectively. This thermal expansion can be absorbed by the 2-mm clearance between the interfacing bolt and the holes of the EMM tab.

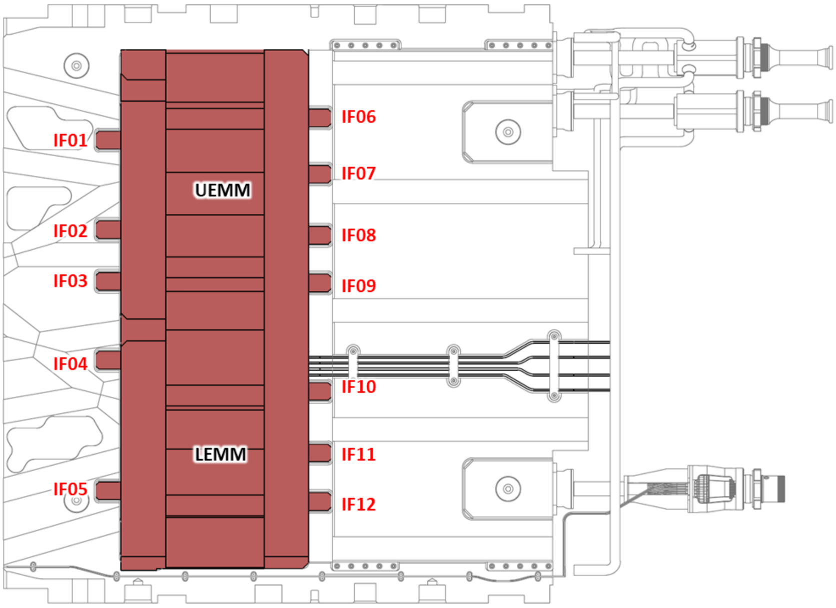


Figure 8 Definition of interfacing points.

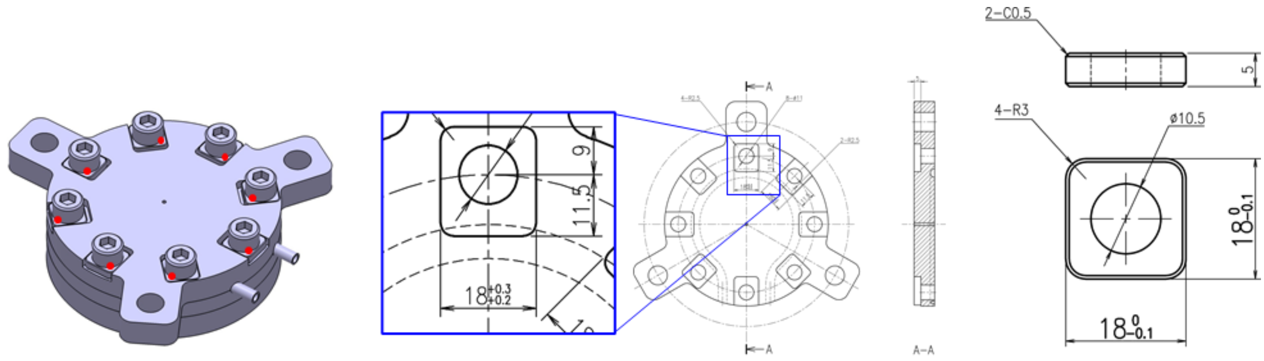
Engineering service

Cooling water is provided by EPP10, and there is no electrical interface between EMM and EPP10. Detailed values such as temperature and pressure of the cooling water are given in the interface sheet [3].

5.3 Prevention of Bolt Loosening

Four counter measures are implemented to prevent loosening of bolt.

- The first one is to use tab washers (see Figure 6 (a) and Figure 7).
- The second one is to use Nord lock washers for the captive bolt of the tab (see Figure 12). A tab washer is not used for the captive bolt because it is difficult for a remote-handling tool to fold and unfold the tab washer in assembly and disassembly in the hot cell facility.
- The third one is to carry out dot welding to “square washer” that is shown in Figure 7(d). Figure 9 shows how to lock the bolt. Since the bolt is welded to the square washer (see Figure 9 (a)), the bolt cannot rotate. The square washer fits in with the groove of the mirror mount. It can slide in the radial direction of the mirror but cannot rotate. The gap between the square washer and the groove is 0.1-0.2 mm (see Figure 9 (b) and (c)). It should be noted that, since the thermal expansion of the heatsink and the mirror mount is larger than that of tungsten mirror, the radial slide of the square washer is necessary for avoiding bending stress of the bolt.
- The fourth one is to carry out dot welding to the nut in Figure 6 (b) to the rod of the mirror assembly.



(a) Position of dot welding (b) Dimension of groove (b) Dimension of square washer

Figure 9. Mechanism of how to avoid the loosening of the bolt that is used to fix the tungsten mirror. The square chamfered washer can move in the radial direction of the mirror, but cannot rotate.

5.4 Prevention of Trapped Volume

In order to prevent trapped volume, a various kind of counter measures are implemented.

- The captive bolt on the tab (see Figure 5) has a through hole of diameter of 2 mm.
- The bolt of the mirror (see Figure 7(d)) has a through hole of diameter of 2 mm.
- The washer in Figure 6 (b) has a slit.
- Threaded holes have a through hole of diameter of 2 mm, and surfaces to contact with a washer have slit. Figure 10 shows examples of the holes and slits to prevent trapped volume.

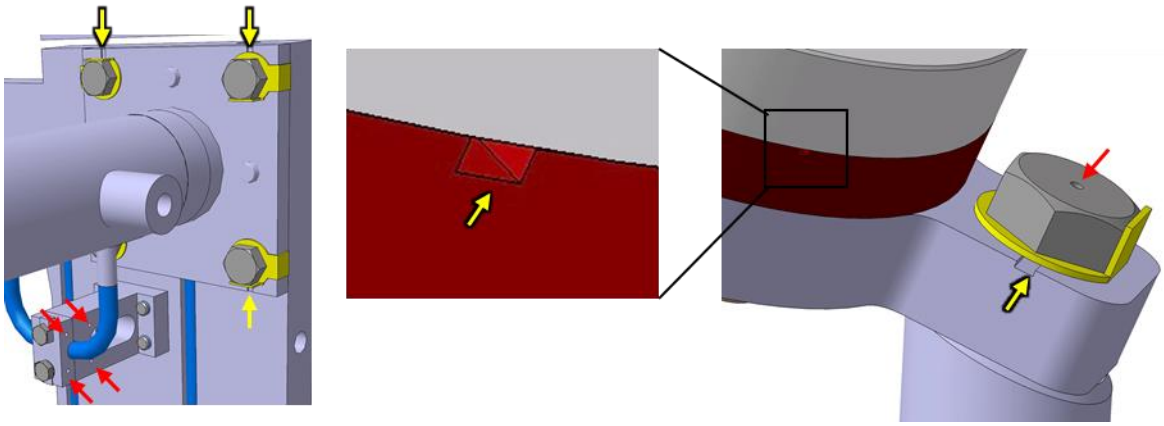


Figure 10. Holes (red arrow) and slits (yellow arrow) to prevent trapped volume.

5.5 Drawings and BOM

The documents below also provide the information about the design.

- Components Classification BOM for CCR [7]
- Component drawing [9]
- Assembly drawing [10]

6 Design Justification

This section provides evidence to support the design shown in Section 5.

Document title	Remarks
Optical Analysis and Design of PBS.55.C6 PoPola [8]	The report [8] shows that the size, the curvature radius and the position of the in-vessel mirrors are

	properly designed for minimizing the loss of laser power.
StIR [11]	StIR shows that all design criterion specified in SDC-IC are met.
Section 7 “Manufacturing”	Manufacturability is described in Section 7 of this document.
Steam ingress test (UVXNCU)	The report, UVXNCU, shows that the reflectivity of tungsten at infrared region does not change owing to the steam ingress test.
Chit resolution report for PoPola CDR Chit #17 “Effect of potential bending of the flat plasma-facing mirrors” [12]	The report [12] evaluated the effect of the thermal deformation of the plasma-facing mirror. According to the evaluation of optical analysis, When M1 and M2 deformation is 20 μm or less, the decrease in laser power returning to the diagnostic room is less than 20%. The analysis for the preliminary design the expected deformation of the mirror is 8 μm and the decrease in the laser power is acceptable.

7 Manufacturing

A report [18] concluded that the design explained in Section 5 is manufacturable by clarifying all the manufacturing process.

Before starting the manufacture of the production to be delivered to ITER, factory qualification tests shall be carried out. The factory qualification test plan is Reference [13]. The foreseen tests for EMM are to evaluate outgassing rate, to qualify welding procedure and to qualify HIP procedure.

At the time of writing this document, cutting oil, cleaning fluid are not determined yet. The cutting oil and cleaning fluid will be specified by a contractor who will be determined after tendering the construction of PoPola retroreflectors. If the contractor would specify a special fluid, the acceptance for use of the fluid will be checked by ITER Vacuum responsible officer in accordance with ITER Vacuum Handbook.

8 Assembly and Installation

Assembly of EMM to DSM

UEMM and LEMM are attached to DSM by bolting. DSM of EPP10 is called “clamshell type” and consists of two parts. Both UEMM and LEMM are fixed to one side. Figure 11 and Figure 12 illustrate how to fix UEMM or LEMM to DSM. M12 bolts made of Alloy 625 are used for fixation, and the bolt pretension is 8 kN.

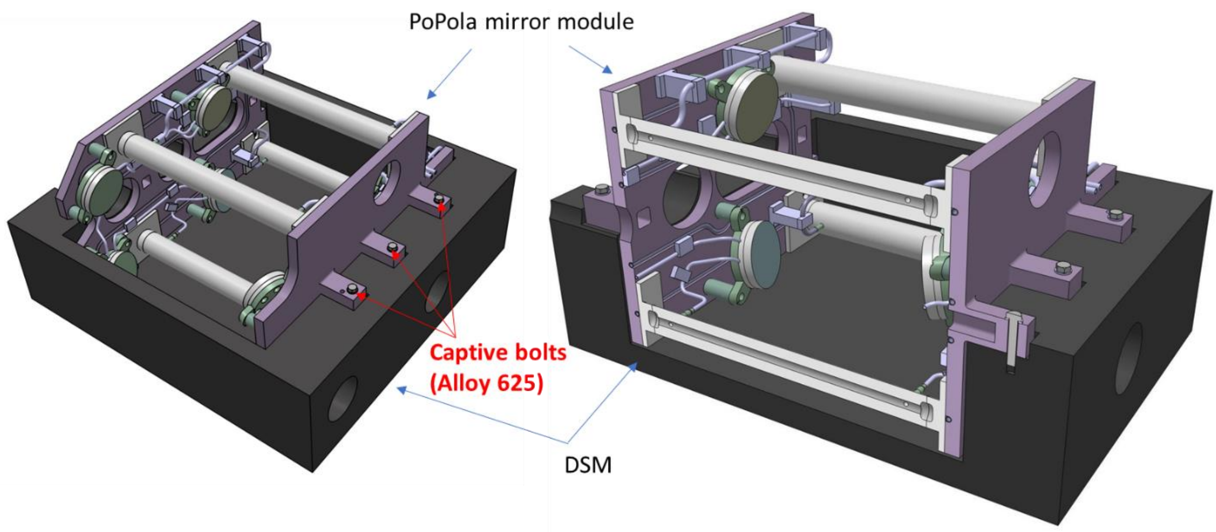


Figure 11. Bolt fixation to connect UEMM and LEMM to DSM.

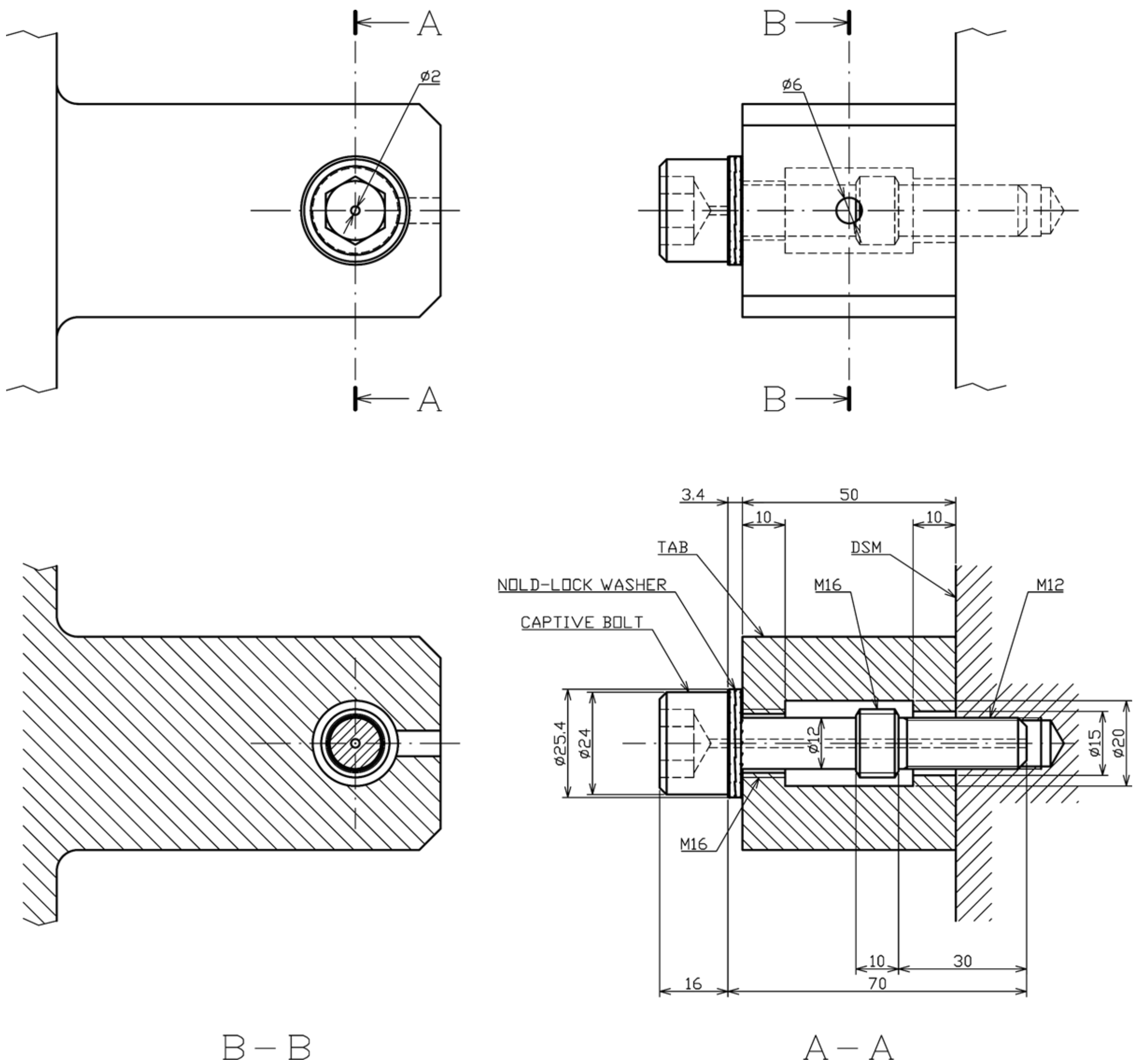


Figure 12. Details of captive bolt at a tab.

PPTF test after assembly

Reference [14] is a document about PPTF test. Major functional test at PPTF is to confirm the alignment of the mirror positions and the mirror angles. The visible laser beam will be injected from the vacuum windows, and it will be checked whether the visible laser beam will be transmitted to the right place of the target in the PPTF tank.

9 Operation, Maintenance and Decommissioning

Operation plan

Since the mirror modules are passive component, there is no operation plan.

Maintenance and inspection plan ([15], [16])

There is no preventive maintenance scheduled in EPP10.

The corrective maintenance is to replace EMM in the hot cell facility. Figure 13 shows disassembly process int the hot cell facility. After open the DSM, an operator will loosen the captive bolt, will attach a special lifting frame to threaded bosses and will lift up the EMM. The special lifting frame (red one in Figure 13) has an interface that RH gripper can hold. By using this interface, a crane swing that would happen when a crane starts lifting can be prevented. When assembling a new EMM, the operator will follow the disassembly procedure in the opposite order. These operations can be carried out by using RH tool in the hot cell facility.

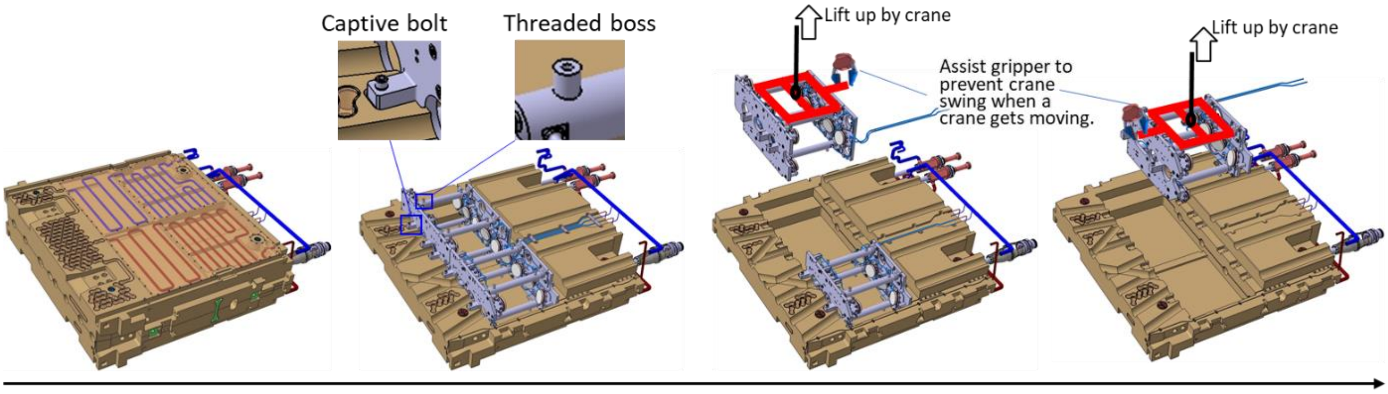


Figure 13. Disassemble process in the hot cell facility.

Decommissioning plan [17]

EMM will be transferred to and stored in a radwaste storage in a manner that EMM will be mounted on DSM.

10 Supplementary materials

10.1 Abandoned design for movable mirror

Movable mirror

In the early stage of preliminary design phase, the design team tried to design a movable mirror. Figure 14 shows the concept of the movable mirror. The design team made electro-magnetic analysis under the condition of Bt = 3.6 T, Bz = -0.9 T, Br = 0.07 T and dBz/dt = 60 T/s.The EM s showed that the moment of 520 Nm was applied to a gimbal mount. Thus, the rigid flexible pivot is necessary for enduring plasma disruption (internal plate thickness of the flexure pivot needs to be 4mm). The design team did not find design solution including pneumatic actuator that was able to move the gimbal with the rigid flexure pivot.

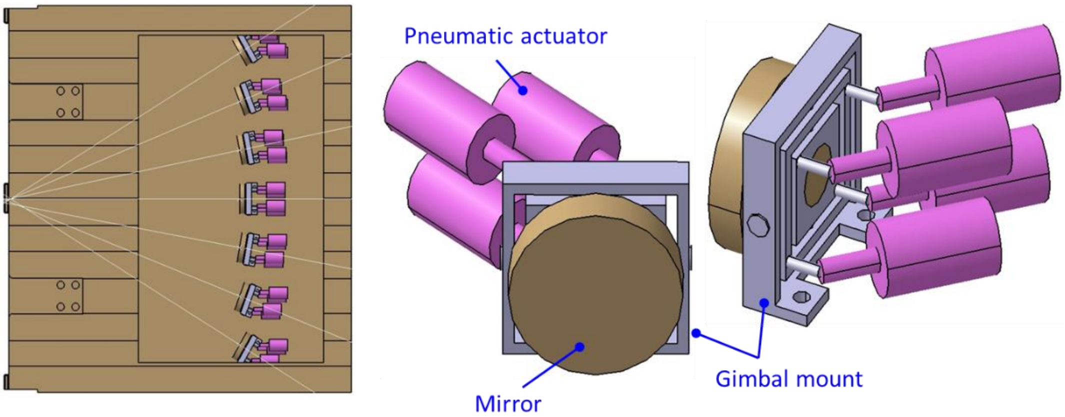


Figure 14. One of abandoned design - movable mirror -

10.2 Abandoned designs to fix cooling water pipe.

After the study shown in Section 10.1, the design team focused on design of a fixed mirror. The next issue is to determine the design to fix a SS cooling pipe to a tungsten mirror.

Tungsten mirror + internal SS pipe

The design team assessed the design that a SS cooling pipe is embedded inside a tungsten mirror by using HIP technique. The aim of this design is to perfect thermal contact between tungsten and SS. The thermal structural analysis show that high stress occurs at the boundary between the tungsten mirror and the SS pipe during baking. This is because the thermal expansion of the SS pipe is larger than that of hole inside the tungsten mirror.

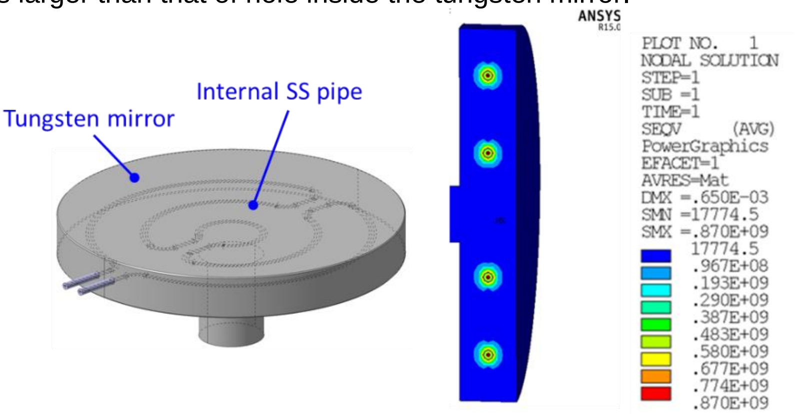


Figure 15. One of abandoned design - tungsten mirror + internal SS pipe -

Tungsten sheet + SS base plate + internal SS pipe

The design team assessed the design that a SS cooling pipe is embedded inside a SS base plate that a tungsten sheet is attached to. The thickness of the tungsten sheet is supposed to be 20-100 μm. The aim of this design is to reduce the stress around in the SS cooling pipe in the previous design, “Tungsten mirror + internal SS pipe”. The thermal structural analysis show that high stress occurs at the boundary between tungsten sheet and SS base plate. This is because the thermal expansion of the SS base plate is larger than that of tungsten sheet.

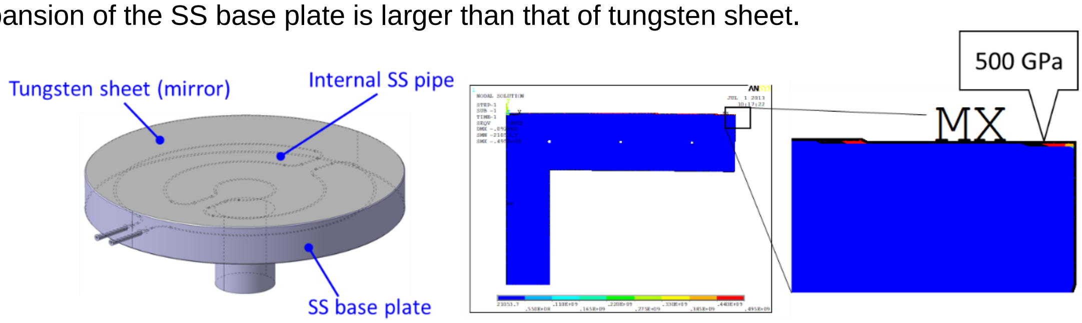


Figure 16. One of abandoned design - tungsten sheet + SS base plate + internal SS pipe -

Tungsten mirror with interlayer (no bolting)

Next, the design team assessed the design that a copper interlayer is jointed to both a tungsten mirror and a SS cooling pipe by HIP technique. The aim of this design is to absorb the difference of thermal expansion of tungsten and SS by using copper interlayer and is to avoid usage of bolts that could be loosen during repetition of thermal expansion. The thermal structural analysis show that high stress occurs at the boundary between the tungsten mirror and the copper interlayer. This is because the thermal expansion of the copper inter layer is larger than that of tungsten mirror.

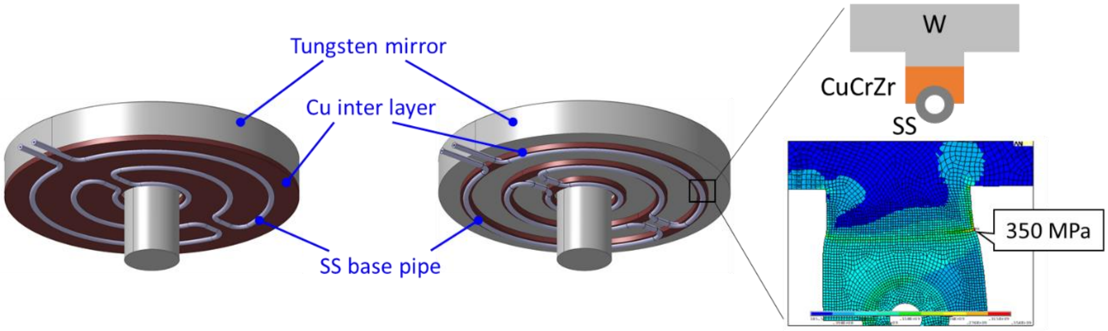


Figure 17. One of abandoned design - Tungsten mirror with copper interlayer -

Bolt + brazing

After studying the above designs, the PoPola design team finally decided to use bolts. Figure 18 (a) shows the initial design to use the bolts. The function of the bolt is to fix a tungsten mirror, a copper heatsink, and a SS mirror mount. Comparing Figure 18 to Figure 17, the SS mirror mount is clearly added to the mirror assembly. The function of the SS mirror mount is a mechanical interface between the tungsten mirror and the PoPola in-EPP10 mirror module.

In the initial design that uses the bolts (i.e. Figure 18 (a)), a brazing technique was employed to join the copper heatsink and a cooling water pipe. The issue of this initial design is the structural integrity assessment of the brazing joint. Figure 18 (b) shows von-mises stress of the abandoned design during VDE. This high stress occurs because of vibration of the cooling pipe. Since Figure 18 (b) is the results of the initial design, the support of the cooling pipe is not optimized, and the vibration of the cooling pipe is not minimized. Even though the von-mises stress at the root of the cooling pipe can be reduced by optimizing the cooling pipe support, there is still a question whether the reduced stress is low enough for ensuring the brazing joint. So, the PoPola design team decided to reject the brazing technique.

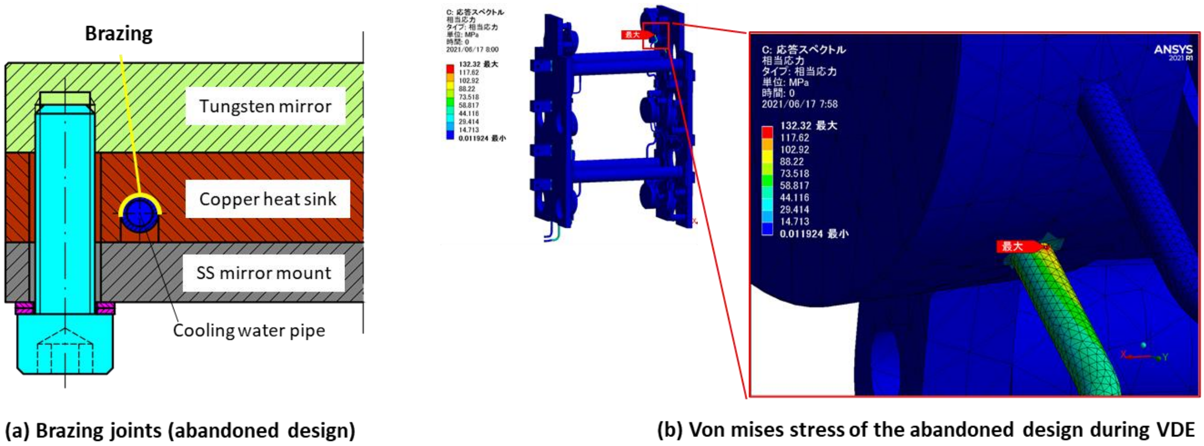


Figure 18. One of abandoned design – Brazing the cooling water pipe -

10.3 Abandoned design to fix mirror mount to base plate.

In Section 10.2, the design of the mirror including cooling channel was fixed. The remaining item to be designed is fixation of the mirror to a support structure (i.e., M1 or M2 baseplate in Figure 5). The design team decided to use rods to fix them. The rod is fixed to M1 or M2 baseplate by a nut, but not by welding. This is because thermal deformation of M1 or M2 baseplate owing to welding is not predictable and can be as large as unacceptable. Since welding joint is not used, there are three design options to fix the mirror to M1 or M2 baseplate by using the rod as shown in Figure 19. It should be noted that the mirror surface is not parallel to M1 or M2 baseplate. This unparallel leads to complex shape of the mirror mount or the rod. In Figure 19 (a), the shape of the rod is simple, while the shape of the mirror mount is so complex that it is difficult to inspect the dimension. In both Figure 19 (b) and (c), the shape of the mirror mount is simple, while the shape of the rod is complex. In Figure 19 (b), the male thread is not coaxial to the rod. On the other hand, in Figure 19 (c), the threaded hole is not coaxial to the rod. Finally, the design of Figure 19 (c) is employed because the mirror mount is simple, and the rod can be placed to a pilot bore of M1 or M2 plate.

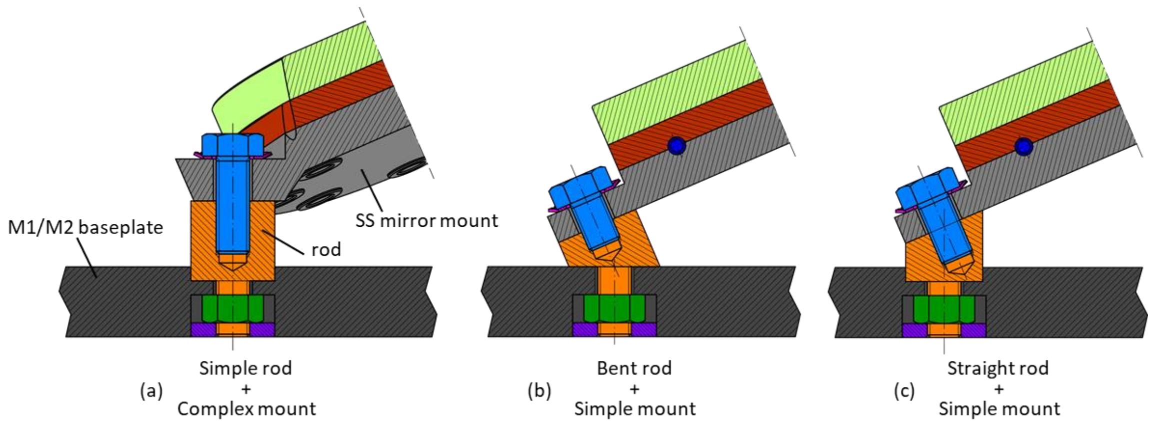


Figure 19. Design options to fix SS mirror mount to base plate.