TITLE

TITOLO

PRIMARY LOOP INSTRUMENTATION OF THE THETIS TEST SECTION FOR THE CIRCE FACILITY

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SUMMARY

SOMMARIO

The present document aims at providing a description of the instrumentation to be installed on the new test section, named THETIS; which will be implemented in the CIRCE facility at ENEA Brasimone Research Centre. The document focuses on the primary system, describing the type of instrumentation to be used for the LBE side, specifying its position for each component of the test section.

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LIST OF ABBREVIATIONS

AIS	Argon Injection System
ARS	Argon Recirculation System
BAF	Bottom of Active Fuel
BT	Bubble Tube
CIRCE	CIRcolazione Eutettico (Eutectic CIRCulation)
ENEA	Agenzia nazionale per le nuove tecnologie, l’energia e lo sviluppo economico sostenibile
FPS	Fuel Pin Simulator
FV	Fitting Volume
GEN-IV	Generation IV
HCSG	Helical Coil Steam Generator
HERO	Heavy liquid mEtal – pRessurized water cOoled tube
LBE	Lead-Bismuth Eutectic
LFR	Lead cooled Fast Reactor
MCP	Main Circulation Pump
MYRRHA	Multi-purpose hYbrid Research Reactor for High-tech Applications
PATRICIA	Partitioning And Transmuter Research Initiative in a Collaborative Innovation Action
PHTS	Primary Heat Transfer System
RVACS	Reactor Vessel Auxiliary Cooling System
TAF	Top of Active Fuel
TC	ThermoCouple
THETIS	Thermal-hydraulic HElical Tubes Innovative System
TS	Test Section

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1 INTRODUCTION

In the framework of the LFRs GEN-IV nuclear plants and fusion technology development, a new steam generator consisting of a helical tube bundle is currently under study. In particular, the PATRICIA (Partitioning And Transmuter Research Initiative in a Collaborative Innovation Action) project (EC – H2020) has been launched by the European Commission to support innovative solutions for the development of MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications), while in fusion field, EUROfusion have dedicated a task for the study of Helical Coil Steam Generators (HCSGs) to be used for the Primary Heat Transfer System (PHTS) of the DEMO plant.

In this framework, the ENEA Brasimone Research Centre supports such R&D activities through experimental campaigns, involving CIRCE (CIRColazione Eutettico), a large scale pool-type facility using Lead-Bismuth Eutectic (LBE) as primary coolant and pressurized water as secondary fluid. A new Test Section (TS) named THETIS (Thermal-hydraulic HElical Tubes Innovative System) for the CIRCE facility is currently under development and it will replace the HERO (Heavy liquid mEtal – pRessurized water cOoled tube) test section, which is presently installed in the CIRCE main vessel. The new test section will be characterized by new features and some new components respect to the previous one. In particular, a vertical mechanical pump and a new prototypical HCSG will be installed and tested.

The tests foreseen for the experimental campaigns aim at investigating on the thermal-hydraulic behaviour of the system in the steady state operation (forced circulation regime), during operational and accidental transients (postulated scenarios) and in natural circulation regime, as well as to characterize from a thermal-hydraulic point of view the performances of the HCSG. The stability of the system in natural circulation regime will be studied considering as heat sink the HCSG (acting as decay heat removal system) and the RVACS (Reactor Vessel Auxiliary Cooling System), in stand-alone or coupled operation.

This document focuses on the instrumentation to be installed on the primary loop, describing the type to be used for the LBE side and specifying its position for each component of the test section.

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2 CIRCE GENERAL LAYOUT

The LBE pool CIRCE is an integral effect type facility [1]. The main systems and components are:

- S100 main vessel (Figure 1), conceived to host the test sections. It has an inner diameter of 1170 mm, a thickness of 15 mm, and a height of about 8500 mm. It is partially filled with about 70 tons of LBE and argon as cover gas maintained in slight overpressure. The main vessel is insulated by rock wool to minimize the thermal losses in the environment and it is equipped with electrical heating cables, installed on its bottom and lateral surfaces. The heating cables can reach an operating temperature range of 250÷300°C. The cover gas of the main vessel is also equipped by a self-controlled discharge system and a passive pressure safety system (rupture disks), in order to prevent accidental overpressure;
- S200 storage tank (Figure 1), in which the LBE is stored during the periods of maintenance and refurbishment of the facility;
- S300 transfer tank (Figure 1), used during the filling and draining phases of the main vessel;
- gas circulation system, composed of two sub-systems: the Argon Recirculation System (ARS) and the Argon Injection System (AIS). The ARS is equipped by a set of 5 compressors connected in parallel and an argon storage tank, acting as gas lung and directly connected to external gas tanks used for argon re-integration. The AIS is connected to the ARS upstream of the set of compressors. The AIS will be disabled since in the new test section the forced circulation of the LBE will be provided by a mechanical pump instead of the gas injection;
- RVACS, which allows the cooling of the external surface of the vessel by mean of air injection;
- a once-through secondary loop to supply water to the HCSG at a maximum pressure of ~180 bar and a temperature of 335°C.

A new test section is currently under development and it will be composed of the following components:

- Fuel Pin Simulator (FPS), electrically heated for the coolant heating; it consists of an electrical pin bundle composed by 37 electrically heated pins with a nominal thermal power of ~1 MW;
- Fitting Volume (FV) which collects the hot LBE rising from the FPS;
- riser connecting the FV to the pump suction;
- Main Circulation Pump (MCP) to perform LBE forced circulation;
- hot pool (separator) which will feed the HCSG;
- HCSG for the heat removal from the primary system; this component works in counter-flow, with the LBE flowing shell side and the water flowing tube side;
- dead volume, which encloses and maintains insulated the power supply rods feeding the FPS.

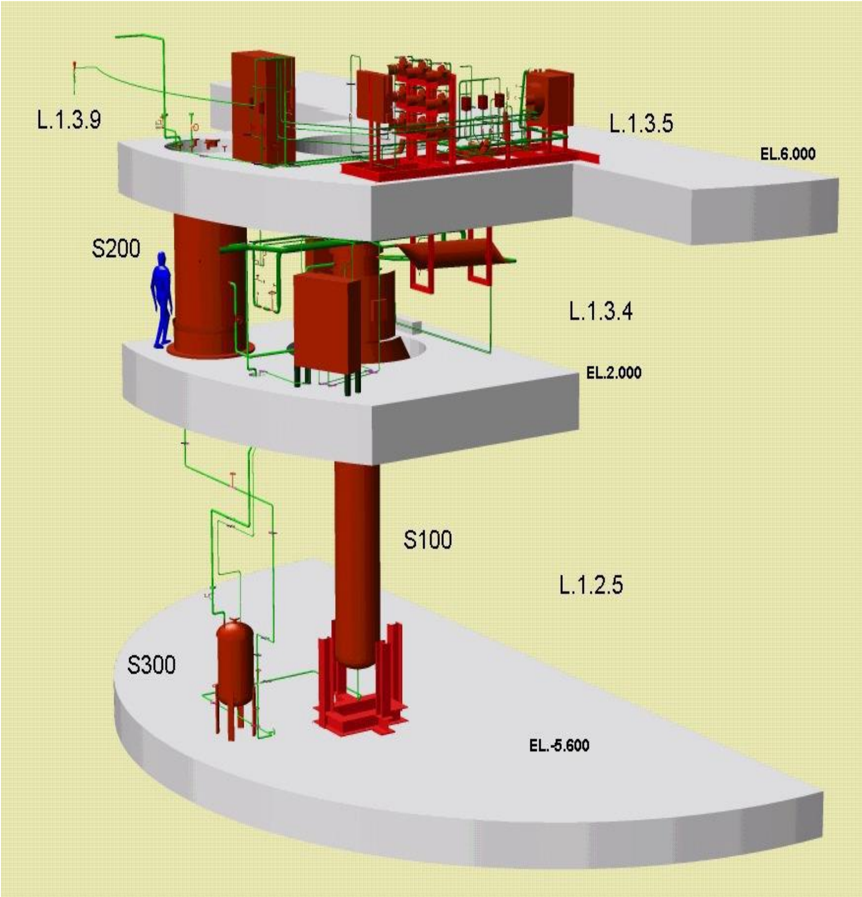

Figure 1 – Schematic view of the CIRCE facility

3 THETIS INSTRUMENTATION

The THETIS test section is highly instrumented for achieving well defined initial and boundary conditions relevant for fission nuclear reactors (e.g. ALFRED and MYRRHA) and fusion power plants (i.e. DEMO). The experimental infrastructure aims at characterizing both pool/LBE and heat exchanger/water side during stationary and transient scenarios. An overall number of about 220 thermocouples, 13 bubble tubes, 1 Venturi flow meter, 3 LBE level sensors and 2 oxygen sensors are implemented and acquired at 1 Hz. In the next sections, the instrumentation of the primary system (LBE side) is detailed according to the installation position.

3.1 Feeding conduit

In the lower part of the feeding conduit a Venturi flow meter has to be vertically implemented to measure the LBE mass flow rate at the inlet of the FPS. The new Venturi flow meter will replace the one used in the previous test section, which is reported in Figure 2. On the basis of such a scheme, the inlet-throat pressure drop is monitored by a differential pressure transmitter (**DP-Ven** in Table 1). The pressure signals of two bubble tubes 8x1 mm (**PE001** and **PE002**) is monitored and indirect measurement of LBE mass flow rate is calculated. The BTs are connected to 1/2" NPT pressure taps, having a level difference of 42 mm (about 0.042 bar of LBE pressure head at working temperature). A similar layout is foreseen for the new Venturi flow meter. The measuring range of the instrument has to be between 5 kg/s to 85 kg/s (maximum mass flow rate elaborated by the pump) [2].

Table 1 – Feeding conduit, BTs position

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**DP-Ven**	Differential pressure	Between inlet and throat taps of Venturi flow meter	6	Figure 2, Figure 27 Table 21	

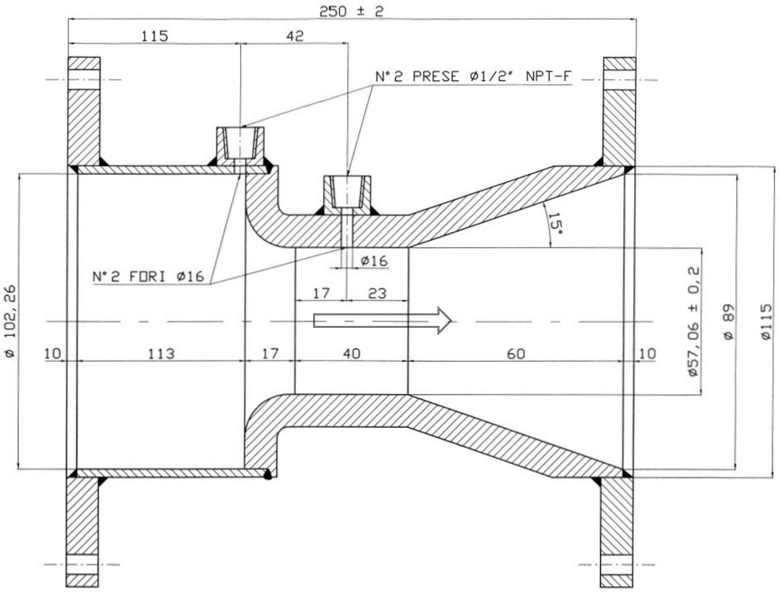

Figure 2 – Example of Venturi flow meter geometry. The Venturi represented is the one used in the HERO test section

3.2 FPS instrumentation

The LBE temperature field in FPS is monitored by 32 *N*-type thermocouples with isolated hot junction and having an accuracy of ±0.1 and ±1°C for TCs of 0.5 and 3 mm, respectively. The boundaries of FPS active region, TAF (Top of Active Fuel) and BAF (Bottom of Active Fuel), are shown in Figure 3. The TCs position is described hereafter, listed in Table 2 and depicted from Figure 4 to Figure 9.

Inlet and outlet FPS LBE temperatures are measured by 9 thermocouples having a diameter of 3 mm:

- **TC-FPS-31 to -33** are placed 10 mm upstream the inlet of the FPS active length (BAF), see Figure 5;
- **TC-FPS-34 to -36** are placed 10 mm upstream the outlet of the FPS active length (TAF), see Figure 5;
- **TC-FPS-37 to -39** are placed at the upper LBE outlet slots, from which LBE enters into the bottom part of the Release pipe, see Figure 4.

Four different sections are monitored in the FPS zone with 27 thermocouples having a diameter of 0.5 mm:

- Section 1 (**TC-FPS-01 to -06**, **TC-FPS-08**), 7 thermocouples are installed 20 mm upstream the middle spacer grid, three of which arranged at sub-channels centre and 4 placed on 4 different pins wall, as shown in Figure 6;
- Section 2 (**TC-FPS-10**, **TC-FPS-14**), 2 thermocouples are placed on 2 pins walls, as in Section 1 (see Figure 7) on the bottom end of middle spacer grid. In this section the pins clad temperature are monitored for evaluating the hot spot factor due to spacer grid;

- Section 3 (**TC-FPS-16**, **TC-FPS-18 to -24**), 8 thermocouples are installed 60 mm upstream the upper spacer grid, for monitoring the same sub-channels centres and pins of sections 1 (see Figure 8);
- Section 4 (**TC-FPS-28 to -30**), 3 thermocouples are placed 60 mm downstream of the lower spacer grid. In this section the LBE bulk temperature is measured in the same sub-channels of other sections, see Figure 9.

Three TCs having a diameter of 0.5 mm are set at sub-channel centre among pins 18, 34 and 35, at half height of the lower, middle and upper spacer grids (**TC-FPS-25 to -27**), as shown in Figure 4.

A second pressure drop measurement will be performed across the FPS (**DP-FPS**) by means of a differential pressure transmitter (see Figure 11), connected through the bubble tube located downstream the Venturi flow meter (**PE002**) and the one positioned downstream the FPS upper spacer grid (**PE003**).

Table 2 – FPS, thermocouples position

N°	ID	Description	Measurement Position	Diam. [mm]	Ref.	Notes
1	**TC-FPS-01**	Sub-channel temperature among Pin 1-2-7	20 mm upstream Middle Spacer Grid; Section 1	0.5	Figure 4 Figure 6	
2	**TC-FPS-02**	Sub-channel temperature among Pin 7-17-18	20 mm upstream Middle Spacer Grid; Section 1	"	Figure 4 Figure 6	
3	**TC-FPS-03**	Sub-channel temperature among Pin 17-33-34	20 mm upstream Middle Spacer Grid; Section 1	"	"	
4	**TC-FPS-04**	Wall temperature Pin 1	20 mm upstream Middle Spacer Grid; Section 1	"	"	
5	**TC-FPS-05**	Wall temperature Pin 7	20 mm upstream Middle Spacer Grid; Section 1	"	"	
6	**TC-FPS-06**	Wall temperature Pin 18	20 mm upstream Middle Spacer Grid; Section 1	0.5	"	
7	**TC-FPS-08**	Wall temperature Pin 34	20 mm upstream Middle Spacer Grid; Section 1	"	"	
8	**TC-FPS-10**	Wall temperature Pin 1	Middle Spacer Grid bottom; Section 2	"	Figure 4 Figure 7	
9	**TC-FPS-14**	Wall temperature Pin 33	Middle Spacer Grid bottom; Section 2	"	"	
10	**TC-FPS-16**	Wall temperature Pin 1	60 mm upstream Upper Spacer Grid; Section 3	"	Figure 4 Figure 8	

N°	ID	Description	Measurement Position	Diam. [mm]	Ref.	Notes
11	**TC-FPS-18**	Wall temperature Pin 18	60 mm upstream Upper Spacer Grid; Section 3	"	"	
12	**TC-FPS-19**	Wall temperature Pin 17	60 mm upstream Upper Spacer Grid; Section 3	"	"	
13	**TC-FPS-20**	Wall temperature Pin 33	60 mm upstream Upper Spacer Grid; Section 3	"	"	
14	**TC-FPS-21**	Sub-channel temperature among Pin 17-33-34	60 mm upstream Upper Spacer Grid; Section 3	"	"	
15	**TC-FPS-22**	Wall temperature Pin 34	60 mm upstream Upper Spacer Grid; Section 3	0.5	"	
16	**TC-FPS-23**	Sub-channel temperature among Pin 7-17-18	60 mm upstream Upper Spacer Grid; Section 3	"	"	
17	**TC-FPS-24**	Sub-channel temperature among Pin 1-2-7	60 mm upstream Upper Spacer Grid; Section 3	"	"	
18	**TC-FPS-25**	Sub-channel temperature among Pin 18-34-35	Through Middle Spacer Grid	"	Figure 4	
19	**TC-FPS-26**	Sub-channel temperature among Pin 18-34-35	Through Upper Spacer Grid	"	"	
20	**TC-FPS-27**	Sub-channel temperature among Pin 18-34-35	Through Lower Spacer Grid	"	"	
21	**TC-FPS-28**	Sub-channel temperature among Pin 17-33-34	60 mm downstream Lower Spacer Grid; Section 4	"	Figure 4 Figure 9	
22	**TC-FPS-29**	Sub-channel temperature among Pin 7-17-18	60 mm downstream Lower Spacer Grid; Section 4	"	"	
23	**TC-FPS-30**	Sub-channel temperature among Pin 1-2-7	60 mm downstream Lower Spacer Grid; Section 4	"	"	
24	**TC-FPS-31**	LBE temperature at FPS inlet	Aligned to bubble tube connections of Lower Spacer Grid; at 120° to TC-FPS-32 and TC-FPS-33	3	Figure 4 Figure 5 (Penetration length 35 mm, among Pin 19-36-37)	
25	**TC-FPS-32**	LBE temperature at FPS inlet	At 120° to TC-FPS-31 and TC-FPS-33	"	" (Penetration length 49.5 mm, among Pin 4-11-12)	

N°	ID	Description	Measurement Position	Diam. [mm]	Ref.	Notes
26	**TC-FPS-33**	LBE temperature at FPS inlet	At 120° to TC-FPS-31 and TC-FPS-32	"	" (Penetration length 64 mm, among Pin 6-7-17)	
27	**TC-FPS-34**	LBE temperature at FPS outlet	Aligned to TC-FPS-31 penetration; at 120° to TC-FPS-35 and TC-FPS-36	"	" (Penetration length 35 mm, among Pin 19-36-37)	
28	**TC-FPS-35**	LBE temperature at FPS outlet	Aligned to TC-FPS-32 penetration; at 120° to TC-FPS-34 and TC-FPS-36	3	" (Penetration length 49.5 mm, among Pin 4-11-12)	
29	**TC-FPS-36**	LBE temperature at FPS outlet	Aligned to TC-FPS-33 penetration; at 120° to TC-FPS-34 and TC-FPS-35	"	" (Penetration length 64 mm, among Pin 6-7-17)	
30	**TC-FPS-37**	LBE temperature at FPS outlet windows	Top windows of FPS hexagonal shroud	"	Figure 4	
31	**TC-FPS-38**	LBE temperature at FPS outlet windows	Top windows of FPS hexagonal shroud	"	"	
32	**TC-FPS-39**	LBE temperature at FPS outlet windows	Top windows of FPS hexagonal shroud	"	"	

Table 3 – FPS, bubble tubes across lower spacer grid

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**DP-FPS**	Differential pressure	Across the FPS, between the PE002 and PE003		Table 21 Figure 27 Figure 11	

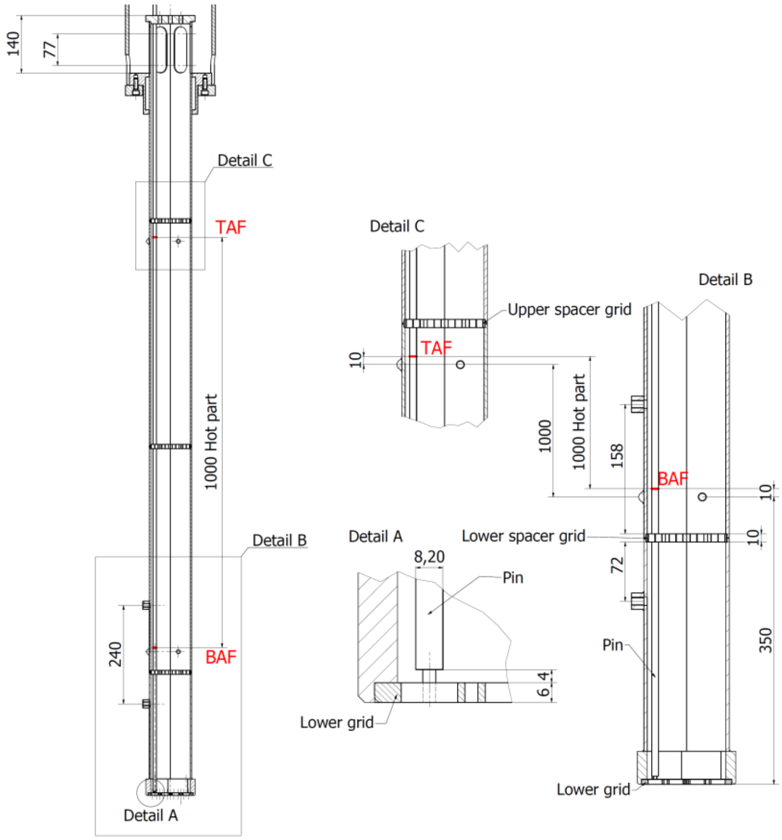

Figure 3 – FPS, active region boundaries and pin detail

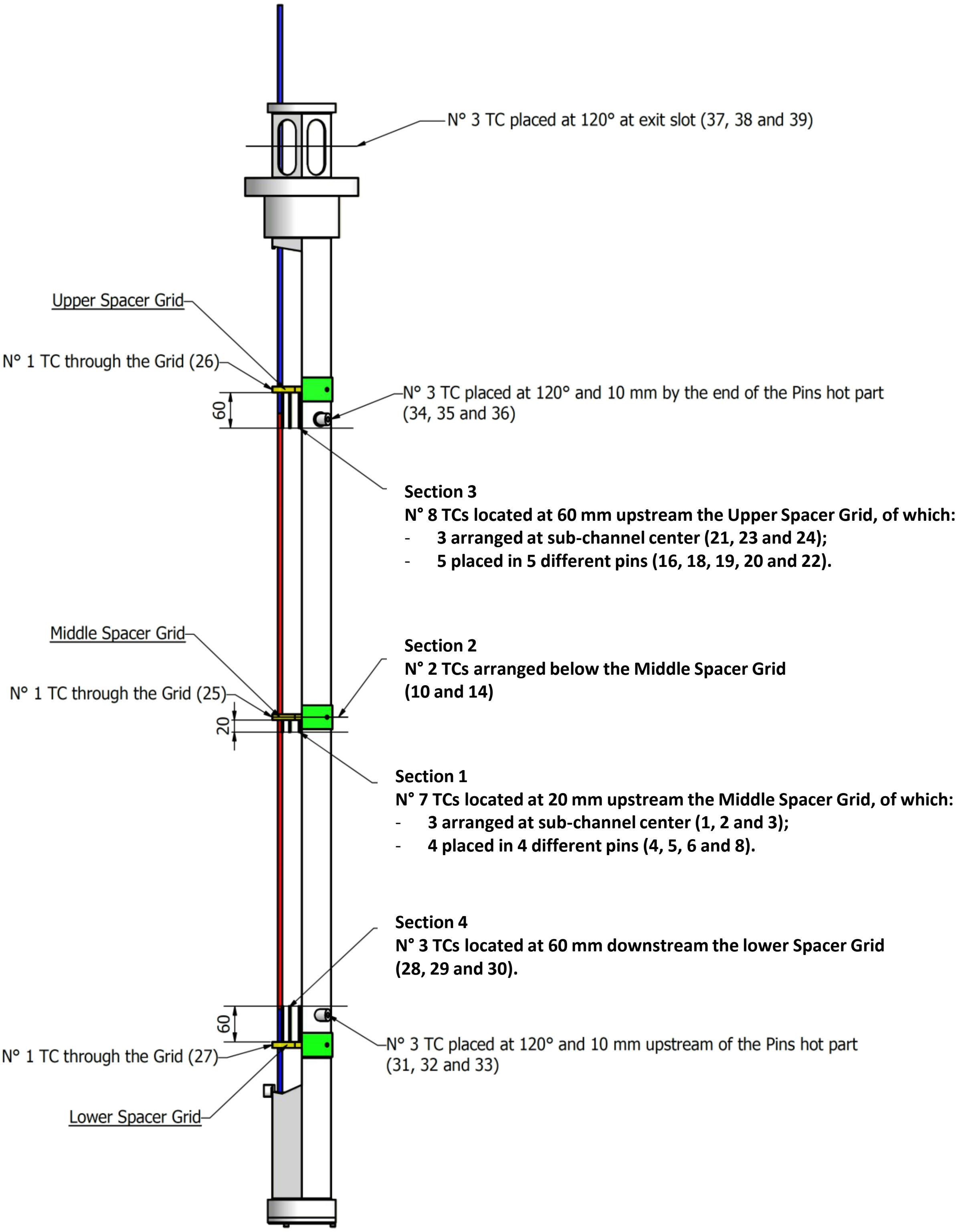

Figure 4 – FPS, measurement sections and thermocouples position (TC-FPS-01 – TC-FPS-39)

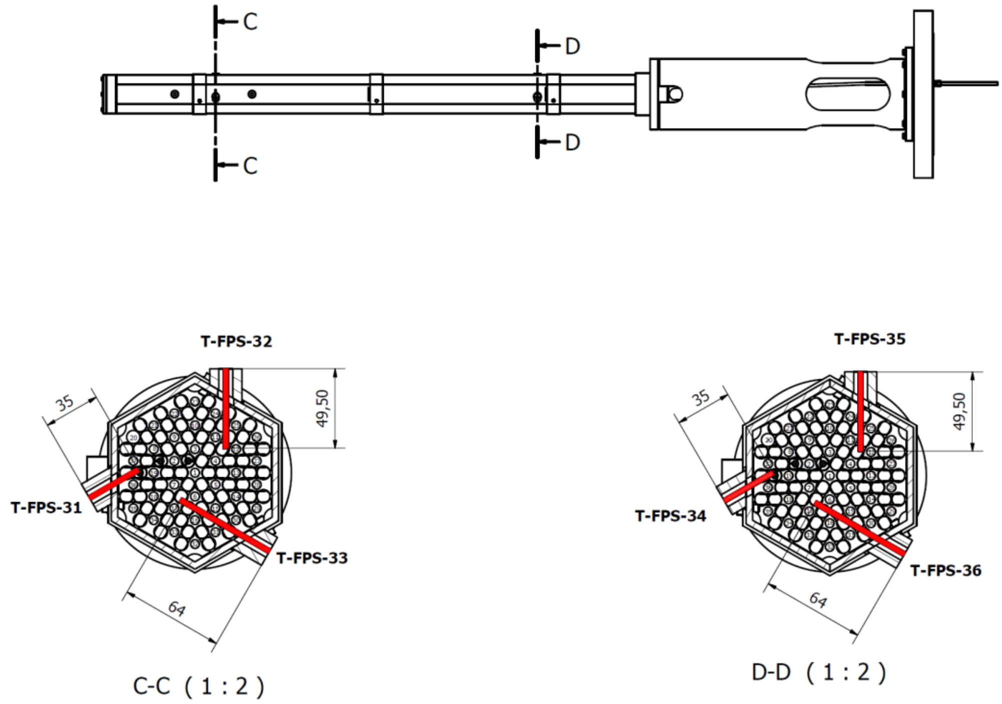

Figure 5 – FPS, 3 mm thermocouples position (TC-FPS-31 – TC-FPS-36)

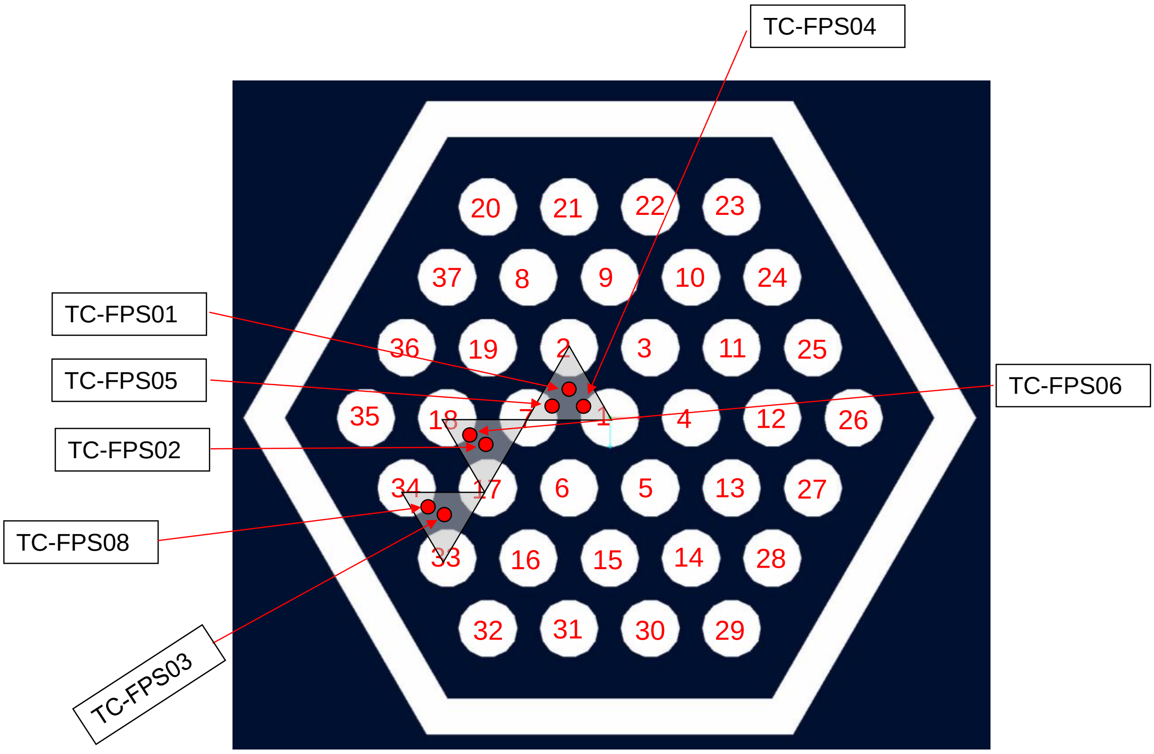

Figure 6 – FPS, thermocouples at section 1 (TC-FPS-01 – TC-FPS-09)

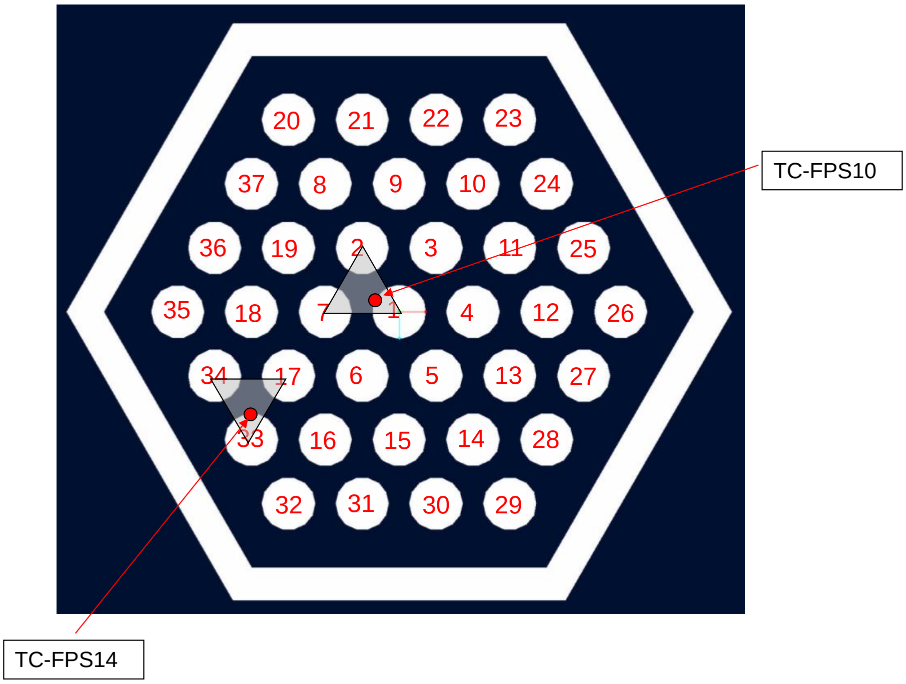

Figure 7 – FPS, thermocouples at section 2 (TC-FPS-10 – TC-FPS-14)

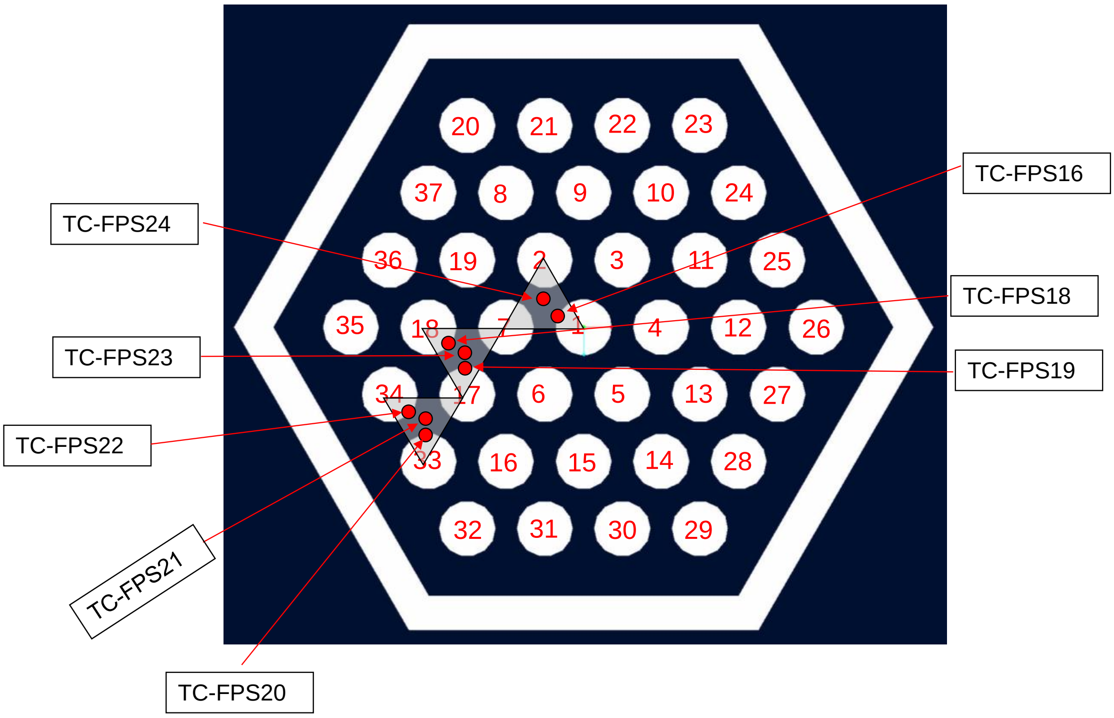

Figure 8 – FPS, thermocouples at section 3 (TC-FPS-16 – TC-FPS-24)

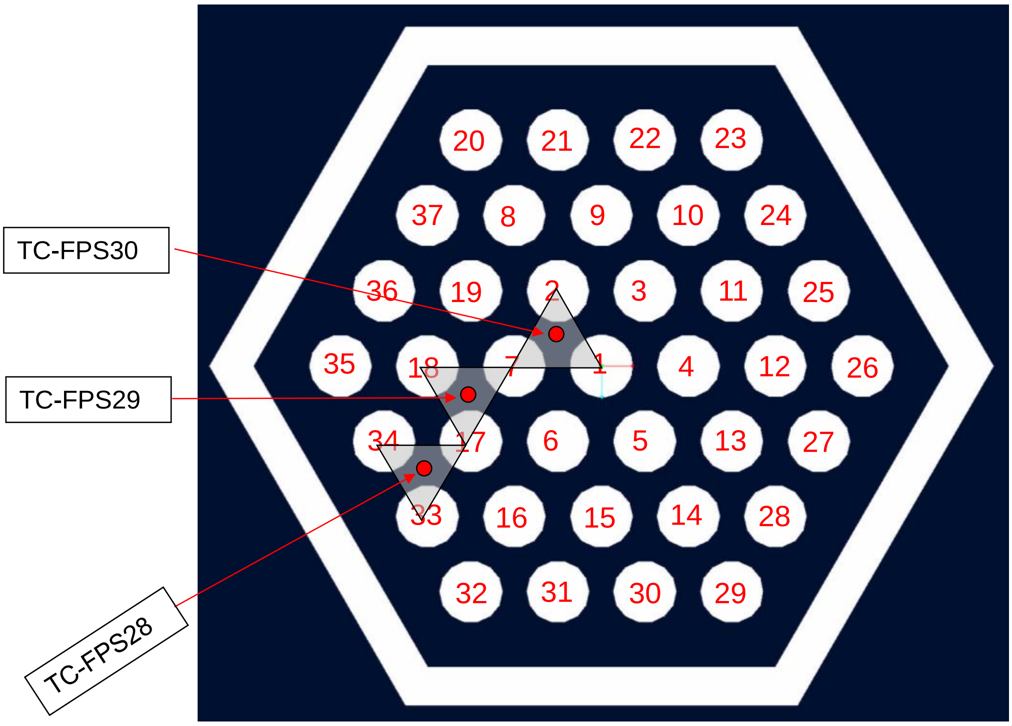

Figure 9 – FPS, thermocouples at section 4 (TC-FPS-28 – TC-FPS-30)

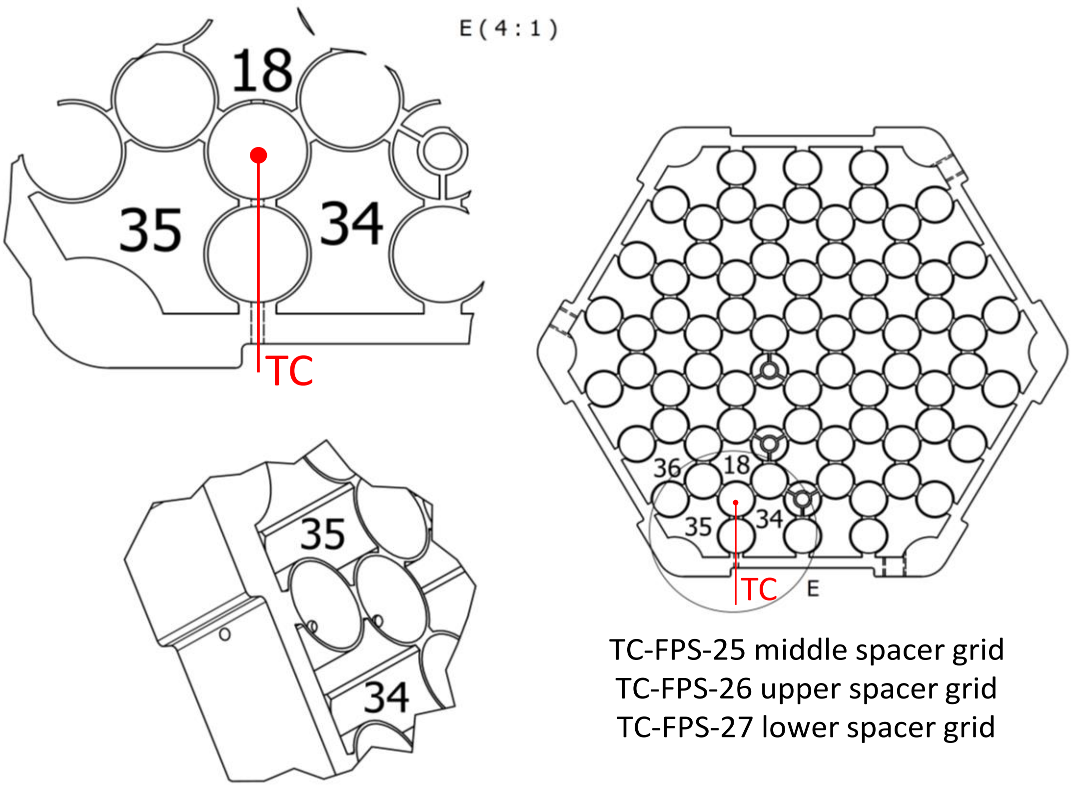

Figure 10 – FPS, thermocouples at middle height of lower, middle and upper spacer grids (TC-FPS-25 – TC-FPS-27)

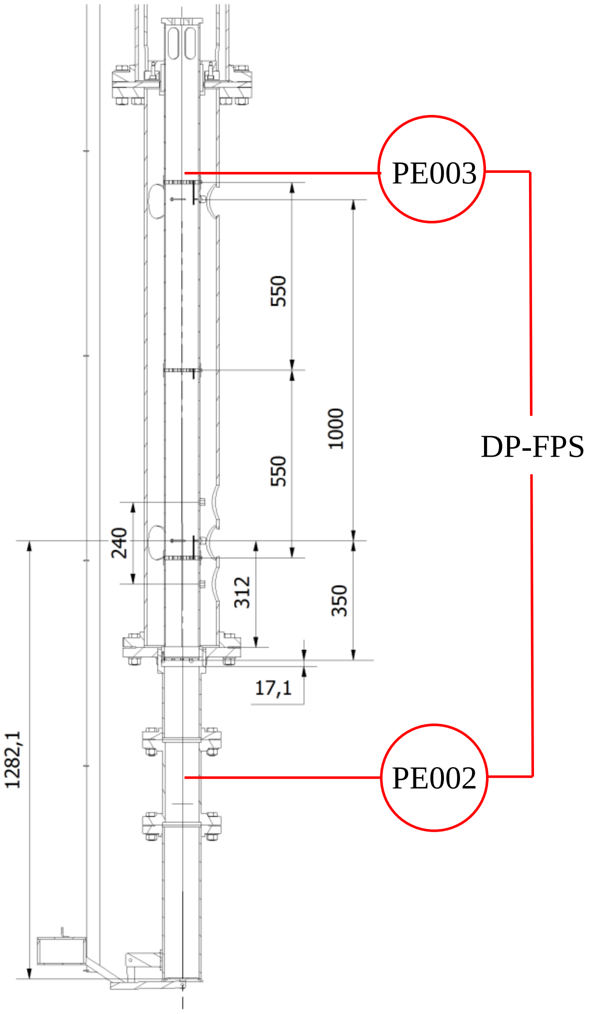

Figure 11 – Bubble tubes position along the FPS

3.3 Fitting volume

In the fitting volume, five *N*-type thermocouples (**TC-FV-1 – TC-FV-5,** 3 mm diameter) are located inside the component and on its external walls. The **TC-FV-01** measures the LBE temperature inside the fitting volume, while the TCs from **TC-FV-02** to **TC-FV-05** are set on the outer surface for wall temperature acquisition, aiming to support the characterization of heat losses into the pool. They are summarized in Table 4. A differential pressure transmitter is used to measure the pressure drops across the fitting volume (**DP-FV**), acquiring the measurement of the bubble tube positioned above the FPS upper spacer grid (**PE003**) and the one positioned upstream the pump impeller (**PE004**). The DP-FV and related bubble tubes are reported in Table 5 and Table 21.

A 1/8” tube is connected below the flange of the FV which connects the component with the dead volume. Such tube is supported by the dead volume up to the separator and it is allows the discharge of the argon during the filling procedure of the S100, avoiding the formation of a gas concentration in the upper part of the FV, in the volume between the riser inlet section and the flange connected to the dead volume.

Table 4 – Fitting volume, thermocouples position

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**TC-FV-01**	LBE temperature	θ = 0° 272.5 mm from FV bottom	3	Figure 12	
2	**TC-FV-02**	Fitting volume outer surface temperature	θ = 90° 272.5 mm from FV bottom	"	Figure 12	
3	**TC-FV-03**	Fitting volume outer surface temperature	θ = 270° 272.5 mm from FV bottom	"	Figure 12	
4	**TC-FV-04**	Fitting volume outer surface temperature	FV outlet pipe	"	Figure 12	
5	**TC-FV-05**	Fitting volume outer surface temperature	FV outlet pipe	"	Figure 12	

Table 5 – Fitting volume, bubble tube position

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**DP-FV**	Differential pressure	Across the FV, between the PE003 and PE004		Figure 27 Table 21	

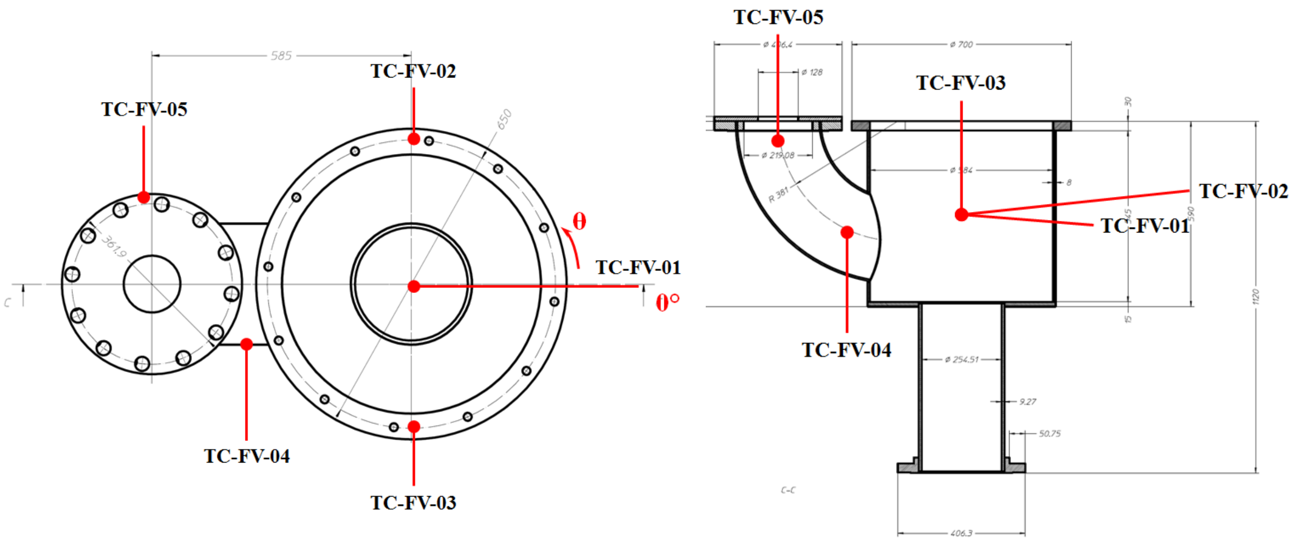

Figure 12 – Fitting volume, thermocouples position

3.4 Riser - pump

The FV is connected to the pump suction by means of a riser. The pump provides the positive pressure head for the circulation. Three *N*-type thermocouples (hot junction isolated, 3 mm diameter) are set in correspondence of the outlet holes of the pump and placed at 120° (**TC-RIT-01**, **TC-RIT-02**, **TC-RIT-03**) and three TCs (hot junction isolated, 3 mm diameter) at the inlet section of the riser at 120° (**TC-RIB-04**, **TC-RIB-05**, **TC-RIB-06**). The TCs positions are reported in Figure 13 and Figure 14).

The mechanical pump is equipped with TCs located upstream and downstream the impeller, as well as before at the inlet and outlet sections of the heat shield. The TCs installed on the pump are reported in Table 7 and Figure 15.

A differential pressure transmitter (Table 8) acquires the signal from the bubble tube positioned below the pump impeller (**PE004**) and the one positioned above the pump impeller (**PE005**), measuring in such a way the pressure drop across the pump impeller (**DP-pump**). An absolute pressure transmitter acquires pressure signal by means of a bubble tube (**PE011**) placed downstream the pump impeller (see Table 21).

For completeness, the document includes in the APPENDIX 1 the data sheets of the pump, reporting the ancillary systems and the related instrumentation:

- CIRCE IOM Rev00;
- PERFORMANCE TEST 2019-123 00001;
- Instrumentation CIRCE Rev02;
- CIRCE - ASSEMBLY & CONNECTIONS.

Table 6 – Riser, thermocouples position

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**TC-RIT-01**	LBE outlet temperature	Centre of the pump outlet holes (θ= 0°)	3	Figure 13, Figure 14	
2	**TC-RIT-02**	LBE outlet temperature	Centre of the pump outlet holes (θ= 90°)	"	Figure 13, Figure 14	
3	**TC-RIT-03**	LBE outlet temperature	Centre of the pump outlet holes (θ= 180°)	"	Figure 13, Figure 14	
4	**TC-RIB-04**	LBE inlet temperature	Upstream pump impeller (θ= 0°)	"	Figure 13, Figure 14	
5	**TC-RIB-05**	LBE inlet temperature	Upstream pump impeller (θ= 120°)	"	Figure 13, Figure 14	
6	**TC-RIB-06**	LBE inlet temperature	Upstream pump impeller (θ= 240°)	"	Figure 13, Figure 14	

Table 7 – Pump, thermocouples position

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**P-MOTOR**	Electric Motor - IEC 200L 4P B5		3	Figure 15	
2	**P-PTC**	PTC Installed Inside The Electric Motor		"	Figure 15	
3	**P-Inlet**	TC TYPE "K" - Pump Suction		"	Figure 15	
4	**P-CBRG1 / P-CBRG2**	TC TYPE "K" - Pcarbon Bearing Inside The Main Vessel		"	Figure 15	
5	**P-OUT1 / P-OUT2**	TC TYPE "K" - Pump Discharge		"	Figure 15	
6	**P-COVERG**	TC TYPE "K" - Cover Gas Zone Inside The Main Vessel		"	Figure 15	
7	**P-COOL-I /P-COOL-O**	TC TYPE "K" - IN/OUT Cooling Jacket		"	Figure 15	
8	**P-SEAL**	TC TYPE "K" - Oil Cooling Seal		"	Figure 15	
9	**P-BBRG**	TC TYPE "K" - Ball Bearing		"	Figure 15	
10	**GAS-SW**	Gas Flow Switch		"	Figure 15	

Table 8 – Riser-pump, bubble tubes position

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**DP-pump**	Differential pressure	Across the pump impeller, between the PE004 and PE005		Figure 27 Table 21	-
2	**PE011**	LBE relative pressure	Downstream the pump impeller	6	Figure 27 Table 21	

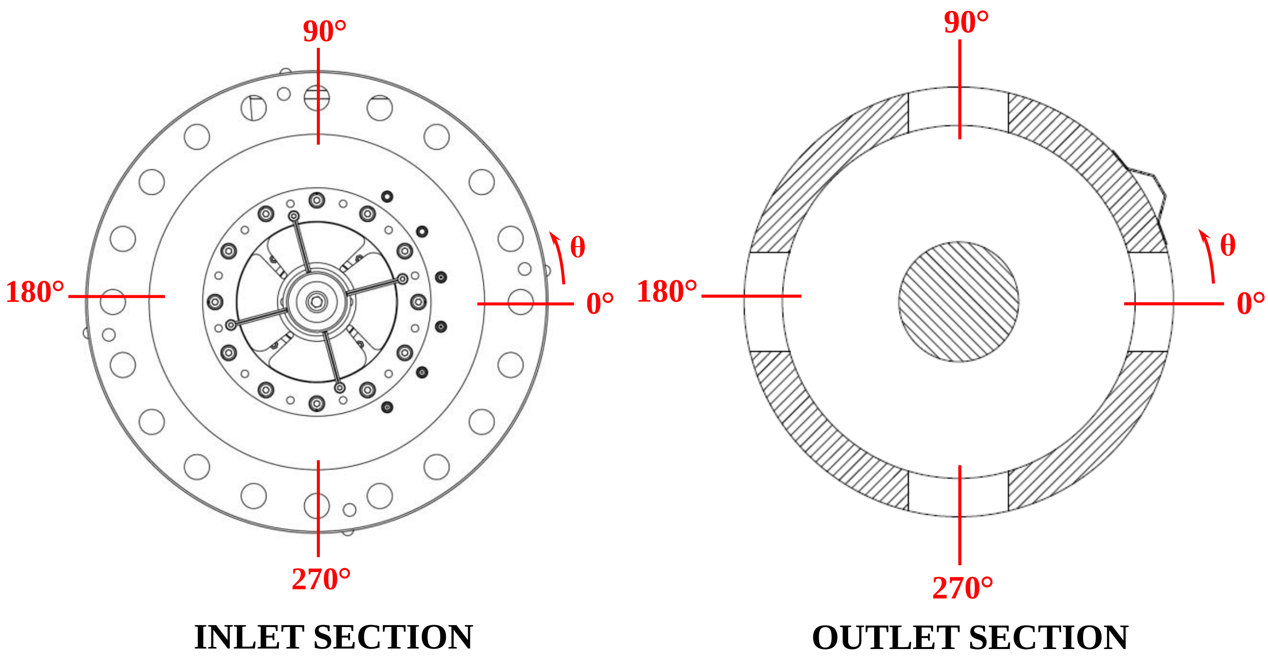

Figure 13 – Riser-pump inlet and outlet section

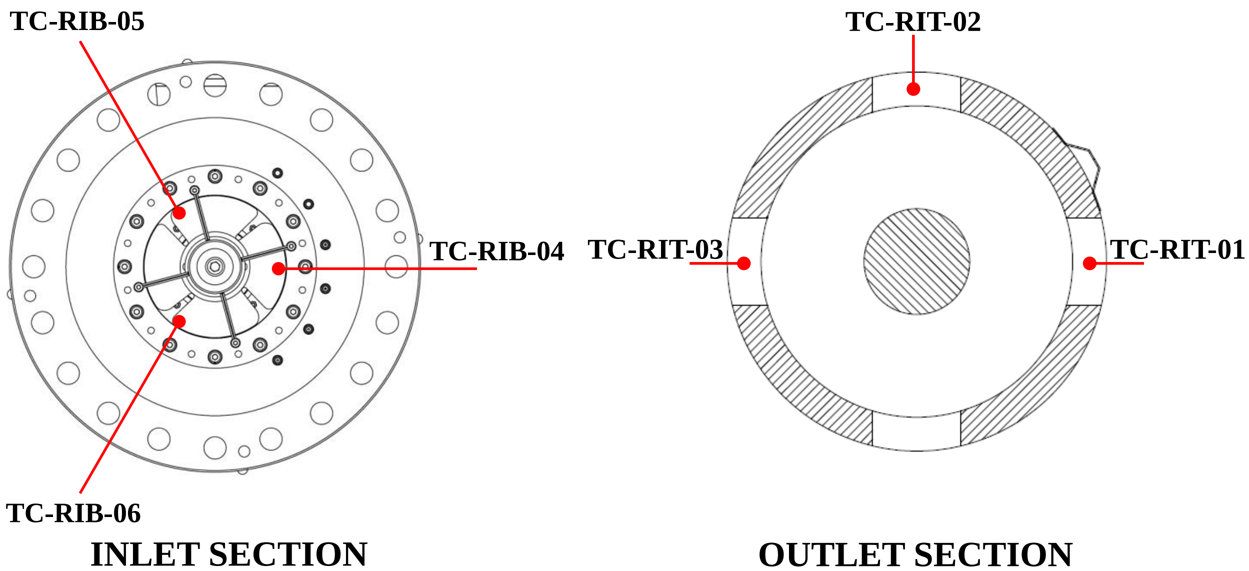

Figure 14 – Riser-pump TCs positions at the inlet and outlet section

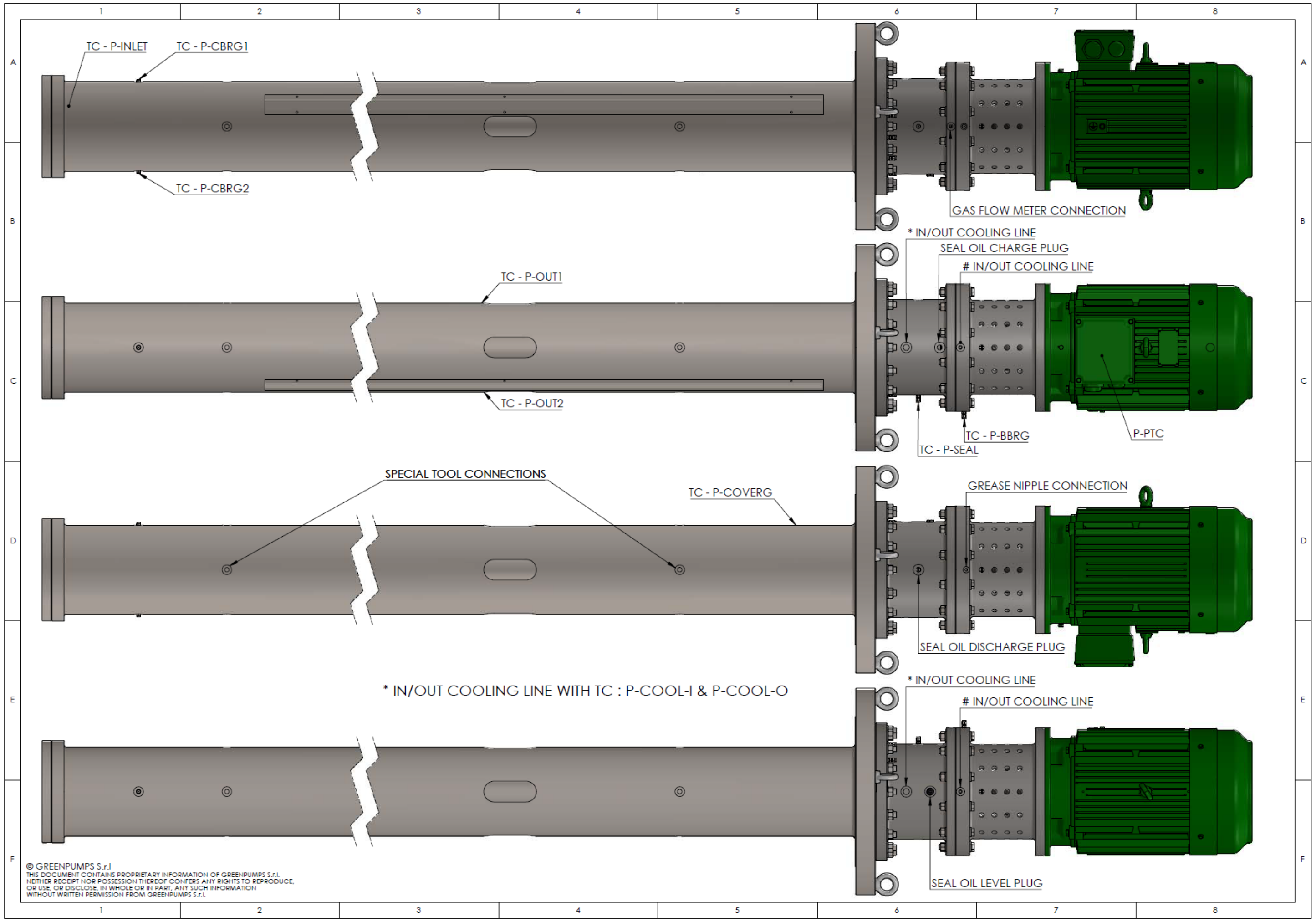

Figure 15 – Pump Instrumentation

3.5 Separator

LBE temperature entering into the separator is monitored by 3 TCS at riser (pump) outlet (**TC-RIT-01/02/03**). The bubble tube **PE006** injects argon about 270 mm below LBE free level (in rest condition) into the separator and at the same level bubble tube **PE008** blows Ar in the CIRCE main pool. Their pressure difference is measured (**DP-lev**) during the LBE circulation phases for monitoring the level in the separator and main pool.

The separator hosts one of the two oxygen sensors foreseen for the CIRCE facility. The sensor will be installed in the test section by means of a dedicated penetration on the TS head and it will measure the oxygen concentration of the hot LBE coming from the FPS.

Three 'ON-OFF' level sensors (Table 10) set in the separator indicate the LBE level during the filling procedure and the operating conditions:

- low level sensor **LE001**, positioned at the middle of the pump outlet holes section (674 mm below the top flange). This level sensor indicates the free level that the LBE must reach at the end of the filling operation. In stagnant conditions (pump, FPS, SG switched off) the sensor must be on. If it is off, the facility can't be operated;
- intermediate level sensor **LE002**, positioned 374 mm below the top flange. In stagnant conditions (no LBE flow rate along the test section) this sensor must be off. When the facility is operated at nominal conditions, the sensor must be on;
- high level sensor **LE003**, installed at 70 mm below the top flange. For a correct operation of the facility, this sensor must be kept off. If on, it indicates that the LBE reached the maximum level and the facility can't be operated.

Table 9 – Separator, bubble tube position

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**DP-lev**	Differential pressure Separator-CIRCE pool	50 mm above the separator bottom	6	Figure 27	

Table 10 – Level sensors set in the Separator

N°	ID	Description	Measurement Position	Ref.	Notes
1	**LE001**	LBE low level sensor in the Separator	Middle of the pump outlet holes (674 mm below the top flange)	Figure 16	Stagnant conditions: ON Nominal Conditions: ON
2	**LE002**	LBE intermediate level sensor in the Separator	374 mm below the top flange (Level 0.0 mm)	Figure 16	Stagnant conditions: OFF Nominal Conditions: ON
3	**LE003**	LBE high level sensor in the Separator	70 mm below the top flange (Level 0.0 mm)	Figure 16	Stagnant conditions: OFF Nominal Conditions: OFF

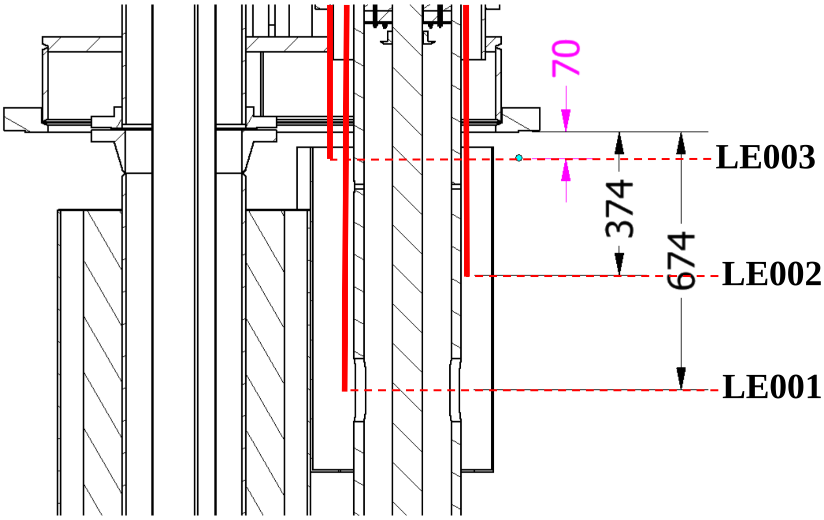

Figure 16 – Separator, level probes (in red)

3.6 Helical Coil Steam Generator

The HCSG is composed by an helical tube bundle having a height of 1.5 m, surrounded by a double wall shell of 1.62 m height. The helical tubes are arranged in three horizontal ranks: the inner rank is composed of 4 tubes, the intermediate one is composed of 5 tubes and the outer rank has 6 tubes. An overall number of 41 TCs (hot junction isolated, *N*-type) is implemented in the LBE side of the HCSG at the following positions:

- ***3 TCs*** are positioned at 120° at the inlet section of the SG (**TC-SG-01**, **TC-SG-02**, **TC-SG-03**, 3 mm diameter) to measure the LBE inlet temperature;
- ***3 TCs*** are installed at 120° at the outlet section (**TC-SG-04**, **TC-SG-05**, **TC-SG-06**, 3 mm diameter) to measure the LBE outlet section;
- ***30 TCs*** having a diameter of 1 mm are positioned at four different sections to monitor the LBE (15 TCs) and wall (15 TCs) temperatures. The TCs are arranged in order to have two TCs installed on each tube, which acts as a support for the TCs up to the measure points. The sections are fixed at four different levels, assuming as level 0.0 mm the bottom part of the helical tubes, as detailed in Figure 19. ***2 additional TCs*** are added in two specific sections and supported by the SG outer shell. The distribution of the TCs is performed as follows:

    - *Level 1* (+300 mm), 7 TCs (4 bulk, 3 wall) are installed to monitor all the sub-channels identified by the tube horizontal ranks and the inner and outer shells walls. The TCs are positioned in such a way to have a bulk and tube wall temperature measurements along the same radial direction. Details on the TCs position are reported in Table 12 and Figure 20;
    - *Level 2* (+600 mm), 8 TCs (4 bulk, 4 wall) are installed for temperature measurements in all the sub-channels. The TCs are positioned in such a way to have a bulk and tube wall temperature measurement along the same radial direction, excepting for the outer sub-channel (between the inner wall of the outer shell and the outer tube rank). Details on the TCs position are reported in Table 13 and Figure 21;

  - *Level 3* (+900 mm), 10 TCs (5 bulk, 5 wall) are installed to monitor all the sub-channels at different positions in the same section. Details on the TCs position are reported in Table 14 and Figure 22;
  - *Level 4* (+1200 mm), 7 TCs (4 bulk, 3 wall) are installed to monitor all the sub-channels. The TCs are positioned in such a way to have a bulk and tube wall temperature measurement along the same radial direction. Details on the TCs position are reported in Table 15 and Figure 23.

- ***3 TCs*** (**TC-SG-07**, **TC-SG-08**, **TC-SG-09**, 3 mm diameter) are installed inside the HCSG stagnant volume to monitor the temperature of the stagnant LBE. In particular, the TCs are positioned in 3 different levels: Level 1 (300 mm from the SG bottom), Level 3 (900 mm) and SG inlet section. The TCs are listed in Table 16 and reported in Figure 24.

Table 11 – HCSG LBE side – TCs positions at the inlet and outlet section

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**TC-SG-01**	LBE inlet temperature	HCSG inlet section (θ= 0°)	1	Figure 17	
2	**TC-SG-02**	LBE inlet temperature	HCSG inlet section (θ= 120°)	"	Figure 17	
3	**TC-SG-03**	LBE inlet temperature	HCSG inlet section (θ= 240°)	"	Figure 17	
4	**TC-SG-04**	LBE outlet temperature	HCSG outlet section (θ= 0°)	"	Figure 17	
5	**TC-SG-05**	LBE outlet temperature	HCSG outlet section (θ= 120°)	"	Figure 17	
6	**TC-SG-06**	LBE outlet temperature	HCSG outlet section (θ= 240°)	"	Figure 17	

Table 12 – HCSG LBE side – TCs positions at Level 1 (+300 mm)

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**TC-B12-L1**	LBE temperature	Rank 1, Tube 2, Level 1	3	Figure 20	
2	**TC-W12-L1**	Wall temperature	Rank 1, Tube 2, Level 1 (wall embedded)	"	Figure 20	
3	**TC-B23-L1**	LBE temperature	Rank 2, Tube 3, Level 1	"	Figure 20	
4	**TC-W23-L1**	Wall temperature	Rank 2, Tube 3, Level 1 (wall embedded)	"	Figure 20	

5	**TC-B32-L1**	LBE temperature	Rank 3, Tube 2, Level 1	"	Figure 20	
6	**TC-W32-L1**	Wall temperature	Rank 3, Tube 2, Level 1 (wall embedded)		Figure 20	
7	**TC-BS1-L1**	LBE temperature	External channel, Level 1		Figure 20	

Table 13 – HCSG LBE side – TCs positions at Level 2 (+600 mm)

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**TC-B11-L2**	LBE temperature	Rank 1, Tube 1, Level 2	"	Figure 21	
2	**TC-W11-L2**	Wall temperature	Rank 1, Tube 1, Level 2 (wall embedded)	"	Figure 21	
3	**TC-B22-L2**	LBE temperature	Rank 2, Tube 2, Level 2	"	Figure 21	
4	**TC-W22-L2**	Wall temperature	Rank 2, Tube 2, Level 2 (wall embedded)	"	Figure 21	
5	**TC-B31-L2**	LBE temperature	Rank 2, Tube 1, Level 2	"	Figure 21	
6	**TC-W31-L2**	Wall temperature	Rank 2, Tube 1, Level 2 (wall embedded)	"	Figure 21	
7	**TC-B36-L2**	LBE temperature	Rank 3, Tube 6, Level 2	"	Figure 21	
8	**TC-B36-L2**	Wall temperature	Rank 3, Tube 6, Level 2 (wall embedded)	"	Figure 21	

Table 14 – HCSG LBE side – TCs positions at Level 3 (+900 mm)

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**TC-B13-L3**	LBE temperature	Rank 1, Tube 3, Level 3	"	Figure 22	
2	**TC-W13-L3**	Wall temperature	Rank 1, Tube 3, Level 3 (wall embedded)	"	Figure 22	
3	**TC-B24-L3**	LBE temperature	Rank 2, Tube 4, Level 3	"	Figure 22	
4	**TC-W24-L3**	Wall temperature	Rank 2, Tube 4, Level 3 (wall embedded)	"	Figure 22	
5	**TC-B21-L3**	LBE temperature	Rank 2, Tube 1, Level 3	"	Figure 22	
6	**TC-W21-L3**	Wall temperature	Rank 2, Tube 1, Level 3 (wall embedded)	"	Figure 22	
7	**TC-B33-L3**	LBE temperature	Rank 3, Tube 3, Level 3	"	Figure 22	

8	**TC-B33-L3**	Wall temperature	Rank 3, Tube 3, Level 3 (wall embedded)	"	Figure 22	
9	**TC-B35-L3**	LBE temperature	Rank 3, Tube 5, Level 3		Figure 22	
10	**TC-W35-L3**	Wall temperature	Rank 3, Tube 5, Level 3 (wall embedded)		Figure 22	

Table 15 – HCSG LBE side – TCs positions at Level 4 (+1200 mm)

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**TC-B14-L4**	LBE temperature	Rank 1, Tube 4, Level 4	"	Figure 23	
2	**TC-W14-L4**	Wall temperature	Rank 1, Tube 4, Level 4 (wall embedded)	"	Figure 23	
3	**TC-B25-L4**	LBE temperature	Rank 2, Tube 5, Level 4	"	Figure 23	
4	**TC-W25-L4**	Wall temperature	Rank 2, Tube 5, Level 4 (wall embedded)	"	Figure 23	
5	**TC-B34-L4**	LBE temperature	Rank 3, Tube 4, Level 4	"	Figure 23	
6	**TC-W34-L4**	Wall temperature	Rank 3, Tube 4, Level 4 (wall embedded)	"	Figure 23	
7	**TC-BS4-L4**	LBE temperature	External channel, Level 4	"	Figure 23	

Table 16 – HCSG LBE side – TCs positions inside the dead volume

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**TC-SG-07**	LBE temperature	Inside the dead volume at Level 1 (300 mm from the SG bottom)	3	Figure 24	
2	**TC-SG-08**	LBE temperature	Inside the dead volume at Level 3 (900 mm from the SG bottom)	"	Figure 24	
3	**TC-SG-09**	LBE temperature	Inside the dead volume at SG inlet (1500 mm from the SG bottom)	"	Figure 24	

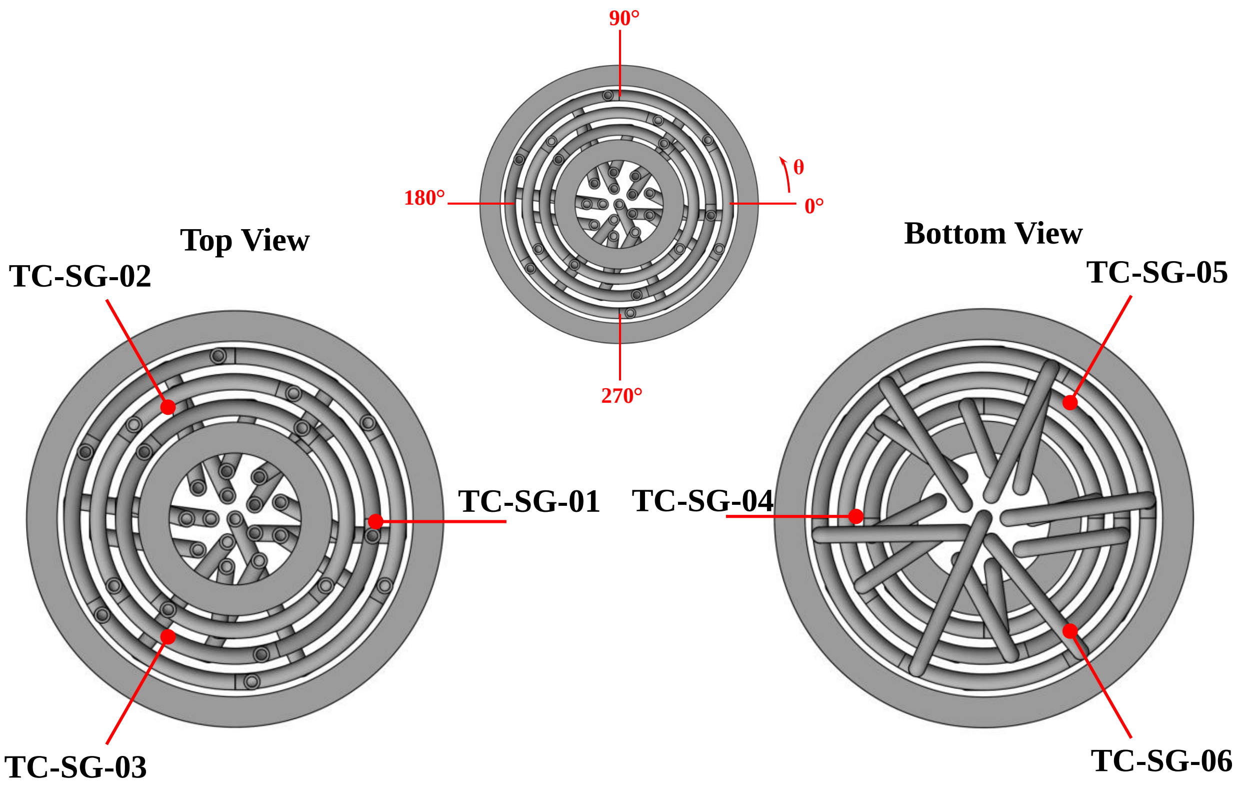

Figure 17 – TCs at the inlet and outlet sections of the HCSG

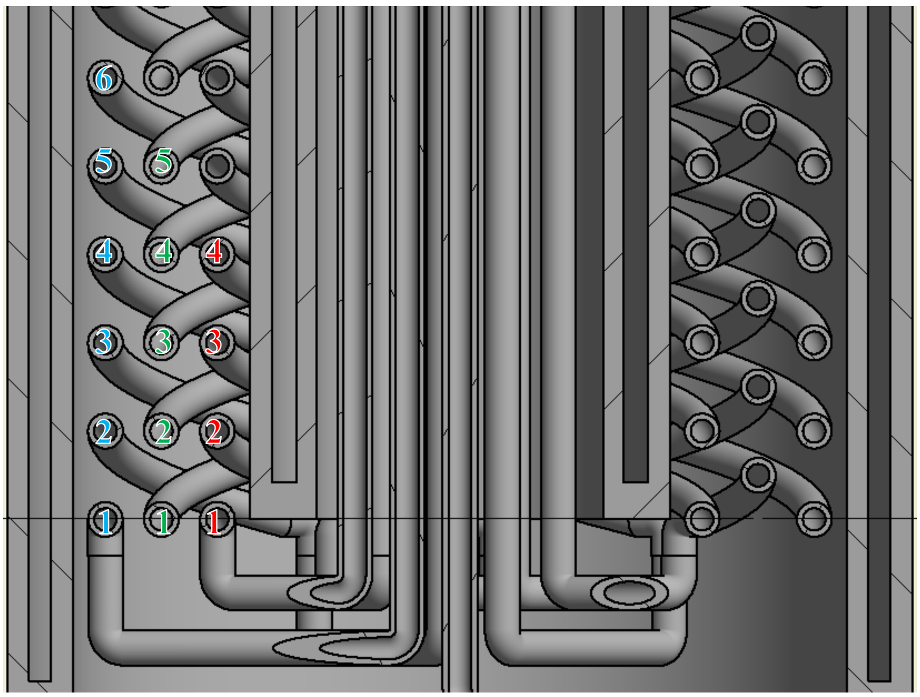

Figure 18 – Detail of the helical tube bundle showing the ID number of each tube for each rank

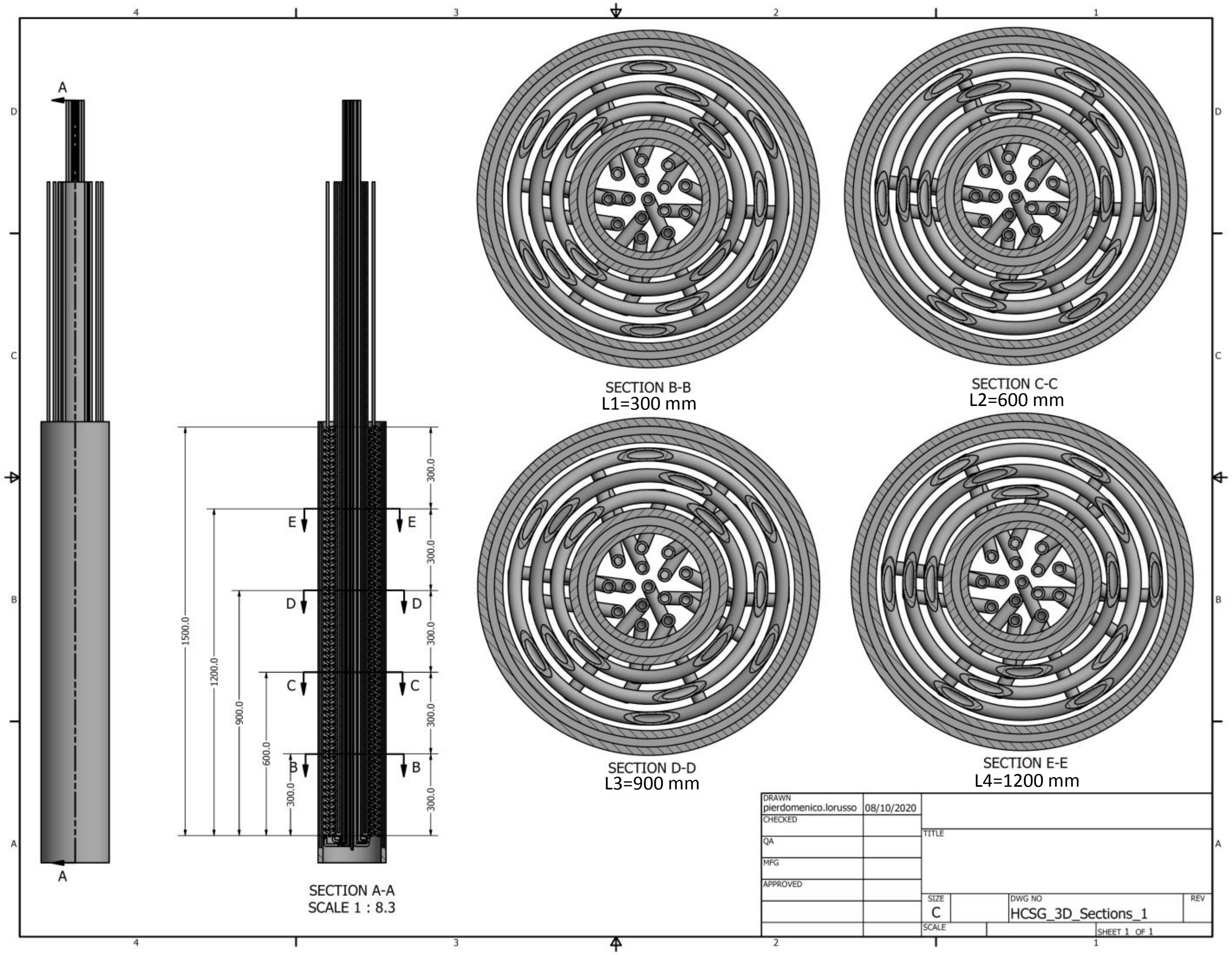

Figure 19 – HCSG instrumentation: details of the section levels

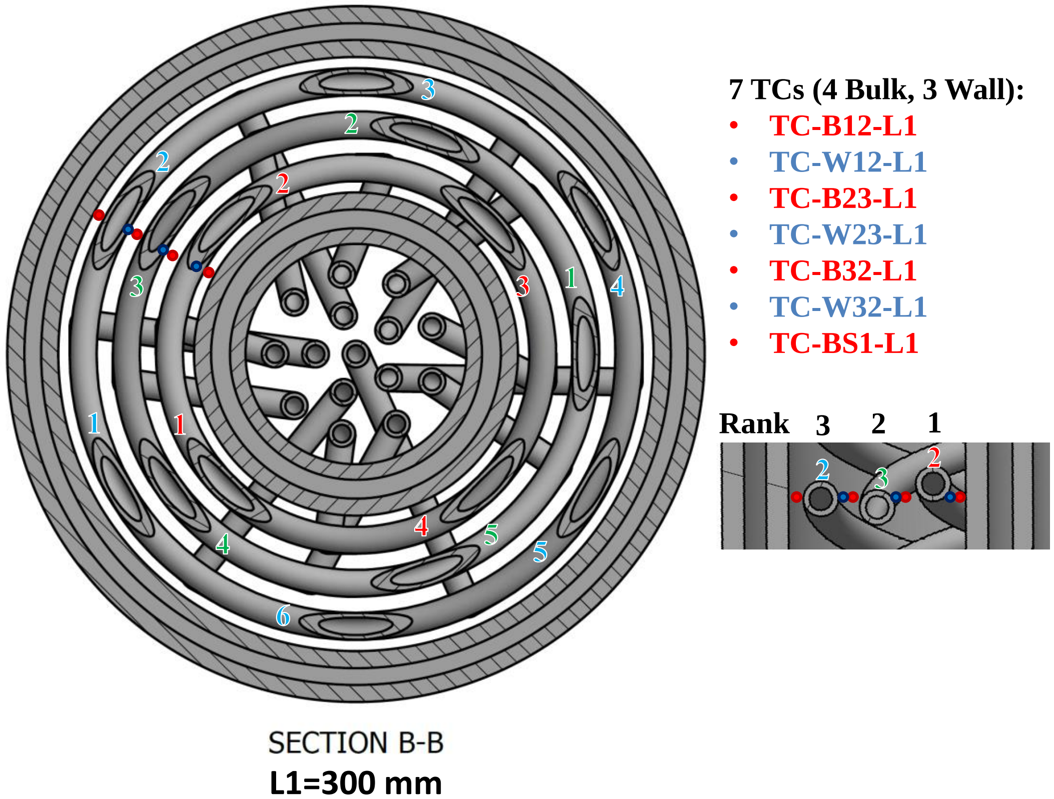

Figure 20 – HCSG instrumentation: bulk TCs (red) and wall TCs (blue) at the Level 1

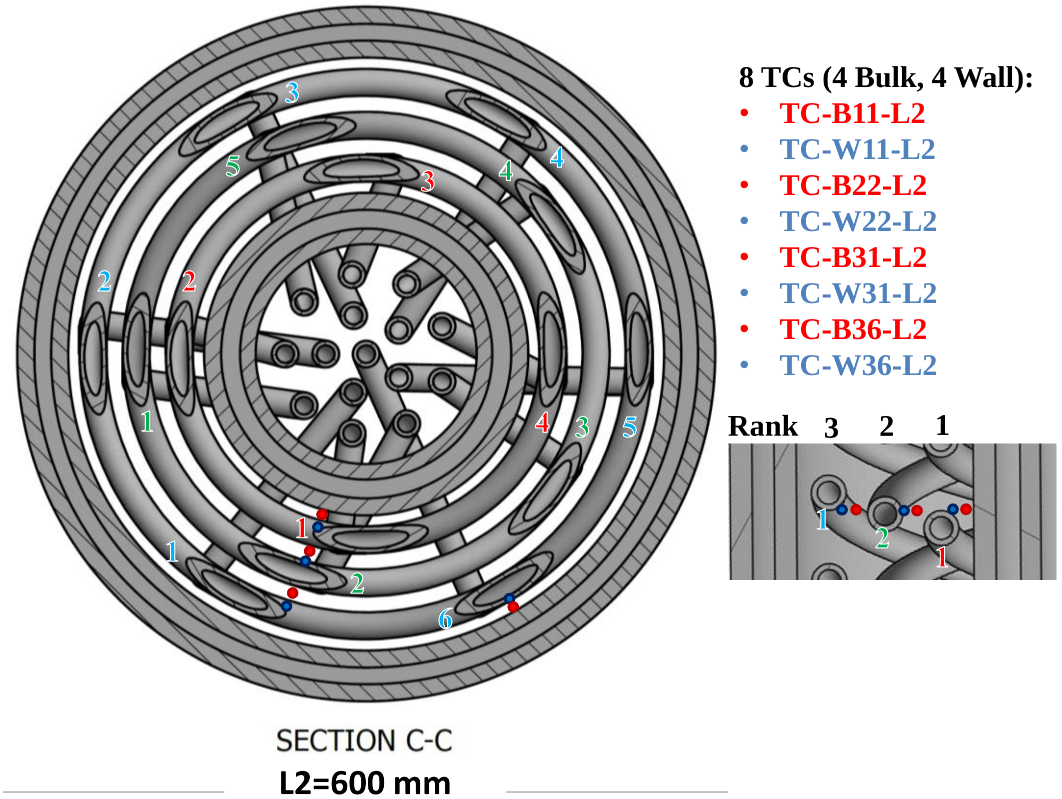

Figure 21 – HCSG instrumentation: bulk TCs (red) and wall TCs (blue) at the Level 2

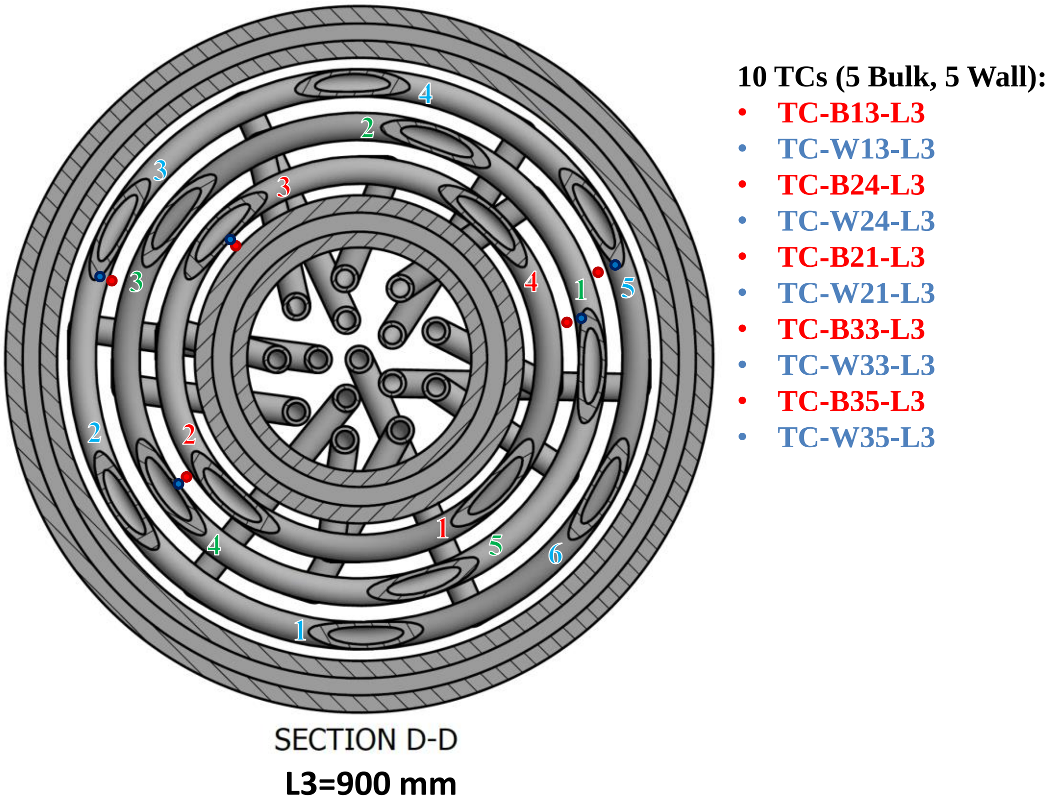

Figure 22 – HCSG instrumentation: bulk TCs (red) and wall TCs (blue) at the Level 3

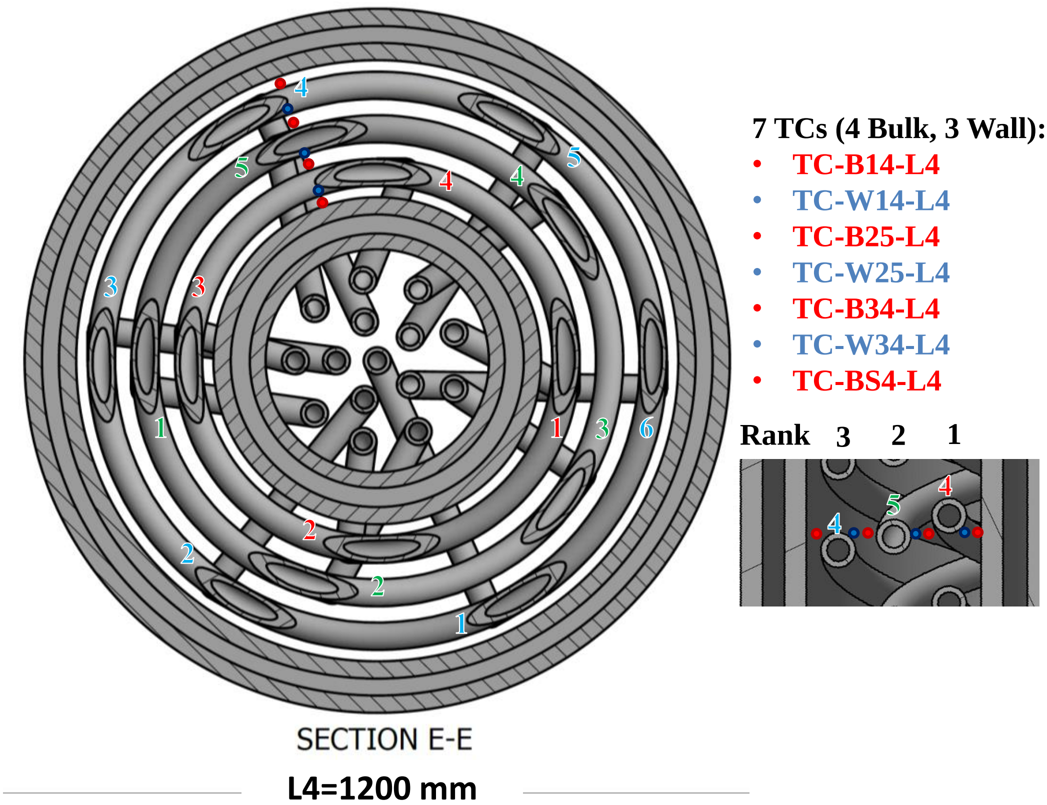

Figure 23 – HCSG instrumentation: bulk TCs (red) and wall TCs (blue) at the Level 3

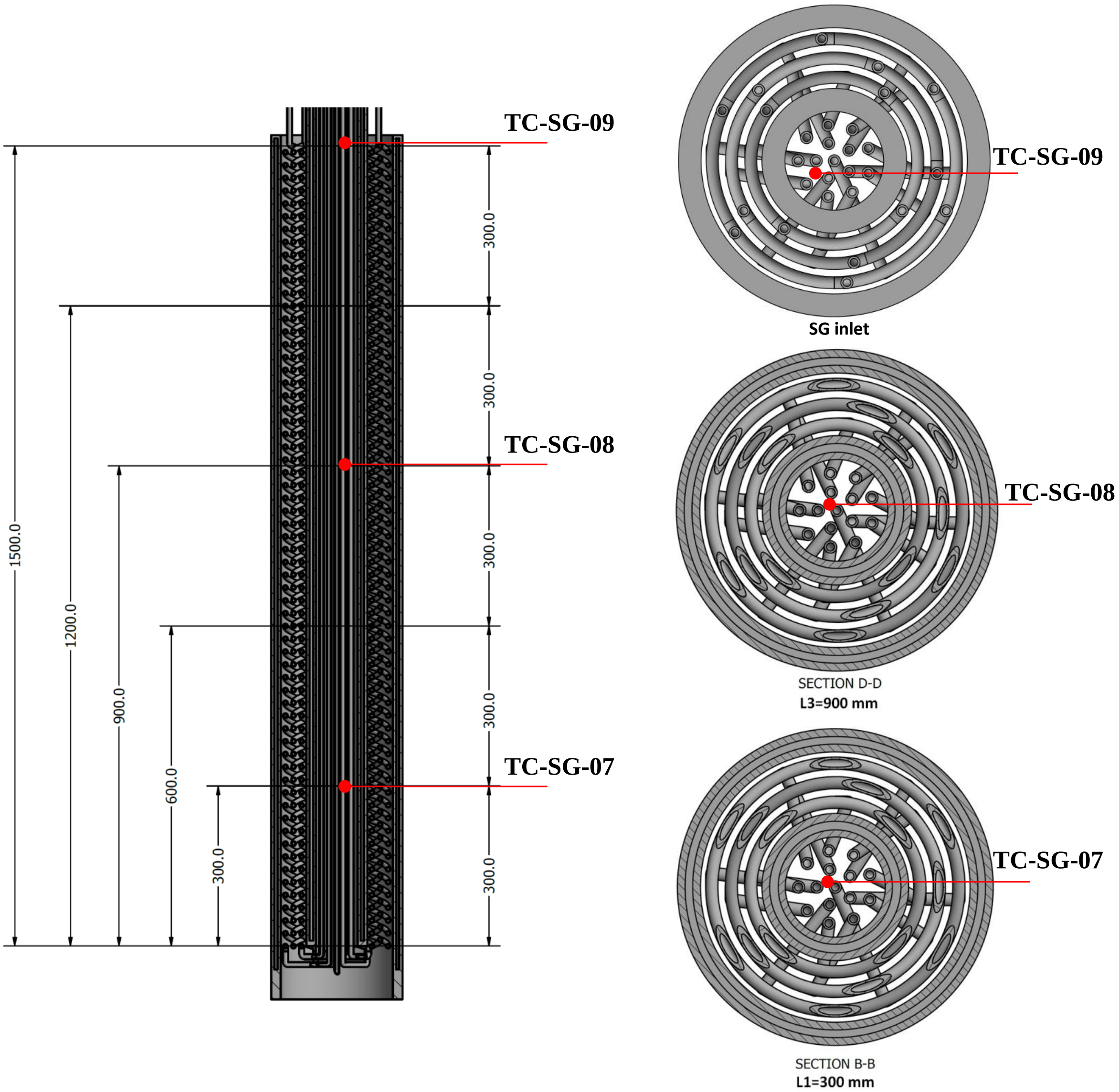

Figure 24 – TCs positions inside the dead volume

3.7 CIRCE Pool

The occurrence and evolution of mixing and stratification phenomena in the LBE pool is monitored by 80 TCs (*N*-type, with isolated hot junction, having a diameter of 3 mm). They are listed in Table 17 with corresponding supporting rods (4 in total, identified by letters A, B, C, D), measurement positions and distances, in mm, from the level “0.0 mm” in correspondence of the upper flange of the test section. The adoption of a new steam generator (HCSG) in comparison to the one used in the previous experimental campaign (CIRCE-HERO), leads to consider the stratification region to occur in a different position. Moreover, due to the experience of the previous experimental campaigns, only 4 lines instead of 9 will be monitored (namely A, B, C, D), being the horizontal stratification negligible. The position of the 4 lines in the pool is reported in Figure 25, while the axial positions of the thermocouples are indicated in Figure 26. The list of pool TCs is reported in Table 17.

Two bubble tubes are placed at two different levels to measure the hydrodynamic head in the main vessel. As shown in Figure 27, one bubble tube (**PE012**) is positioned at 4700 mm below the top flange, while a second bubble tube (**PE013**) is positioned at 8200 mm below the top flange. The bubble tubes installed in the pool are reported in Table 21.

An oxygen sensor will be placed inside the main pool. The sensor will be installed in the test section by means of a dedicated penetration on the TS head and it will measure the oxygen concentration of the cold LBE surrounding the test section.

Table 17 – Mixing and stratification in CIRCE pool

N°	ID	Description	Measurement Position	Distance below level 0 [mm]	Ref.	Notes
1	**TC-MS-01**	Supported by rod at separator	A	600	Figure 25, Figure 26	
2	**TC-MS-02**	Supported by rod at dead volume	B	600	"	
3	**TC-MS-03**	Supported by rod at dead volume	C	600	"	
4	**TC-MS-04**	Supported by rod at dead volume	D	600	"	
5	**TC-MS-05**	Supported by rod at separator	A	1200	"	
6	**TC-MS-06**	Supported by rod at dead volume	B	1200	"	
7	**TC-MS-07**	Supported by rod at dead volume	C	1200	"	
8	**TC-MS-08**	Supported by rod at dead volume	D	1200	"	
9	**TC-MS-09**	Supported by rod at separator	A	1800	"	
10	**TC-MS-10**	Supported by rod at dead volume	B	1800	"	
11	**TC-MS-11**	Supported by rod at dead volume	C	1800	"	
12	**TC-MS-12**	Supported by rod at dead volume	D	1800	"	
13	**TC-MS-13**	Supported by rod at separator	A	2200	"	
14	**TC-MS-14**	Supported by rod at dead volume	B	2200	"	
15	**TC-MS-15**	Supported by rod at dead volume	C	2200	"	
16	**TC-MS-16**	Supported by rod at dead volume	D	2200	"	
17	**TC-MS-17**	Supported by rod at separator	A	2320	"	
18	**TC-MS-18**	Supported by rod at dead volume	B	2320	"	

N°	ID	Description	Measurement Position	Distance below level 0 [mm]	Ref.	Notes
19	**TC-MS-19**	Supported by rod at dead volume	C	2320	"	
20	**TC-MS-20**	Supported by rod at dead volume	D	2320	"	
21	**TC-MS-21**	Supported by rod at separator	A	2440	"	
22	**TC-MS-22**	Supported by rod at dead volume	B	2440	"	
23	**TC-MS-23**	Supported by rod at dead volume	C	2440	"	
24	**TC-MS-24**	Supported by rod at dead volume	D	2440	"	
25	**TC-MS-25**	Supported by rod at separator	A	2560	"	
26	**TC-MS-26**	Supported by rod at dead volume	B	2560	"	
27	**TC-MS-27**	Supported by rod at dead volume	C	2560	"	
28	**TC-MS-28**	Supported by rod at dead volume	D	2560	"	
29	**TC-MS-29**	Supported by rod at separator	A	2680	"	
30	**TC-MS-30**	Supported by rod at dead volume	B	2680	"	
31	**TC-MS-31**	Supported by rod at dead volume	C	2680	"	
32	**TC-MS-32**	Supported by rod at dead volume	D	2680	"	
33	**TC-MS-33**	Supported by rod at separator	A	2800	"	
34	**TC-MS-34**	Supported by rod at dead volume	B	2800	"	
35	**TC-MS-35**	Supported by rod at dead volume	C	2800	"	
36	**TC-MS-36**	Supported by rod at dead volume	D	2800	"	
37	**TC-MS-37**	Supported by rod at separator	A	2920	"	
38	**TC-MS-38**	Supported by rod at dead volume	B	2920	"	
39	**TC-MS-39**	Supported by rod at dead volume	C	2920	"	
40	**TC-MS-40**	Supported by rod at dead volume	D	2920	"	
41	**TC-MS-41**	Supported by rod at separator	A	3040	"	
42	**TC-MS-42**	Supported by rod at dead volume	B	3040	"	

N°	ID	Description	Measurement Position	Distance below level 0 [mm]	Ref.	Notes
43	**TC-MS-43**	Supported by rod at dead volume	C	3040	"	
44	**TC-MS-44**	Supported by rod at dead volume	D	3040	"	
45	**TC-MS-45**	Supported by rod at separator	A	3600	"	
46	**TC-MS-46**	Supported by rod at dead volume	B	3600	"	
47	**TC-MS-47**	Supported by rod at dead volume	C	3600	"	
48	**TC-MS-48**	Supported by rod at dead volume	D	3600	"	
49	**TC-MS-49**	Supported by rod at separator	A	4200	"	
50	**TC-MS-50**	Supported by rod at dead volume	B	4200	"	
51	**TC-MS-51**	Supported by rod at dead volume	C	4200	"	
52	**TC-MS-52**	Supported by rod at dead volume	D	4200	"	
53	**TC-MS-53**	Supported by rod at separator	A	4800	"	
54	**TC-MS-54**	Supported by rod at dead volume	B	4800	"	
55	**TC-MS-55**	Supported by rod at dead volume	C	4800	"	
56	**TC-MS-56**	Supported by rod at dead volume	D	4800	"	
57	**TC-MS-57**	Supported by rod at separator	A	5400	"	
58	**TC-MS-58**	Supported by rod at dead volume	B	5400	"	
59	**TC-MS-59**	Supported by rod at dead volume	C	5400	"	
60	**TC-MS-60**	Supported by rod at dead volume	D	5400	"	
61	**TC-MS-61**	Supported by rod at separator	A	6000	"	
62	**TC-MS-62**	Supported by rod at dead volume	B	6000	"	
63	**TC-MS-63**	Supported by rod at dead volume	C	6000	"	
64	**TC-MS-64**	Supported by rod at dead volume	D	6000	"	
65	**TC-MS-65**	Supported by rod at separator	A	6600	"	
66	**TC-MS-66**	Supported by rod at dead volume	B	6600	"	

N°	ID	Description	Measurement Position	Distance below level 0 [mm]	Ref.	Notes
67	**TC-MS-67**	Supported by rod at dead volume	C	6600	"	
68	**TC-MS-68**	Supported by rod at dead volume	D	6600	"	
69	**TC-MS-69**	Supported by rod at separator	A	7200	"	
70	**TC-MS-70**	Supported by rod at dead volume	B	7200	"	
71	**TC-MS-71**	Supported by rod at dead volume	C	7200	"	
72	**TC-MS-72**	Supported by rod at dead volume	D	7200	"	
73	**TC-MS-73**	Supported by rod at separator	A	7800	"	
74	**TC-MS-74**	Supported by rod at dead volume	B	7800	"	
75	**TC-MS-75**	Supported by rod at dead volume	C	7800	"	
76	**TC-MS-76**	Supported by rod at dead volume	D	7800	"	
77	**TC-MS-77**	Supported by rod at separator	A	8200	"	
78	**TC-MS-78**	Supported by rod at dead volume	B	8200	"	
79	**TC-MS-79**	Supported by rod at dead volume	C	8200	"	
80	**TC-MS-80**	Supported by rod at dead volume	D	8200	"	

Table 18 –Bubble tube installed in CIRCE pool

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**PE012**	LBE relative pressure	Inside the main vessel, 4700 mm from the top flange	6	Figure 27	
2	**PE013**	LBE relative pressure	Inside the main vessel, bottom part	6	Figure 27	

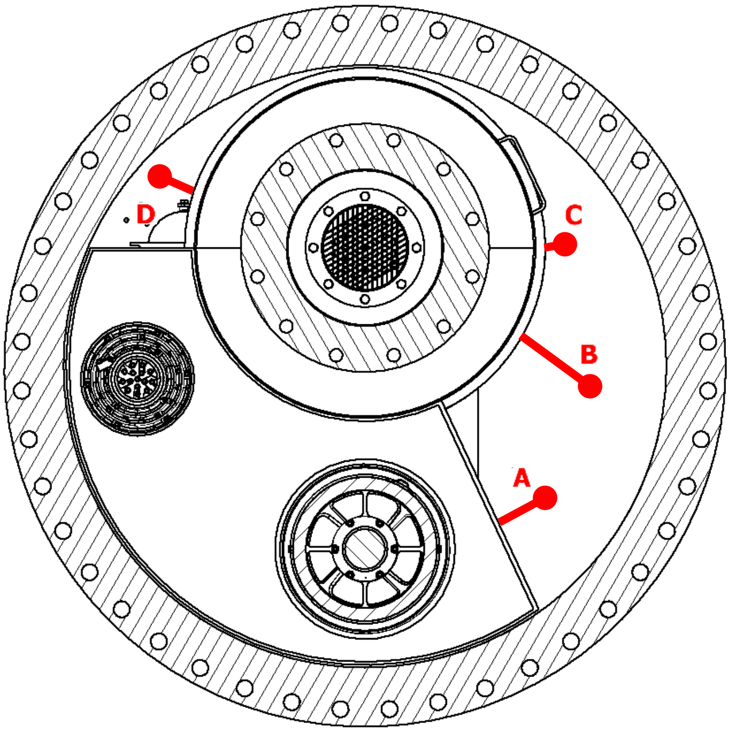

Figure 25 – Azimuthal positions of thermocouples for mixing and stratification in CIRCE pool (top view).

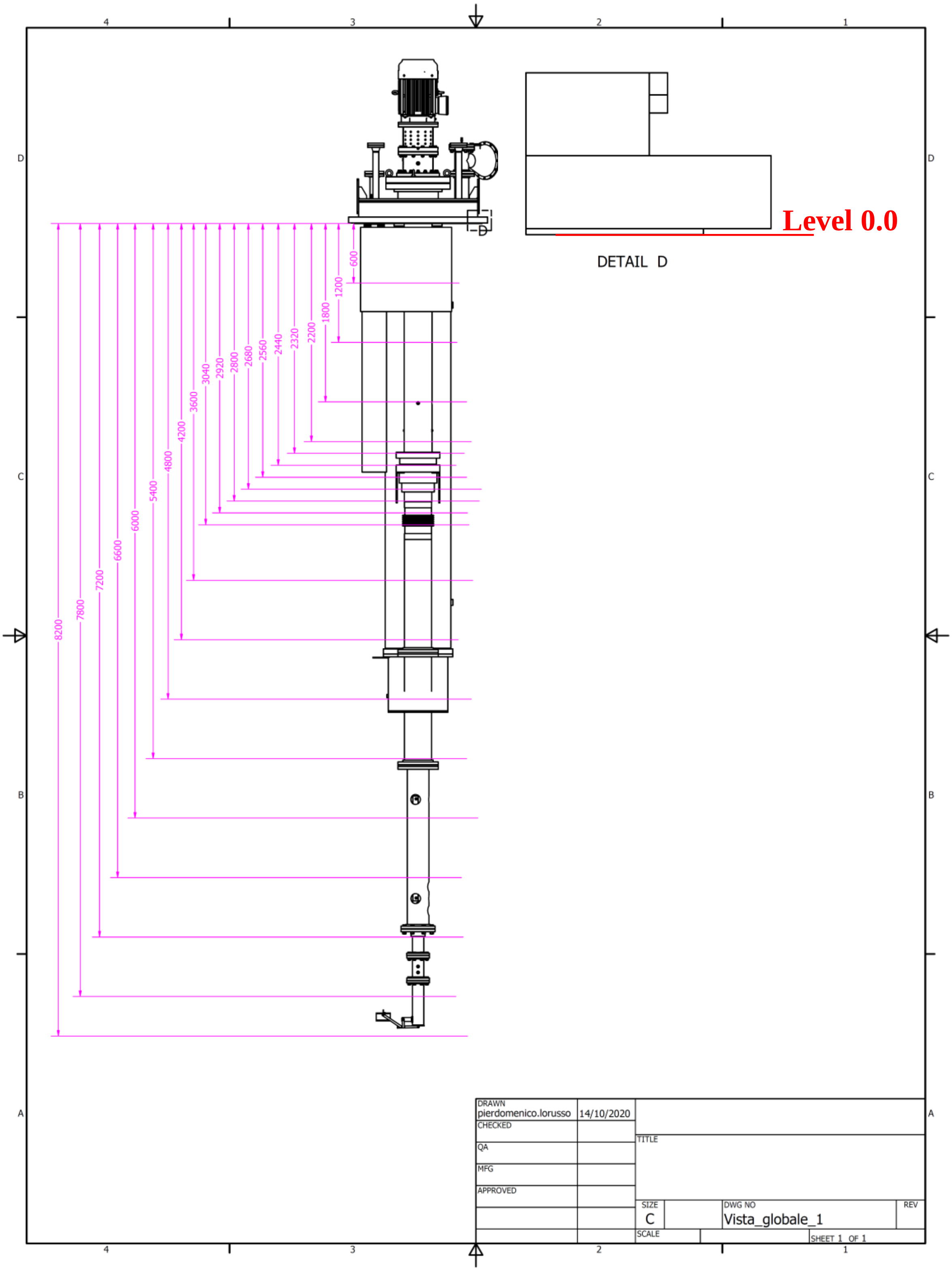

Figure 26 – Vertical positions of thermocouples for mixing and stratification in CIRCE poo

3.8 Cover gas

A TC *N*-type, with isolated hot junction (3 mm diameter), named **T-CG-01** acquires the temperature in the cover gas, in the region above the dead volume. A relative pressure transmitter **PE007** monitors the cover gas pressure. The cover gas instrumentation is reported in Table 21 and Table 26.

Table 19 –Thermocouples installed in cover gas

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**T-CG-01**	Cover gas temperature	Cover gas	6	Figure 27	

Table 20 –Bubble tube installed in cover gas

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**PE007**	CIRCE main vessel pressure	Cover gas	6	Figure 27	

Table 21 – Summary of bubble tubes positions inside the S100

N°	ID	Description	Measurement position	Diam. [mm]	Ref.	Notes
1	**PE001**	LBE differential pressure	115 mm above the Venturi lower flange	6	Figure 2 Figure 27	
2	**PE002**	LBE differential pressure	157 mm above the Venturi lower flange	6	Figure 2 Figure 27	
3	**PE003**	LBE differential pressure	Downstream the FPS upper spacer grid	6	Figure 27	
4	**PE004**	LBE differential pressure	Upstream the pump impeller	6	Figure 27	
5	**PE005**	LBE differential pressure	Downstream the pump impeller	6	Figure 27	
6	**PE006**	LBE differential pressure	50 mm above the separator bottom (separator)	6	Figure 27	
7	**PE007**	CIRCE main vessel pressure	Cover gas	6	Figure 27	

8	**PE008**	LBE differential pressure	50 mm above the separator bottom (main pool)	6	Figure 27	
9	**PE011**	LBE relative pressure	Downstream the pump impeller	6	Figure 27	
10	**PE012**	LBE relative pressure	Inside the main vessel, at the FV level	6	Figure 27	
11	**PE013**	LBE relative pressure	Inside the main vessel, bottom part	6	Figure 27	

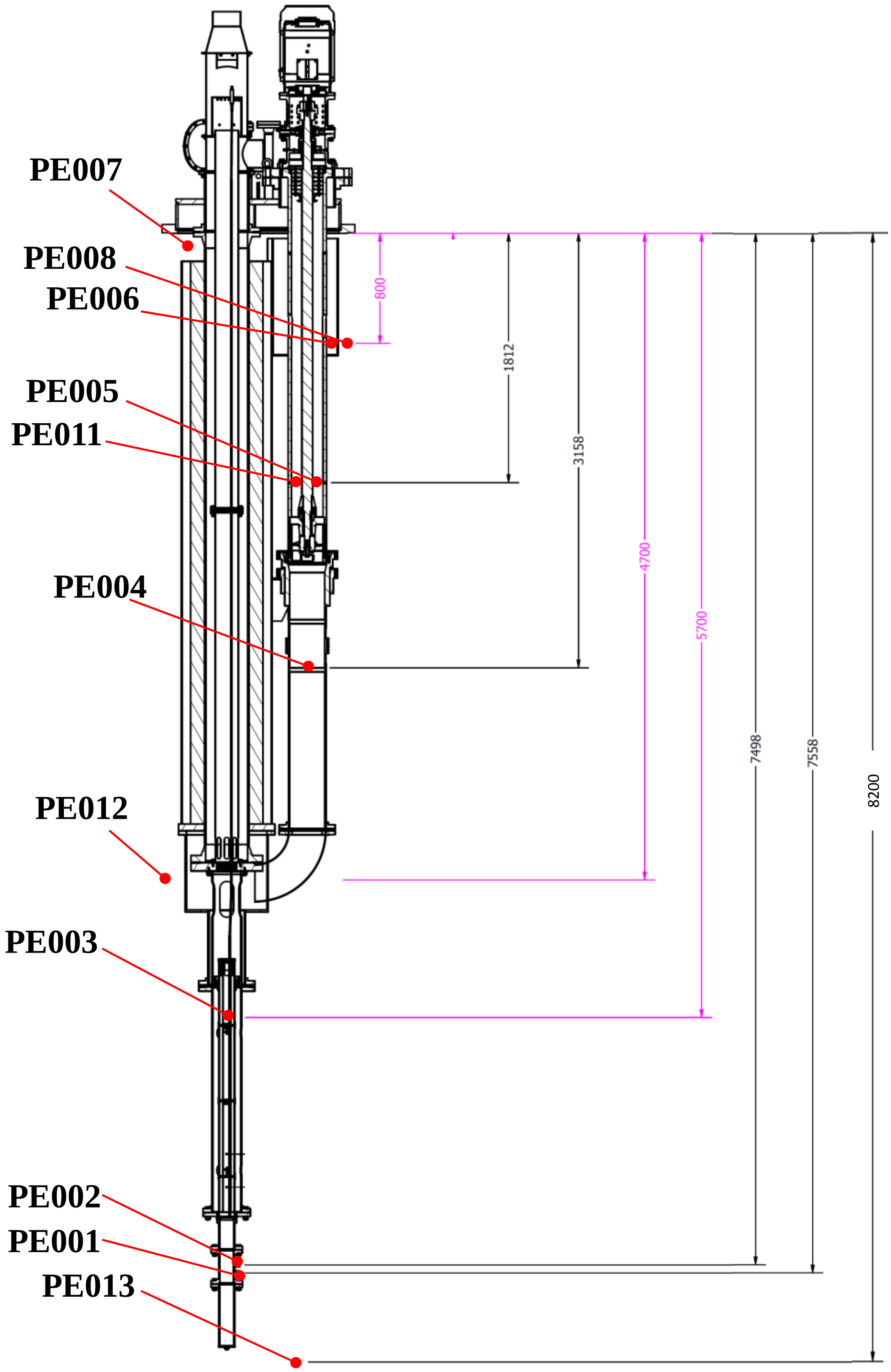

Figure 27 – Bubble tube positions along the test section and inside the mail vessel

3.9 S100 Main Vessel outer wall temperature

The outer wall temperature of the CIRCE vessel S100 is measured by 17 *N*-type TCs (with isolated hot junction and diameter of 3 mm), whose vertical (distance "y") and azimuthal position (angle θ) are listed in Table 22 and shown in Figure 28. The level 0.0 mm shown in Figure 28 is set at the lower surface of the supporting plate, which is 410 mm below the upper surface of the vessel flange. **TE104** and **TE105** are set in the upper thick part of the cylindrical vessel, and **TE123** and **TE124** are positioned in the bottom dished head.

During the refurbishment of the facility, an additional number of 15 *N*-type TCs (with isolated hot junction and diameter of 3 mm) will be installed all around the S100 main vessel, on the outer surface of the thermal insulator layer. Such TCs will be positioned following the same axial and azimuthal distribution of the corresponding TCs installed on the S100 wall (from TE110 to TE124). The addiction of the TCs on the outer surface of the insulator aims at achieving a better estimation of the heat losses from the pool to the environment. Details of the new TCs position are reported in Table 23.

Table 22 – Thermocouples on the outer wall of S100

N°	ID	Description	Measurement Position	Ref.
1	**TE104**	Temperature on the outer wall of S100 shell	y= +190 mm; θ= 270°	*Figure 28*
2	**TE105**	Temperature on the outer wall of S100 shell	y= +190 mm; θ= 90°	"
3	**TE110**	Temperature on the outer wall of S100 shell	y= -2065 mm; θ= 180°	"
4	**TE111**	Temperature on the outer wall of S100 shell	y= -1650 mm; θ= 270°	"
5	**TE112**	Temperature on the outer wall of S100 shell	y= -1235 mm; θ= 0°	"
6	**TE113**	Temperature on the outer wall of S100 shell	y= -820 mm; θ= 90°	"
7	**TE114**	Temperature on the outer wall of S100 shell	y= -405 mm; θ= 180°	"
8	**TE115**	Temperature on the outer wall of S100 shell	y= -4010 mm; θ= 240°	"
9	**TE116**	Temperature on the outer wall of S100 shell	y= -3315 mm; θ= 0°	"
10	**TE117**	Temperature on the outer wall of S100 shell	y= -2620 mm; θ= 120°	"
11	**TE118**	Temperature on the outer wall of S100 shell	y= -6070 mm; θ= 240°	"
12	**TE119**	Temperature on the outer wall of S100 shell	y= -5405 mm; θ= 0°	"
13	**TE120**	Temperature on the outer wall of S100 shell	y= -4709 mm; θ= 120°	"
14	**TE121**	Temperature on the outer wall of S100 shell	y= -7380 mm; θ= 240°	"
15	**TE122**	Temperature on the outer wall of S100 shell	y= -6760 mm; θ= 60°	"

N°	ID	Description	Measurement Position	Ref.
16	**TE123**	Temperature on the outer wall of S100 dished head	y= -8025 mm; θ= 270°	"
17	**TE124**	Temperature on the outer wall of S100 dished head	y= -8025 mm; θ= 90°	"

Table 23 – Thermocouples on the outer wall of S100 insulator

N°	ID	Description	Measurement Position	Ref.
1	**TE125**	Temperature on the outer wall of S100 insulator layer	y= -2065 mm; θ= 180°	"
2	**TE126**	Temperature on the outer wall of S100 insulator layer	y= -1650 mm; θ= 270°	"
3	**TE127**	Temperature on the outer wall of S100 insulator layer	y= -1235 mm; θ= 0°	"
4	**TE128**	Temperature on the outer wall of S100 insulator layer	y= -820 mm; θ= 90°	"
5	**TE129**	Temperature on the outer wall of S100 insulator layer	y= -405 mm; θ= 180°	"
6	**TE130**	Temperature on the outer wall of S100 insulator layer	y= -4010 mm; θ= 240°	"
7	**TE131**	Temperature on the outer wall of S100 insulator layer	y= -3315 mm; θ= 0°	"
8	**TE132**	Temperature on the outer wall of S100 insulator layer	y= -2620 mm; θ= 120°	"
9	**TE133**	Temperature on the outer wall of S100 insulator layer	y= -6070 mm; θ= 240°	"
10	**TE134**	Temperature on the outer wall of S100 insulator layer	y= -5405 mm; θ= 0°	"
11	**TE135**	Temperature on the outer wall of S100 insulator layer	y= -4709 mm; θ= 120°	"
12	**TE136**	Temperature on the outer wall of S100 insulator layer	y= -7380 mm; θ= 240°	"
13	**TE137**	Temperature on the outer wall of S100 insulator layer	y= -6760 mm; θ= 60°	"
14	**TE138**	Temperature on the outer wall of S100 dished head (above the insulator layer)	y= -8025 mm; θ= 270°	"
15	**TE139**	Temperature on the outer wall of S100 dished head (above the insulator layer)	y= -8025 mm; θ= 90°	"

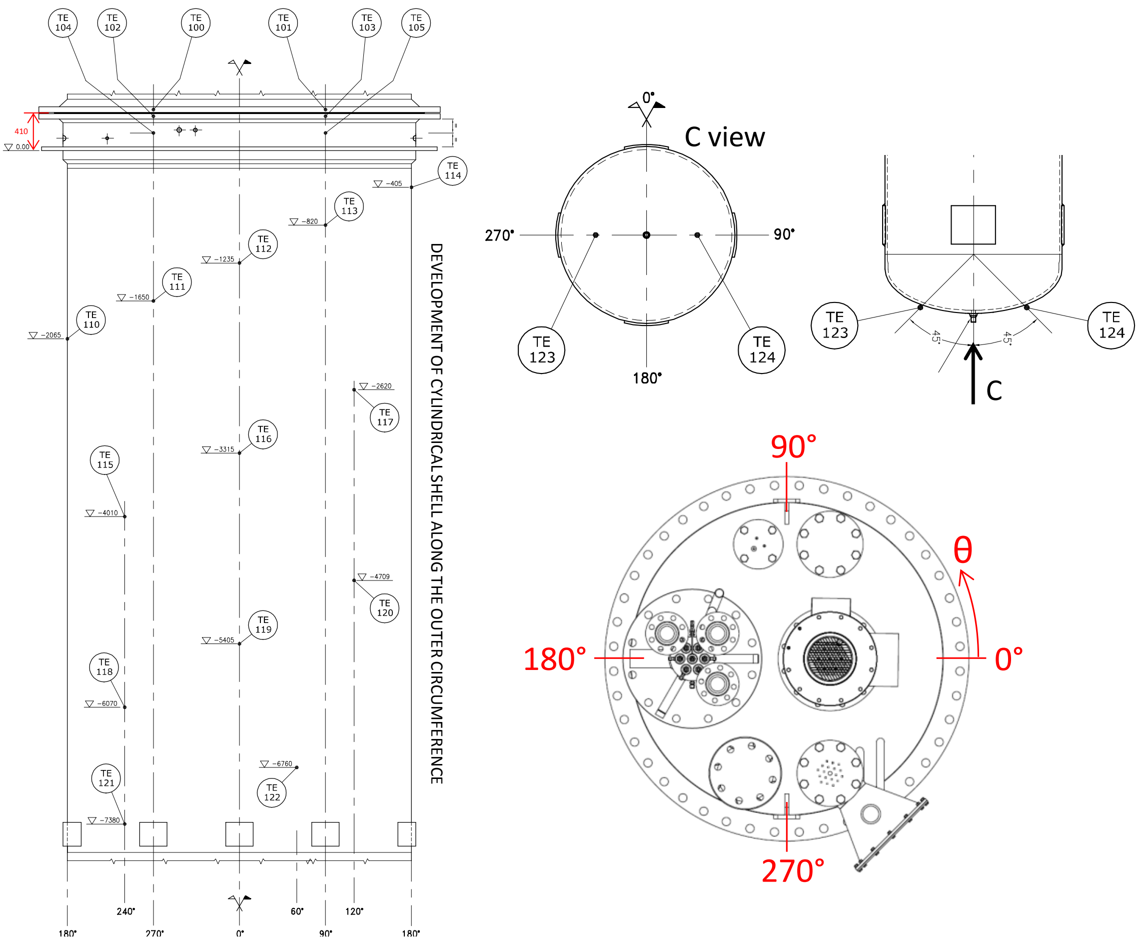

Figure 28 – Thermocouples set on S100 outer wall

3.10 S100 RVACS

Concerning the CIRCE RVACS, the air loop will be equipped with two TCs (minimum) in order to measure the air temperature at the inlet and outlet sections of the RVACS active length (**TC-RV-01**, **TC-RV-02**). Furthermore, three TCs will be positioned on the S100 wall surface (**TC-RV-03/04/05**) and three TCs will be placed on the outer surface of the RVACS insulator layer (**TC-RV-06/07/08**), at three different levels along the RVACS active length. The preliminary position of the TCs for the RVACS monitoring is reported in Figure 29 and listed in Table 24.

The air flow rate through the RVACS will be measured by means of an anemometer installed upstream the RVACS inlet section.

Table 24 – Thermocouples installed on RVACS

N°	ID	Description	Measurement Position	Ref.
1	**TC-RV-01**	Temperature of the air at the RVACS inlet section	----	Figure 29 Figure 30
2	**TC-RV-02**	Temperature of the air at the RVACS outlet section	----	Figure 29 Figure 30

N°	ID	Description	Measurement Position	Ref.
3	**TC-RV-03**	Temperature on the outer wall of S100	y= -100 mm (from level 0.0 in Figure 29)	Figure 29 Figure 30
4	**TC-RV-04**	Temperature on the outer wall of S100	y= -1100 mm (from level 0.0 in Figure 29)	Figure 29 Figure 30
5	**TC-RV-05**	Temperature on the outer wall of S100	y= -2100 mm (from level 0.0 in Figure 29)	Figure 29 Figure 30
6	**TC-RV-06**	Temperature on the outer wall of RVACS insulator layer	y= -100 mm (from level 0.0 in Figure 29)	Figure 29 Figure 30
7	**TC-RV-07**	Temperature on the outer wall of RVACS insulator layer	y= -1100 mm (from level 0.0 in Figure 29)	Figure 29 Figure 30
8	**TC-RV-08**	Temperature on the outer wall of RVACS insulator layer	y= -2100 mm (from level 0.0 in Figure 29)	Figure 29 Figure 30

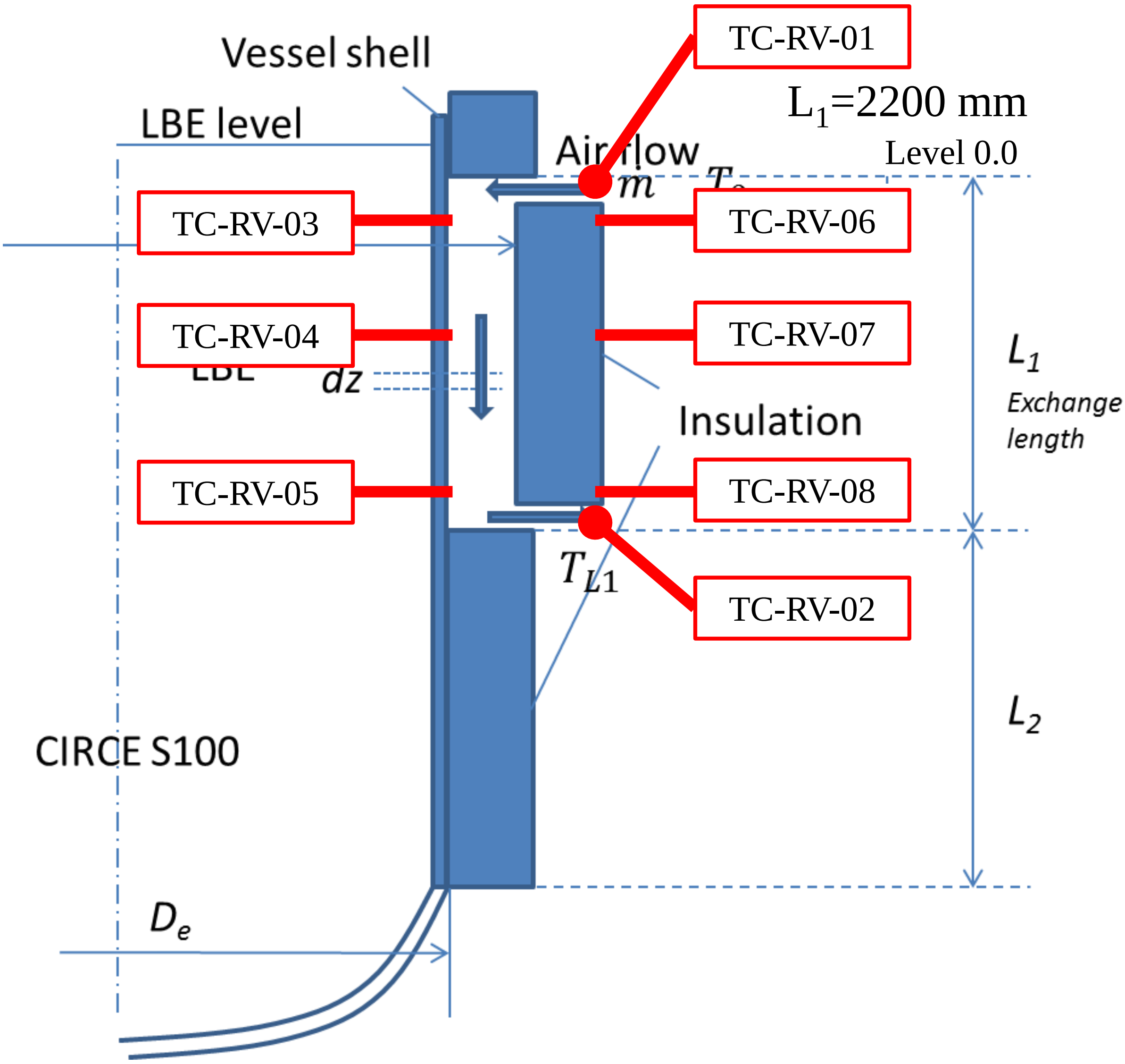

Figure 29 – Thermocouples set on RVACS

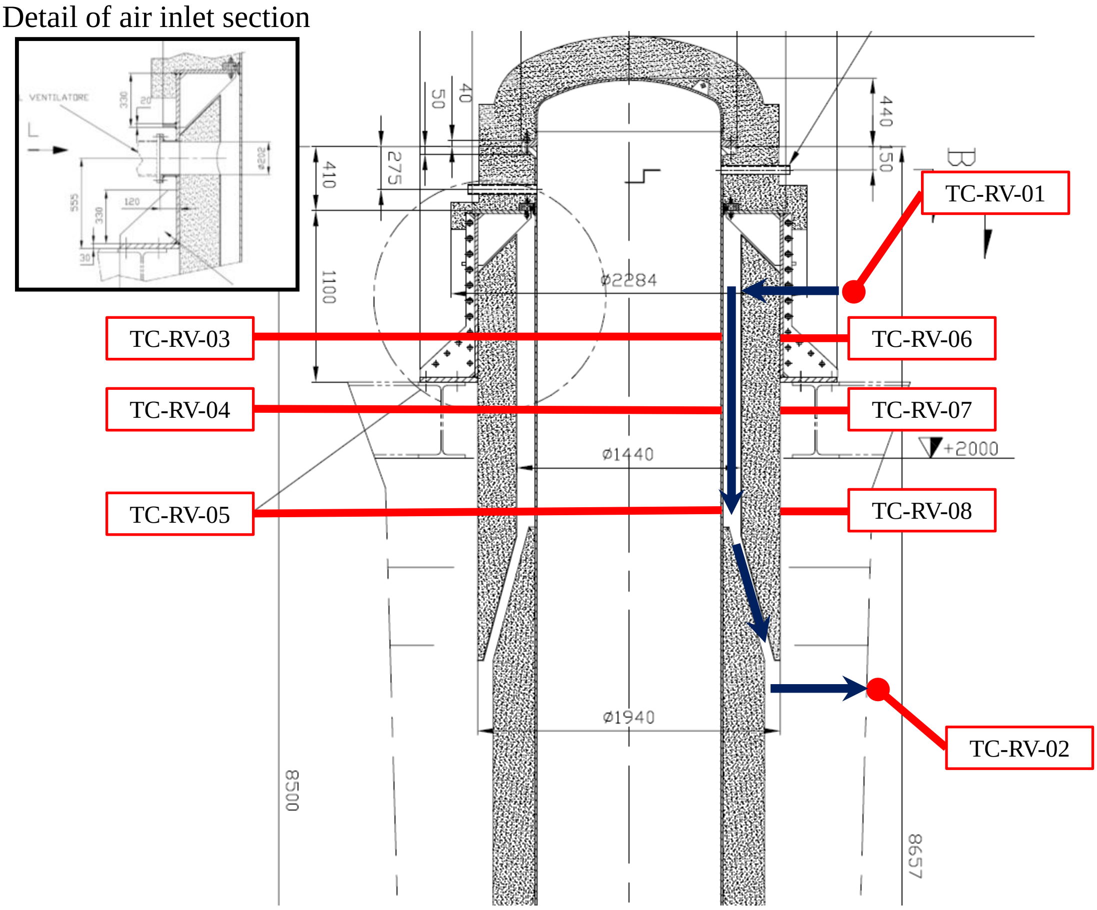

Figure 30 – Detailed view of the RVACS TCs

3.11 Dead volume and FPS tails cooling system

The dead volume will be coupled with an air cooling system dedicated to remove the thermal power produced by Joule effect from the electrical connections (cold tails) of the FPS. The cooling system will be equipped with a total of 8 TCs (*N*-type, 3 mm diameter): 2 installed at the air inlet and outlet sections and 6 positioned on the cladding of different cables inside the dead volume (see Table 25). The air flow rate inside the dead volume will be measured by means of an anemometer installed upstream the dead volume inlet section.

Table 25 – Thermocouples installed on the FPS cooling system and inside the dead volume

N°	ID	Description	Measurement Position	Ref.
1	**TC-CL-01**	Temperature of the electrical cable cladding	----	"
2	**TC-CL-02**	Temperature of the electrical cable surface	----	"
3	**TC-CL-03**	Temperature of the electrical cable surface	----	"

N°	ID	Description	Measurement Position	Ref.
4	**TC-CL-04**	Temperature of the electrical cable surface	----	"
5	**TC-CL-05**	Temperature of the electrical cable surface	----	"
6	**TC-CL-06**	Temperature of the electrical cable surface	----	"
7	**TC-CL-07**	Temperature of the air at the FPS cooling system inlet section	----	"
8	**TC-CL-08**	Temperature of the air at the FPS cooling system outlet section	----	"

3.12 Miscellaneous signals

Derived quantities are summarized in Table 26: the pin wall temperature at about TAF level (**tpin**, computed on the basis of Nusselt number provided by Ushakov 1977correlation, power given from FPS to LBE (**Q-FPS**), power lost by LBE and acquired by water through HCSG (**Q-SG-LBE** and **Q-SG-H_2O**, respectively), LBE mass flow rate computed on the basis of **DP-Ven** signal (**Mm(LBE)**) and of power and temperature increase through the FPS, **Mm(LBE,HS)**.

Table 26 – Miscellaneous signals

ID	Description	Measurement Position	Measuring range	Ref.	Notes
Time	Acquisition time	---	---	---	
Tpin	Computed pin wall temperature	FPS outlet section, based on Nusselt by Ushakov eq. 10.104	---	---	
Mm(LBE)	LBE mass flow rate	Based on Venturi flow meter signal DP-Ven	---	"	
Q-FPS	Power supplied from FPS to LBE	Derived value, computed as $f(\dot{m}, Cp, \Delta T)_{LBE}$	---	"	
Q-SG-LBE	Power lost by LBE through SGBT	Derived value, computed as $f(\dot{m}, Cp, \Delta T)_{LBE}$	---	"	
Mm(LBE,HS)	LBE mass flow rate	Derived value, computed as $\dot{m}$=Power/($Cp \cdot \Delta T_{FPS}$)	---	"	

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4 CONCLUSIONS

The present document describes the instrumentation to be installed on the primary system of the new test section foreseen for the CIRCE facility. The main components of the test section (FPS, fitting volume, pump, separator, HCSG) and the main vessel are instrumented in order to monitor with accuracy the main phenomena intended to be reproduced during the experimental campaigns The primary system instrumentation consists of:

- 223 thermocouples with the following distribution:
    - 32 TCs in the FPS;
    - 5 TCs in the FV;
    - 16 TCs in the riser-pump;
    - 41 TCs in the HCSG
    - 80 TCs in the S100 pool;
    - 1 TC in the S100 cover gas;
    - 32 TCs on the outer wall of the S100;
    - 8 TCs inside the RVACS;
    - 8 TCs in the dead volume and FPS tails cooling system;
- 11 bubble tubes installed along the test section and inside the main vessel;
- 1 Venturi flow meter installed on the feeding conduit;
- 2 oxygen sensors (one in the separator, one in the main pool);
- 2 anemometers installed on the RVACS and FPS tails cooling system, respectively.

For each instrument, the main data are reported, as well as the position for the installation on the corresponding component has been identified.

The instrumentation reported in this document can be subjected to minor modifications and improvements, coherently with the needs arising from the design activity.

REFERENCES

[1] A. Pesetti, N. Forgione, V. Narcisi, P. Lorusso, F. Giannetti, M. Tarantino, A. Del Nevo ENEA CIRCE-HERO Test Facility: Geometry And Instrumentation Description CI-I-R-343, ENEA report, June, 22, 2018.

[2] M. Tarantino, PRIMARY PUMP per impianto sperimentale a metallo liquido pesante CIRCE, CI-D-S-355, ENEA report, October, 11, 2018.

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APPENDIX 1

Pump data sheets

I N S T R U C T I O N S

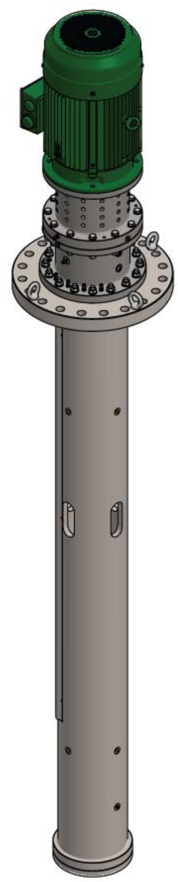
FOR THE INSTALLATION, OPERATION AND MAINTENANCE

OF

G R E E N P U M P S

CIRCE

LBE CENTRIFUGAL VERTICAL PUMP



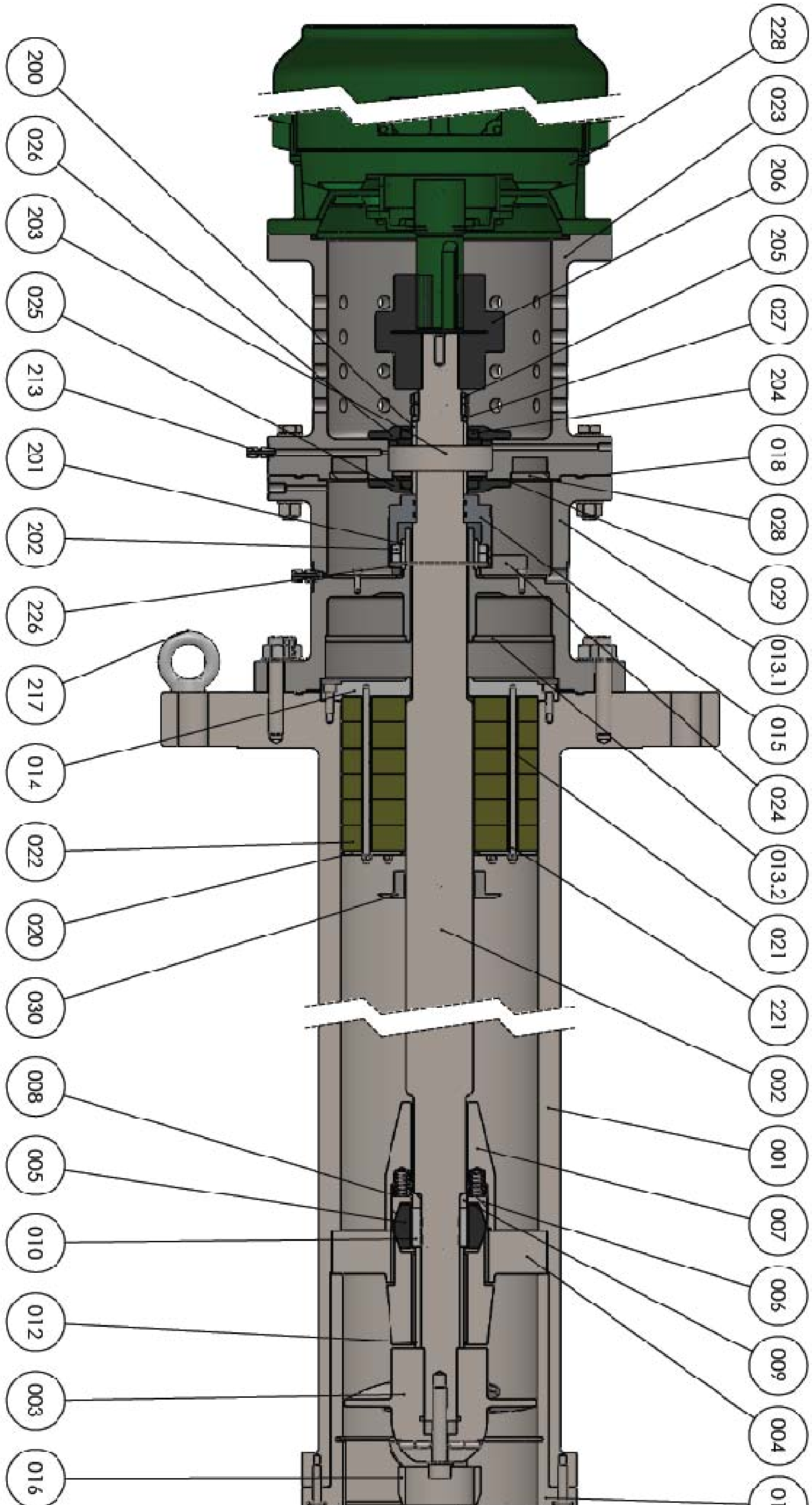
To obtain the best performance from your GREENPUMPS pump, please read these instructions carefully. Failure to observe the recommended procedures may result in damage to your GREENPUMPS pump, and may also invalidate the supplier's guarantee.

GREENPUMPS
MAG - DRIVE SEAL- LESS PUMPS

INDEX

GREENPUMPS
MAG - DRIVE SEAL- LESS PUMPS

PUMP SECTION VIEW AND PART LIST



ITEM n°	CODE	DESCRIPTION	Quantità	MATERIAL
1	CIRCE001	VERTICAL MODULE	1	AISI 304
2	CIRCE002	SHAFT	1	AISI 316 Ti
3	CIRCE003	IMPELLER	1	CF8M
4	CIRCE004	IMPELLER PCARBON BEARING HOLDER	1	AISI 304
5	CIRCE005	PCARBON BEARING FOR MCA 3'R	1	GRAPHITE
6	CIRCE006	IMPELLER PCARBON BEARING REAR THRUST RING	1	AISI 304
7	CIRCE007	IMPELLER PCARBON BEARING FRONT THRUST RING	1	AISI 304
8	CIRCE008	PCARBON BEARING SPRING	6	AISI 304
9	CIRCE009	SLEEVE BEARING SPACER	1	AISI 304
10	CIRCE010	STD- MCA 3'R SLEEVE BEARING	1	SILICON CARBIDE
11	CIRCE011	IMPELLER WEAR RING	1	AISI 304
12	CIRCE012	IMPELLER SPACER	1	AISI 304
13,01	CIRCE013.01	SEAL FRAME	1	AISI 304
13,02	CIRCE013.02	SEAL FRAME WELDED COVER	1	AISI 304
14	CIRCE014	MIDDLE FLANGE	1	AISI 304
15	CIRCE015	OIL SEAL RING	1	AISI 304
16	CIRCE016	DIFFUSER	1	AISI 304
16,01	CIRCE016.1	DIFFUSER PART01	1	AISI 316
16,02	CIRCE016.02	DIFFUSER PART02	4	AISI 316
18	CIRCE018	STD - MCA 2'R XX - 315 GASKET	2	GRAPHITE
19	CIRCE019	THERMO PROBE CONNECTION	6	AISI 304
20	CIRCE020	HEAT SHIELD PLATE	1	AISI 304
21	CIRCE021	HEAT SHIELD SPACER	8	AISI 304
22	CIRCE022	HEAT SHIELD	6	THERMAL INSULATING
23	CIRCE023	BALL BEARINGS SUPPORT	1	Fe
24	CIRCE024	LUBRICATING OIL SHEET	1	AISI 304
25	CIRCE025	BALL BEARINGS BOTTOM COVER	1	Fe
26	CIRCE026	BALL BEARINGS UPPER COVER	1	Fe
27	CIRCE027	WASHER	1	AISI 304
28	CIRCE028	BEARING FRAME WELDED COVER	1	Fe
29	CIRCE029	BALL BEARING COVER GASKET	2	NA1100
30	CIRCE030	SEAL RING	1	AISI 304
31	CIRCE031	OMEGA	1	AISI 304 / 316
200	CIRCE200	LIP SEAL WEAR RING IR 55x65x28	2	CARBON STEEL
201	CIRCE201	LIP SEAL WEAR RING IR 80x90x35	1	CARBON STEEL
202	CIRCE202	PTFE LIP SEAL 90x110x10	2	PTFE
203	CIRCE203	ANGULAR CONTACT BALL BEARING SKF QJ311N2MA	1	CARBON STEEL
203	GPCLEARM 203	WASHER M16	25	AISI 304
204	CIRCE204	VITON LIP SEAL 65x90x10	2	VITON
205	CIRCE205	FERRULE - KM10 SELF - LOCKING	2	Fe
206	CIRCE206	ELASTIC JOINT RU - STEEL A51	1	Fe
208	CIRCE208	TCEI M16x90	1	AISI 304
209	CIRCE209	TCEI M10x45	12	AISI 304
210	CIRCE210	CURVED SPRING LOCK WASHER M10	12	AISI 304
211	CIRCE211	TCEI M8x16	4	AISI 304
212	CIRCE212	SOCKET SET SCREW CONE POINT M8x20	4	AISI 304
213	CIRCE213	SS_3M0_1_2_BT	8	AISI 316
214	CIRCE214	THREADED BAR M18	16	AISI 304
215	CIRCE215	WASHER M18	16	AISI 304
216	CIRCE216	NUT M18	16	AISI 304
217	CIRCE217	EYEBOLT M20	4	CARBON STEEL
218	CIRCE218	OIL LEVEL CAP	1	AISI 304
219	CIRCE219	TE M16x100	12	AISI 304
220	CIRCE220	NUT M16	12	AISI 304
221	CIRCE221	THREADED BAR M6	8	AISI 304
222	CIRCE222	SPRING LOCK WASHER M6	12	AISI 304
223	CIRCE223	NUT M6	8	AISI 304
224	CIRCE224	TCEI M8x25	8	AISI 304
225	CIRCE225	TCEI M6x16	4	AISI 204
226	CIRCE226	CIRCLIP DIN 472 D.110	1	AISI 304
227	CIRCE227	WASHER M8	2	AISI 304
228	CIRCE228	MOTOR 4P 30kW IEC 200 B5 400/3/50	1	
		HYDRAULIC POWER UNIT	1	
110	CIRCE110	CIRCE110 SPECIAL TOOL	1	
111	CIRCE111	CIRCE111 SPEACIAL TOOL 01	1	
112	CIRCE112	CIRCE 112 SPECIAL TOOL 02 (PP)	1	

The pump is provided with:

- Hydraulic power unit
- Oil pipes
- Special tools
- Thermocouples

THIS INSTRUCTION MANUAL is intended to guide those responsible for the installation, operation and maintenance of GREENPUMPS CIRCE pump. Please read it carefully, before you install and operate your GREENPUMPS pump.

1. ON RECEIVING YOUR PUMP

1.1 Prior to unpacking, check for physical damage to the packing and the pump unit and notify the forwarding agent **IMMEDIATELY** if any damage is found.

1.2 Check the nameplate on the pump against the purchase order documents to be sure that the correct size of pump and materials of construction have been supplied. If a motor has been supplied, check that the power, speed, and voltage are correct.

1.3 When shipped, the pumps are suitable for short term storage only. If long term storage is necessary before the pump will be put into operation, we suggest to contact your pump supplier for long term storage recommendations.

2. INSERT THE PUMP IN THE VESSEL

Before to place the pump in the vessel, check that suction and discharge ports are clean and without any foreign objects.

2.1 With the help of a proper lifting device, assure the pump at the lifting lugs located on the main flange.

NEVER USE THE MOTOR OR OTHER COMPONENTS TO LIFT-UP THE PUMP

2.2 Place the gasket on the vessel main flange.

2.3 Gently lower the pump inside the vessel flange, assuring that main flange holes are aligned with vessel flange holes.

PAY ATTENTION TO THE THERMOCOUPLES CONNECTED TO THE PUMP

2.4 When pump is positioned on the vessel flange, suction must be located in the proper seat on the vessel bottom.

2.5 Tight all the bolts and properly fix the pump to the vessel flange.

3. AUXILIARIES CONNECTIONS

Auxiliaries system are:

- Hydraulic power unit
- Cover gas leakage flowmeter (R01)

Connect all the auxiliaries systems with the connections specified here below.

ALL CONNECTION PIPINGS AND NOZZLE ARE SUPPLIED WITH PUMP AND HYDRAULIC POWER UNITS

IMPORTANT NOTE:

NEVER BEND THE POWER UNITS PIPES, THEY CAN BE SEVERALLY DAMAGED
PLEASE KEEP WIDE CURVES

3.1 Hydraulic power unit

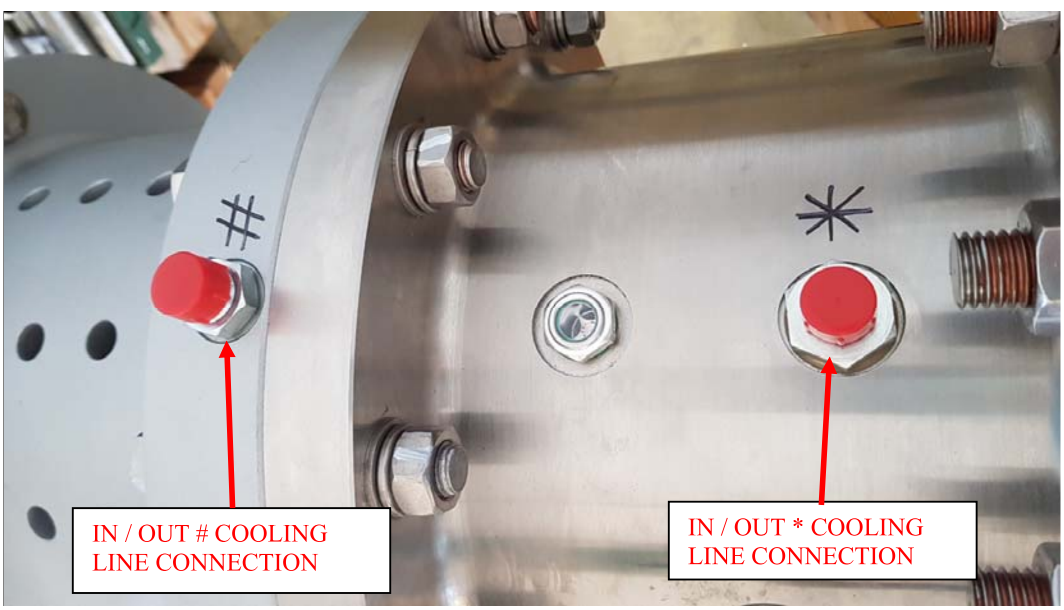
3.1.1 Pump Side

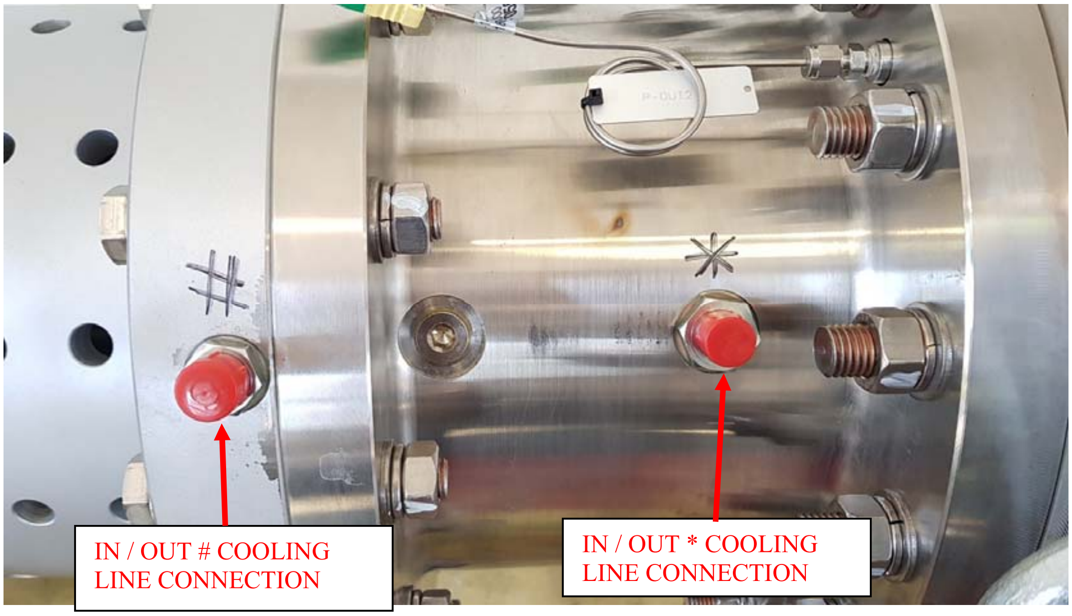
Assemble the quick connections on the pump.

- Inlet connection: n° 1 # cooling line quick connection
- Outlet connections: n° 1 # cooling line quick connections

- Inlet connection: n° 1 * cooling line quick connection
- Outlet connections: n° 1 * cooling line quick connections

See below picture for details





Connect the oil pipe to the cooling connection line quick connection.

Note: oil pipe IN/OUT are interchangeable on pump side

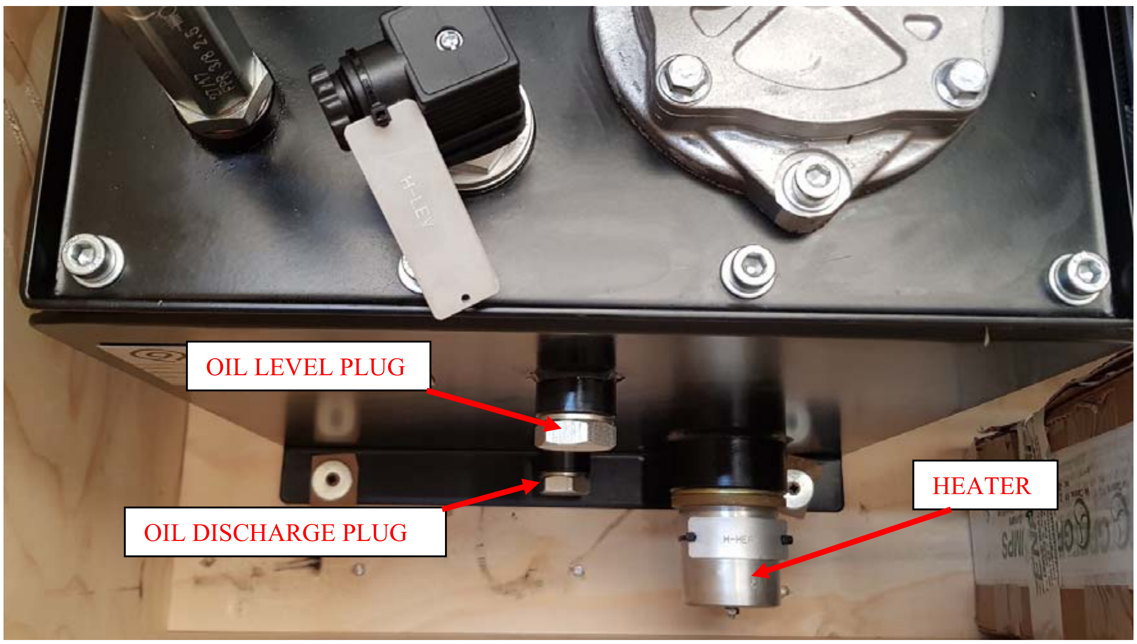
3.1.2 Hydraulic power unit side

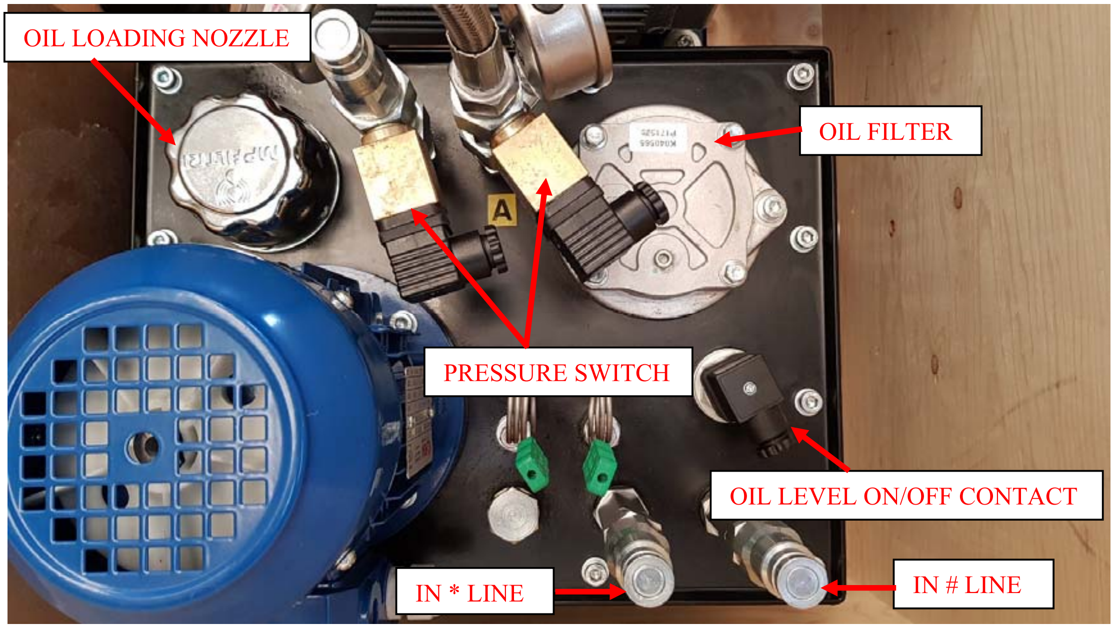
Fill the hydraulic power unit with:

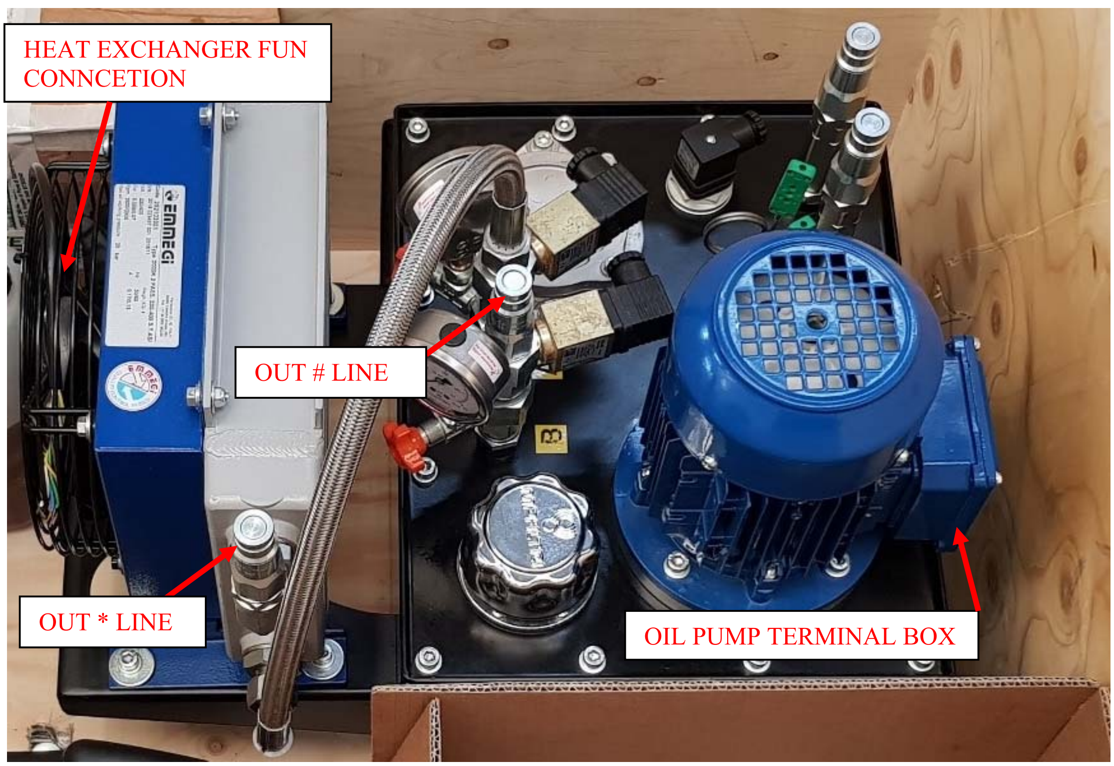
Approximately n°25 Liters of 5W40 Oil (Automotive Oil)

Unscrew the ''oil level plug''. (See picture below)

Fill the oil from ''Oil loading nozzle'' (See picture below) until the oil level reach the ''oil level plug'', than close the plug.







Connect the oil pipe to the cooling connection line quick connection.

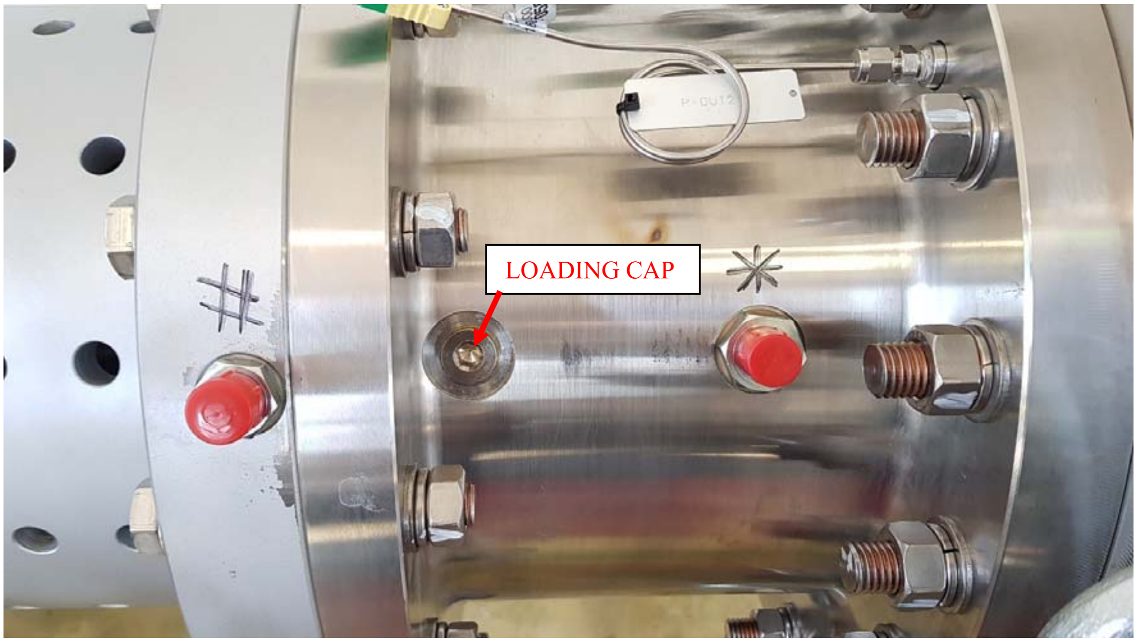
- Inlet connection: n° 1 # cooling line quick connection
- Outlet connections: n° 1 # cooling line quick connections

- Inlet connection: n° 1 * cooling line quick connection
- Outlet connections: n° 1 * cooling line quick connections

3.2 Oil level pump

Fill the seal frame with oil from the loading cap until it reach the level cap.

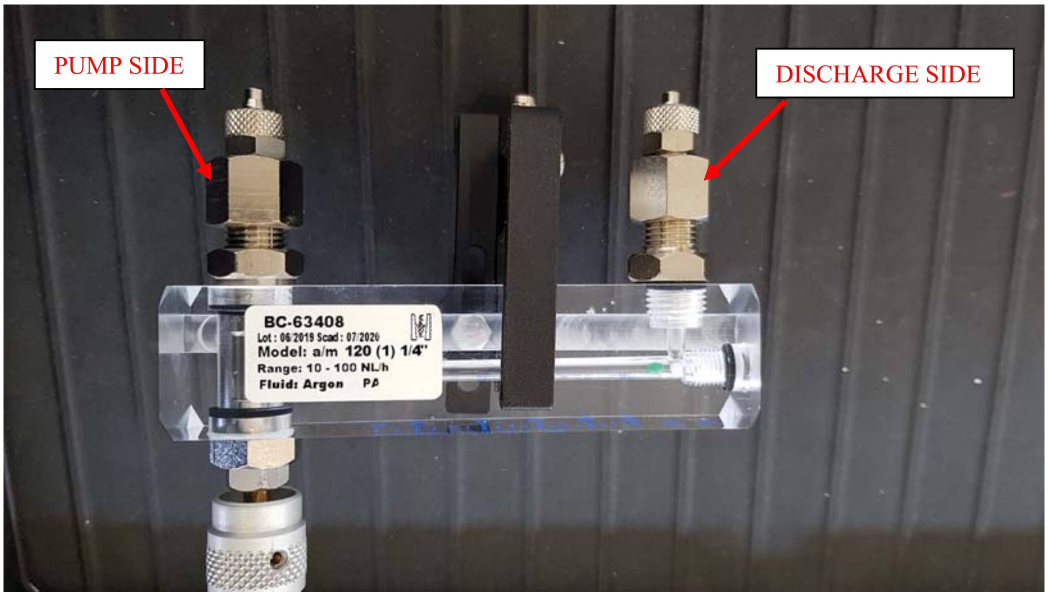
5W40 Oil (Automotive Oil)



Opposite side:

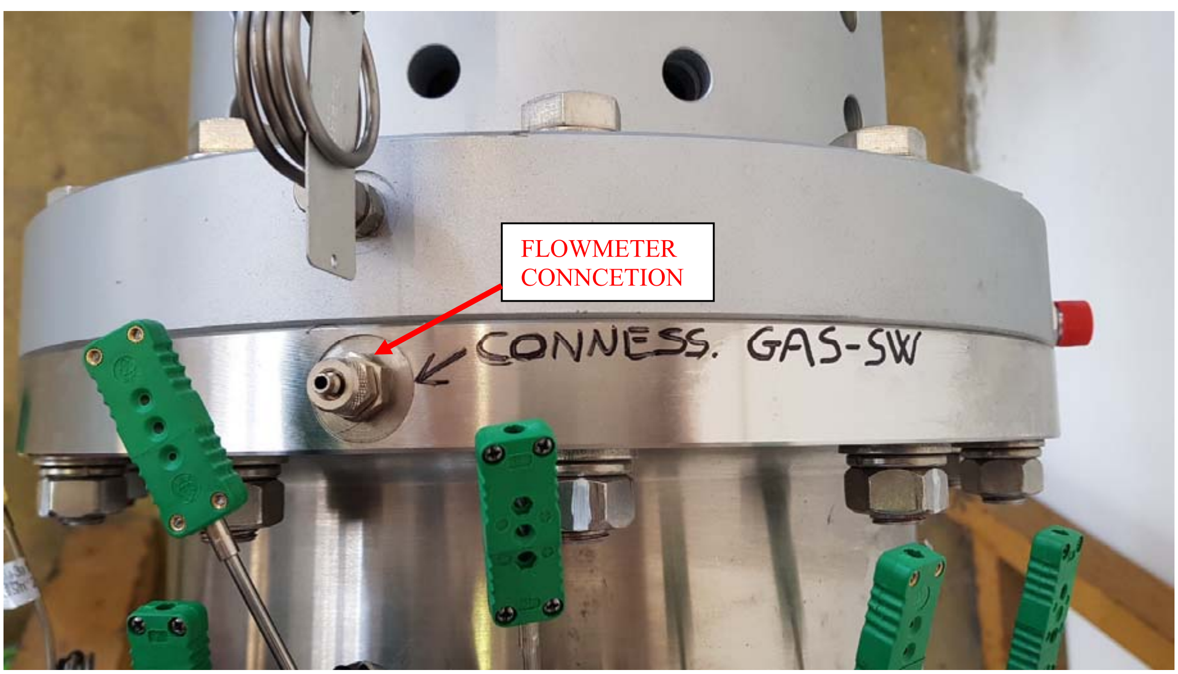
3.3 Mechanical seal flowmeter leakage controller

Connect the mechanical seal flowmeter to the pump as indicated in the below pictures.



Please use a Teflon Ø4x6 pipe supplied with the pump.

After the first week of commissioning, check the flowmeter value and set properly the flowmeter switch (Contact Greenpumps factory for setting value).



ATTENTION: NEVER START-UP THE PUMP WITHOUT ALL THE AUXILIARY SYSTEMS CONNECTED AND PROPERLY OPERATING, SEE THE INSTRUCTION OF EACH SYSTEM.

4. ELECTRICAL CONNECTION SYSTEM

On board LBE pump electrical connection system is composed by:

- LBE pump electrical motor (P-MOTOR) See point 4.1
- LBE pump electrical motor PTC (1 pc) (P-PTC) See supplier manual

Off board LBE pump electrical connection system is composed by:

- Hydraulic power unit motor and instrumentations (See supplier manual).
- Mechanical seal leakage flowmeter switch (See supplier manual).

PUMP MUST BE OPERATED THROUGH AN INVERTER

The electrical connection to the motor should be carried out by a properly qualified electrician, using cable, cable glands and connection procedures suitable for the electrical load and for the location of the installation.

It is the responsibility of the pump user to ensure that a safe electrical installation is made and maintained.

4.1 LBE pump electrical motor P-MOTOR

4.1.1 Isolate the electric supply cable from the power supply.

4.1.2 Bring the cable end into the terminal box through a suitable cable gland.

4.1.3 Follow the motor manufacturer's instructions for electrical connection.

Check that the terminal links are correctly positioned for the supply voltage.

Ensure that the earth connection is properly and securely made.

4.1.4 Before replacing the terminal box lid, check that the sealing surfaces and the gasket or O-ring seal are clean and in good condition.

4.1.5 To confirm the direction of rotation (refer to the rotational arrow on the pump motor) use the following procedure:

Slowly start the motor with inverter, 3/4 Hz for a few second will be ok, look if direction of the motor fun is correct. If the direction of rotation is incorrect, reverse any two of the three-phase power leads to the motor or by inverter.

4.2 Connect all the auxiliary systems

- LBE pump electrical motor PTC (3 pcs)	See supplier manual
- LBE pump TC	See supplier manual
- Hydraulic power unit motor and instrumentations	See supplier manual
- Mechanical seal leakage flowmeter switch	See supplier manual

Please check correct rotation for the hydraulic power unit motor!

5. PREPARATION FOR START-UP

Prior to starting the pump following operations must be done:

5.1 Hydraulic power unit

5.1.1 Switch on the oil heater (H-HEAT) on the Hydraulic power unit tank and wait until the oil reach 15°C (minimum working temperature) (H-OIL1 / H-OIL2).

5.1.2 Switch on the Hydraulic Power Unit pump motor.

5.1.3 Wait until the oil temperature read on H-OIL1 / H-OIL2 reach 20°C than keep this temperature value.

5.1.4 20°C is the temperature of standard pump running that we need always keep and monitoring.

5.1.5 Maximum working temperature 30°C

5.2 Pump and Vessel

5.2.1 Switch on the pump/vessel heater and ensure that pump temperature increase maximum 50°C per hour.

5.2 Fill the pool with LBE

Once points 5.1 and 5.2 are completed and the temperature around the pump is not lower than 300°C, then you can fill the pool with LBE and reach the working temperature.

WARNING! HYDRAULIC POWER UNIT MUST BE ALWAYS SWITCH ON WHEN INTERNAL PUMP TEMPERATURE IS ABOVE 100°C

ATTENTION!!! LBE PUMP MAXIMUM TEMPERATURES ARE THE FOLLOWING:
WORKING 480°C
DESIGN TEMPERATURE 500°C

WARNING! DO NOT RUN THE PUMP DRY

5.3 Check that the liquid supply is at the correct temperature, with any necessary heating/cooling in operation.

6. SHUT DOWN

6.1 Switch off the LBE pump (P-MOTOR)

MAXIMUM DECREASING TEMPERATURE 50°C PER HOUR

6.2 When pump is completely stopped, than make the following actions:

6.2.1 Drain the vessel.

6.2.2 Switch off the hydraulic power unit (H-MOTOR) when the pump temperature achieve 100°C.

7. PUMP OPERATIONS

7.1 Care must be taken to make sure that the sleeve bearing in the pump is replaced in enough time to prevent mechanical rubbing. This condition can be detected by an increase in power consumption and loss of pump performance. In addition the pump may vibrate or operate noisily.

7.2 Follow the motor manufacturer's recommendations and keep the motor bearings maintained and greased.

7.3 Mechanical seal need to be replaced when the consumption of flushing gas increase from the usual value.

7.4 GREENPUMPS pumps are dynamically balanced during manufacture and are tested prior to dispatch to ensure that they run smoothly and without vibration. Replacement impellers are also balanced prior to dispatch.

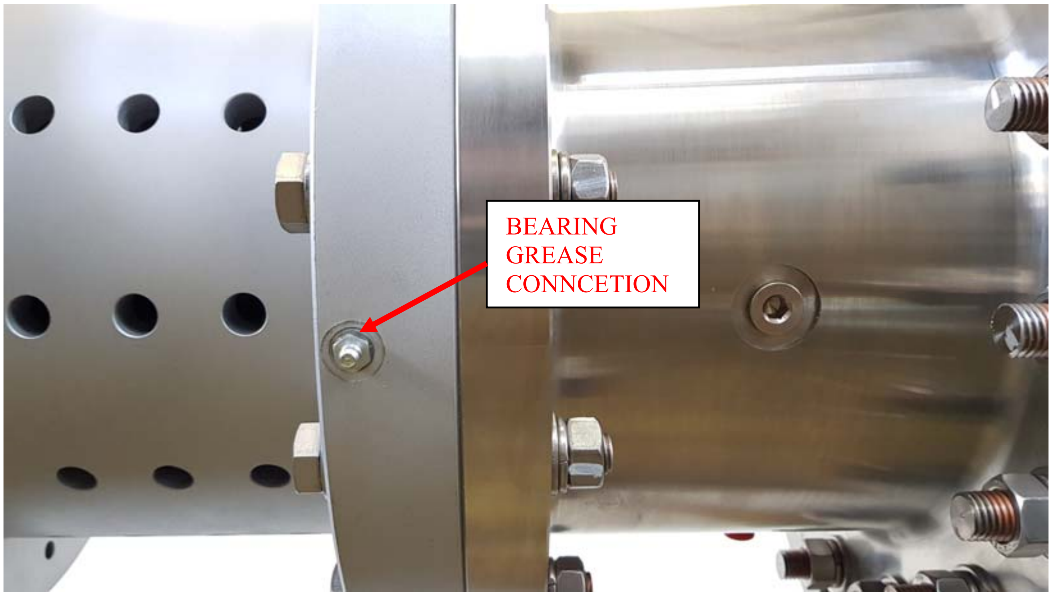
7.5 Temperature sensors are fitted to the pump, check regularly to ensure that it is working properly.

8. MAINTENANCE SCHEDULE

Provided the pumped liquid is clean and free of suspended solids, and the pump is operated within the manufacturer's stated performance limits and is not allowed to run dry.

Parts to be inspected	Action to be taken	Frequency
Pure carbon stationary bearing	Check stationary bearing for wear.	Every time pump will be opened.
Pump bearing (see pag. below)	Grease the bearing	Every 300 hours
Motor bearings	Follow the motor manufacturer's recommendations and keep the motor bearings maintained.	Follow the motor manufacturer's recommendations.
O-Rings and Lipseal	Change all the O-Ring and Lipseal.	Every time pump will be opened.
Mechanical Seal	Replace or recovery.	In case of failure or when leakage are excessive.
Impeller	Check impeller clearance. (See specific drawing)	Every time pump will be opened or in case pump will not reach flow and/or head.
Mechanical Seal Oil Level (see 3.2)	Verify oil level when pump is shut down	Every 300 hours

Complete inspection after the first 5000 hours !


BEARING
GREASE
CONNCETION

9. DECOMMISSIONING THE PUMP

9.1 Check that the pump has been fully drained and flushed out, before you start work on it.

9.2 Check that pump is at ambient temperature.

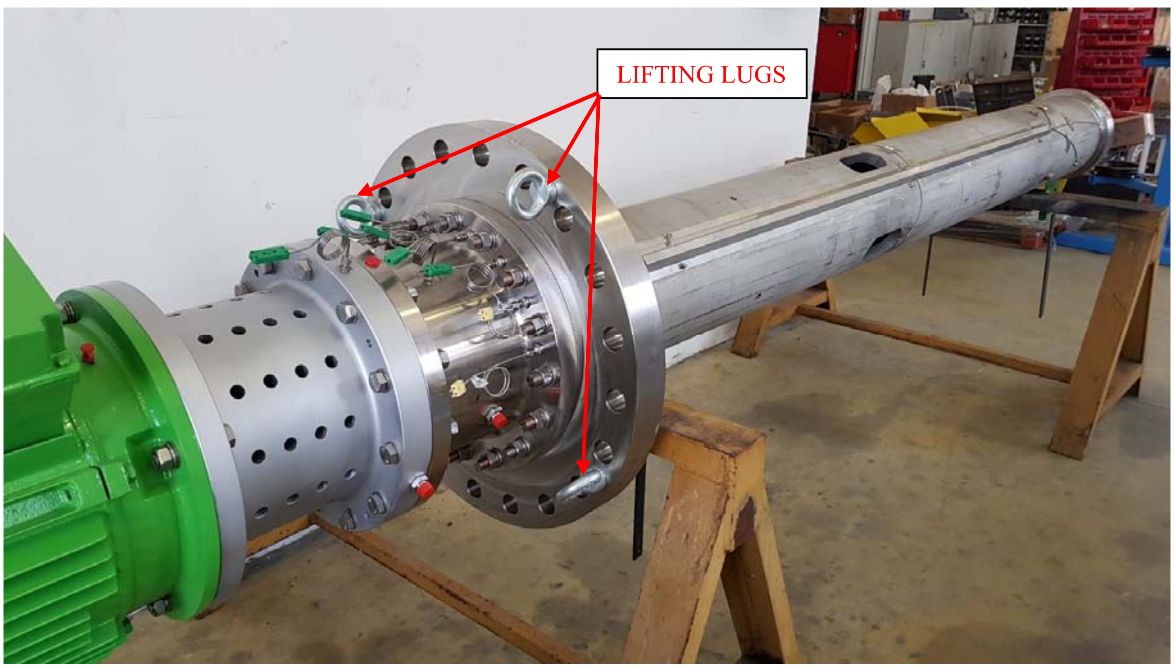
9.3 Isolate the motor from its electrical supply.

9.4 Isolate the pump from the rest of the hydraulic system. Isolate and disconnect any auxiliary pipework or electrical connection from the pump.

9.5 Unscrew the main flange bolts.

9.6 With the help of a proper lifting device remove the pump using the lifting lugs located on the main flange.

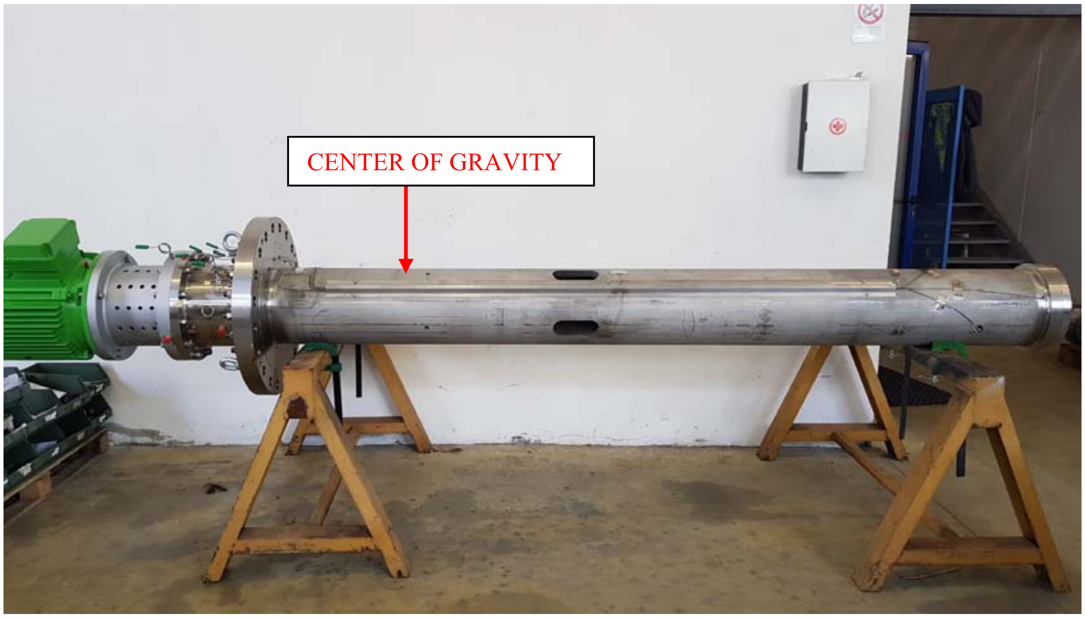
PAY ATTENTION TO THE THERMOCOUPLES CONNECTED TO THE PUMP



NEVER USE THE MOTOR OR OTHER COMPONENTS TO LIFT-UP THE PUMP

9.7 Remove the gasket on the vessel main flange.

After pump is removed from the vessel, need to be placed in horizontal position on proper support and keep it held in order to avoid rotation, shifting or falling.



While you are dismounting the pump, take present that center of gravity change.

Pay attention that once pump is horizontally, a small quantity of oil will drop out from the cooling jacket oil chamber.
A small quantity of oil could also leak from the piping on nozzles.

It is the pump user's responsibility to ensure that the pump is in a safe condition before it is opened or worked on. If the pump is removed and stored, or returned to its supplier or to a third party for repair or overhaul, it must be clearly LABELLED, stating what substances or residues it may contain, warning the recipient of any possible hazard to health.

10. DISASSEMBLING THE PUMP

These operations should be carried out only by skilled personnel. Damage caused by careless or improper disassembly or reassembly is excluded from the supplier's guarantee.

WORK IN A CLEAN AREA!

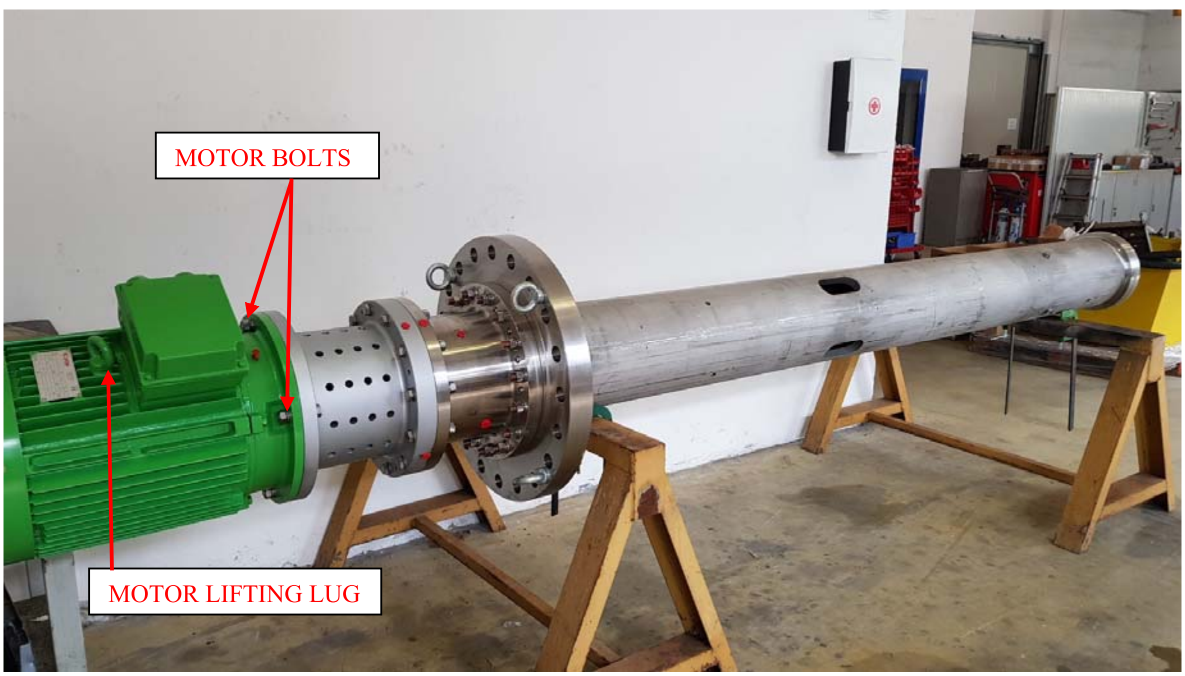
DO NOT USE FORCE!

The pump should be taken apart with the help of the labeled sectional drawing(s) supplied with it.

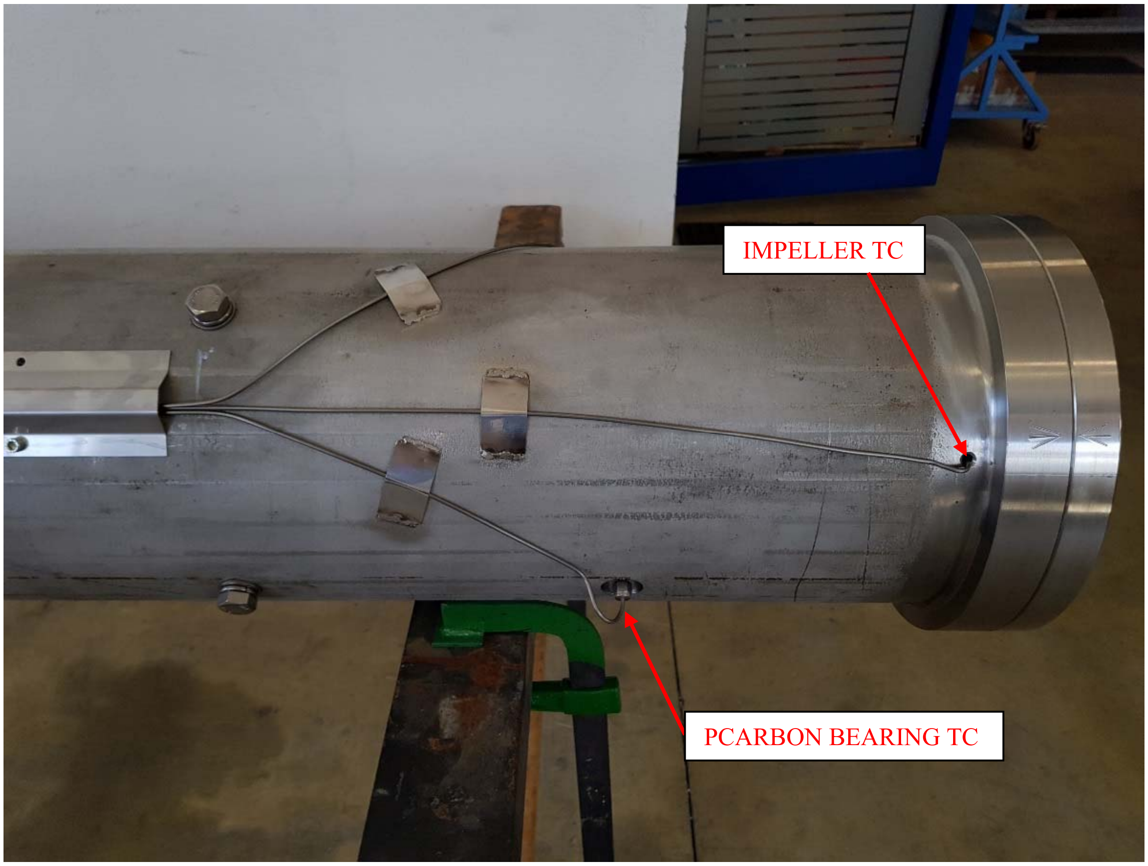
10.1 Pump Assembly

10.1.1 Remove all the auxiliary connections.

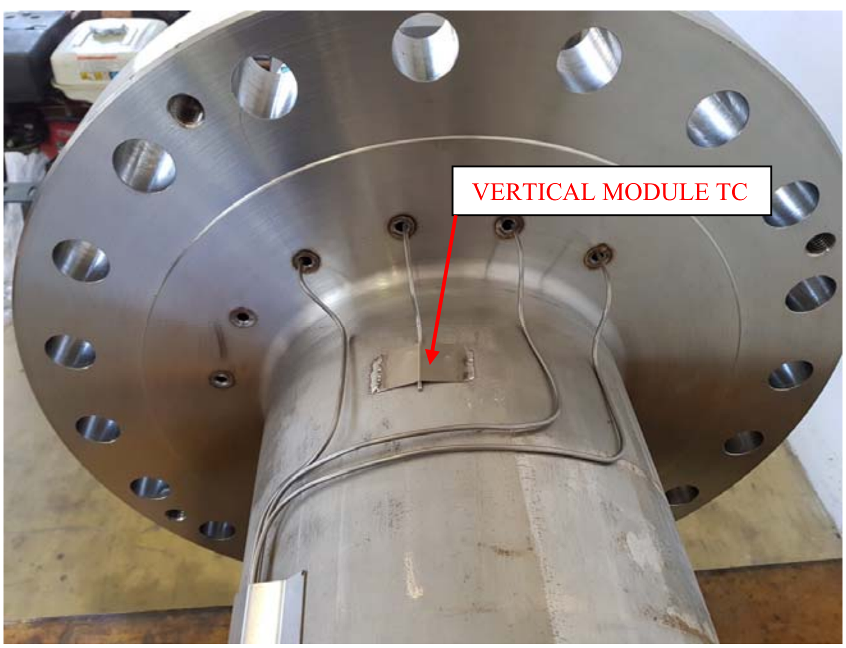
10.1.2 Unscrew the bolts that connect the motor to the ball bearing support. Then shift the motor using its lifting lugs.

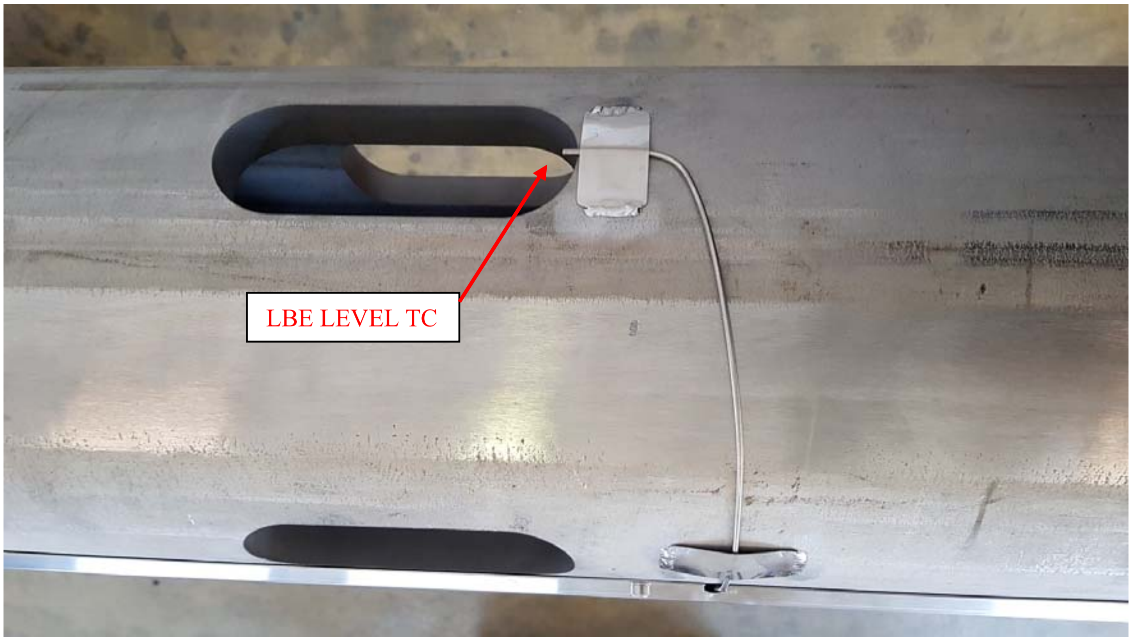


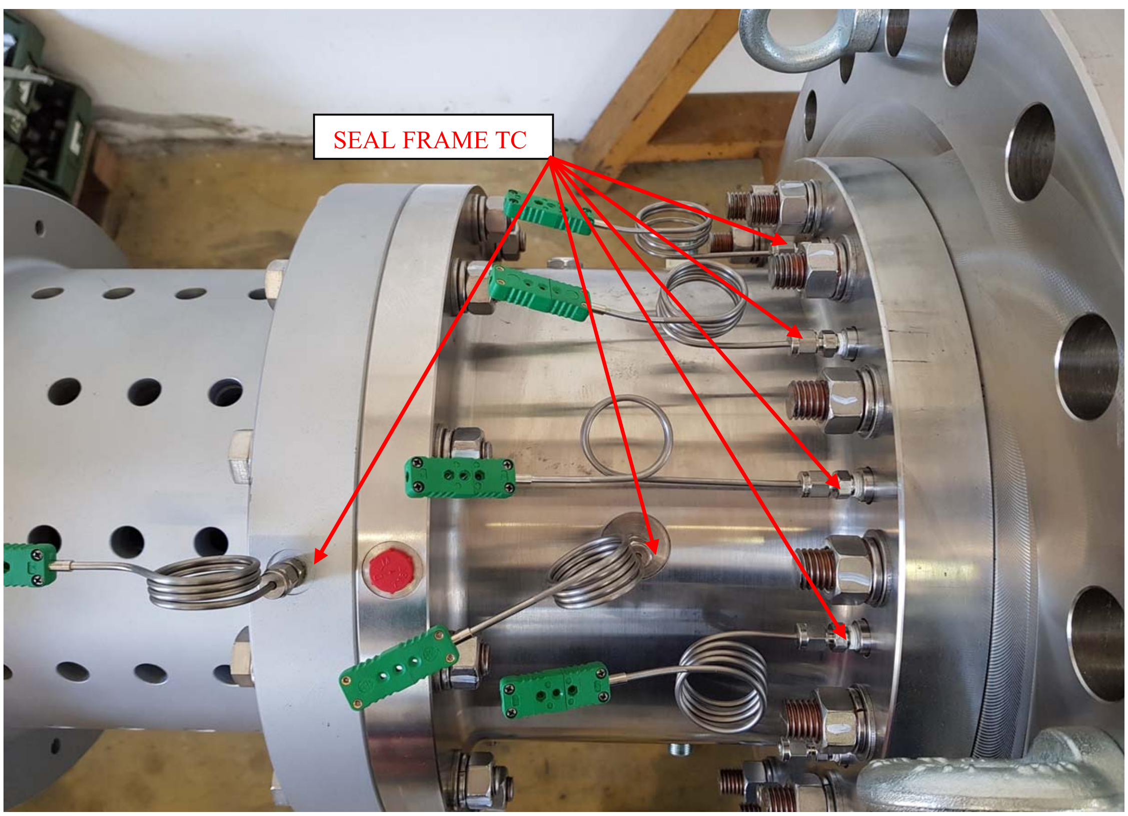
10.1.3 Remove PCarbon bearing TC and impeller TC



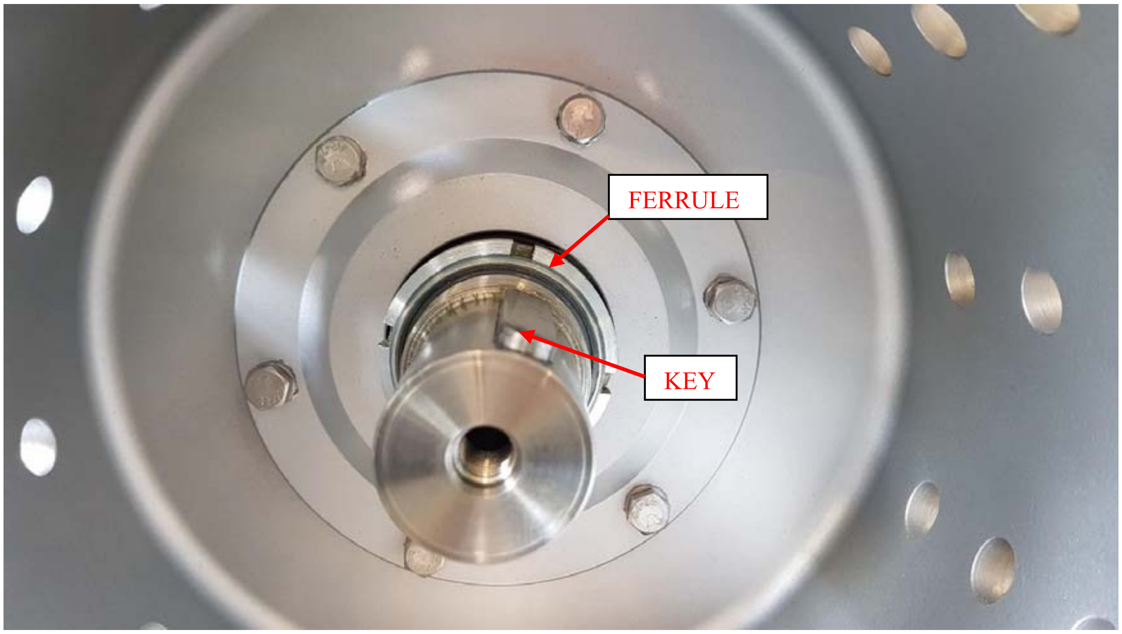
10.1.4 Remove vertical module TC, LBE level TC and seal frame TC.



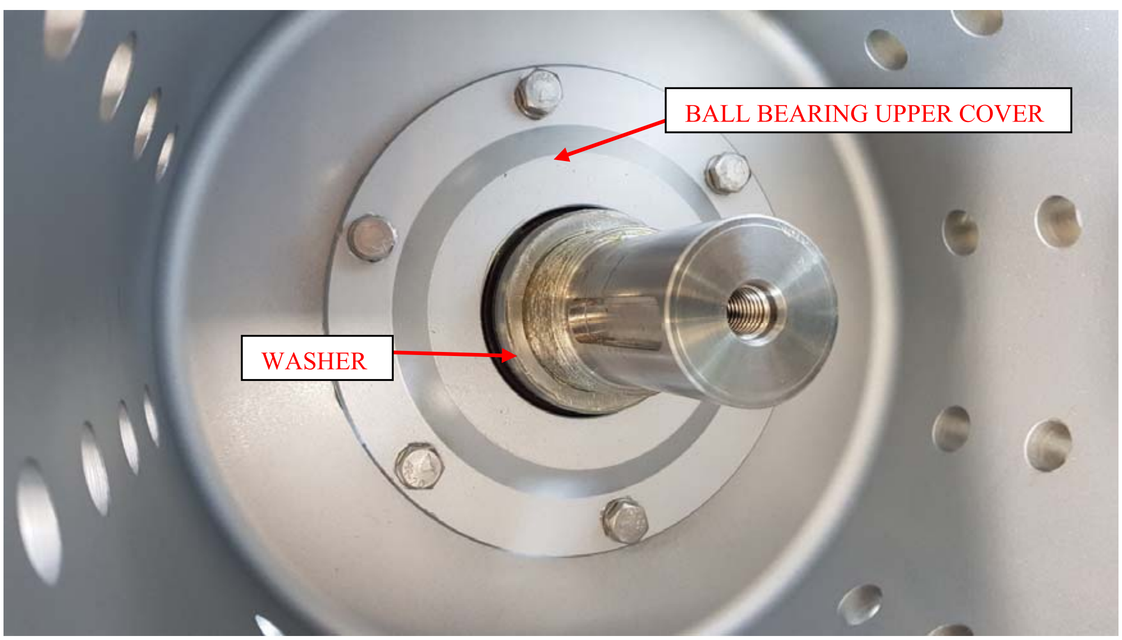

LBE LEVEL TC


SEAL FRAME TC

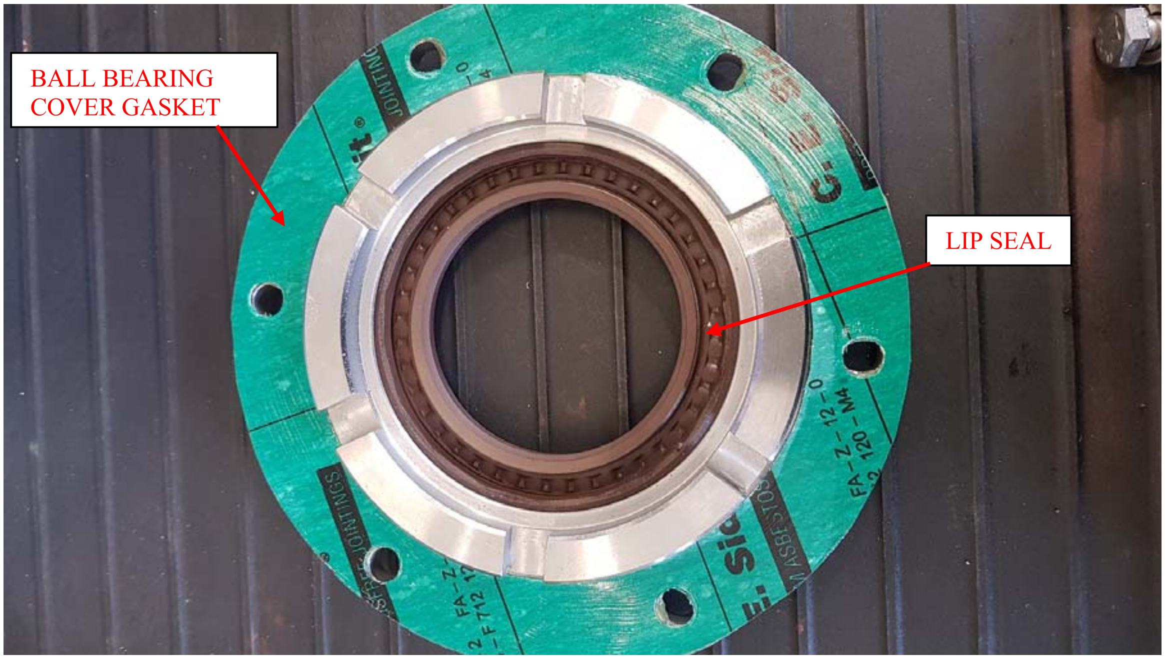
10.1.5 From ball bearing support (023) side remove the key and unscrew the ferrule (205)



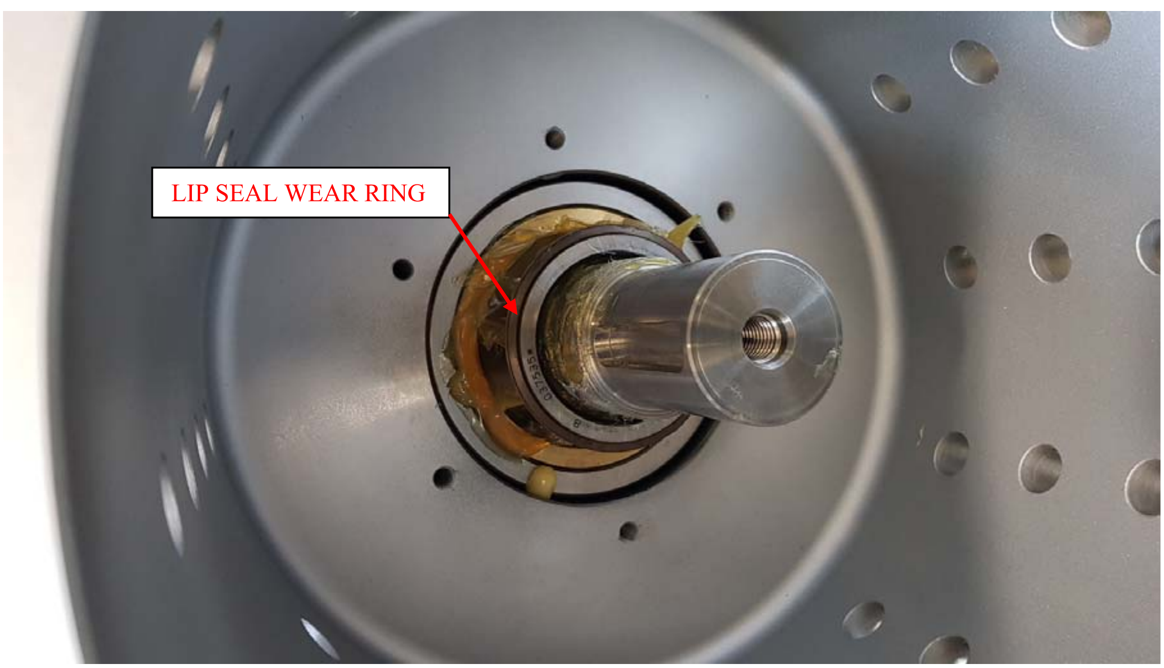
10.1.6 Remove the washer (027) and unscrew ball bearing upper cover (026) bolts



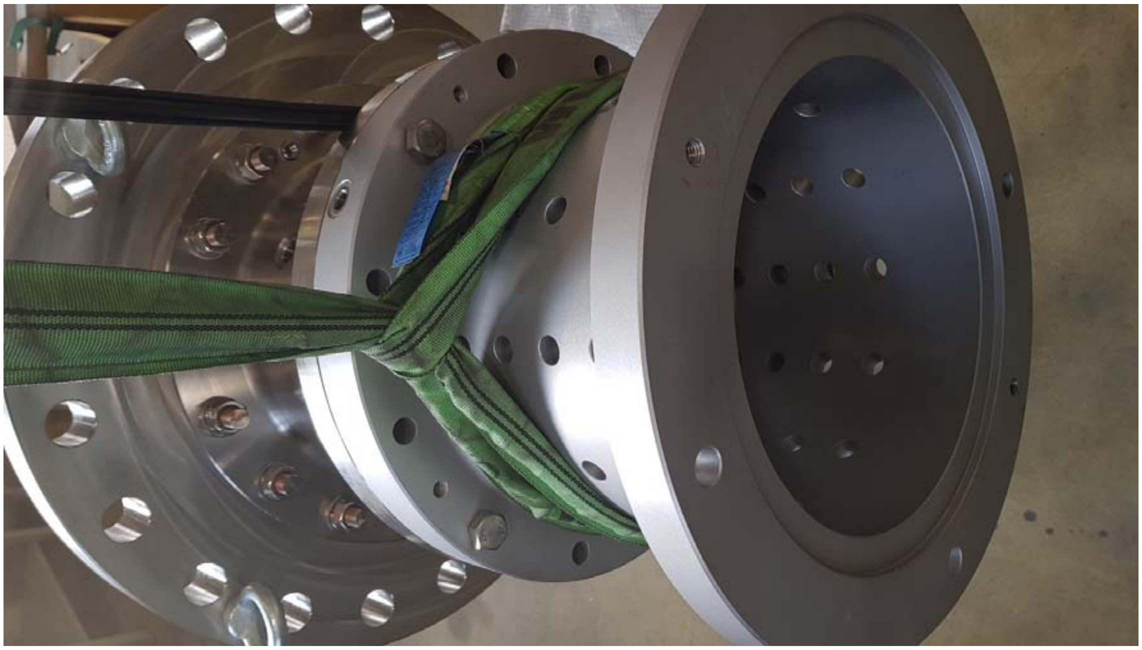
10.1.7 Shift the ball bearing upper cover (026)



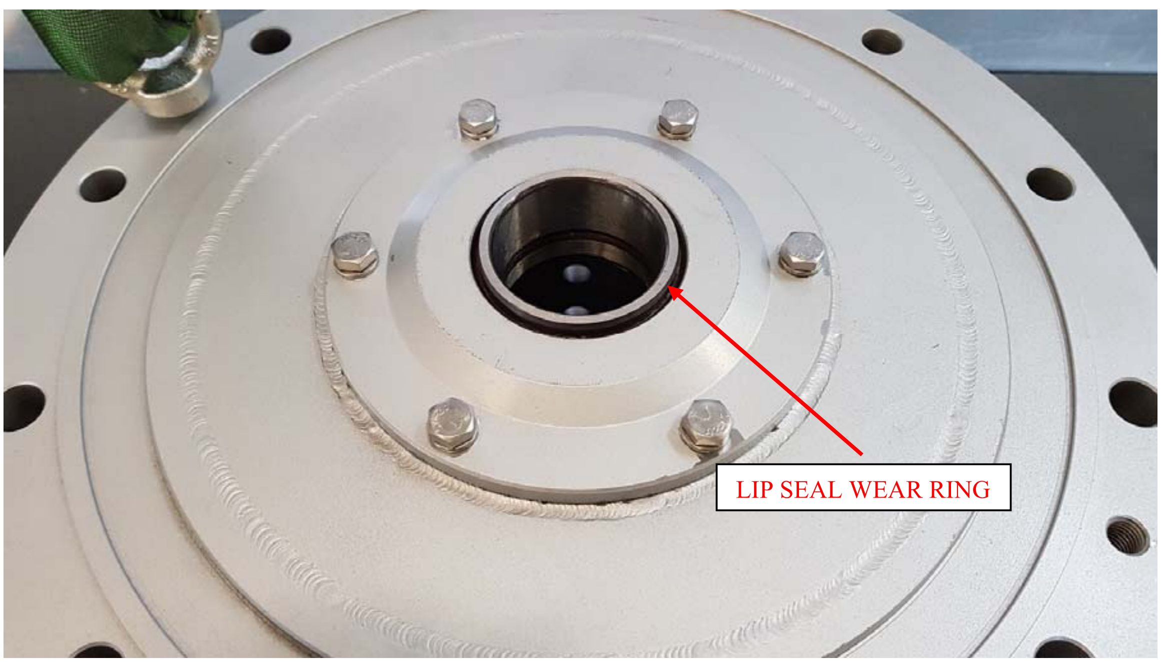
10.1.8 Remove lip seal wear ring (200)



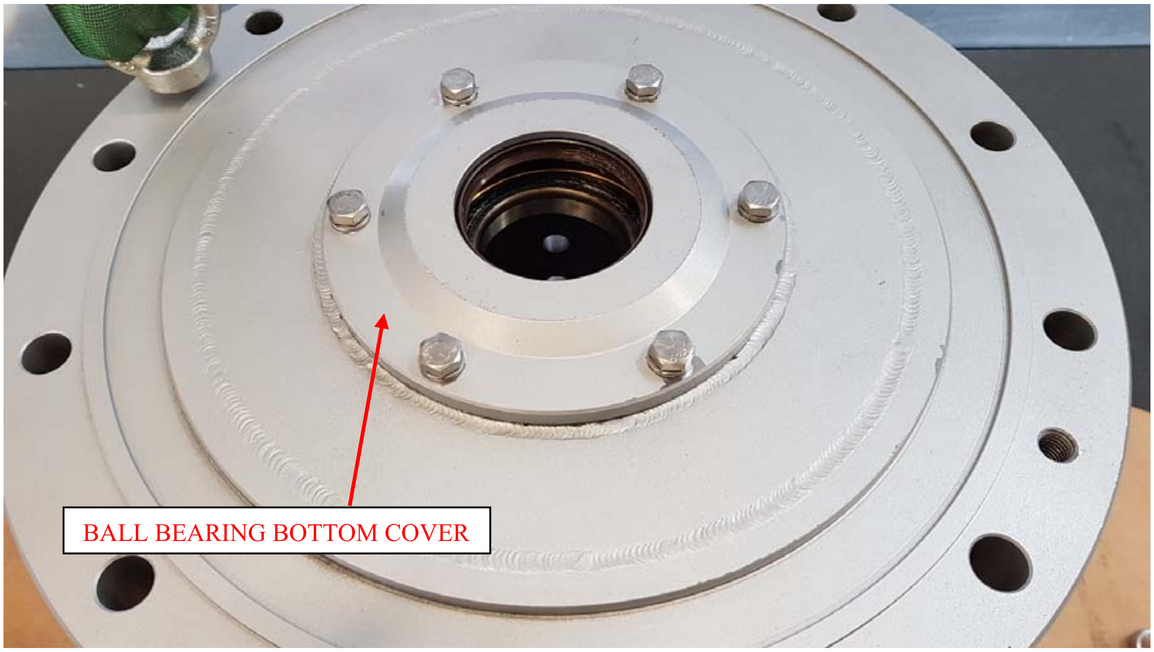
10.1.9 With the help of a belt unscrew the ball bearing support bolts and remove ball bearing support (023)



10.1.10 Remove lip seal wear ring (200)

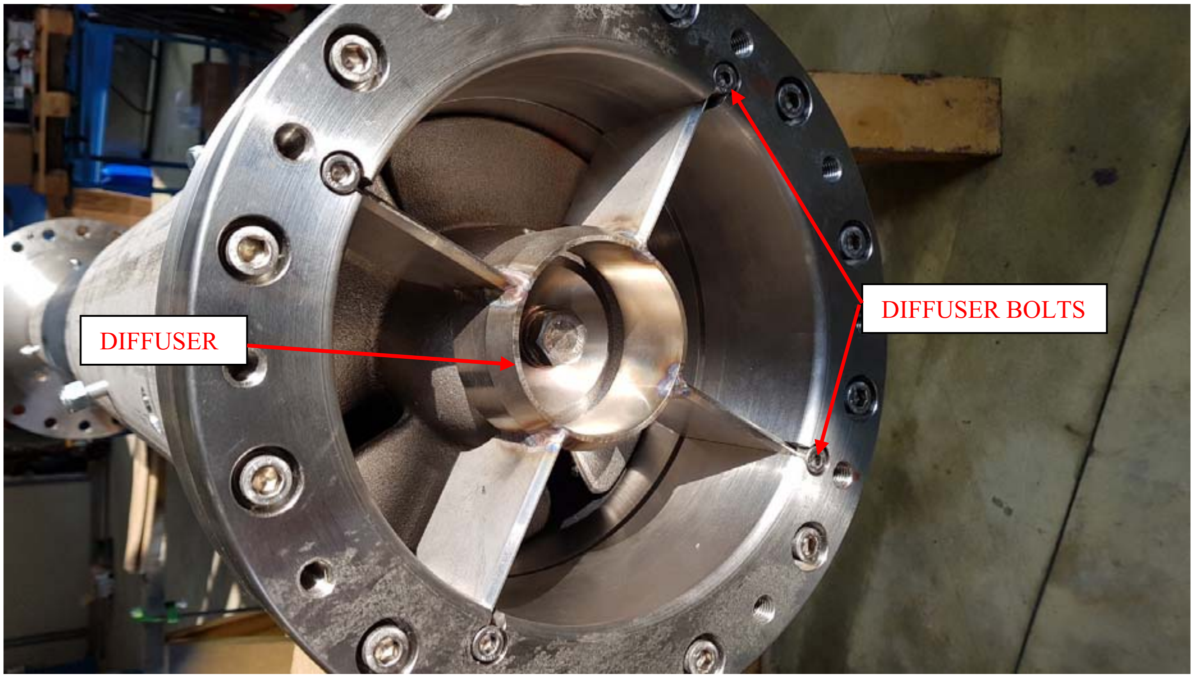


10.1.11 Remove ball bearing bottom cover (025) and its gasket (029)

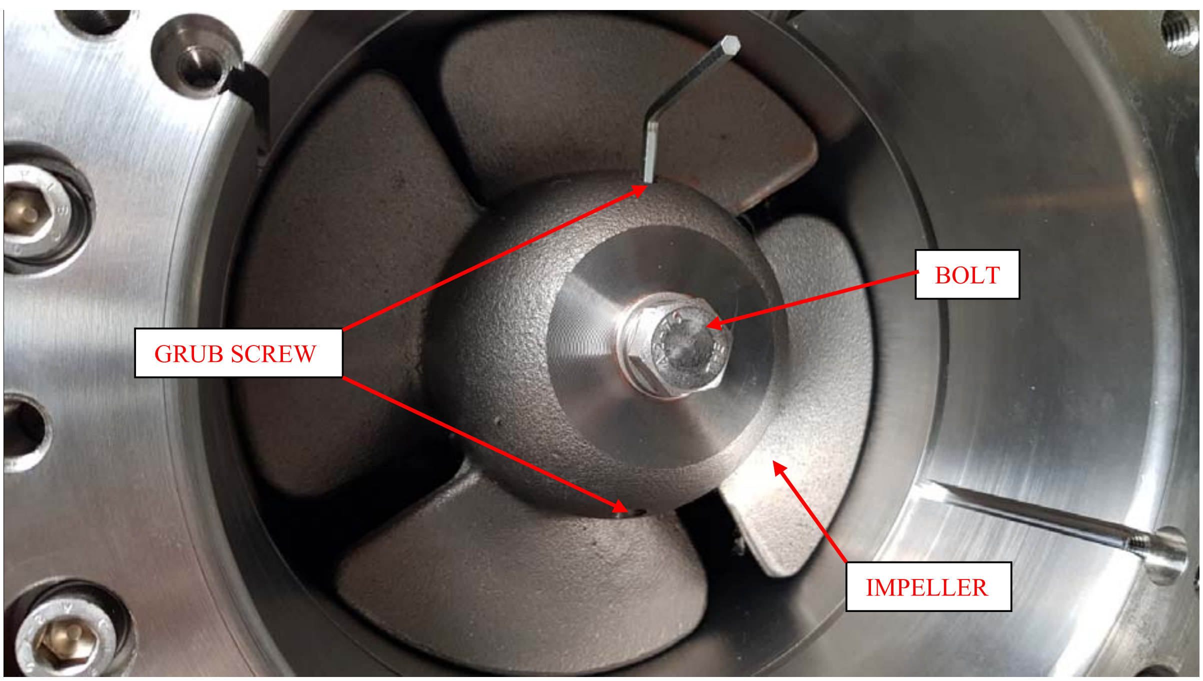


10.1.12 Shift the ball bearing (203) from ball bearing support (023).

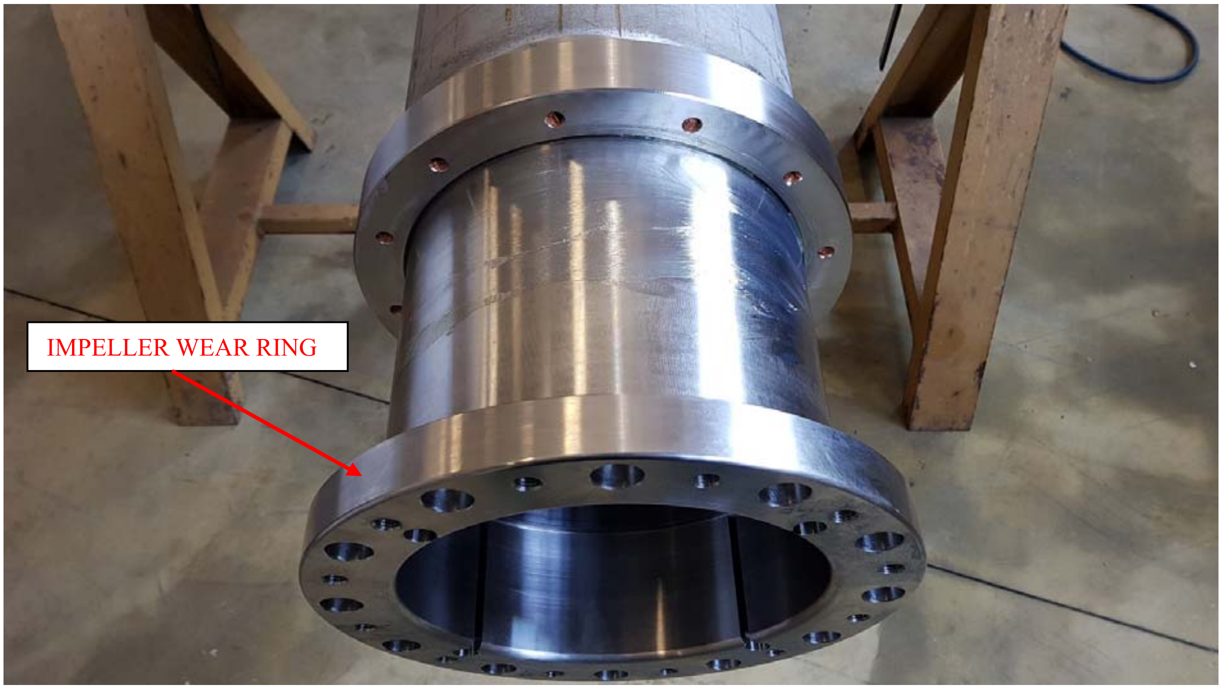
10.1.13 Slightly unscrew diffuser bolts and remove the diffuser (016).



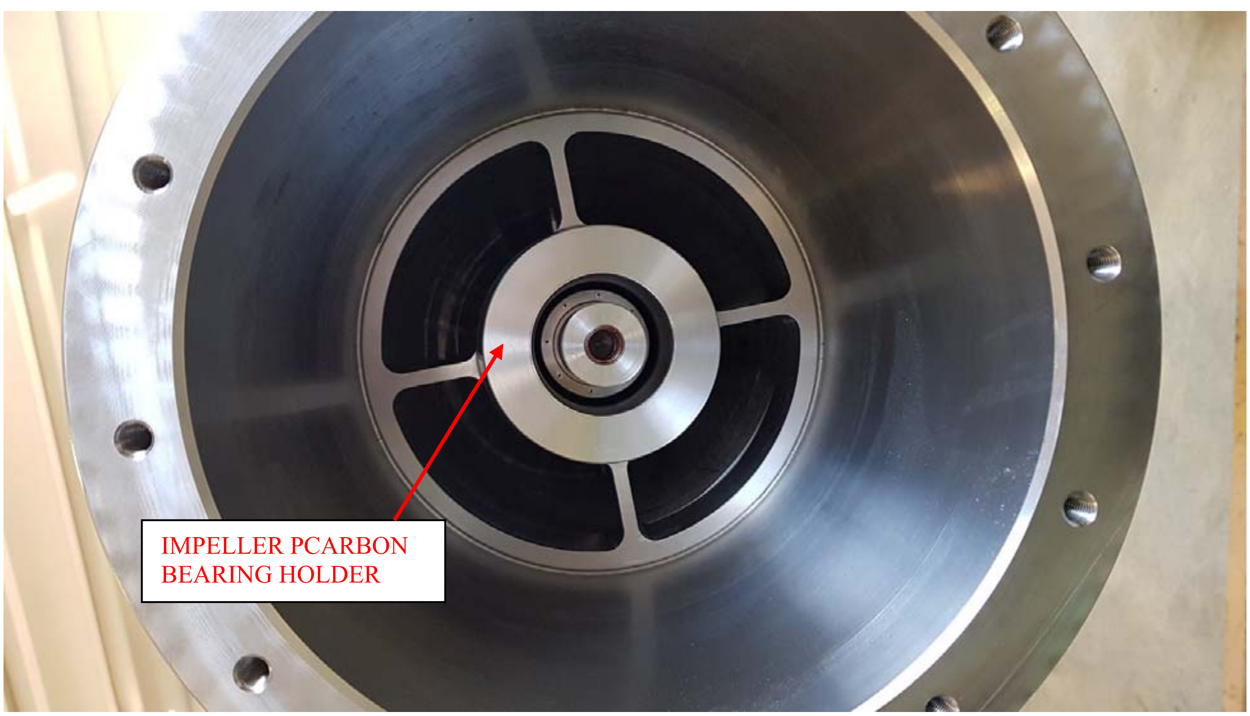
10.1.14 Unscrew the grubs into impeller opposite side, then unscrew the bolt and shift the impeller



10.1.15 Unscrew the bolts of impeller wear ring (011) and shift it.



10.1.16 Remove impeller PCarbon bearing holder (004)

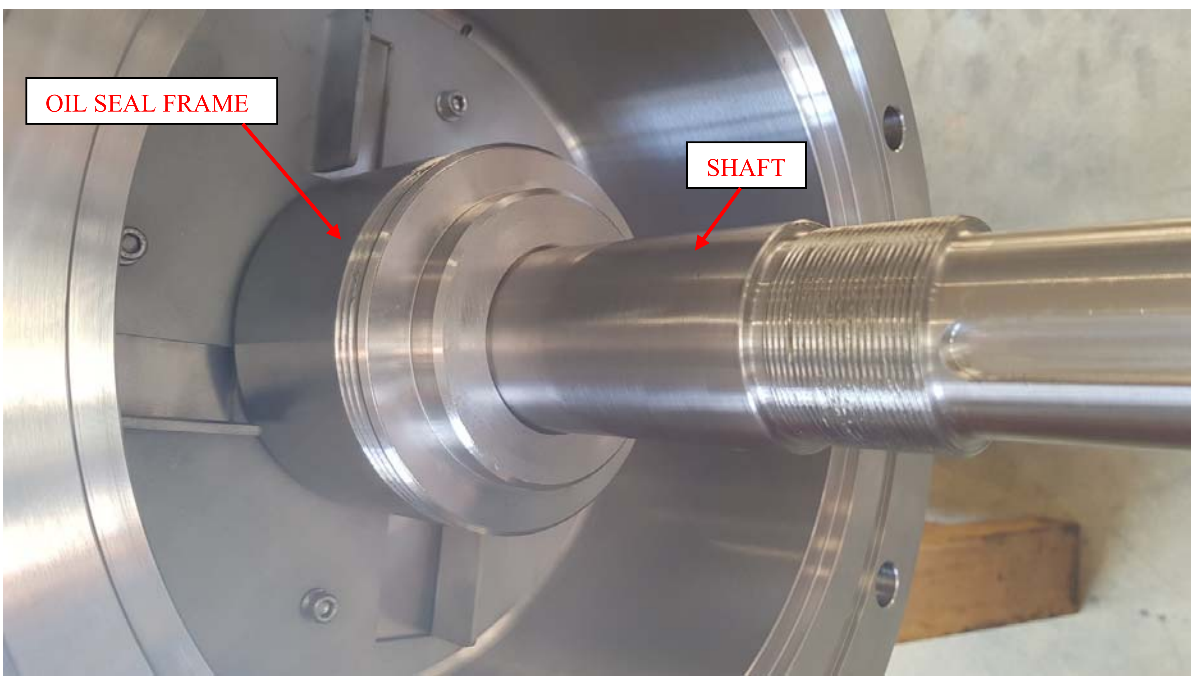


10.1.17 Unscrew the bolts and remove impeller PCarbon bearing front thrust ring (007)

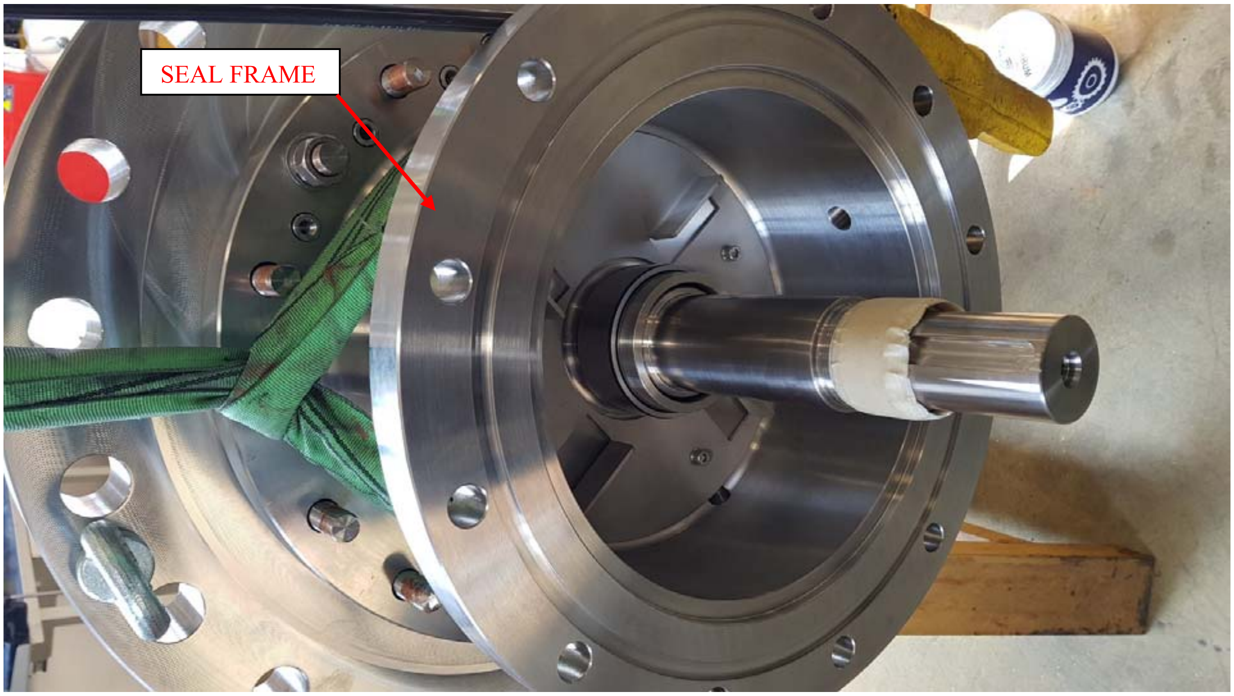
10.1.18 Remove PCarbon bearing (005)

10.1.19 From the seal frame side remove the gasket (018)

10.1.20 Shift the oil seal ring (015) from the shaft (002)

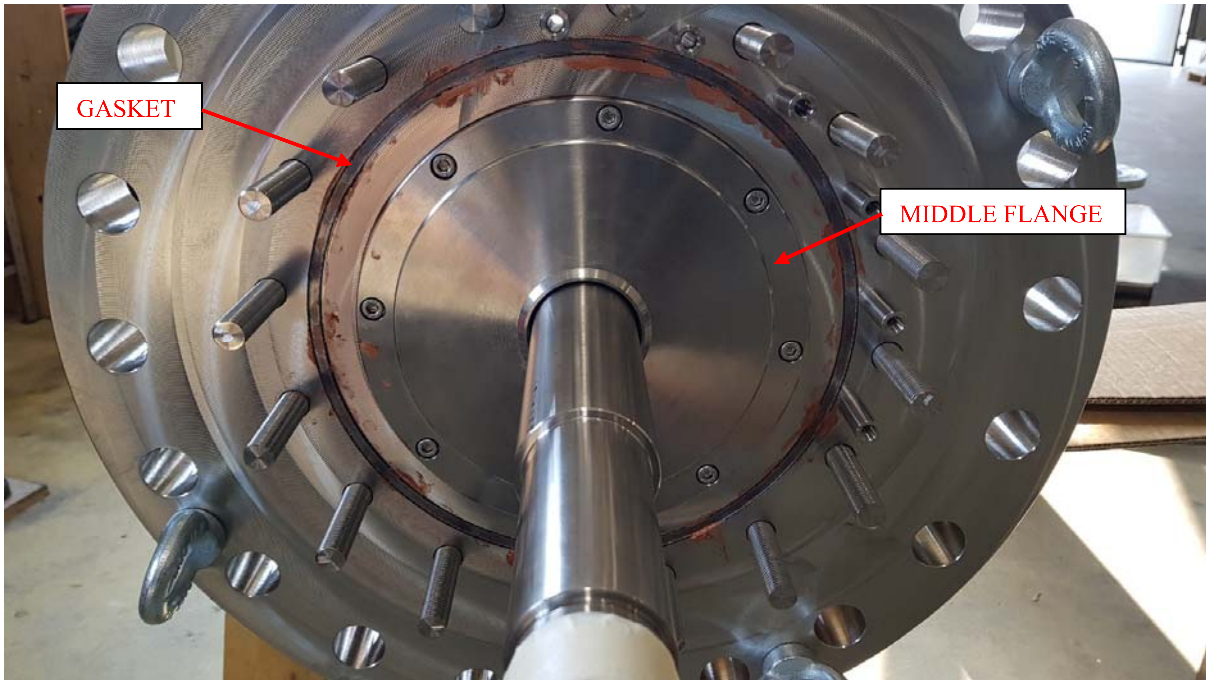


10.1.21 Unscrew the bolts and remove the seal frame (013) with the help of a bend



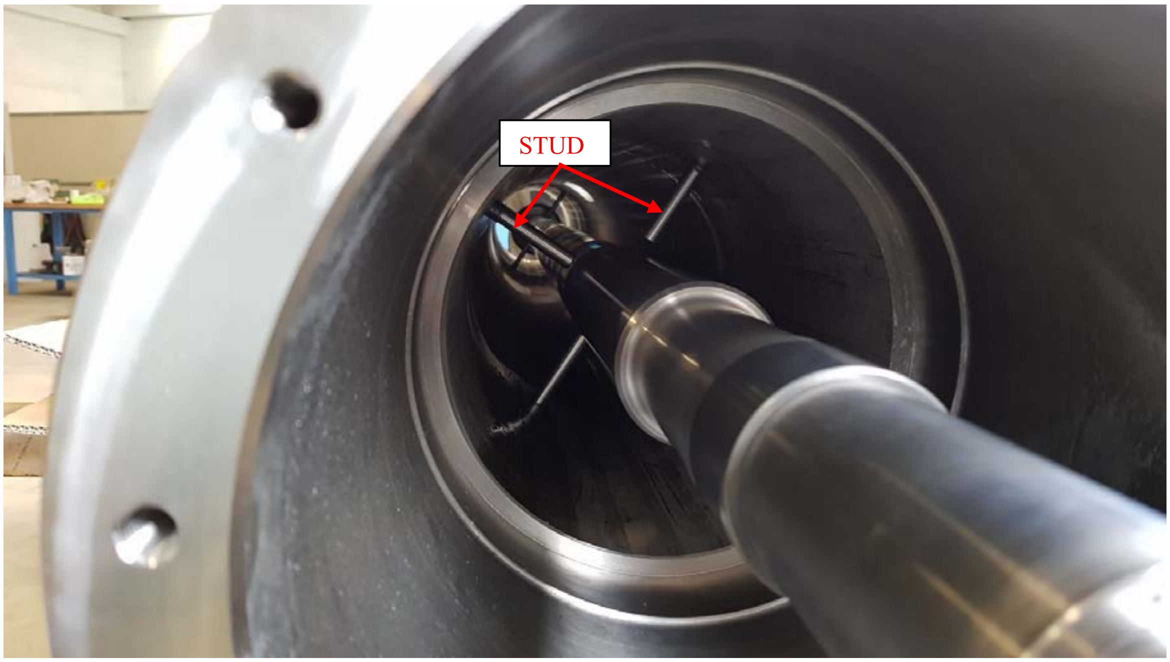
10.1.22 Unscrew the bolts and remove the lubricating oil sheet (024)

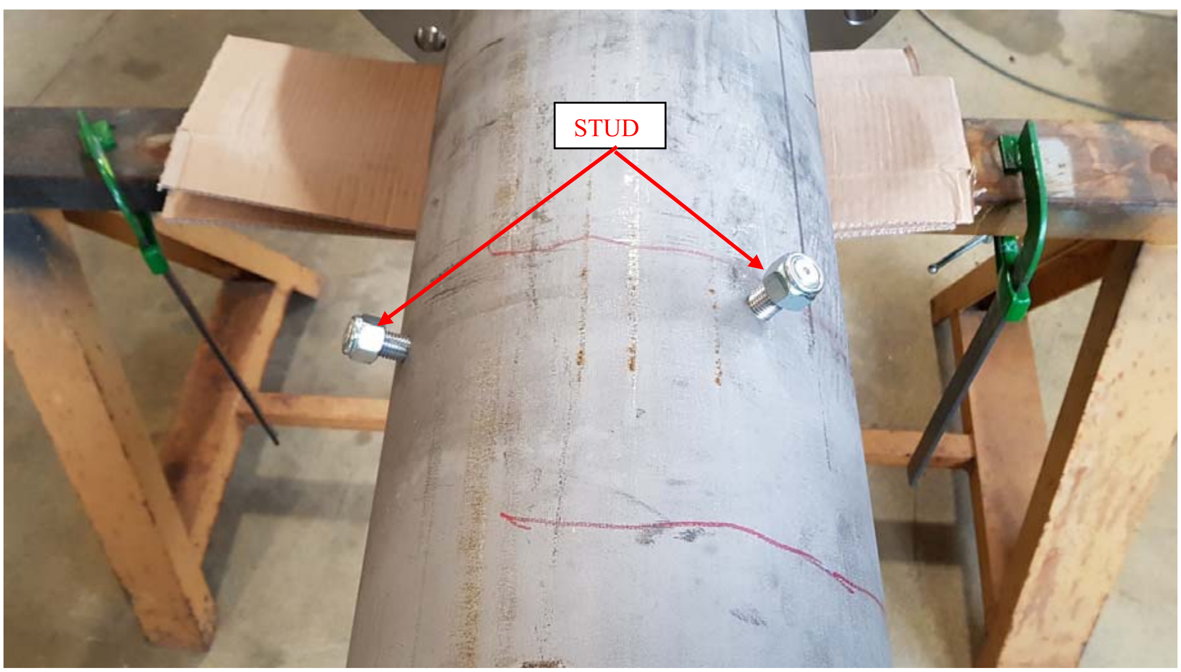
10.1.23 Remove gasket (018) in the vertical module (001) and after unscrew and shift the middle flange (014). In this way is removed the heat shield package (020,021,022)



10.2 Shaft Disassembly

10.2.1 Insert the studs into their housing to steer the shaft (002) from vertical module (001)





10.2.2 Shift the shat (002) from vertical module (001)

GREENPUMPS
MAG - DRIVE SEAL- LESS PUMPS

11. INSPECTION PRIOR TO REASSEMBLY

Clean all the parts carefully. Mechanical seal package should be washed in a clean solvent and allowed to dry, then greased (See photo below). Check all pump parts and replace worn ones.

11.1 Check the clearances between the collar of the impeller (001) and the wear ring (020) in the pump casing.

11.2 Check the clearances between the Pcarbon bearing (005) and the impeller sleeve.

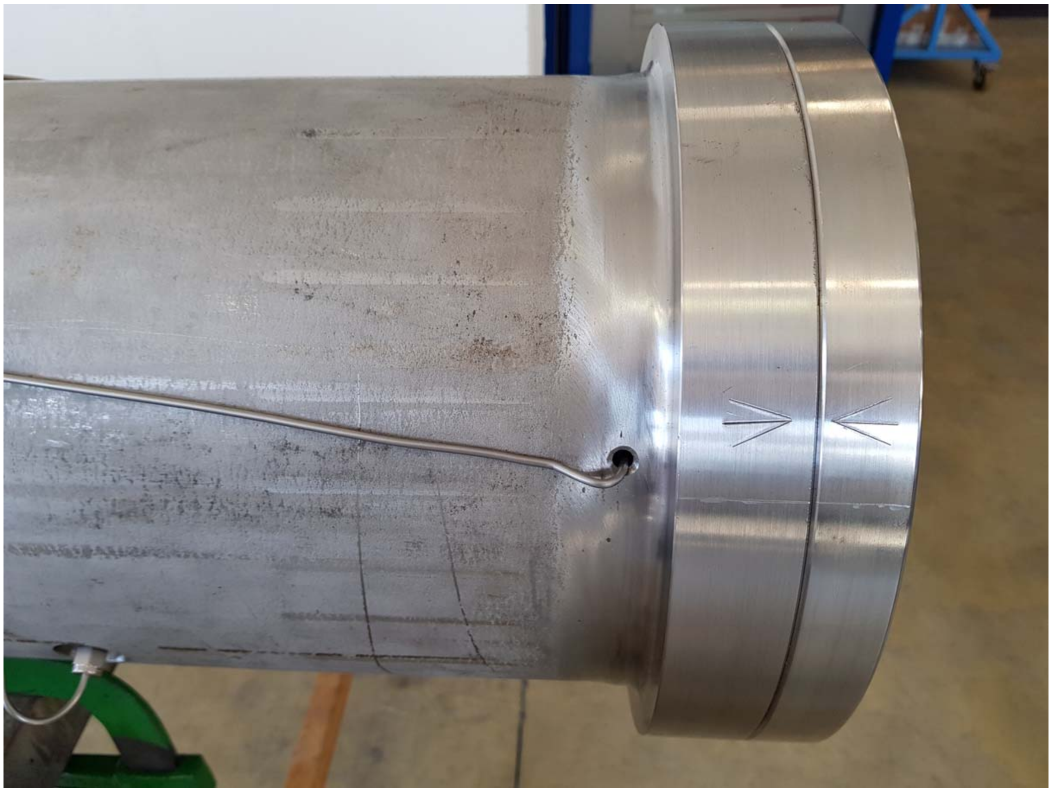
12 REASSEMBLING THE PUMP

WORK IN A CLEAN AREA!

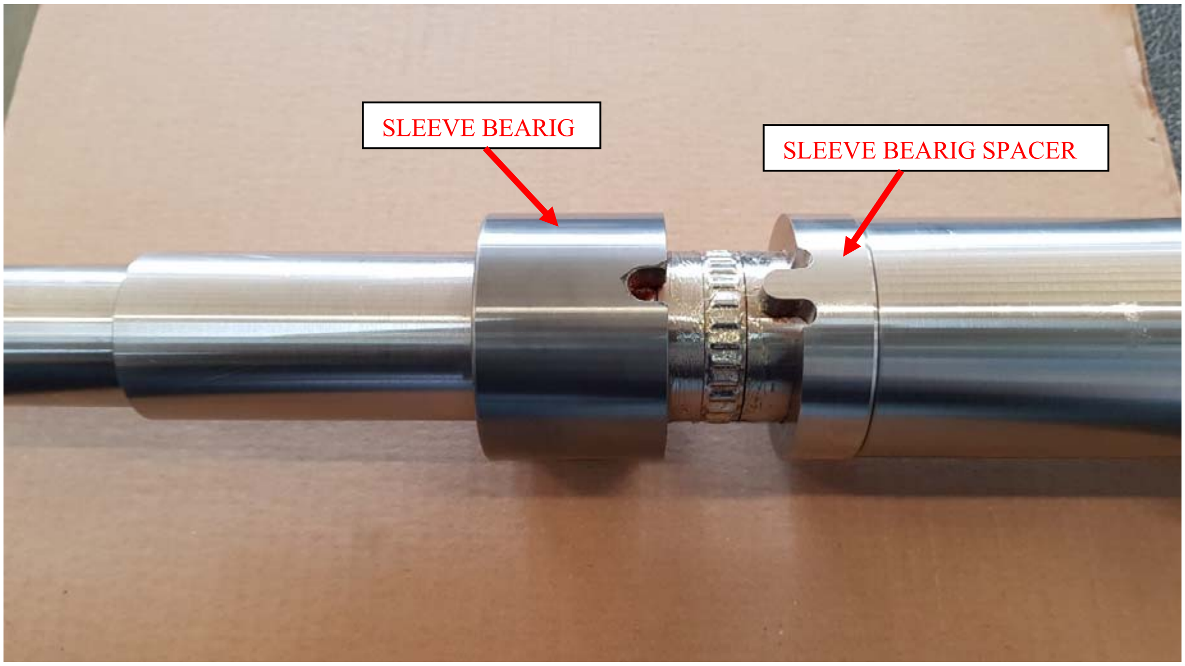
DO NOT USE FORCE!

IF LUBRICANTS OR THREADLOCKING COMPOUNDS (e.g. \`LOCTITE') ARE USED ON ANY INTERNAL THREAD OR OTHER WETTED SURFACE IN THE PUMP, THEY MUST BE COMPATIBLE WITH THE PUMPED LIQUID. (If in doubt consult the manufacturer of the compound)

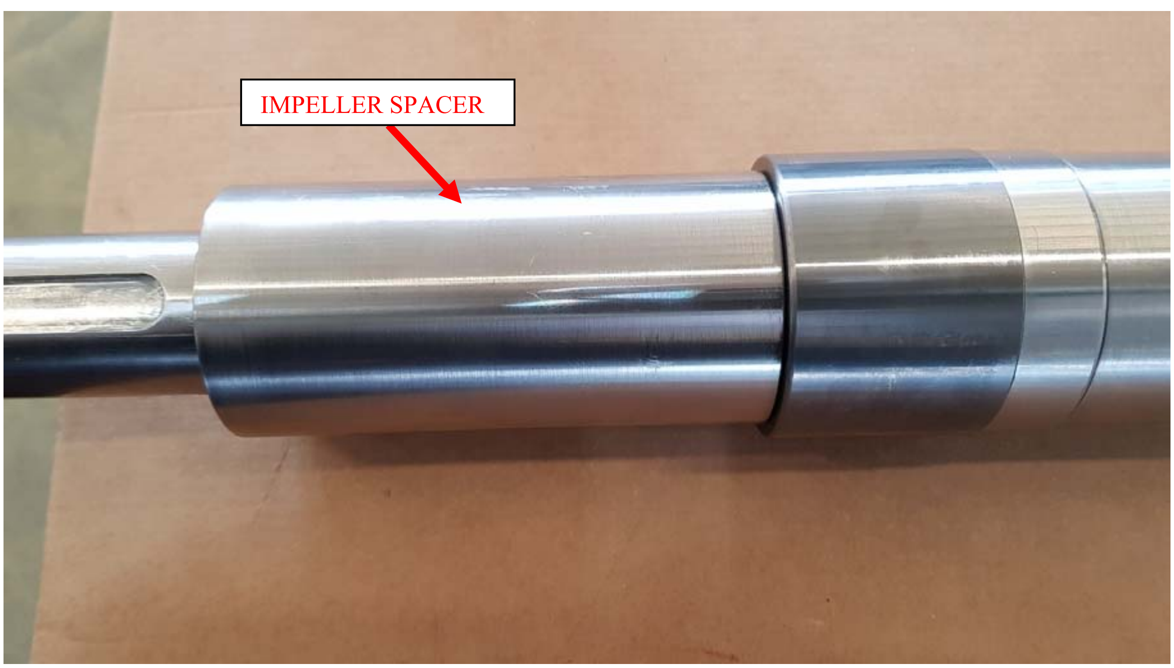
When you are re-assembling the pump, please take care to check centering pins and specific numbering where indicated in the specific item. (See below example)



12.1 Insert the sleeve bearing spacer (009) and sleeve bearing (010) into the shaft (002)



12.2 Insert impeller spacer (012)



12.3 To install the shaft (002) into vertical module (001) help with special tool (112)

12.4 Follow in the reverse way the disassembling procedures.

13. PUMP OPERATING PROBLEMS: CAUSES AND REMEDIES

Regular inspection, and preventive maintenance when necessary, will help to prevent breakdowns.
There are many possible reasons why a pump may not run properly. If your GREENPUMPS pump does not run satisfactorily, be prepared to look critically at the system as well as at the pump itself.
This section lists some possible pumping problems and indicates how they may be overcome. Your pump supplier will do his best to assist you further if necessary.

13.1 Insufficient flow

13.2 No flow

13.3 Excessive flow

13.4 Motor overheats and/or cuts out

13.5 Pump runs noisily and/or vibrates

13.6 Overheated external pump bearings

13.1	**INSUFFICIENT FLOW**	
	Causes	**Remedies**
13.1.1	Actual total discharge head exceeds rated head of pump.	Increase speed of rotation if possible. Fit larger diameter impeller. Reduce total head of system. Increase discharge pipework size.
13.1.2	Pump rotating in reverse.	Check direction of rotation.
13.1.3	Low inlet pressure, giving rise to cavitation and loss of efficiency.	Check for inlet obstructions or restrictions. Check for excessive liquid viscosity: increase liquid temperature if necessary.
13.1.4	Wear of impeller collar and/or wear ring.	Check condition of impeller collar and wear ring. Replace if excessively worn.

13.2	**NO FLOW**	
	Causes	**Remedies**
	Motor has stopped.	Check power supply. Check motor condition.
13.3	**EXCESSIVE FLOW**	
	Causes	**Remedies**
	Actual total discharge head is below rated head of pump.	Reduce speed of rotation if possible. Fit smaller diameter impeller.
13.4	**MOTOR OVERHEATS AND/OR CUTS OUT**	
	Causes	**Remedies**
13.4.1	See 13.3.	As in 13.3.
13.4.2	Excessive liquid density.	Reduce flow rate by partly closing discharge valve.
13.4.3	Pump has seized or is about to seize.	Check pump for free rotation. Check pump internally for obstructions.
13.4.4	Motor bearings are failing.	Replace motor bearings. Investigate cause of overload/failure.
13.4.5	Undersized motor.	Fit a larger motor: check first with your pump supplier.
13.5	**PUMP RUNS NOISILY AND/OR VIBRATES**	
	Causes	**Remedies**
13.5.1	Worn, eroded, fouled or damaged impeller or internal bearings.	Check pump internally for wear, damage or obstruction.
13.5.2	Worn external pump	Check bearings and replace if necessary.

	bearings or motor bearings.	
13.5.3	Pump discharge is not properly fixed at the vessel.	Fix the pump discharge at the vessel.
13.5.4	Mis-aligned or badly secured pipework.	Check pipework alignment and support.
13.5.5	Pump started while rotating in reverse.	Stop pump immediately and allow discharge line to drain completely before re-starting.
13.6	**OVERHEATED (EXTERNAL) PUMP BEARINGS**	
	Causes	**Remedies**
13.6.1	See 13.5.1 to 13.5.5.	As in 13.5.1 to 13.5.5.
13.6.2	Lack of oil, or incorrect oil in bearing housing.	Check oil level: refill, or drain and replace oil if necessary. Replace bearings if necessary. Check Hydraulic power unit malfunction.