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Report

Final Report of the Concept Design of the RH System for VVPSS Maintenance

This report describes the concept design of the VVPSS RH system as the final deliverable of the ITER contract : IO/CT/16/4300001287 with TELEROBOTS Labs. The subtasks are- Subtask-1.1: Concept design of the cleaning tools- Subtask-2.1: Concept design of the bolting tools - Subtask-2.2: Concept design of the confinement tools- Subtask-2.3: Concept design of the seal preparation tools- Subtask-3.1: Assessment of the contamination level and cleaning efficiency for the VVPSS components

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Final Report of the Concept Design of the RH System for VVPSS Maintenance

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Review

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0	10/10/2016	Becchi	Canepa	Barbieri	Internal
1	22/10/2016	Becchi	Canepa	Barbieri	First release
2	26/10/2016	Becchi	Canepa	Barbieri	Integrated with received comments

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Abbreviations

VVPSS	Vacuum Vessel Pressure Suppression system
RD	Rupture Disc;
BLV	Bleed Line Valve;
HCB	Hot Cell Building
DTR	Drain Tank Room;
HD	Harmonic Drive;
RHS	Remote Handling System
VST	Vapour Suppression Tank
Dof	degree of freedom
BT	Bolting tool;
STP	Seal Track Preparation
NB	Neutral Beam
NBI	Neutral Beam Injector

For any other abbreviations please refers to: ITER Abbreviations (2MU6W5)

1 Subject

Scope of this document is to resume the activities related to ITER contract : IO/CT/16/4300001287.

In line with task specification the activity was monitored thanks to weekly web meeting as well as several meeting held in person at ITERHQ. The complete documentation presented in the meeting is stored in the IDM project repository that can be found on the following link:
2016_Concept Design of the RH System for VVPSS Maintenance (ITER_D_SKDN73)

As requested in the contract amended technical specifications (IDM ref.: SKL6F8) the following sub-task were developed and are discussed in this report:

1. Subtask-1.1: Concept design of the cleaning tools (see section 3);
2. Subtask-2.1: Concept design of the bolting tools (see section 4);
3. Subtask-2.2: Concept design of the confinement tools (see section 5);
4. Subtask-2.3: Concept design of the seal preparation tools (see section 6);
5. Subtask-3.1: Assessment of the contamination level and cleaning efficiency for the VVPSS components (see section 7)

Reference operational sequences for the presented tools including handling is presented in section 8

Requirement compliance matrix with specific comments and references in added at the end of the report (section 9).

Main relevant interface modifications for VVPSS PRH are outlined in sec. 10.

Preliminary cost assessment of the solutions/devices defined in the reference configuration (called "NB configuration") and in the IO developed alternative "DTR" configuration is also developed but is not integrated in this report and kept as independent document.

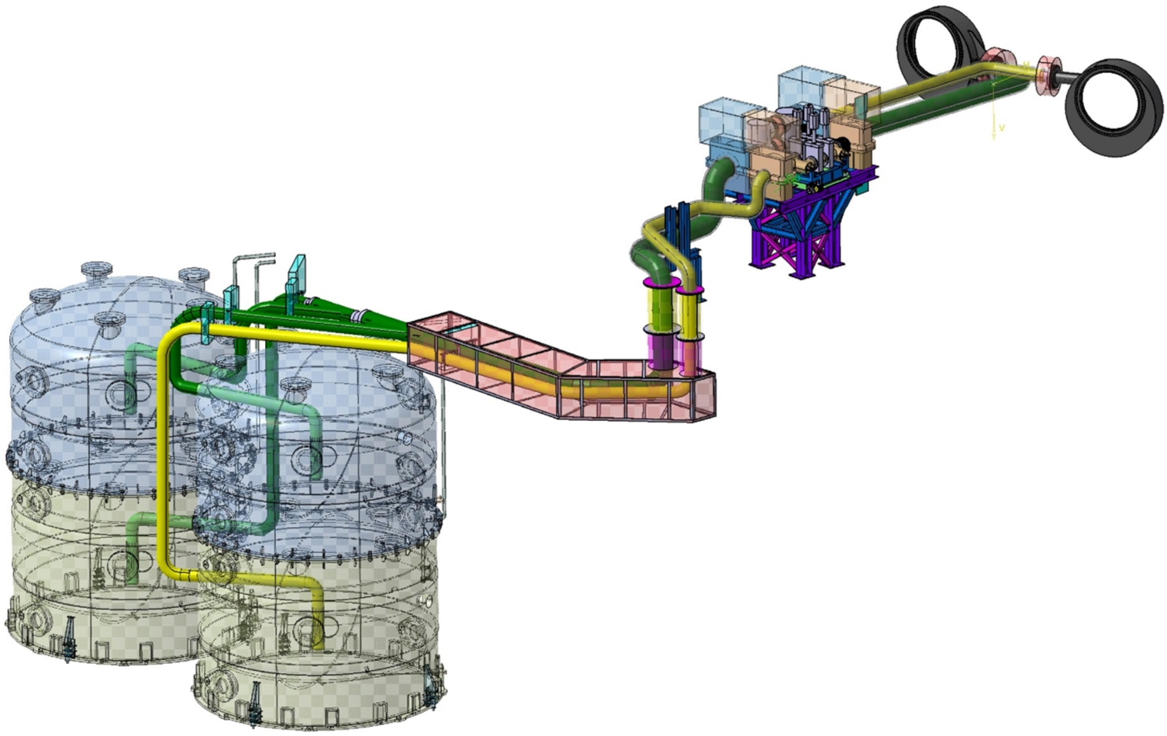


fig. 1 overall view of the VVPSS.

2 References

Main cited references are below listed:

[1] Technical Specification for the Concept Design of the RH system for VVPSS Maintenance (ITER-D-SKL6F8);

[2] ITER VACUUM FLANGE USE DESIGN GUIDANCE (ITER_D_PA3BXP);

3 Concept design of the cleaning tools

The following table reports the subtask requirements with some updates/comment based on the contract outcomes.

REQ	Concept design of the cleaning tools	remarks/updates
1.01.01	Cleaning sequences shall be developed during the normal operation and accident cases.	in normal operation/maintenance only local cleaning for flange disconnection is foreseen (only upstream flange). After accident flanges, upstream and downstream lines are cleaned. No cleaning of RD and BLV assembly foreseen
1.01.02	Cleaning methods shall be defined during the normal operation case and accident cases.	vacuum cleaning is used locally for flange disconnection in normal operation. After accident waterjet cleaning is used for downstream line cleaning while vacuum cleaning is used in upstream line.
1.01.03	The cleaning tool shall be capable of being deployed remotely from the equatorial cask to the operating configuration.	deployment of cleaning tools from equatorial cask to working configuration is foreseen by NBRHS.
1.01.04	The cleaning tool shall be capable of clean the internals of the rupture disk and valve modules. Note that a demonstration is required describing the accessibility of the tool to all the surface of the component.	according to present cleaning strategy no RD assembly and BLV assembly internals cleaning is foreseen. The two groups will be confined with mechanical expansion caps and transferred to the HCB without further cleaning.
1.01.05	The cleaning tool shall be capable of clean the internal surface of the upstream and downstream relief lines. The internal surface includes the flange or any other surfaces that can be contaminated.	see 1.01.01/1.01.02
1.01.06	Parts of the cleaning tool which are in contact with the water shall be water proof.	all components located within the waterjet cleaning tool confinement will be waterproof
1.01.07	The cleaning tool shall be remote handling compatible for refurbishment and decontamination in the hot cell building. The decontamination means removal of any contamination in the tool so that maintenance by human worker is possible. The refurbishment means replacement of the contamination collection canisters or its own consumable parts.	see S.1.08
1.01.08	The cleaning operation during the regular maintenance of the rupture disk shall be RH class 1.	
1.01.09	The cleaning operation after the accidents shall be RH class 2.	

tab. 1 cleaning tool requirements

As preliminary reference a short overview of the VVPSS line in consideration of the cleaning task is below reported:

- The upstream line is made by two parallel pipes starting from NB connection to RD assembly (DN 300 in yellow in the picture and DN 500 in green). Each pipe has a length of about 12 m;
- The downstream line is made by two parallel pipes starting from RD assembly to tanks bifurcation (DN 300 in yellow in the picture and DN 500 in green). Each pipe has a length of about 20 m;
- The tank lines are made by four DN 200 with different length (max length 15 m).

According to the discussed intervention scenario upstream and downstream lines can be accessed by RD/BLV assembly flanges when the two units are removed.

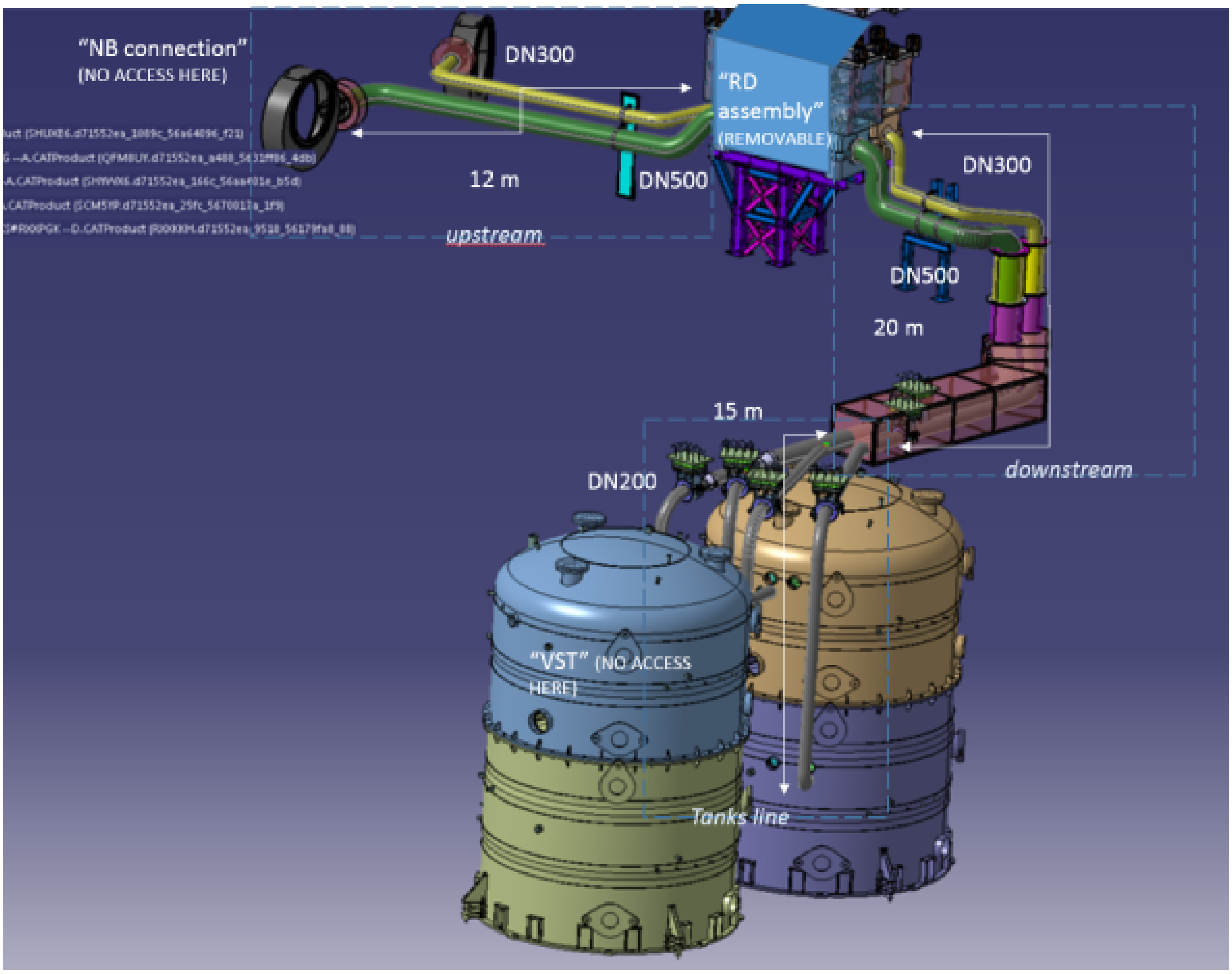


fig. 2 cleaning reference dimensions

3.1 Cleaning solutions

This section discusses the application of the selected cleaning technologies to upstream and downstream VVPSS lines.

Aspiration and waterjet application is presented. CO2 pellet blasting, originally included in the technical specification was then removed in the technical specification amendment.

3.1.1 Dust aspiration cleaning

Dust aspiration is considered as the only applicable solution for upstream line cleaning. As water draining is critical in the VVPSS box and upstream line, water cleaning is consequently discarded.
The actual cleaning strategy is to avoid upstream pipe cleaning both in normal operation and after accident.
A remotely operated deployable device could be considered and developed in case based on the experimental results on upstream dust deposition in ITER non-nuclear phase.
A review of previous performed studies on articulated robot (snake robot) shown no suitable mature solution that should ensure complete upstream pipe access by aspirated cleaning.
A crawler based solution was already developed as conceptual design in the previous VVPSS configuration (i.e. the RD and BLV located at L3 level). Crawler based cleaning is discussed in the following sections.
As below discussed dust aspiration is also the reference solution for flanges and confinement box cleaning.

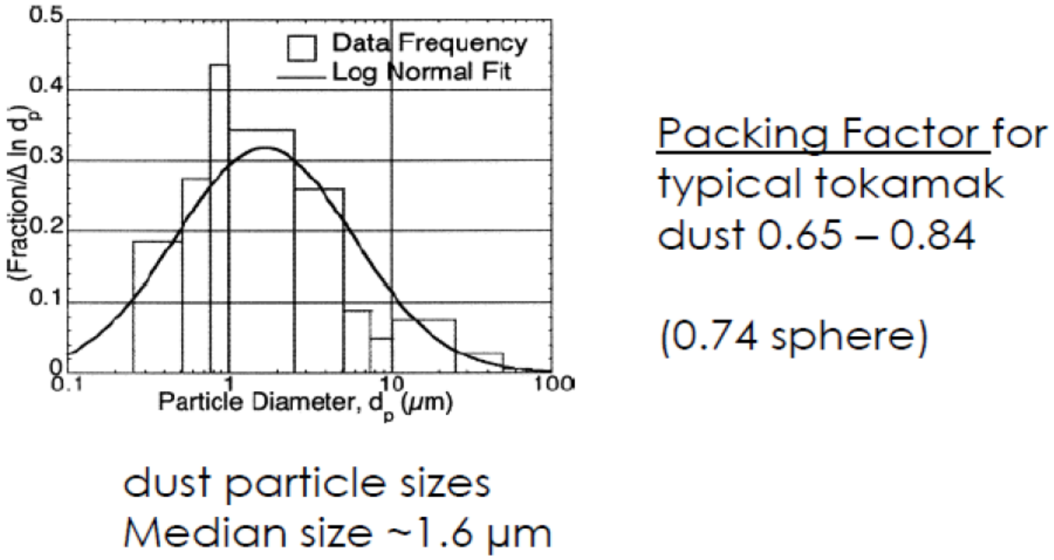


fig. 3 ITER reference dust dimensional specification

In consideration of the foreseen dust particle size and expected dust deposition (see section 7 for more details) the standard solution implemented for dust aspiration is to use an HEPA filter directly connected between the aspiration pipe and a blower. Small dimension of dust particles considered in the ITER reference specification make not efficient a dust/air cyclone separation as most of the particles will not stop in the cyclone.
The following picture shows as reference the result of test performed on HEPA filter according to EN-1822-3:2009 on a standard HEPA filter (ALTAIR COL270B-TFM-H HEPA PTFE).

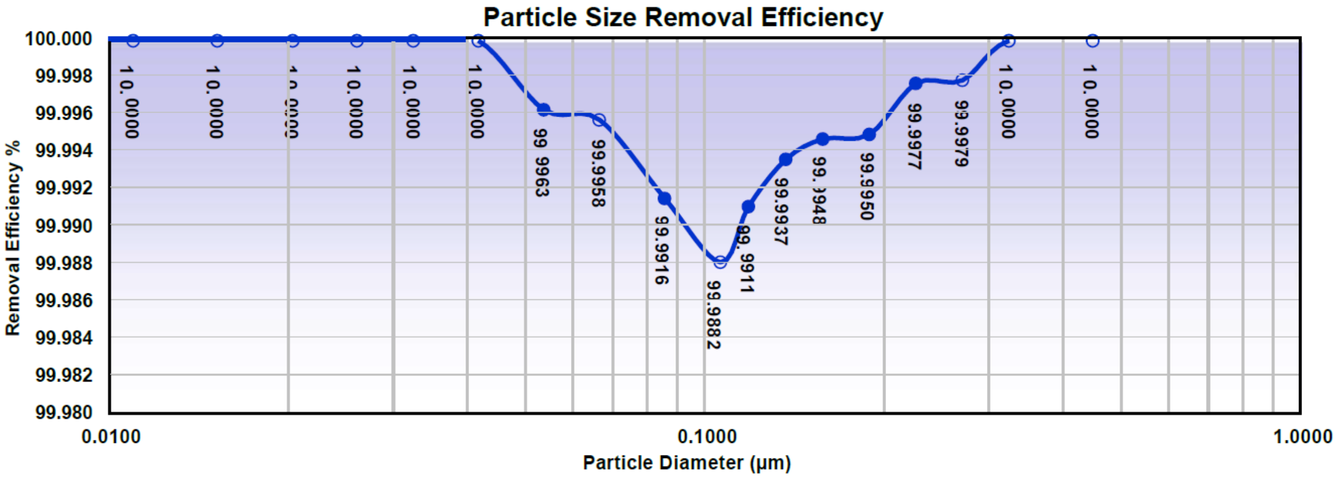


fig. 4 HEPA typical particle removal efficiency

HEPA filter size was preliminarily dimensioned starting from previous Telerobot labs experience in the realization of sampling tools for Nuclear power plant decommissioning.

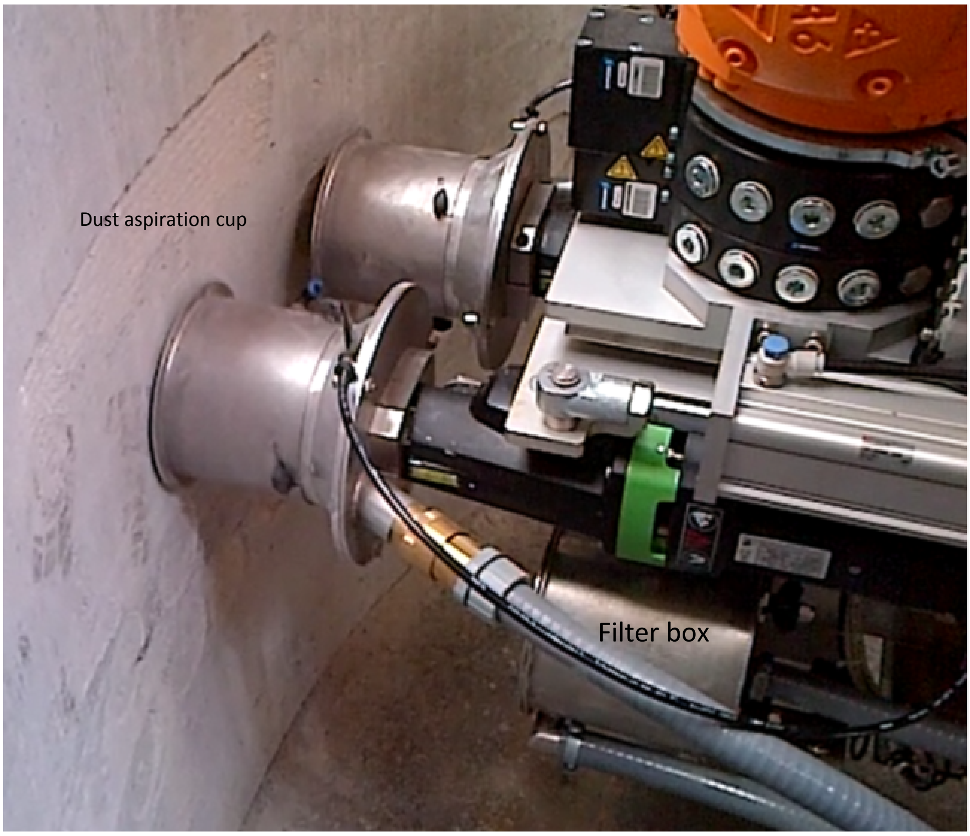


fig. 5 dust sampling tool

Dust aspiration HEPA filter surface was dimensioned based on the measured dust aspiration performances of the filter used in the sampling tool (as amount of dust/filter surface) and on the conservative estimation of the accumulated dust inside the upstream DN500 pipe section (following experimental data reported in sec.7).

GARIGLIANO NPP sampling filter		
H	100	mm
D	120	mm
Af	0.315	m2
filter target dust	40	g
max filter dust (EXPERIMENTAL DATA)	80	g
VVPSS RH HEPA FILTER		
H	300	mm
D	300	mm
Af	5	m2
max filter dust (extrapolated)	**1269.841**	g
upstream DN500 approx length	12	m
upstream DN500 surface	18.84956	m2
conservative dust sediment	56	g/m2
total dust	1055.575	g

tab. 2 HEPA filter draft calculation

A specific validation with a representative aspirator layout on a ITER relevant mock-up should be performed to validate this assumption.

For dust resuspension from the surfaces, brushing is not an option because of general prescription on internal surfaces on UHV vessels and pipe maintenance. Air flow dust resuspension is one of the possible alternatives to water jet. The reference solution considered in this stage is to use a fraction of the blower exhaust, thanks to pipe parallel to the aspiration one, to create efficiently turbulence inside the aspiration head (the same solution was already tested in other similar off-shore cleaning tool from Telerobot labs). The same solution could be further optimized using two coaxial pipes that connect the cleaning head.

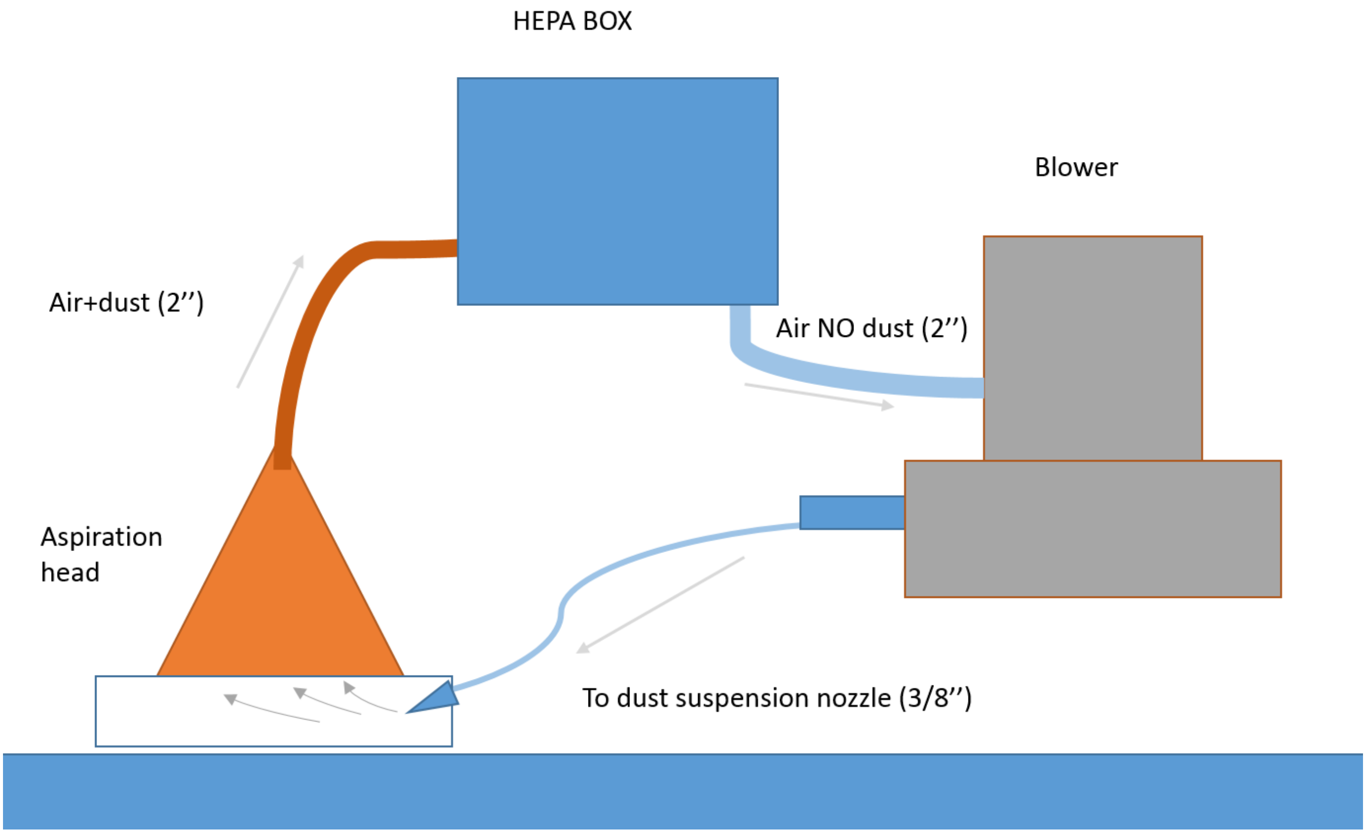


fig. 6 dust aspiration diagram

3.1.2 *Waterjet cleaning*

Water jet cleaning is the current reference solution for downstream line cleaning.
In this stage two different solutions are considered to clean with waterjet the downstream line:

- Deployable self-propelled waterjet head;
- Rotating cleaning head.

Fixed nozzles inside the line are not included in this stage in the study since removable cleaning devices are considered preferable in order to reduce the internal line asperities that could increase the dust deposition.

3.1.2.1 Self-pulled nozzle head

For main lines a self-propelled cleaning head can be deployed from the designed access port.
The cleaning head is connected to a water hose on a reel.
The conceptual design of a cleaning tool for downstream line self-propelling head deployment is discussed later in this section.
In the following picture is shown an application example of a Stoneage Badger 6” cleaning head. Even if preliminary applicability of such solution was discussed with the supplier, specific tests on real scale representative mock-up are suggested to test cleaning head reference performance (cleaning speed and water consumption).
Main advantage of this kind of solution are its availability (standard solution is commercially available) and its simplicity.
As visible in the picture multiple bends can be overcome even with the head traveling upward inside a pipe.

The main limitation is the lack of directional control of the head that prevent its application in case of “Y” line ramification.

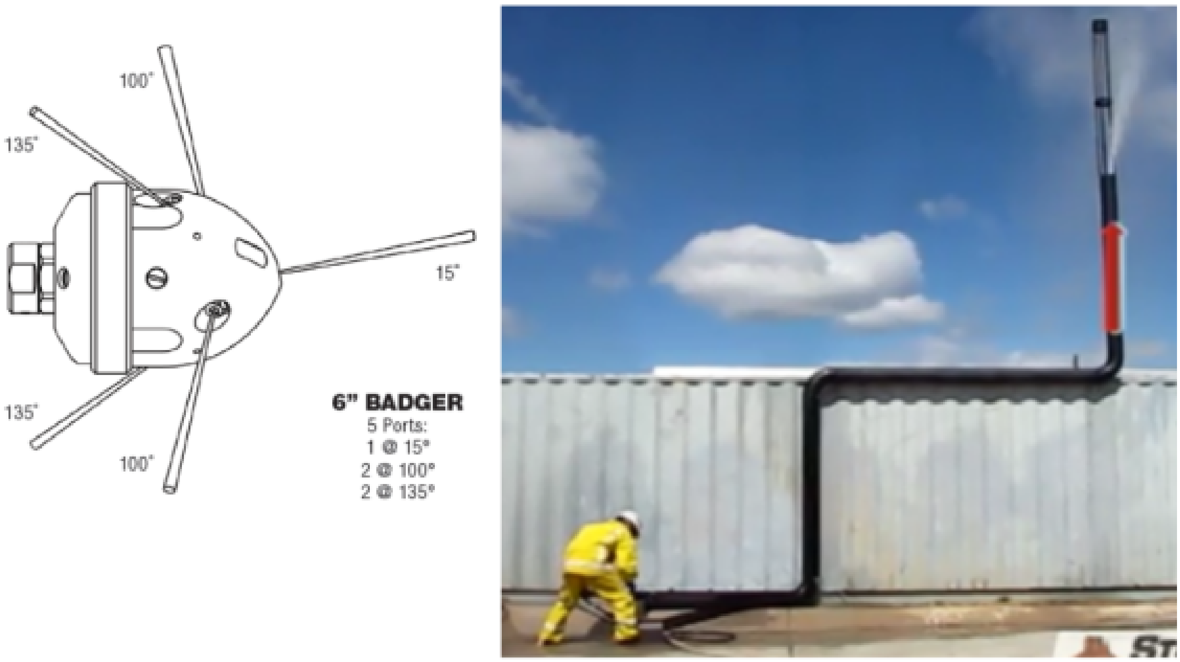


fig. 7 self propelled cleaning head

3.1.2.2 Manifold cleaning head

Pipe ramification, manifold and local complex geometries could be hard or even impossible to clean with a self-propelled waterjet cleaning head. The head attitude inside the pipe is controlled by the water nozzles while its position inside the line is controlled by the length of pipe released from the reel. No active steering is possible with a standard cleaning head.

A different removable rotating head can be used to clean local complex geometries as manifold or pipe dead end if accessed locally through some small access flanges (as first reference 40 mm ID could already be sufficient in consideration of the cleaning head below reported as reference).

According to the position of the access flange and the expected local dose rate flange opening could be done directly by human intervention or by RH.

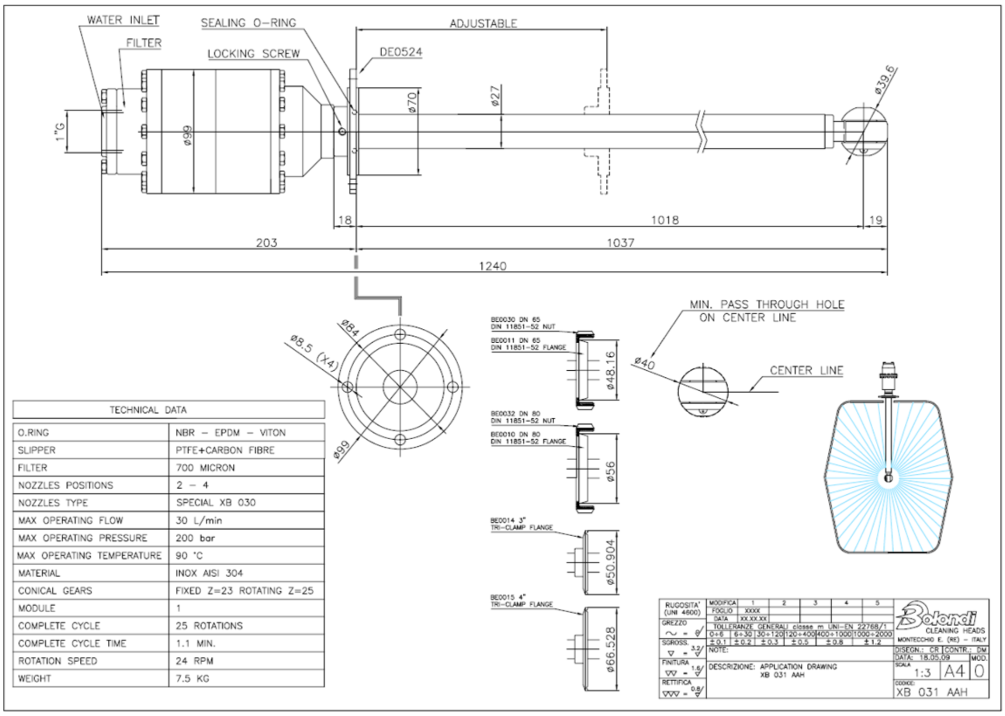


fig. 8 manifold cleaning head

3.1.2.3 High Pressure Unit

In consideration of the pipe dimension thanks to the support of a Badger head distributor a first draft calculation on the needed High pressure Unit (HPU) was performed (this data for the lack of direct trials on representative mock-up must be kept as first indication).

badger head working pressure	500	bar
badger head nozzles	6	
flow per nozzle	5	l/min
total flow rate	30	l/min
HPU ref. electrical power	**40**	**kW**

tab. 3 HPU ref. data

As a commercial equivalent reference, the PCT 2/45 E was selected and its main component as electric motor and high pressure pump are integrated in the waterjet cleaning tool. As general interface 6 bar clean water supply is available at NB cell (Interface Sheet (IS) between Liquid & Gas Distribution (PBS 65) and Remote Handling (PBS 23) *(ITER_D_2W4BLL v5.0)*). To power the high pressure cleaning tool a standard electric high pressure needs to be integrated in the cleaning tool.

UNITS › UNITÀ	
Weight Peso	850 Kg - 1874 lbs
Dimensions Dimensioni	220 cm x 120 cm x 120 cm 86,6 inch x 47,2 inch x 47,2 inch
PUMP › POMPA	
Type Tipo	Triplex horizontal pump with special ceramic plungers and plunger cooling system for pressures above 1000 bar. Lubrication splash type. Volumetrica a 3 pistoni con sistema raffreddamento tenute per pressioni oltre i 1000bar. Lubrificazione a sbattimento.
Head Testata	Stainless steel Inox
Safety valve Valvola di sicurezza	Norm CE a norma CE
Gauge Manometro	Stainless steel filled with glycerin Inox in bagno di glicerina
MOTOR › MOTORE	
Type Tipo	Asynchronous, 3-phase/ 4 poles, 400V@50Hz, aircooled, efficiency IE2, B3 form, F/B class insulation, IP55 protection Asincrono, trifase, 4 poli, 400V@50Hz, efficienza IE2, ventilazione esterna, forma B3, isolamento classe F/B, protezione IP55
Max power Potenza max	45 kW@1500 rpm

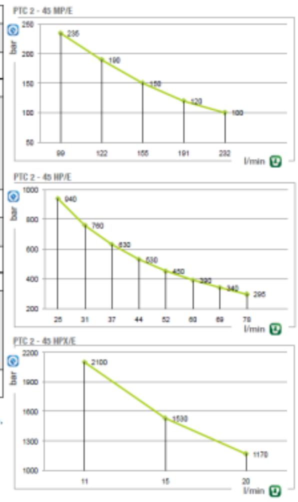
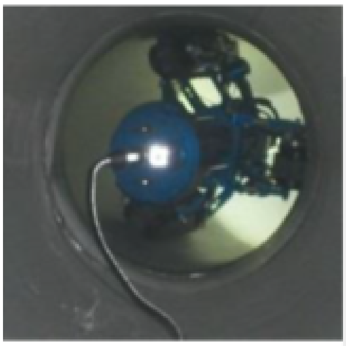


fig. 9 HPU

3.1.2.4 Crawler based waterjet cleaning

A solution to perform the complete line cleaning with waterjet consist in integrating an high pressure waterjet cleaning head with a crawler vehicle that could negotiate pipe bifurcation as well as diameter and manifold translation.

The Inuktun VT100 shown in the following picture is a good example of a commercial available device for pipe inspection in the civil and off shore market. The application example below reported shows the dimensions of 8" LP Compressor pipe with two 90° bends and three 45° degree bends with horizontal and vertical sections successfully inspected with this device (23 m in total). Controlled traction/steering and attitude and remote inspection could make the navigation inside a manifold feasible.



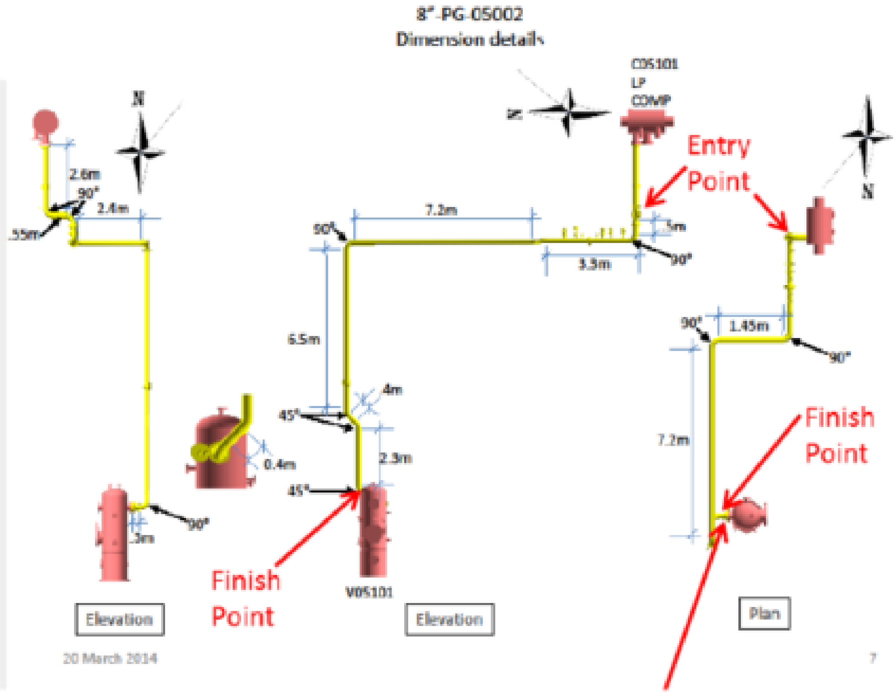


fig. 10 in pipe tractor module

3.2 Vacuum cleaning robot

This section introduces the conceptual design of the vacuum cleaning tool as developed integrating the different technologies before presented.
NOTE: for the tool deployment and work cycle, refer to §8 where the full VVPSS service sequence is described.

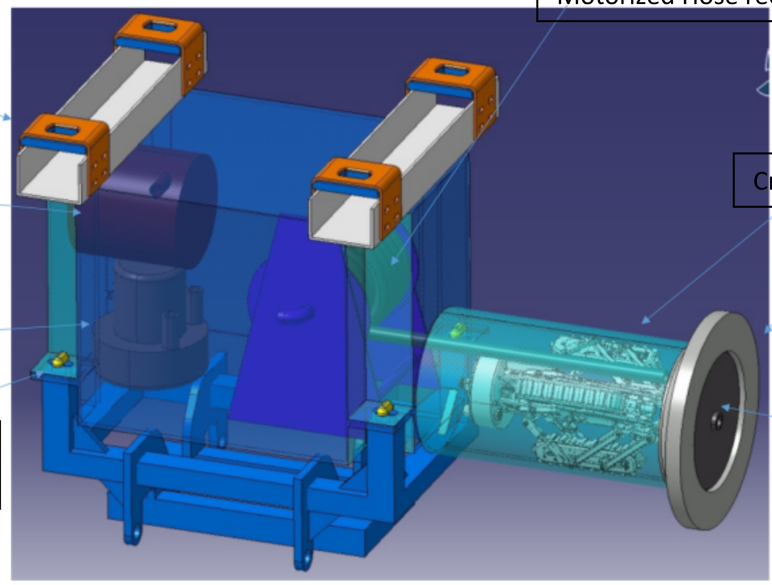


fig. 11 aspiration cleaning tool reference layout

The vacuum cleaning tool is integrated inside a deployable dedicated cask that is laid on the RD/BLV alignment frame with the monorail transporter on the same RD/BLV mechanical interfaces.
Once the cleaning tool in place it is connected to the VVPSS line using the confinement box tool described in section 5. The reference cleaning scenario considers this tool to be used to clean the two upstream pipe sections from RD/BLV upstream flanges to the VVPSS Boxes. Non-nuclear experimental phase of ITER will confirm the need of this cleaning tool.
The aspiration cleaning tool is fully enclosed in a confinement box that, in operation, becomes part of the primary confinement. As visible in the pictures the frontal section of the tool is the storage for a crawler vehicle used to move inside the pipe with the aspiration tool.
The crawler, as discussed is based on an existing commercial device, is teleoperated inside the pipe and is connected with a reel to the main cleaning tool cask. The reel manages both the crawler tether (for power supply and control/video) and the aspiration pipe. 15 m of 50 mm OD aspiration pipe are here used as reference for the reel dimensions.

On the frontal part of the crawler an actuated cleaning head, controlled with two motors, position and moves the aspiration nozzle along the pipe surface. Correct cleaning is monitored with crawler on-board camera.

The rear section of the cleaning tool hosts the pipe/cable reel, HEPA filter box and aspiration unit. The aspirator exhausts inside the cleaning tool as the system works inside the confinement box. Differential pressure sensor could be added to monitor actively the global efficiency of the confinement.

Removable covers, part of the tool confinement allows internal tool cleaning and decontamination for maintenance. A dedicated cover allows the replacement of the HEPA filter box. HEPA filter is foreseen with a simple RH interface so to be removed and replaced with its filter box minimizing the risk of dust spread.

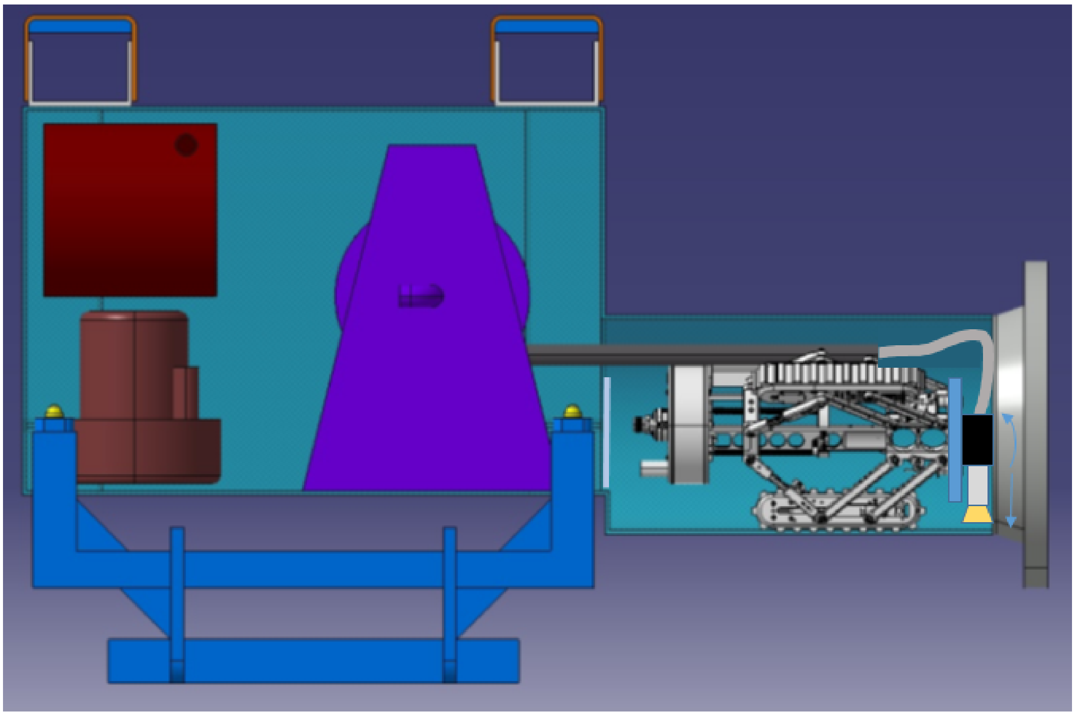


fig. 12 aspiration cleaning tool internal section

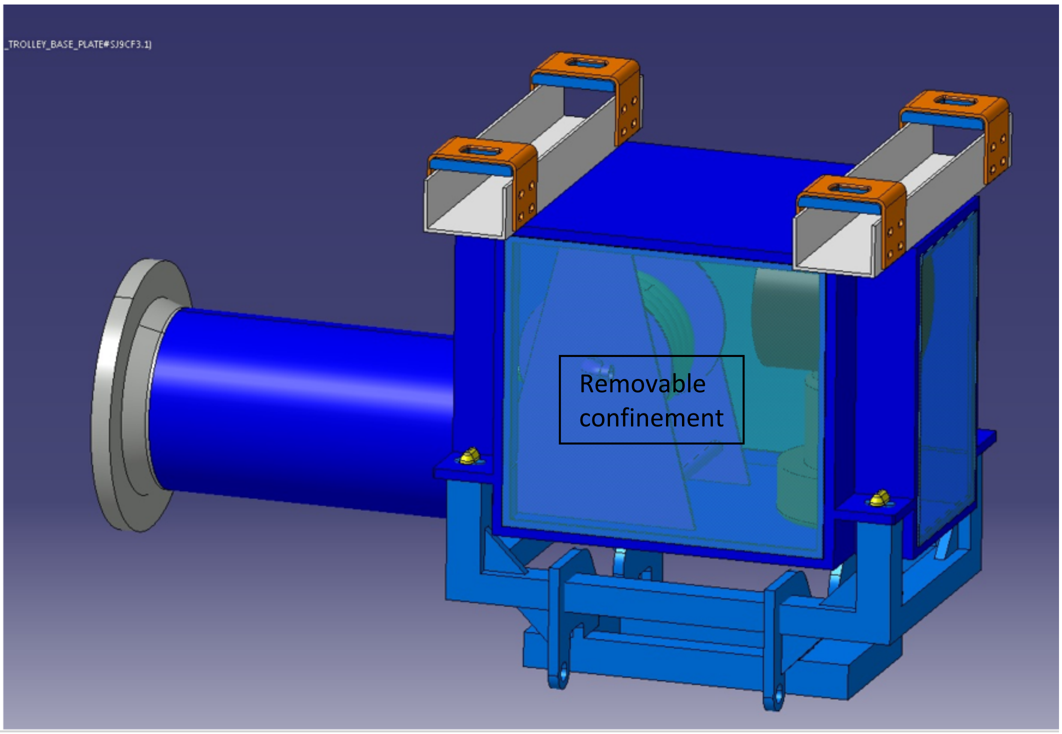


fig. 13 aspiration cleaning tool removable confinement

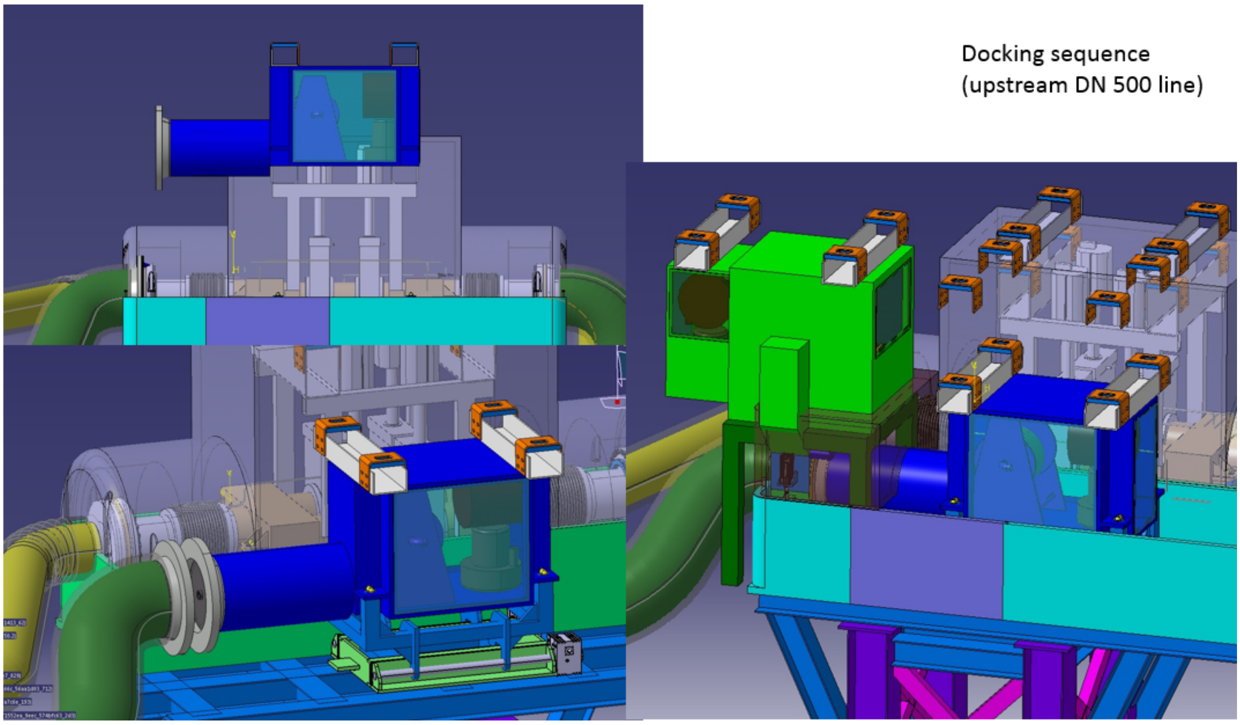


fig. 14 aspiration cleaning tool deployment sequence

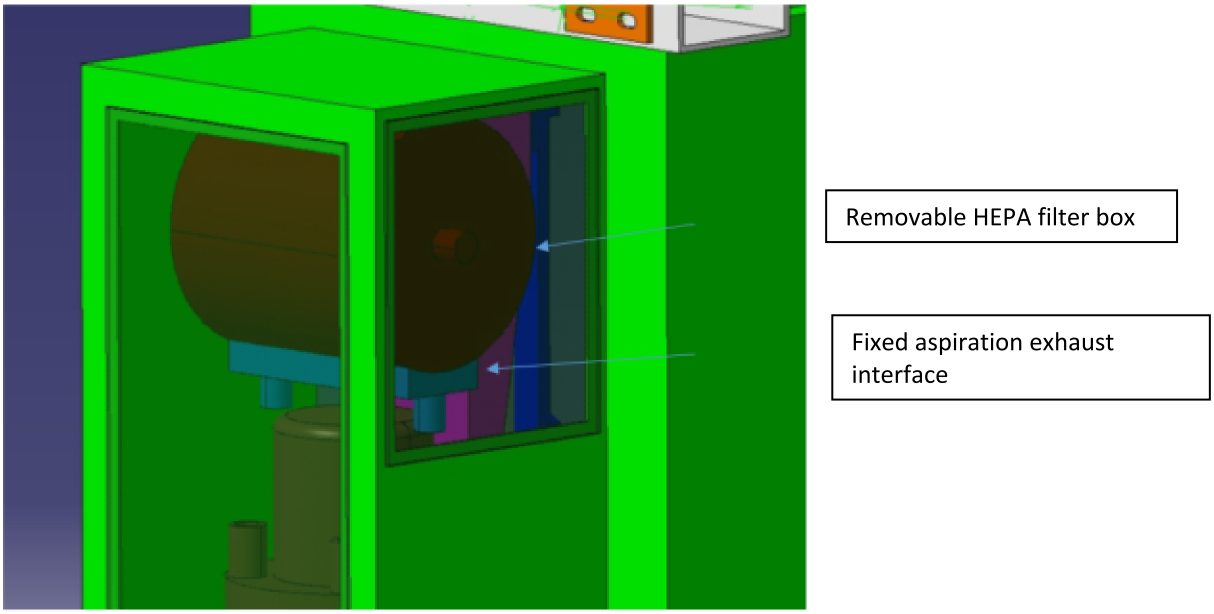


fig. 15 HEPA filter box typical layout

3.3 Waterjet cleaning robot

The water jet cleaning tool is based on a layout similar to the aspiration tool.
According to the reference cleaning scenario this tool will be used to clean the downstream pipe sections from RD/BLV downstream flanges to DTR located VST manifolds.
Waterjet cleaning tool is based on the DN300 pipe configuration. As in the RD/BLV main assembly reference design, bellow is used to compensate reference support frame misalignment with the line docking flange.

A rubber front seal is used for flange connection sealing. Rubber seal requires sealing lower specific load than double metallic seal and is more alignment tolerant with a reduced risk of surface damage. Three RH screws are positioned spaced on the flange for added docking safety.

An internal sleeve design shields bellow from water and ensures that any water spillage is drained to the VVPSS line. The same cleaning tool is used also on DN500 pipe replacing the docking flange. The tool cask has the alignment docking interfaces for both RD and BLV alignment frames.

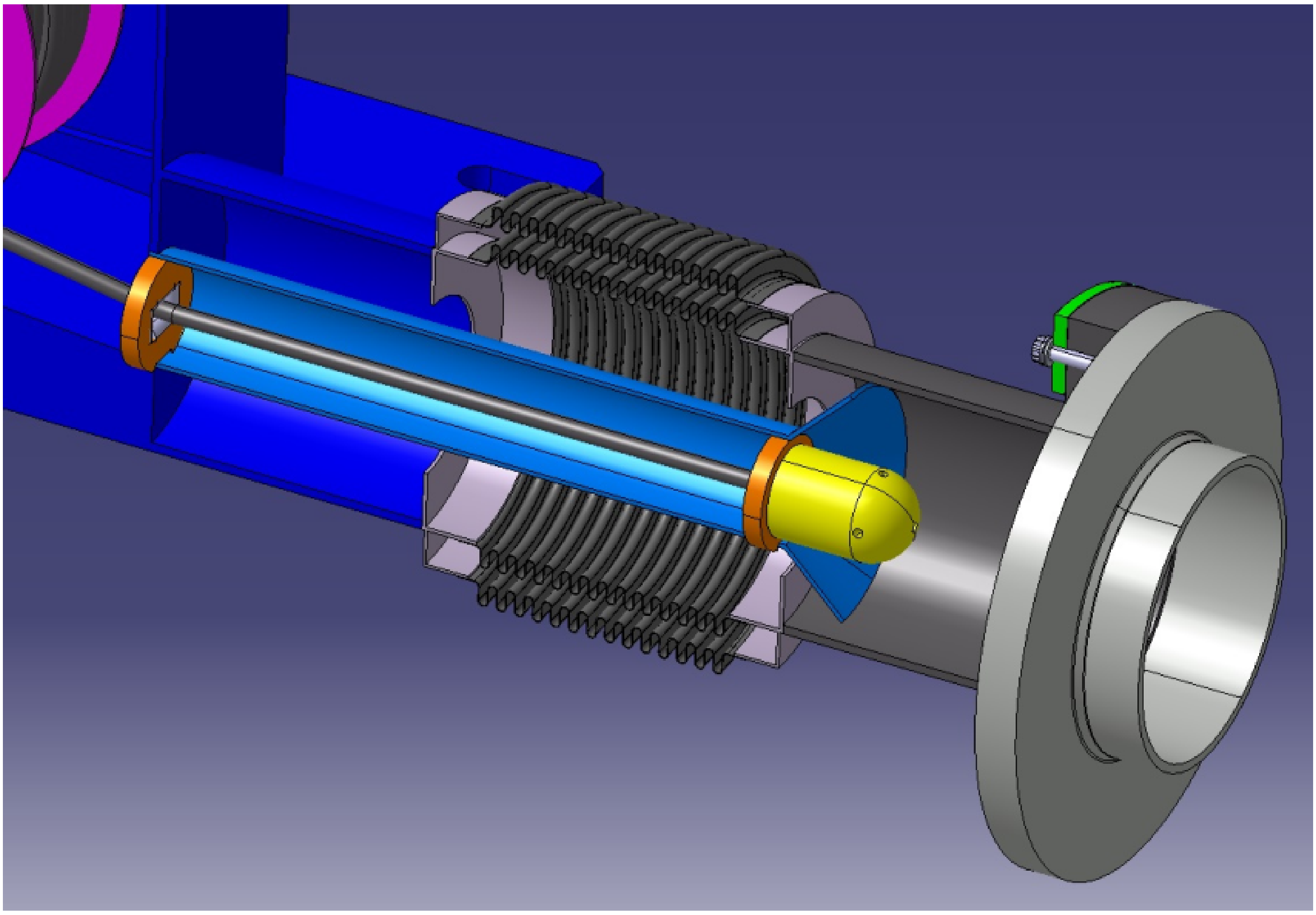


fig. 16 waterjet cleaning tool frontal section (DN300 setup)

Waterjet cleaning tool docking sequence is shortly resumed:

- The tool is moved from HCB to TB on RD/BLV stillage;
- The tool is lifted with monorail crane using generic adaptor and positioned on the RD/BLV alignment frame in neutral position;
- Confinement box is positioned on the two flanges to create a local confinement and remove closure plates;
- Alignment frame moves cleaning tool flange towards the fixed line flange;
- The flange self-align to the fixed flange thanks to the fixed flange dowel pins and corresponding receptacles;
- Flange face contact is then secured fastening with manipulator and standard bolting tool the three bolts available on the cleaning tool flange.

This simplified alignment and docking sequence is tentatively implemented for the cleaning tool. The feasibility of this approach should be carefully investigated in the next detailed design phase based on final flange design and bellow characteristics.

The implementation of the reference RD/BLV replacement sequence integrating in the cleaning tool rack such as the bolting tool rails as well as three bellow compression tools is considered a possible back-up solution.

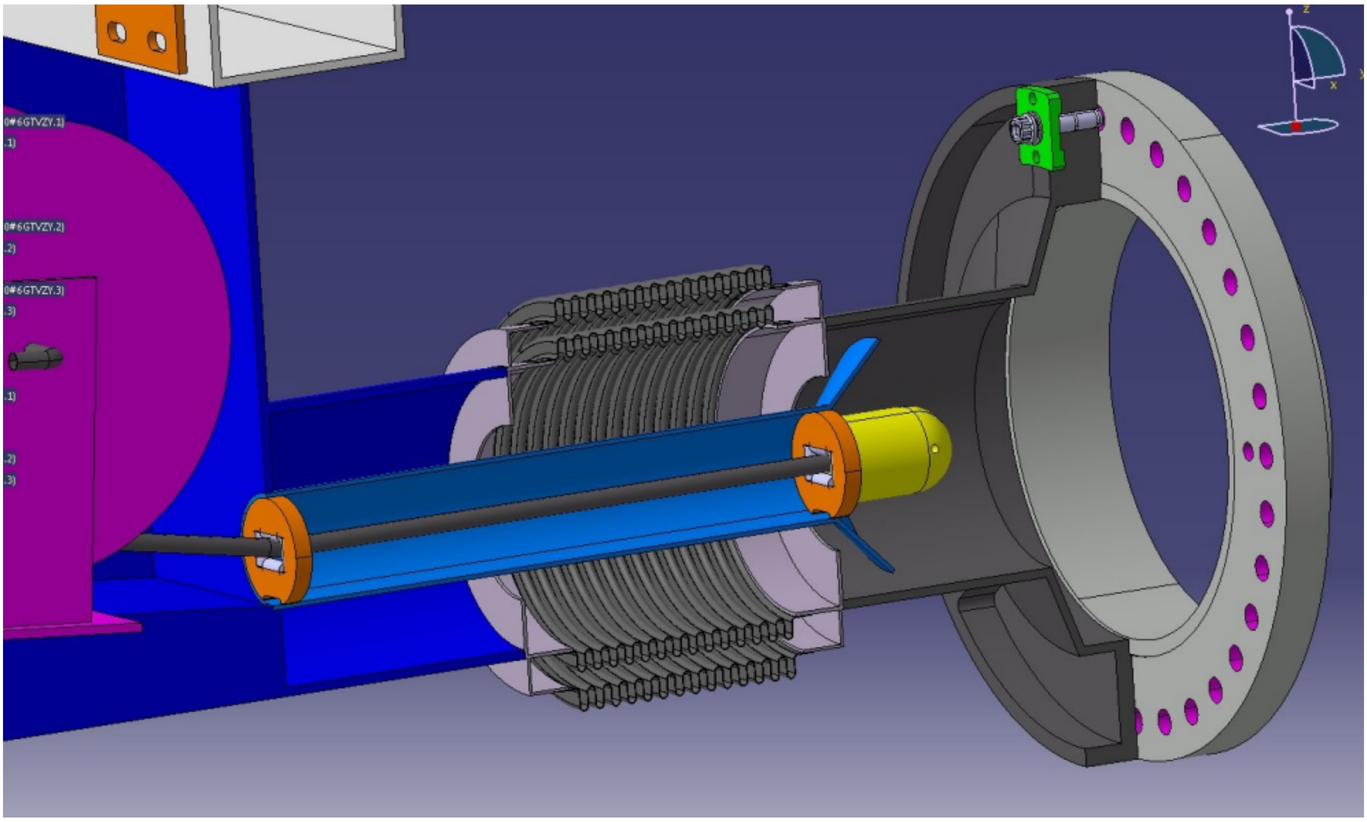


fig. 17 waterjet cleaning tool frontal section (DN500 setup)

As discussed the waterjet cleaning head is stored in the frontal section of the tool. A small confinement box positioned behind the cleaning head hosts the high pressure motorized hose reel.

The reel dimensions are based on commercial existing motorized reels in stainless steel and provide up to 45 m of 1/2" high pressure hose. The high pressure water pump unit is installed on the rear section of the tool inside the tool main frame but outside of the confinement box so to limit as far as possible the confined space.

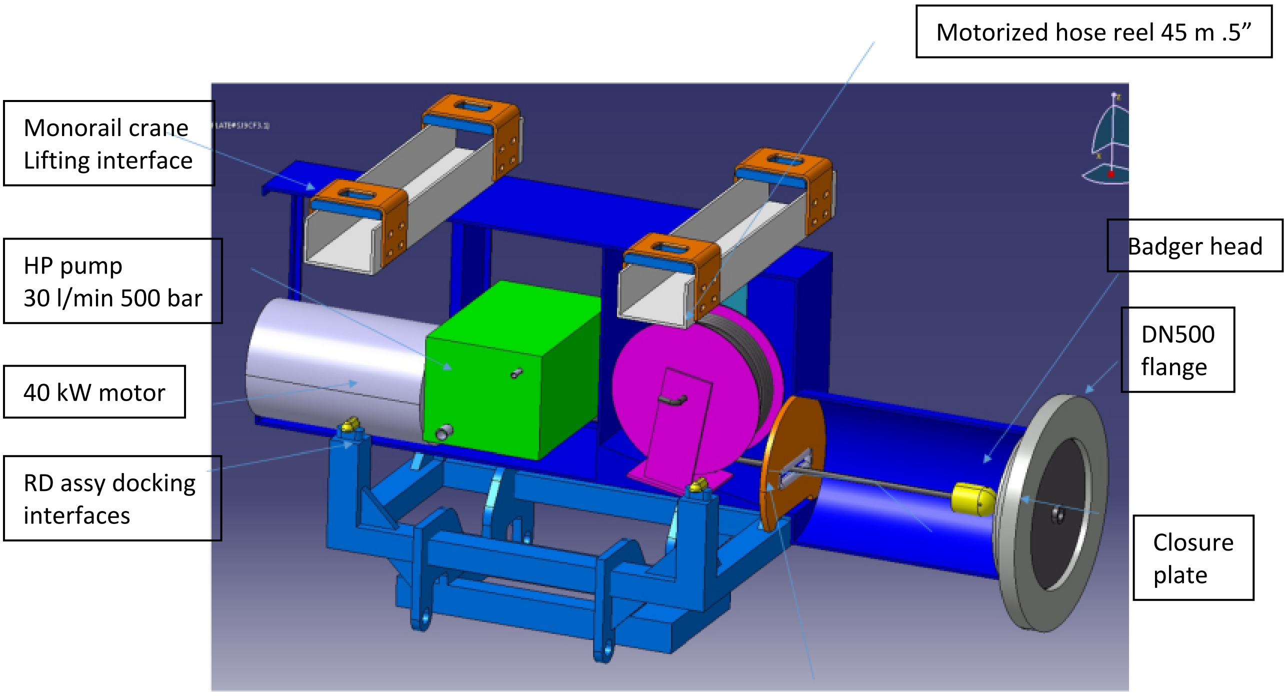


fig. 18 waterjet cleaning tool main component (simplified layout)

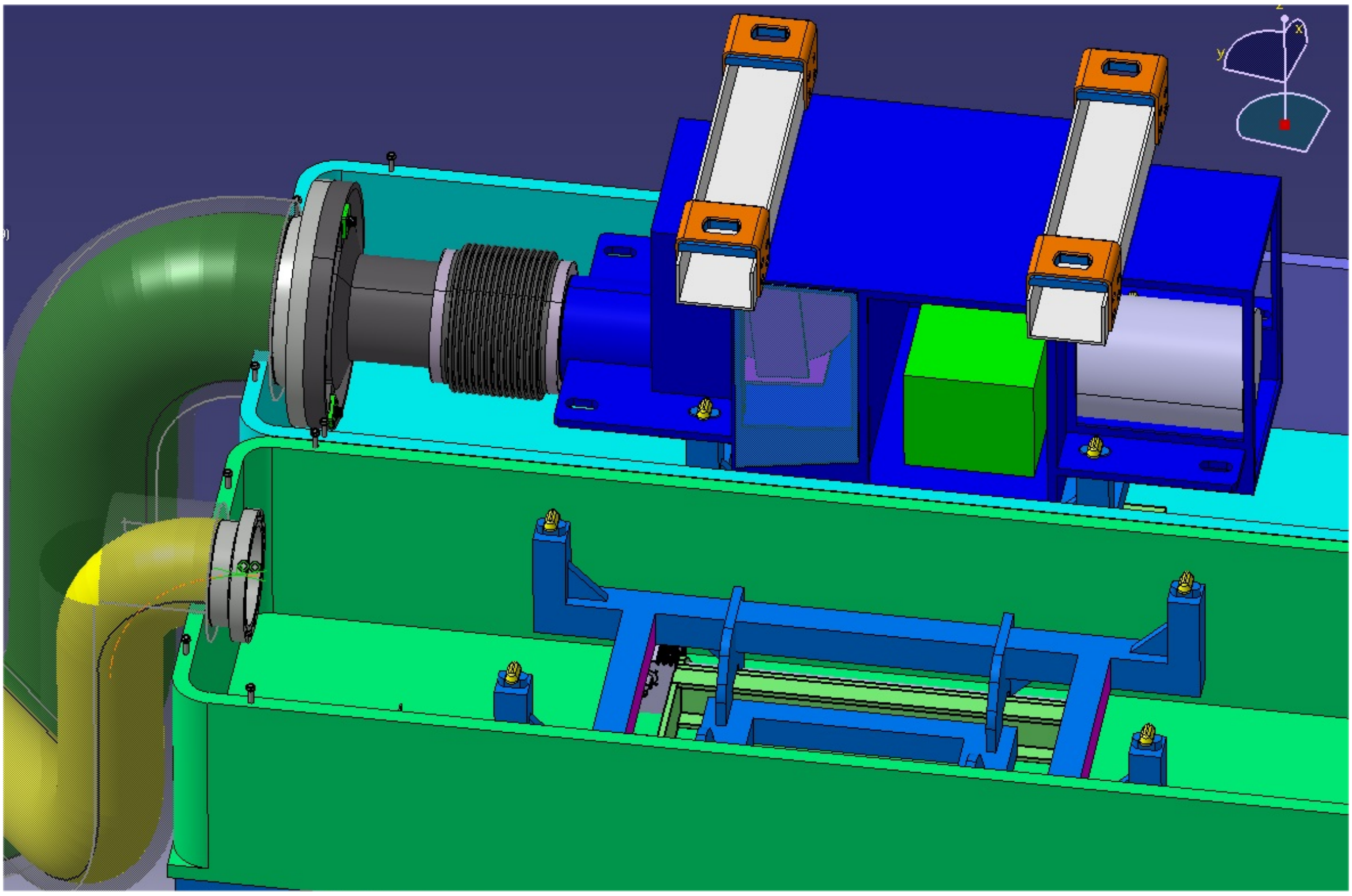


fig. 19 waterjet cleaning tool main connected to DN500 line

4 Concept design of the bolting tools

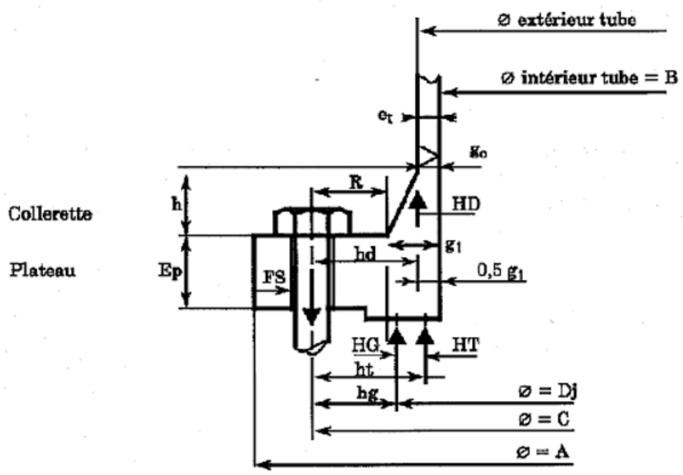
The following table reports the subtask requirements with some updates/comment based on the contract outcomes.

REQ	Concept design of the bolting tools	remarks/updates
2.1.01	Unbolting/bolting sequences shall be developed during the normal operation and accident cases.	unbolting/bolting sequence is performed by RH with the support of NB manipulator (see sec.8)
2.1.02	The bolting tool shall be capable of being deployed remotely from the equatorial cask to the operating configuration.	deployment of tools from equatorial cask to working configuration is foreseen by NBRHS (see sec. 8)
2.1.03	The bolting tool shall perform the bolting operation in a symmetrical way in order not to damage the metallic seal.	twin bolting heads work in parallel (see sec. 4.4)
2.1.04	The bolting tool shall be capable of measuring the bolting torque.	integrated bolting head are based on COTS precision devices that fulfil this requirement (see sec. 4.2)
2.1.05	The bolting tool shall be remote handling compatible for refurbishment and decontamination in the hot cell building. The decontamination means removal of any contamination in the tool so that maintenance by human worker is possible. The refurbishment means replacement of failed parts.	little or no contamination is foreseen on bolting tool that is used outside the VV confinement. See sec. 8 for further detail about tools deployment, recovery and decontamination.
2.1.06	The unbolting/bolting operation during the regular maintenance of the rupture disk shall be RH class 1.	
2.1.07	The unbolting/bolting operation after the accidents shall be RH class 2.	

tab. 4 bolting tool REQ

4.1 Flange design review and tightening bolt sizing

CAD flange design is based on the DN 500 reference dimensions defined according to RCC-M verification performed and DN 300 RF-FF design. No specific verification was done on this design.



flange inner diameter	$B_f := 488.94mm$
flange outer diameter	$A_f := 755mm$
Thickness	$g_{0f} := 9.53mm$
Diameter of drilling circle	$C_f := 670mm$
Thickness of flange	$E_{pf} := 55mm$
Thickness of skirt	$g_{1f} := 27mm$
Height of skirt	$h_f := 63mm$
Poisson ratio	$\nu_f := 0.3$

fig. 20 DN500 reference calculations

Axially retaining features are embedded in the two green plates. Four spokes engages four radial slots in the thicker section of the flange (fixed part). A limited axial play is left to avoid over constrained flange. An angular displacement of +/-1° is left so to align the two flanges

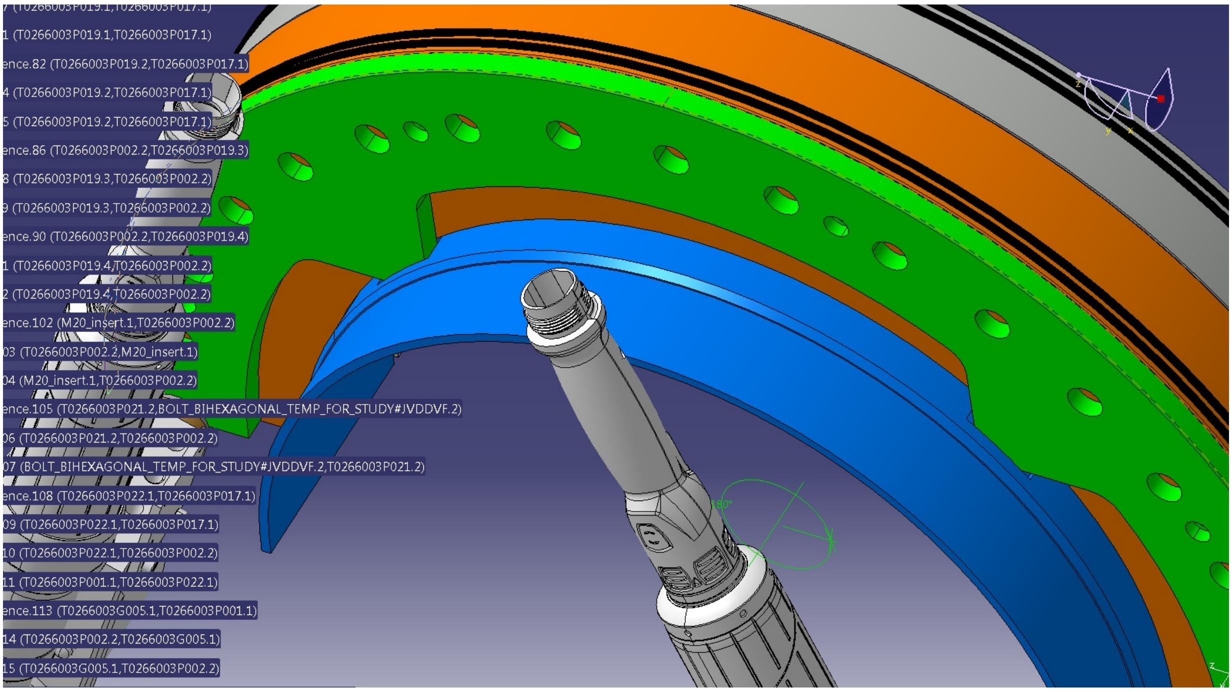


fig. 21 DN500 axial retention plate

Conical centring pin are also integrated in the flange design so to compensate, exploiting the bellow compliance possible misalignment (see following picture for preliminary misalignment specification)

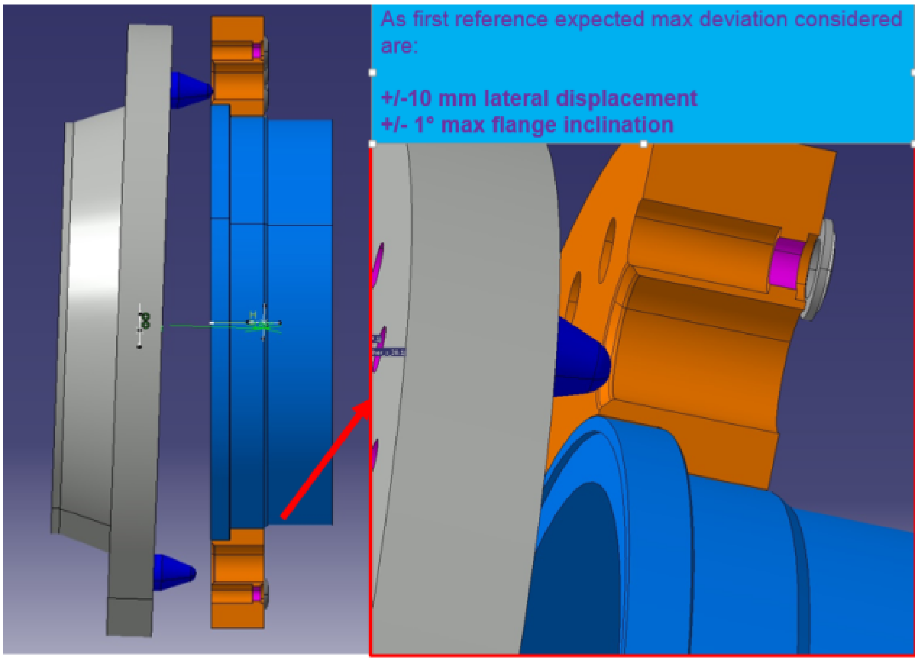


fig. 22 max flange deviation specifications

The same concept is also scaled to the DN300 flange used for BLV connection (the two flanges are shown in the following pictures). Also in this case the design of the DN 300 flange is oriented to RHS and not supported by verification.

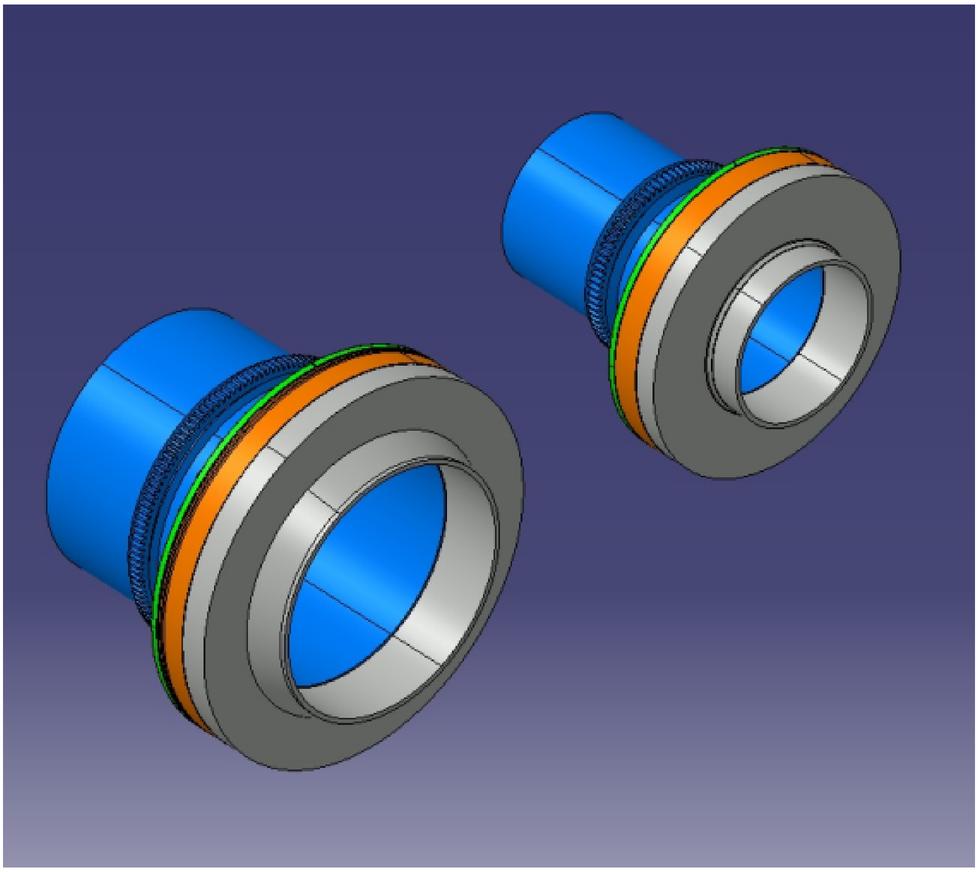


fig. 23 DN 300 flange and DN 500

Flange bolts size is based on the DN 300 RF-FF design developed by the VV team with no further specific verification in this stage.

4.2 BT commercial reference

The dimensioning bolts size for the bolting tool design is the DN 500 M20 screw, the corresponding expected max bolting torque was set to 662 Nm.

Table 4: Bolting tool torque specification.

Bolt thread size (mm)	Bolt running torque (Nm)	Nominal tightening torque requirement (Nm)	Estimated nominal pre-load (kN), assuming K=0.15	Nominal tightening torque requirement, allowing for ±5% tool accuracy (Nm)	Worst case tightening torque after ±5% tool accuracy (Nm)	Worst case break-out torque (assuming 200%) (Nm)
M12	<25	60	35	63	66	132
M16	<25	160	65	168	176	352
M20	<25	300	101	315	331	662
M24	<25	520	146	545	572	1144
M30	<25	1030	232	1081	1136	2271
M36 (layshaft only)	<25	1800	338	1890	1984	3969

tab. 5 bolting torque

The consequent commercial reference was found in a Desoutter bolting tool based on the EAD280-370 integrated with 4x torque multiplier able to deliver a max torque of 950 Nm at 92 rpm.

The same bolting head is kept for standardization also for the DN 300 bolting tool even if different tuning and different bolt setup is considered in this case.

EAD280-370 TECHNICAL DESCRIPTION

Metric | Imperial

Discover all our EAD280-370 products by Desoutter Industrial Tools. Find the complete range of EAD280-370 products and contact Desoutter Industrial Tools for a quote or a demonstration.

Part Number	6151656840
Model	EAD280-370
Free Speed	370 rpm
Maximum Torque (Fwd)	280 Nm
Min. Torque	60 Nm
Recommended Torque	250 Nm
Net Weight	6.1 kg
Length	681 mm

fig. 24 Desoutter commercial bolting tool (motor only)

4.3 BT space reservation

Bolting tool space reservation is dimensioned over two bolting tool symmetrically oriented in consideration of the two bolt limit positions (fully extracted and fully bolted) and of the needed bolting head disengagement space.

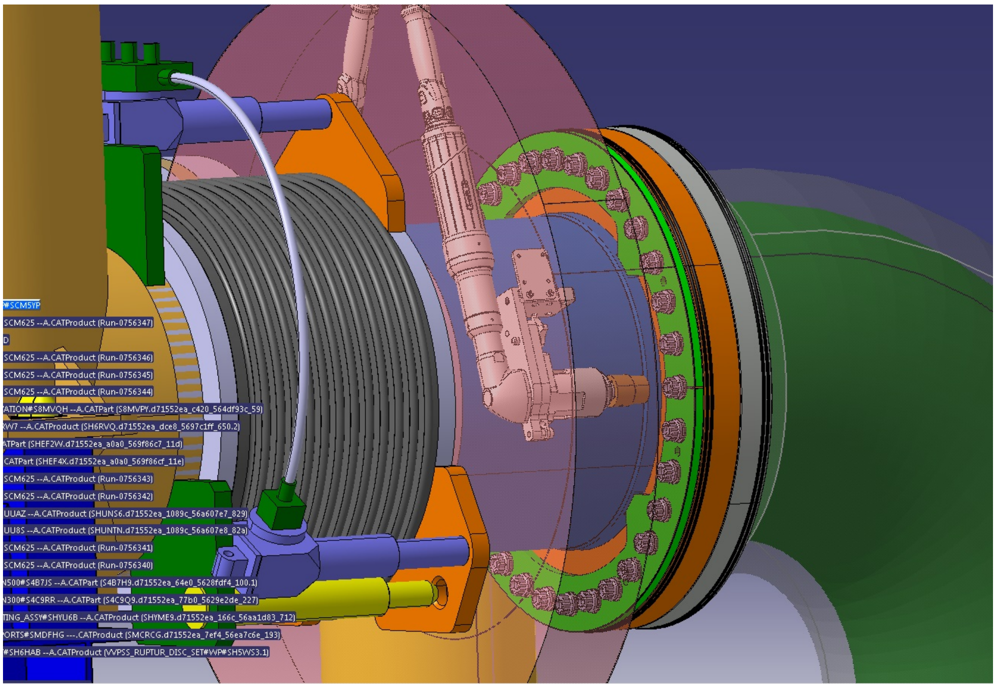


fig. 25 updated flange design/space reservation

4.4 BT deployment frame

The two bolting heads are supported by a deployment frame that docks on two machined rail welded on the rotating flange pipe section.

Each bolting tool is moved axially on two recirculating ball guides and a motorized screw. The bolting head is provided with a torque reaction lever and is connected to the axial support with a rotational compliance not to load the deployment frame with the bolting torque.

The frame in held on the pipe with two actuated stabilizing wheel set that clamp the frame on the rail.

A central drive unit coupled to the pipe with pinion/gear transmission moves the bolting heads to perform the bolting/unbolting sequence. All the described actuation should be provided with auxiliary connection for failsafe operation so that the same can be disengaged/removed with the intervention of the manipulator.

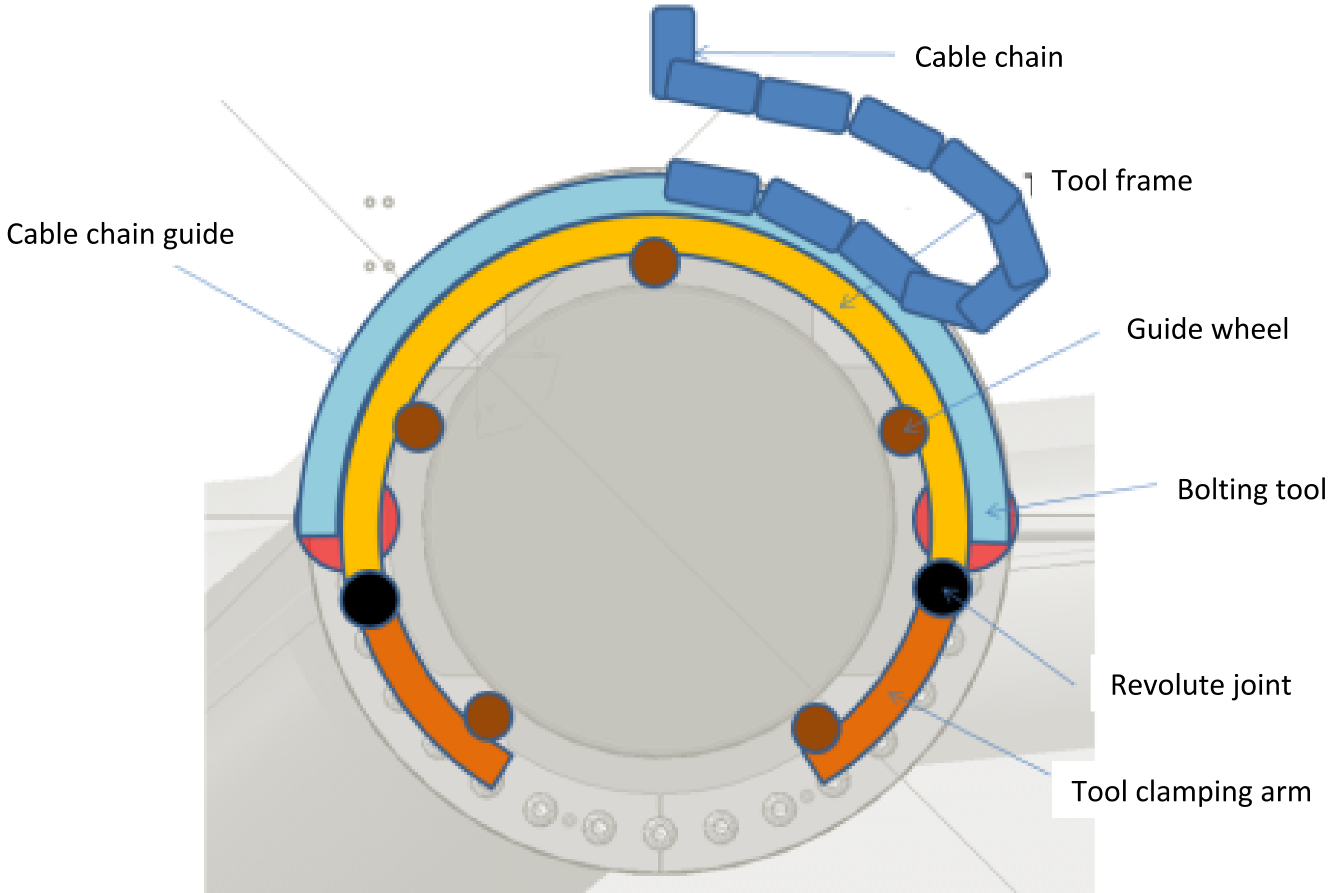


fig. 26 bolting tool conceptual design

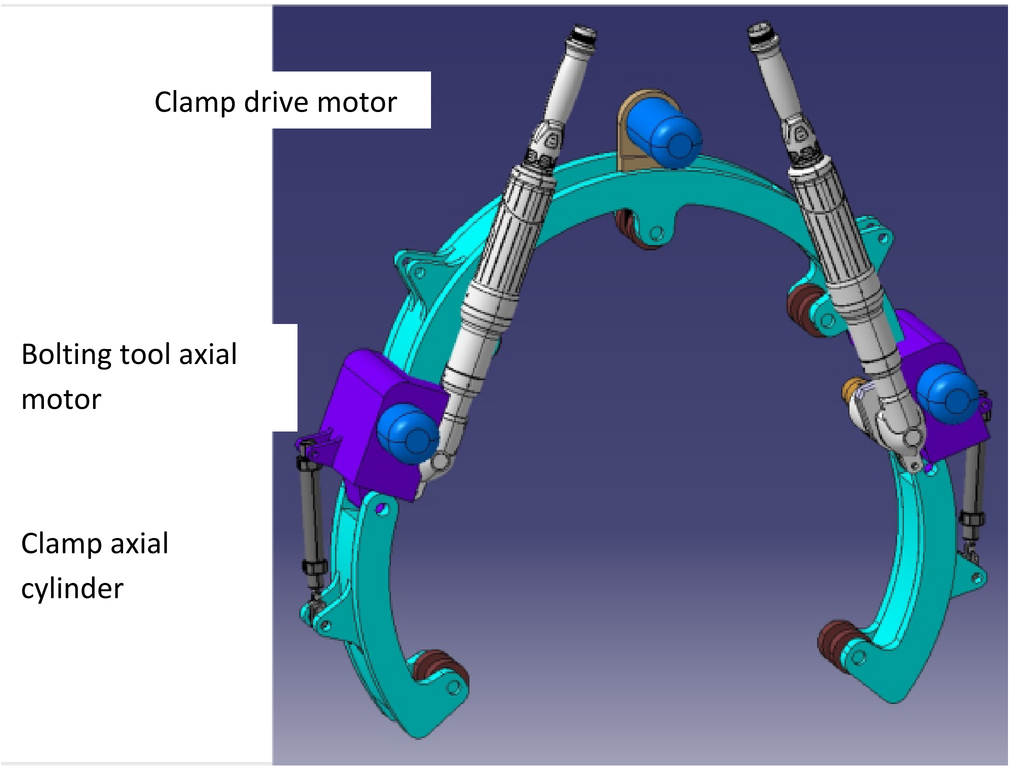


fig. 27 bolting tool conceptual design

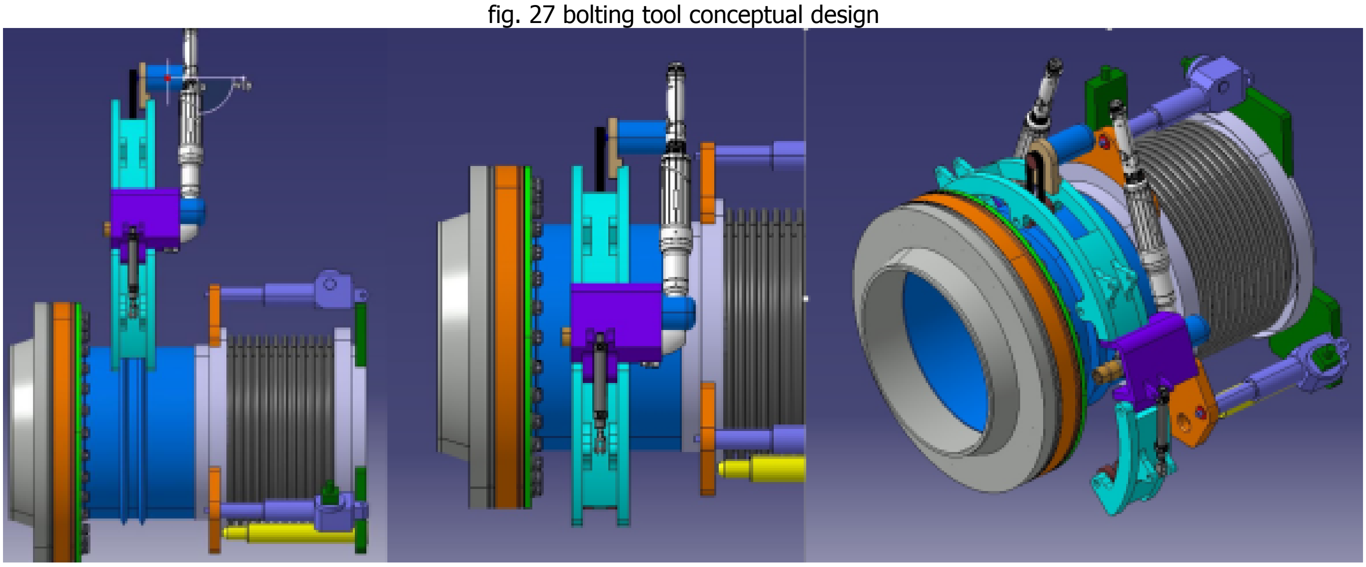


fig. 28 bolting tool clamping sequence

To define internal space reservation in the bolting tool design some first approximation calculation are below reported and discussed.

bolting tool mass estimation				
	qty			
bolting head	2	15	30	
bolting head traslation unit	2	5.5	11	
main rotation motor	1	5	5	
main frame+guides	1	10	10	
lateral clamps+actuation	2	5	10	
cables+cable guides (local)	1	4	4	
total mass			70	kg

tab. 6 DN500 bolting tool mass estimation

A first mass estimation is defined. Based on this clamping force is calculated in the reference configuration of the BT rotated by 180° with the contribution of only one clamp supporting the tool full weight (safety factor 2) and pneumatic cylinder are consequently dimensioned.
The above picture shows the lever/link configuration with tool in the described configuration on the preliminary cad release while the following table shows minimal cylinder size.

The following table resumes the assumption and calculations done to dimension the electrical actuators for the axial displacement of the bolting head and the bolting tool rotation.
Each bolting head is supported/guided by four-paired recirculating cart on two parallel guides. The axial displacement is controlled with a ball screw with translating nut. The screw is actuated with a frameless brushless motor integrated in a custom made motor frame. This solution is here preferred to the integration of a standard housed motor because of the higher freedom in the system design and the smaller overall dimensions achievable.
A similar layout is considered for the actuation of the drive pinion that controls the rotation of the bolting tool. In this case the pinion is assembled on the output flange of a standard Harmonic Drive gearbox that is again integrated with a frameless motor.
To allow system recovery in case of failure all motors are provided with protruding shaft on the rear side so to drive the actuation in case of need with an external bolting tool (task performed by the manipulator).

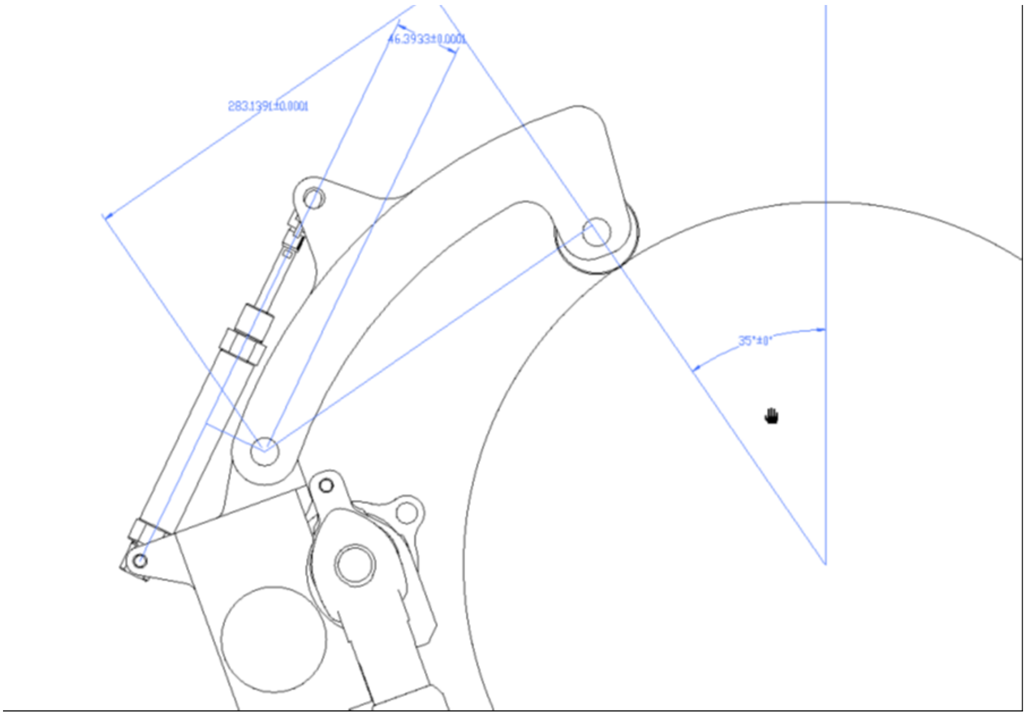
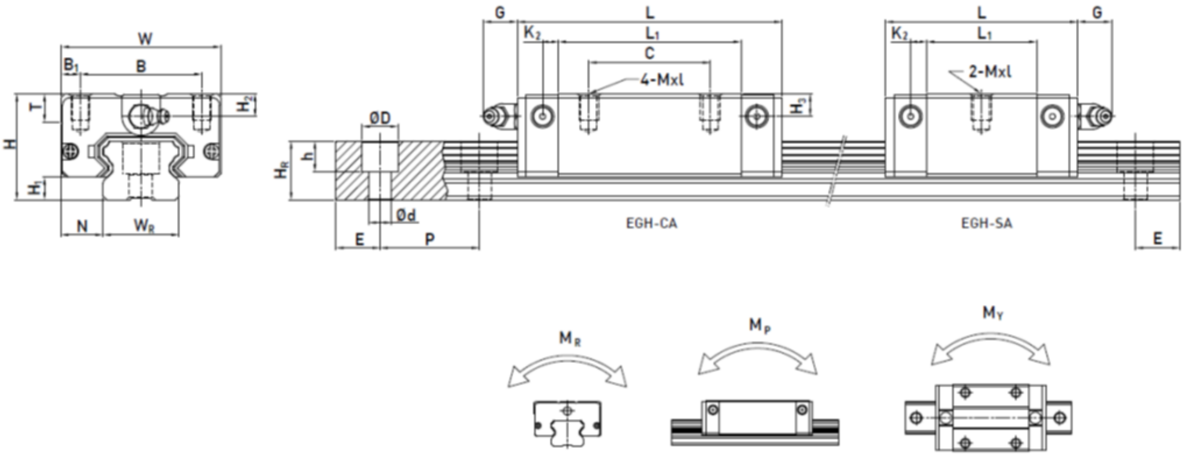


fig. 29 preliminary clamp lever configuration.

clamp actuation verification							
alfaF (compression force inclination)	35	°	0.610865238				
F	85.45422	N	two cylinder in parallel Only one is considered here as safety				
LF	283	mm	pressure wheel lever				
Lc	60	mm	cylinder lever				
Fc	403.0591	N					
Pref	0.6	Mpa					
Dcyl	29.24582	mm	minimal cylinder diameter				

tab. 7 DN500 clamp calculation

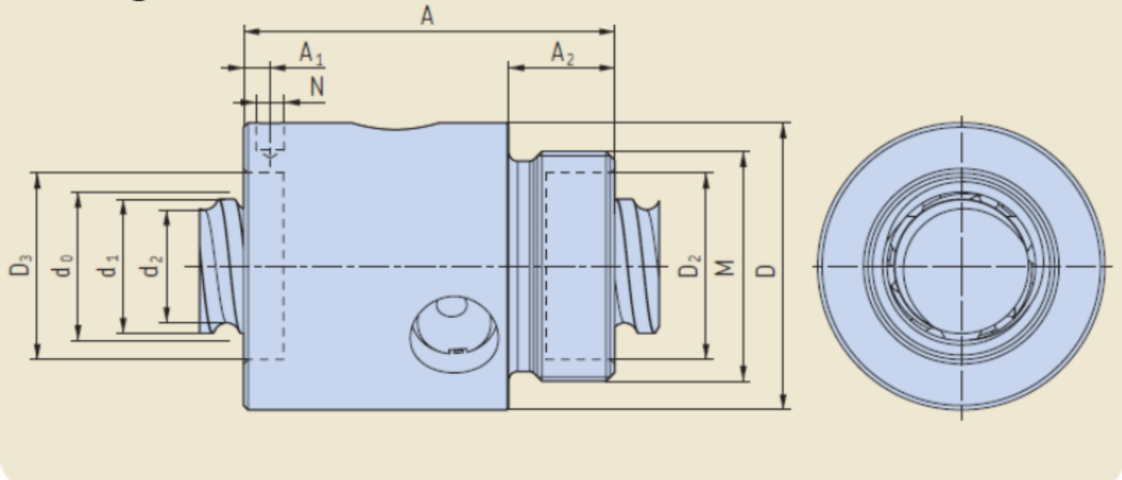
Bolting head guides



Model No.	Dimensions of Assembly (mm)			Dimensions of Block (mm)													Dimensions of Rail (mm)							Mounting Bolt for Rail	Basic Dynamic Load Rating	Basic Static Load Rating	Static Rated Moment			Weight	
	H	H_1	N	W	B	B_1	C	L_1	L	K_1	K_2	G	Mxl	T	H_2	H_3	W_R	H_R	D	h	d	P	E	(mm)	C(kN)	C_0 (kN)	M_R kN-m	M_P kN-m	M_Y kN-m	Block kg	Rail kg/m
EGH15SA	24	4.5	9.5	34	26	4	-	23.1	40.1	14.8	3.5	5.7	M4x6	6	5.5	6	15	12.5	6	4.5	3.5	60	20	M3x16	5.35	9.40	0.08	0.04	0.04	0.09	1.25
EGH15CA							26	39.8	56.8	10.15															7.83	16.19	0.13	0.10	0.10	0.15	

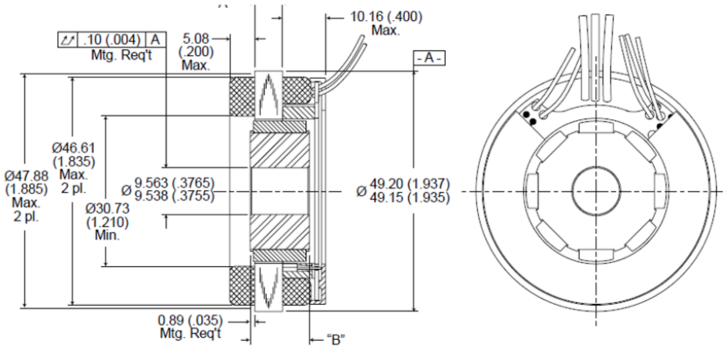
fig. 30 HIWIN bolting head support guides

Bolting head screw



Appellativo	Vite		Madrevite		Senza raschiaolio	Con raschiaolio		Chiave di serraggio			Senza raschiaolio	
	d_2	d_1	D h10	M 6g	A +/-0,3		A_2	(FACOM)	N	A_1 ± 0,2	D_2	D_3
—	mm											
SHS 6x2 R	4,7	6,0	16,5	M14x1,0	20	-	7,5	126-A35	3,2	3	8,3	-

fig. 31 SKF bolting head ball screw



Motor Parameters	Symbols	Units	01212
Max Cont. Output Power	HP Rated	HP	0.243
at 25°C amb.	P Rated	Watts	181
Speed at Rated Power	N Rated	RPM	8100
Max Mechanical Speed	N Max	RPM	18000
Continuous Stall Torque	Tc	oz-in	43.5
at 25°C amb.		N-m	0.307
Peak Torque	Tp	oz-in	168
		N-m	1.18
Max Torque	Tsl	oz-in	168
for Linear KT		N-m	1.18

MODEL NUMBER	RBE-01210	RBE-01211	RBE-01212	RBE-01213	RBE-01214	RBE-01215
"A" Dimension	5.72 (0.225)	12.7 (0.500)	19.05 (0.750)	25.4 (1.000)	33.02 (1.300)	50.8 (2.000)
"B" Dimension	12.07 (0.475)	19.05 (0.750)	25.4 (1.000)	31.75 (1.250)	39.37 (1.550)	57.15 (2.250)
Tolerance ± .010 on "A" Dimension.						

fig. 32 KOLLMORGEN axial translation motor selection

Change size	20-2UH	Unit	
Ratio		i []	160
Repeatable peak torque		T_R [Nm]	64
Average torque		T_A [Nm]	34
Rated torque		T_N [Nm]	28
Momentary peak torque		T_M [Nm]	95
Maximum input speed (grease lubrication)		$n_{in\ (max)}$ [min^{-1}]	6500
Average input speed (grease lubrication)		$n_{av\ (max)}$ [min^{-1}]	3500
Moment of inertia		J_{in} [$x10^{-4}$ kgm^2]	0.09
Weight		m [kg]	0.65
Transmission accuracy		[arcmin]	< 1
Torsional stiffness		K_3 [$x10^3$ Nm/rad]	25
Ambient operating temperature		[°C]	0 ... 60
Output bearing			
Dynamic radial load		$F_{R\ dyn\ (max)}$ [N]	828
Dynamic axial load		$F_{A\ dyn\ (max)}$ [N]	1240
Dynamic tilting moment		$M_{dyn\ (max)}$ [Nm]	91

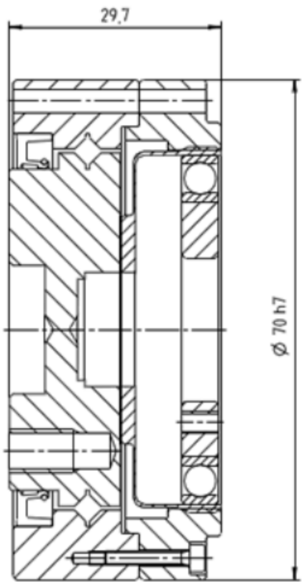
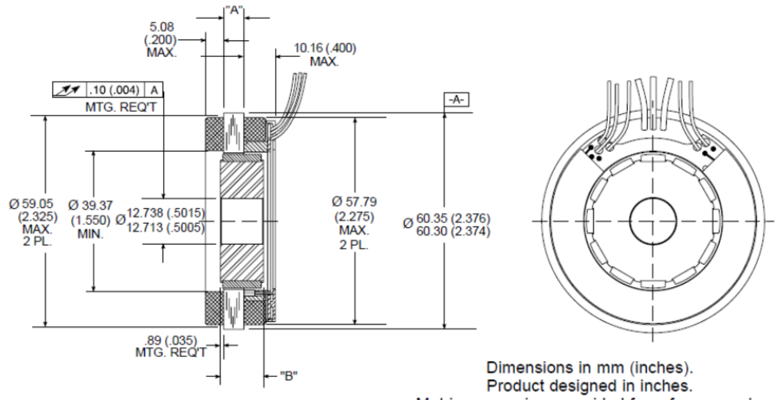


fig. 33 HARMONIC DRIVE gearhead



Motor Parameters	Symbols	Units	01514
Max Cont. Output Power	HP Rated	HP	0.264
at 25°C amb.	P Rated	Watts	197
Speed at Rated Power	N Rated	RPM	3570
Max Mechanical Speed	N Max	RPM	16500
Continuous Stall Torque	Tc	oz-in	114
at 25°C amb.		N-m	0.808
Peak Torque	Tp	oz-in	403
		N-m	2.85
Max Torque	Tsl	oz-in	403
for Linear KT		N-m	2.85

Dimensions in mm (inches).
Product designed in inches.
Metric conversions provided for reference only.

MODEL NUMBER	RBE-01510	RBE-01511	RBE-01512	RBE-01513	RBE-01514	RBE-01515	RBE-01516
"A" Dimension	5.72 (0.225)	12.7 (0.500)	19.05 (0.750)	25.4 (1.000)	33.02 (1.300)	38.1 (1.500)	50.8 (2.000)
"B" Dimension	12.07 (0.475)	19.05 (0.750)	25.4 (1.000)	31.75 (1.250)	39.37 (1.550)	44.45 (1.750)	57.15 (2.250)
Tolerance ± .010 on "A" Dimension.							

fig. 34 KOLLMORGEN rotation motor selection

To complete the bolting tool conceptual design umbilical cable routing with is also integrated as visible in the following updated pictures. The commercial reference of the cable chain is also reported.

Standard lifting point and manipulator interfaces for bolting tool alignment are also added to the final tool design.

bolting head actuator unit

specifications

axial stroke	60	mm	
axial nominal force	500	N	
radial offset(for flexional verification)	100	mm	TBC
overload margin	1.5		
Design max load	750	N	
max flexional load	75	Nm	

guideways calculation

railsize	15	mm	paired
Mf	200	Nm	max flexional load (paired)
C	11000	N	
offset (distance btw rails)	60	mm	TBC
Mt	660	Nm	max torsional reaction load (the bolting tool frame is NOT supposed to support bolting reaction torquel

linear actuation calculation

ballscrew size

D	6	
p	2	
Fn (design load)	1000	N
efficency	0.8	
Min (based on actuator design max load)	0.298415518	Nm

motor selection

KOLLMORGEN RBE 01212

Mn	0.3	Nm	

main rotation unit

tangential reaction force	274.4	N	
safety factor	5		
design tangential force	1372	N	
Dp	60	mm	(tentative)
Mout	82.32	Nm	
gearhead	HFUC2UH 20		
i	160		
eta	0.6		
Min	0.8575	Nm	
motor	RBE 01515		
Mn	0.89	Nm	

tab. 8 DN500 bolting tool motor/actuation calculation

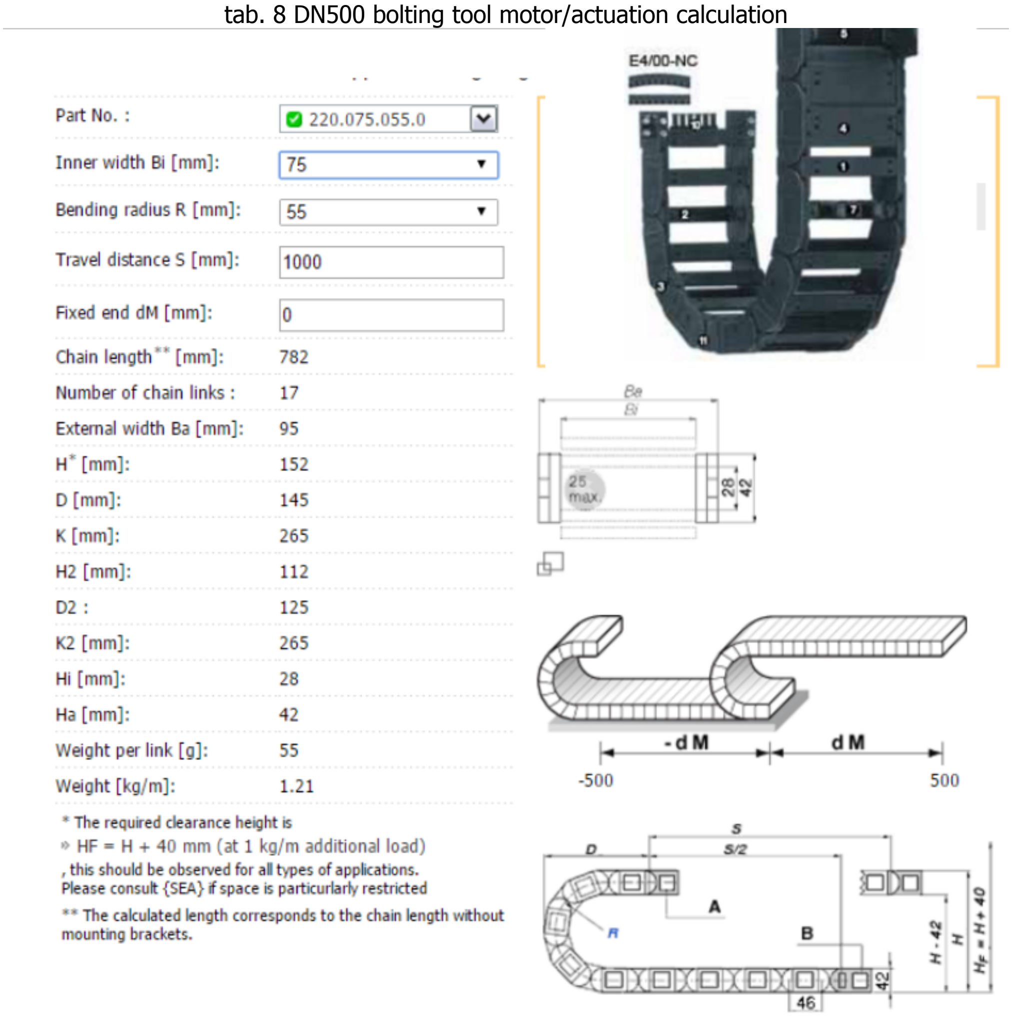


fig. 35 Cable chain commercial equivalent

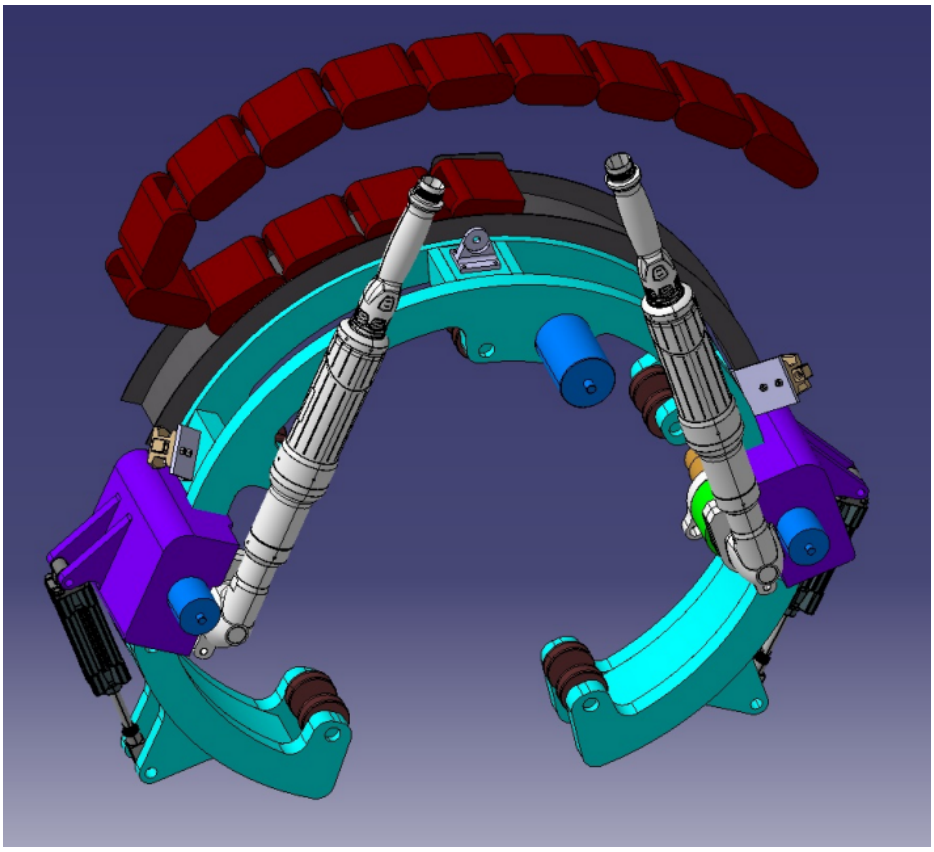


fig. 36 updated bolting tool design (DN500)

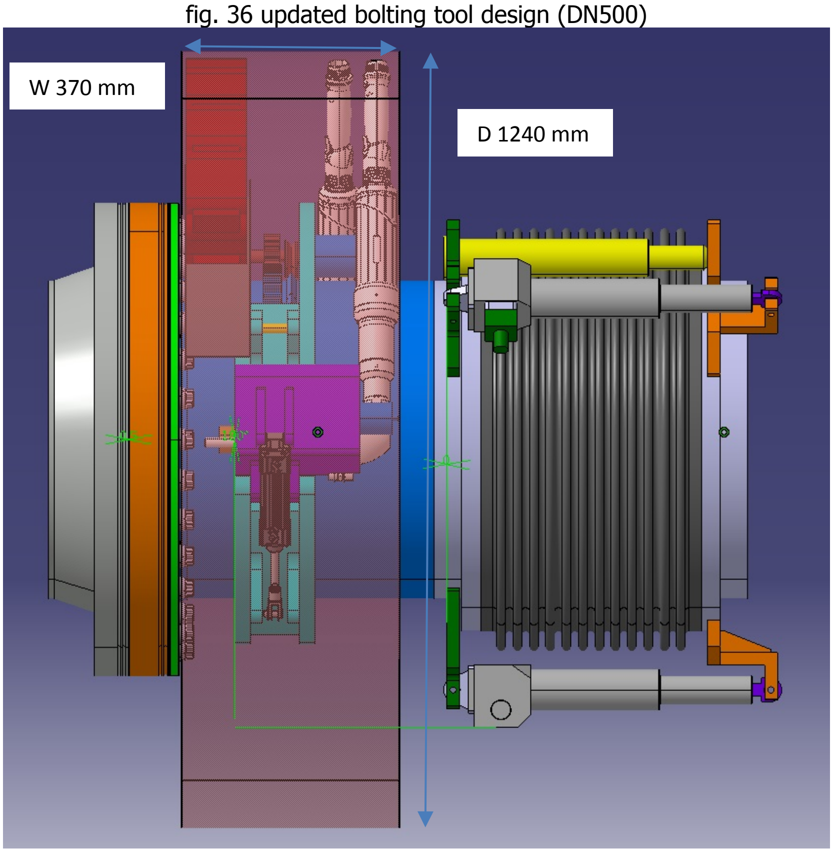


fig. 37 updated bolting tool design on pipe (DN500)

The same concept was also scaled to DN300 flange.

As anticipated a flange verification according to RCC-M will be mandatory to finalize the conceptual design presented.

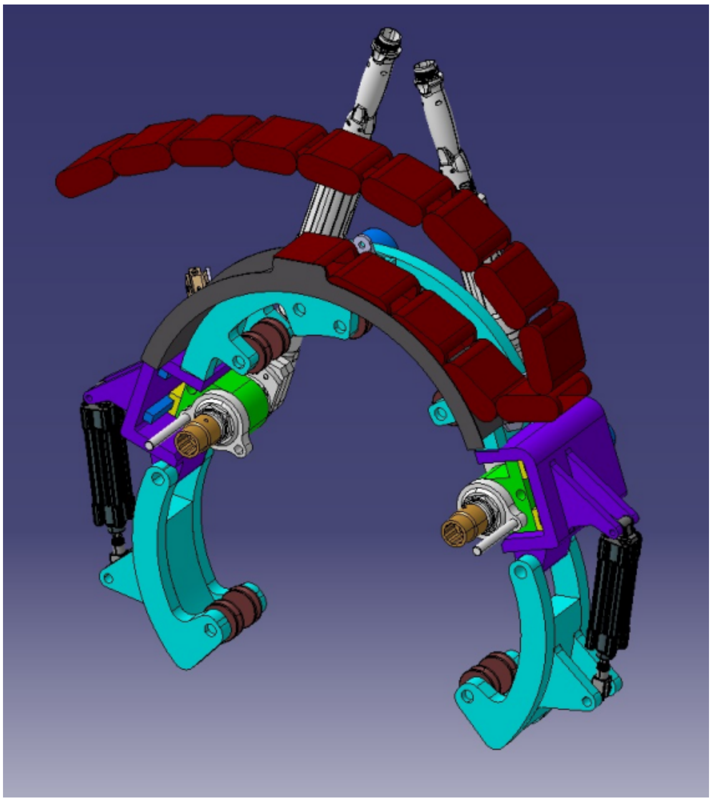


fig. 38 bolting tool on DN300

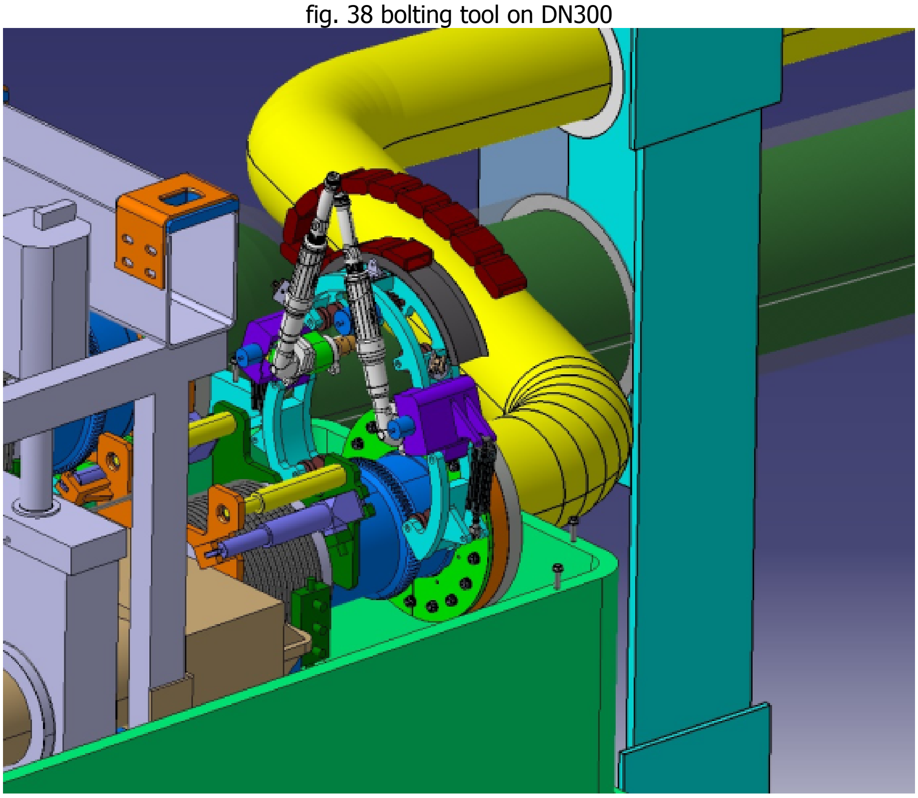


fig. 39 bolting tool on DN300 (docking phase)

4.5 Alternative solution- quick disconnect device for RH (quick disconnect device for RH)

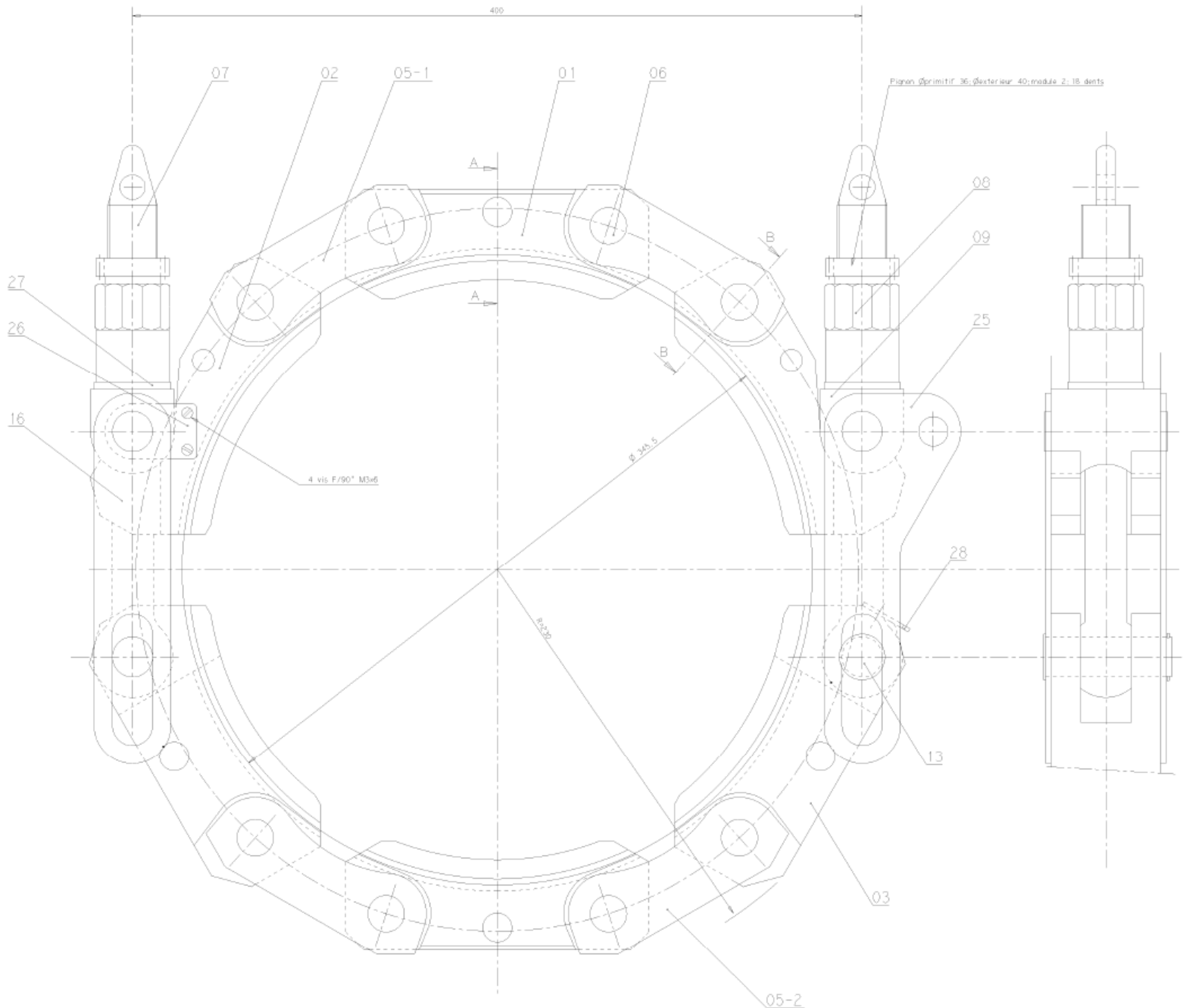


fig. 40 Technetics QDS

An alternative flange connection/disconnection design based on conical chain collar was also investigated.

The reference supplier of metallic seal used in ITER (Garlock/technetics) provided as reference the design of a collar validated on similar sealing performance at CEA in the 90s.

The flange design baseline was kept on the standard bolted flange design keeping this option for future reference.

5 Concept design of the confinement tools

The following table reports the subtask requirements with some updates/comment based on the contract outcomes.

REQ	Concept design of the confinement tools	remarks/updates
2.2.01	Confinement sequences during the maintenance operation shall be developed during the normal operation and accident cases.	confinement sequence is foreseen for RD and BLV replacement in both scenarios
2.2.02	The confinement tool shall be capable of being deployed remotely from the equatorial cask to the operating configuration.	deployment of tools from equatorial cask to working configuration is foreseen by NBRHS (see sec. 8)
2.2.03	Confinement shall be provided to the upstream relief line to isolate the VV from the NB cell.	closure plates are positioned on both upstream and downstream flanges to ensure static confinement when RD/BLV not in place. NO specific calculation/verification is done within the scope of the conceptual design in terms of max backpressure. No specification in this sense was defined. Some further detailed studies and verifications are recommended.
2.2.04	Confinement shall be provided to the downstream relief line to isolate the Drain Tank from the NB cell.	see 2.2.03
2.2.05	Confinement means of the relief lines shall allow preparation of the sealing track.	seal tracks are exposed when closure plate in position (see sec.6)
2.2.06	Confinement shall be provided to the rupture disk and valve module during its transportation.	closure plate are positioned on two sides of removable flange of RD/BLV assy (see sec. 5.4)
2.2.07	The confinement tool shall be remote handling compatible for refurbishment and decontamination in the hot cell building. The decontamination means removal of any contamination in the tool so that maintenance by human worker is possible. The refurbishment means replacement of failed parts.	see S.1.08
2.2.08	The bellows compression tool shall provide preloading to keep the confinement when bolts are removed.	bellow compression tool is based on the concept design developed by IO for NB injector front end components. Such tool is permanently connected to the bellow and is operated connecting a bolting tool or dedicated actuating device by means of the RH manipulator (see sec.5.1)
2.2.09	The bellows compression tool shall provide compression of the bellows to secure gaps between flanges during the confinement operation.	compression tool actuation defined according to bellows known specs. Commercial equivalent considered as conceptual design reference
2.2.10	The alignment tool shall provide alignment when installing the components by the monorail crane.	alignment tool already developed and integrated from IO
2.2.11	The alignment tool shall provide movement during the confinement operation.	see above
2.2.12	The alignment tool shall provide mechanical support of the components during the machine operation.	see above
2.2.13	The alignment tool shall be capable of accommodating the movement of the relief line during the machine operation and during the NB front end component maintenance.	see above

2.2.14	The lower confinement box shall provide confinement during the confinement operation.	the confinement is based on a removable upper thermal insulation box, a fixed lower thermal insulation box and a deployable clamshell confinement tool.
2.2.15	The lower confinement box shall provide mechanical support of the components during the machine operation.	this apply to lower fixed thermal insulation box out of the scope of this contract
2.2.16	The lower confinement box shall be capable of accommodating the movement of the relief line during the machine operation and during the NB front end component maintenance.	see above
2.2.17	The confinement operation during the regular maintenance of the rupture disk shall be RH class 1.	
2.2.18	The confinement operation for the RH maintenance after the accidents shall be RH class 2.	

tab. 9 confinement tool REQ

5.1 bellow compression tool

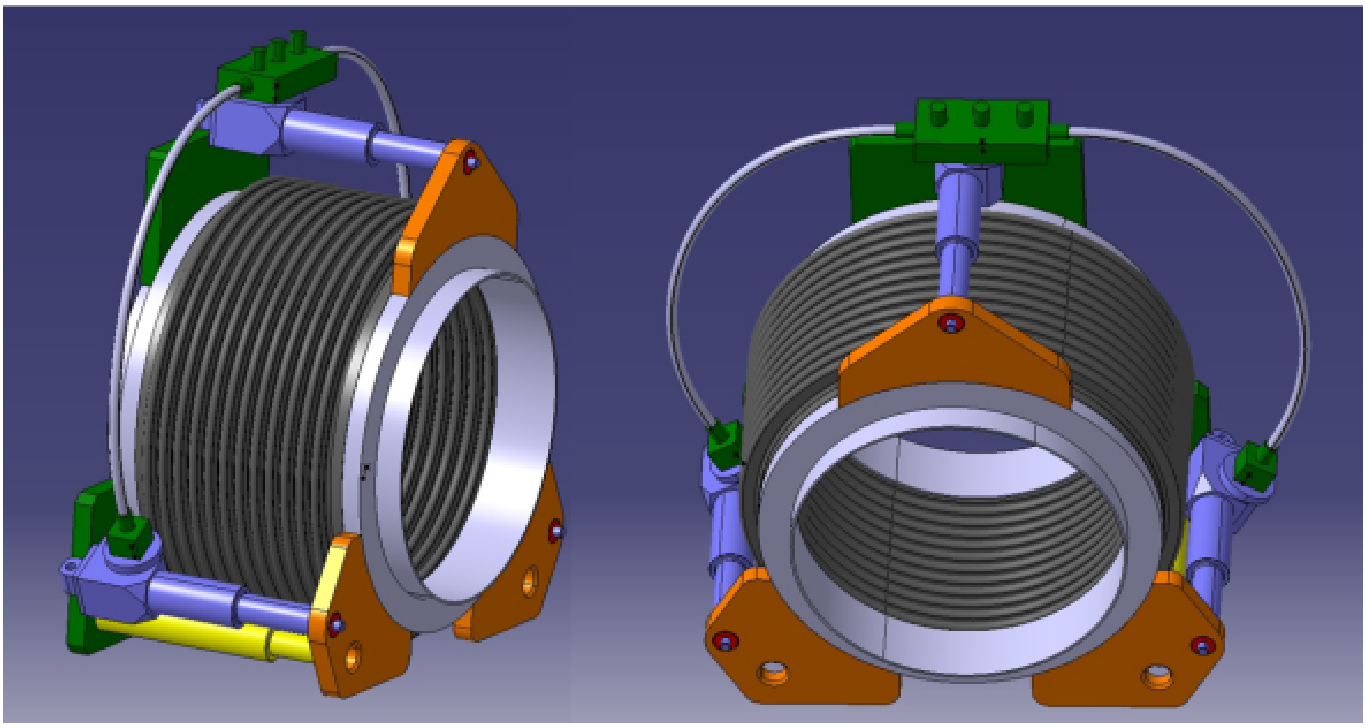


fig. 41 bellow compression tool conceptual draft design

The bellow compression tool was based on the same solution implemented in the NB injector's front end component bellow. Three mechanical screw jacks surround the bellow and are connected with a transmission of flexible shaft to a single docking position where a bolting tool or a dedicated multiple head bolting device is connected by the Manipulator of the NB RH System.

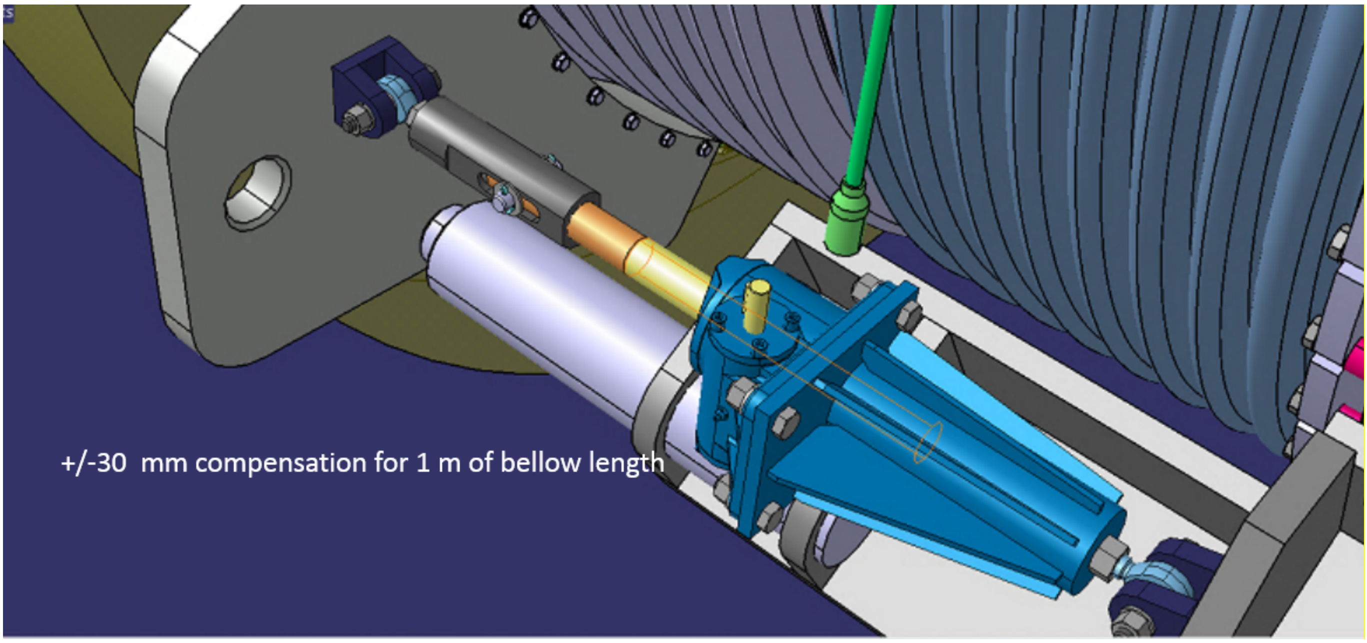


fig. 42 NB injection front end component bellow compression tool

The above picture shows the updated reference design of the bellow compression tool adopted in the NB injector front end component. A standard screw jack connected to a flexible shaft transmission is linked to the two bellow flanges with two spherical joint. A limited stroke slider integrated in one of the two connections ensures a limited play when the screw jack is in its “idle” state (the reference pin is in the middle of the slider slot). In this case the slider play is 60 mm (+/-30 mm) with a bellow nominal length of about 1 m. In the VVPSS design another commercial mechanical screw jack is used as dimensional reference. The forces requested to the actuator are derived from known bellow stiffness reported in the following table.

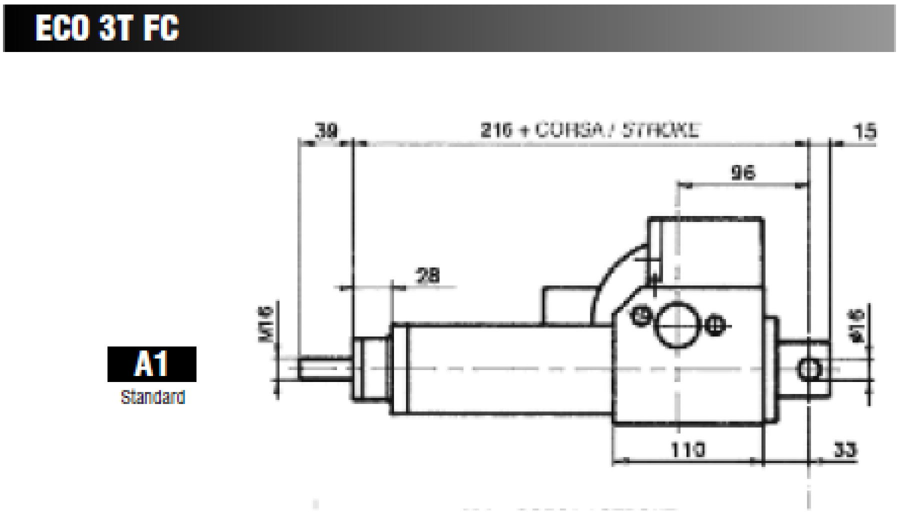


fig. 43 screwjack commercial reference

Forza nominale / Nominal force	[daN]	900	900	700
Velocità nominale / Nominal speed	[mm/sec]	5	10	22
Diametro vite / Screw diameter	[mm]	25	25	25
Passo vite / Screw lead	[mm]	5	5	5
Rapporto di riduzione / Reduction ratio		1/20	1/12	1/5

tab. 10 screwjack reference specifications

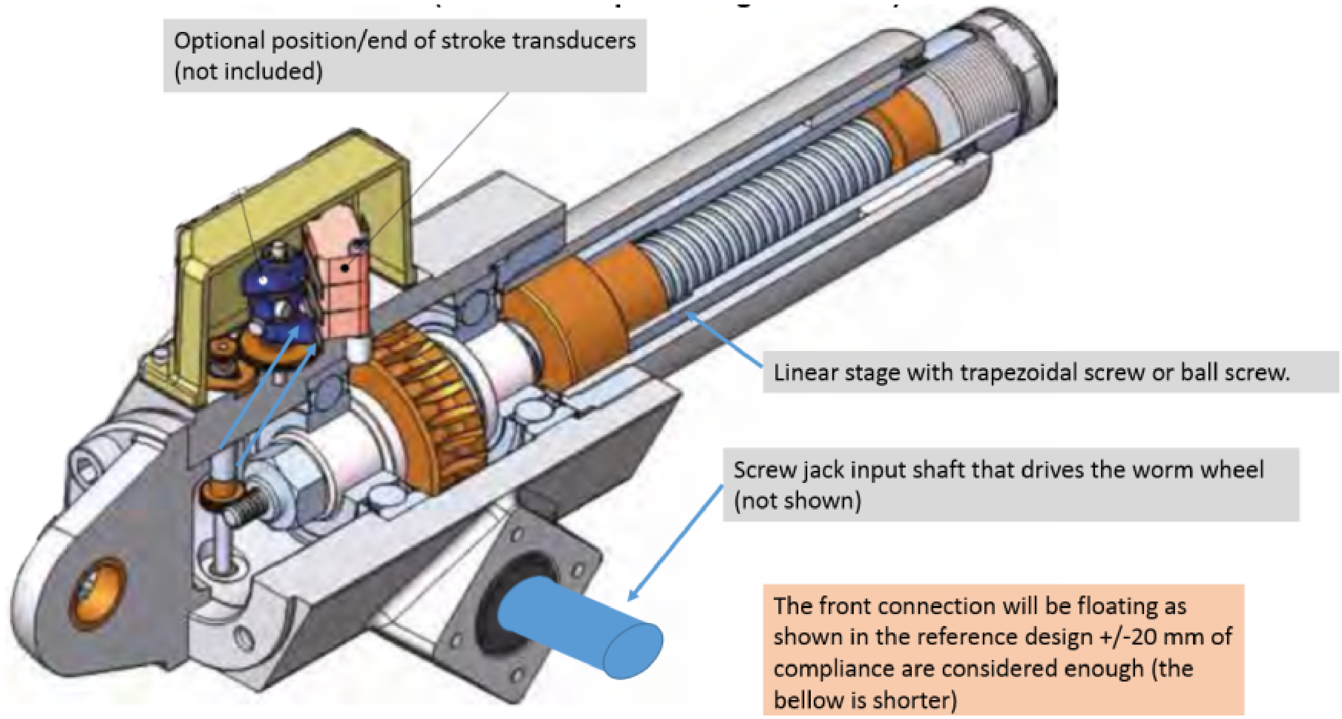


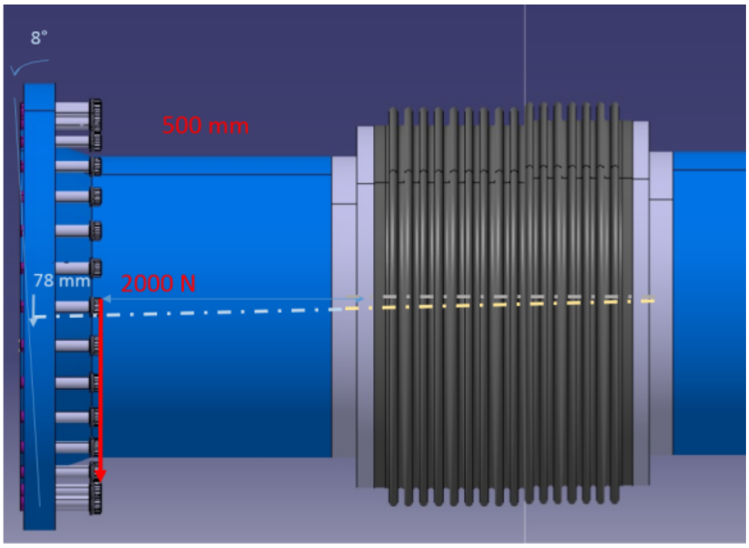
fig. 44 screwjack commercial reference (details)

Table 1 : Allowed displacement for bellows

bellow	reference	nominal axial movement absorption 2δN [mm]	lbg [mm]	outside diameter [mm]	nominal lateral movement absorption 2λN [mm]
DN500	ABN02.0500.204.0	204	276	569	33
DN600	ABN02.0600.209.0	209	286	674	30
DN300	ABN 02.0300.210.1	210	280	371	53
DN350	ABN 02.0350.210.0	210	294	402	51
penetration DN700	LRN 06.0700.211.0	-	-	-	211
penetration DN500	LRR 06.0500.207.0	-	-	-	207

Table 8 : Stiffnesses setup in CAESAR model

	Stifnesses		
	Axial [N/mm]	Transversal [N/mm]	Bending [N.m/deg]
DN500	72	401	45
DN600	78	583	69
Total DN500+DN600	150	984	114
DN300	52	118	13
DN350	60	147	19
Total DN300+DN350	112	265	32
penetration DN700	1	80	0
penetration DN500	1	39	0



T= 2000 N
Mf=1000 Nm

Vertical displacement: Z= 2 mm;
Flange rotation: teta= 8°

Force needed to compress the bellows for 100 mm:
Fc=15000 N (5000 N per screw jack)

tab. 11 bellow compression and deflection

As clarified in the sketch that follows the integration of the slider in this case is made directly inside the actuator exploiting some free space available in the frontal actuator connection. In consideration of the smaller bellow design the maximum compensation is reduced to +/-20 mm (40 mm full stroke). In this case the actuators are designed to achieve the full bellow compression (100 mm) with 40 mm stroke compensation (the actuator mechanical stroke is 140 mm).

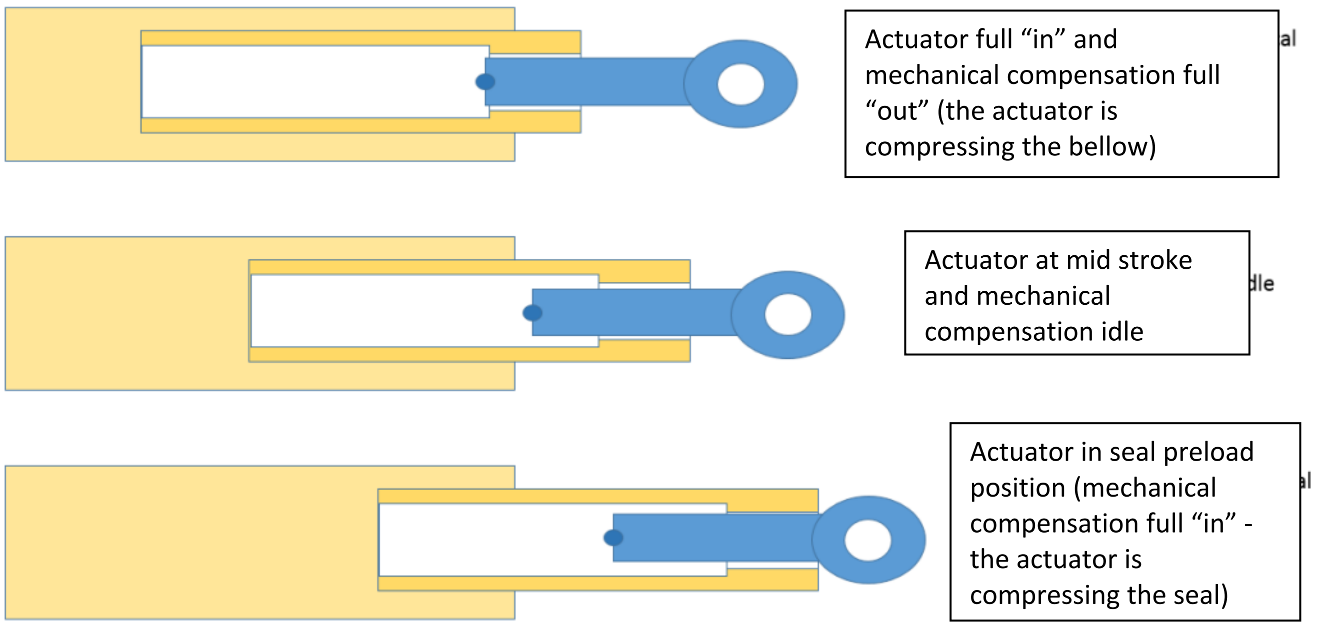


fig. 45 floating connection arrangement

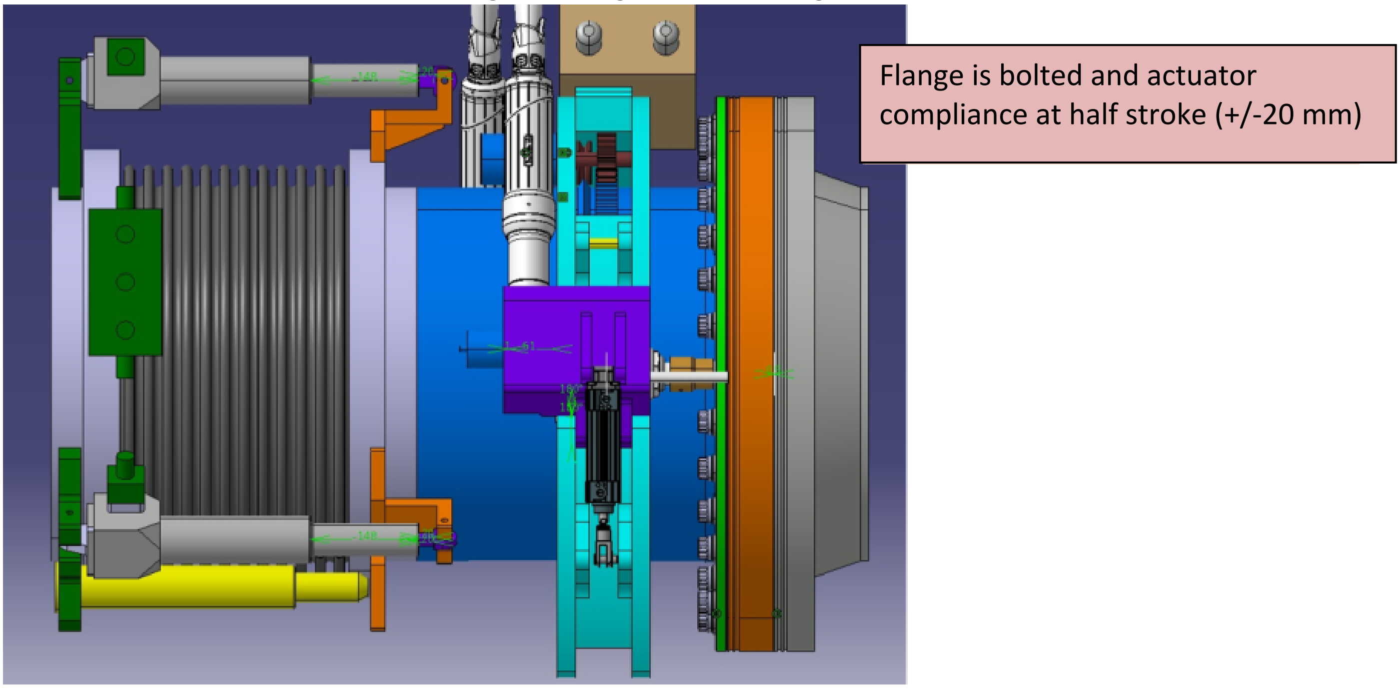
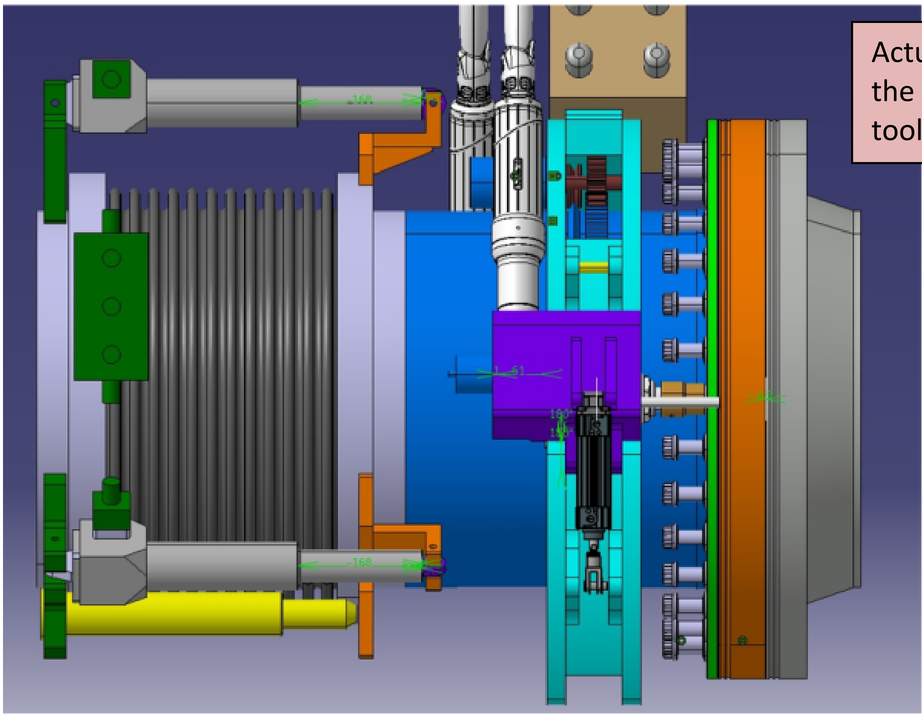
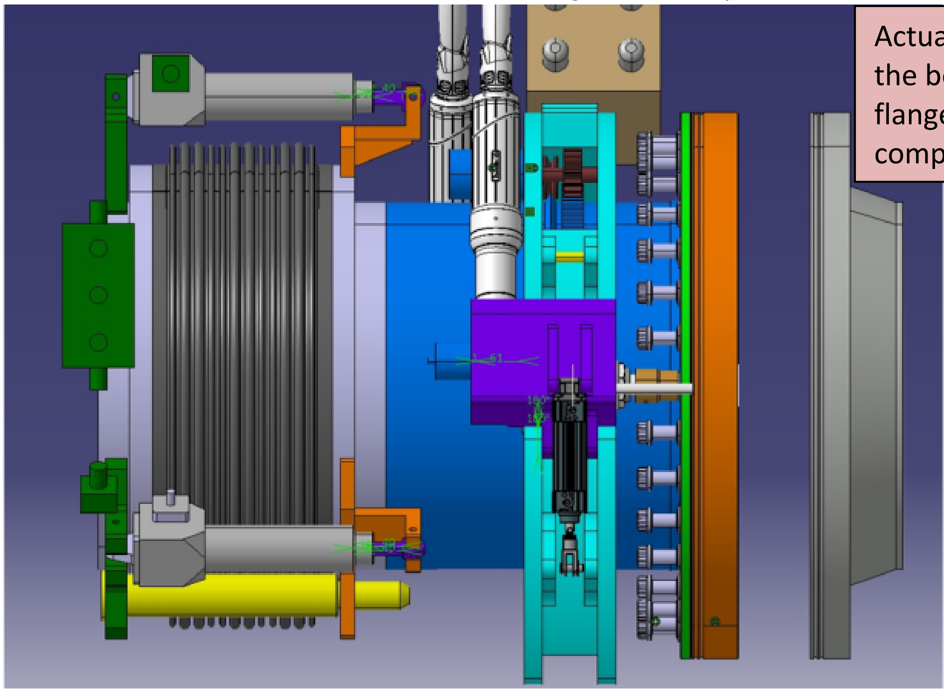


fig. 46 neutral configuration



Actuator are pushing the seal while the bolts are released by Bolting tool. Actuator compensation full IN

fig. 47 seal compressed



Actuator are pulling compressing the bellow. The gap btw the flanges is 100 mm. Actuator compensation full OUT

fig. 48 bellow compressed

The same design above discussed was then scaled and adapted to BLV assembly DN 300 connection together with bolting tool rail and reservation space. The following pictures show the RD/BLV assembly layout with the final interfaces in place.

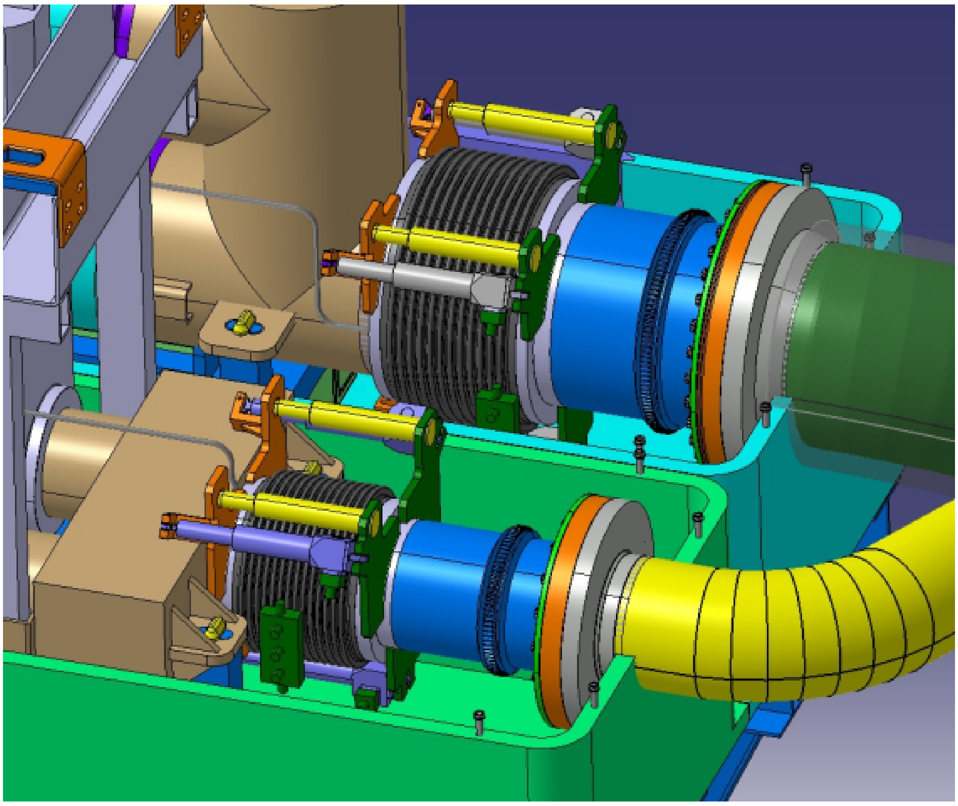


fig. 49 bellow compression tool on DN500 and DN300 (final configuration)

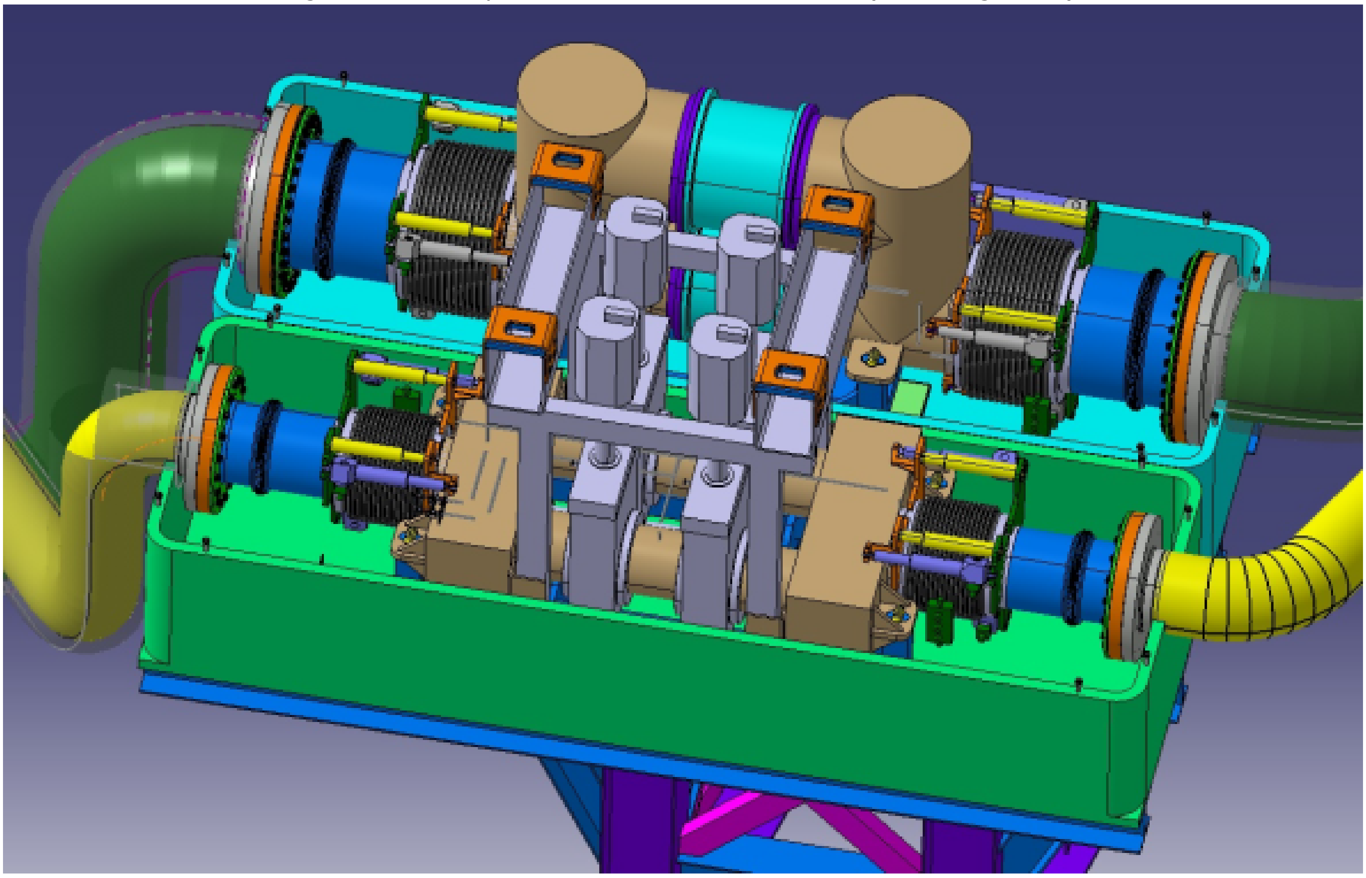


fig. 50 RD/BLV assy overall view (upper thermal shield removed)

5.2 confinement box

A dedicated device was developed to perform the flange disconnection, cleaning and confinement.
The "confinement box" surrounds the two flanges with a clamshell confinement so to connect the gap created between the flanges to the internal volume of the confinement box where two different RH systems are stored.
Confinement box plays also a relevant role in restoring fire shielding when the upper thermal insulation box is removed.

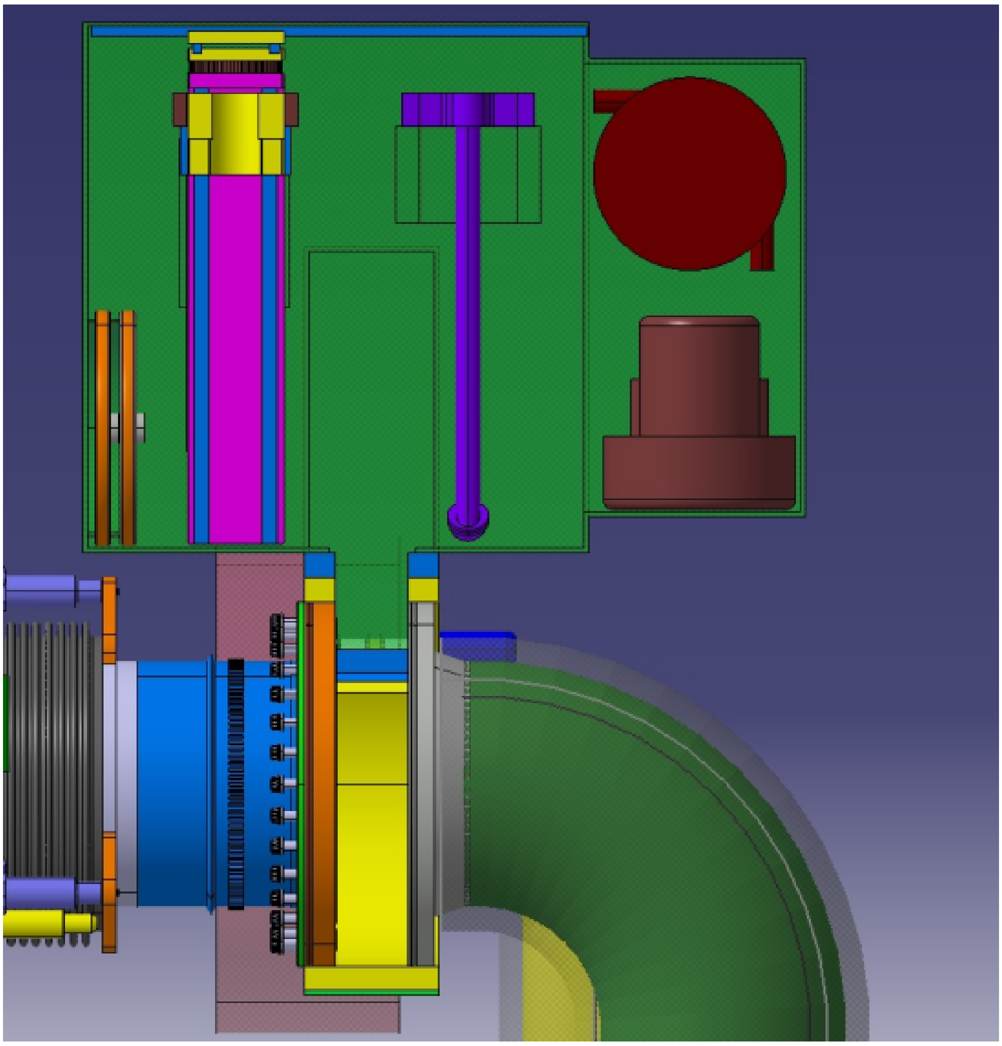


fig. 51 confinement box internals first draft design

For first reference the operational sequence of the confinement box is reported:

1. Confinement box is positioned over the flange and clamshell is closed;
2. Bellows are compressed and a gap btw the two flange is created;
3. The upper section of the clamshell opens connecting the inside of the confinement box with the flange gap;
4. The flange and seals surfaces are inspected and the cleaning head is lowered and the exposed surfaces are completely decontaminated with embedded dust aspirator head;
5. The cap insertion device is actuated and the two caps are inserted;
6. Once completed the sequences, upper section of clamshell is closed;
7. Clamshell is open and confinement box removed.

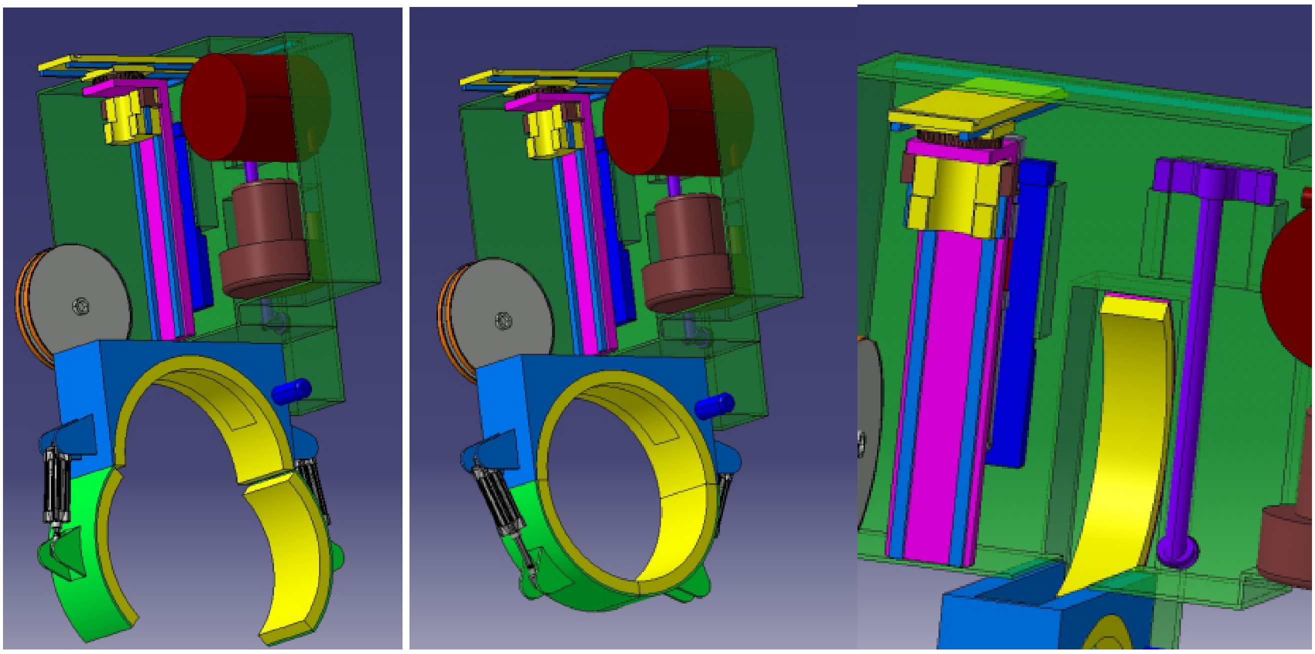


fig. 52 clamshell activation sequence

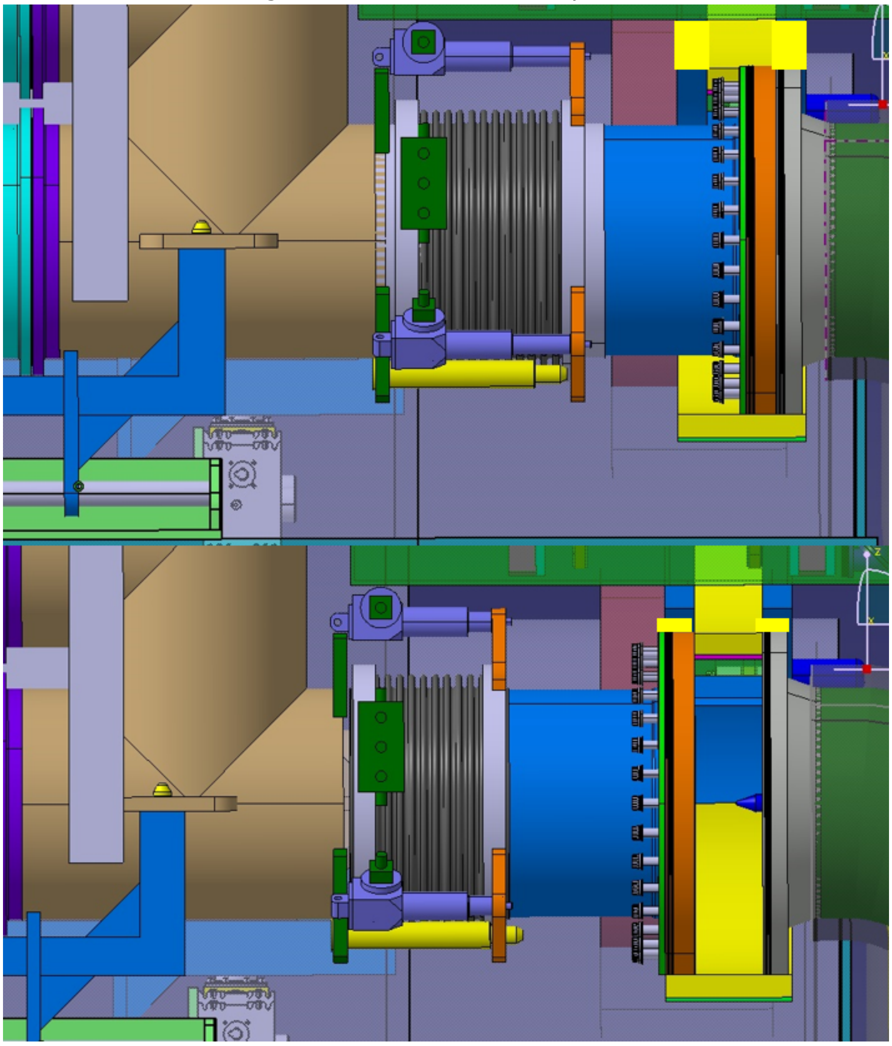


fig. 53 bellow compression

Inside the confinement box an actuated manipulator docks to different tools to perform the above described cycle:

cap insertion/removal gripper;
A RH vacuum cleaner.
The manipulator has two dofs in the plane (x/y) a rotational dof around Z and a two stages vertical slider.

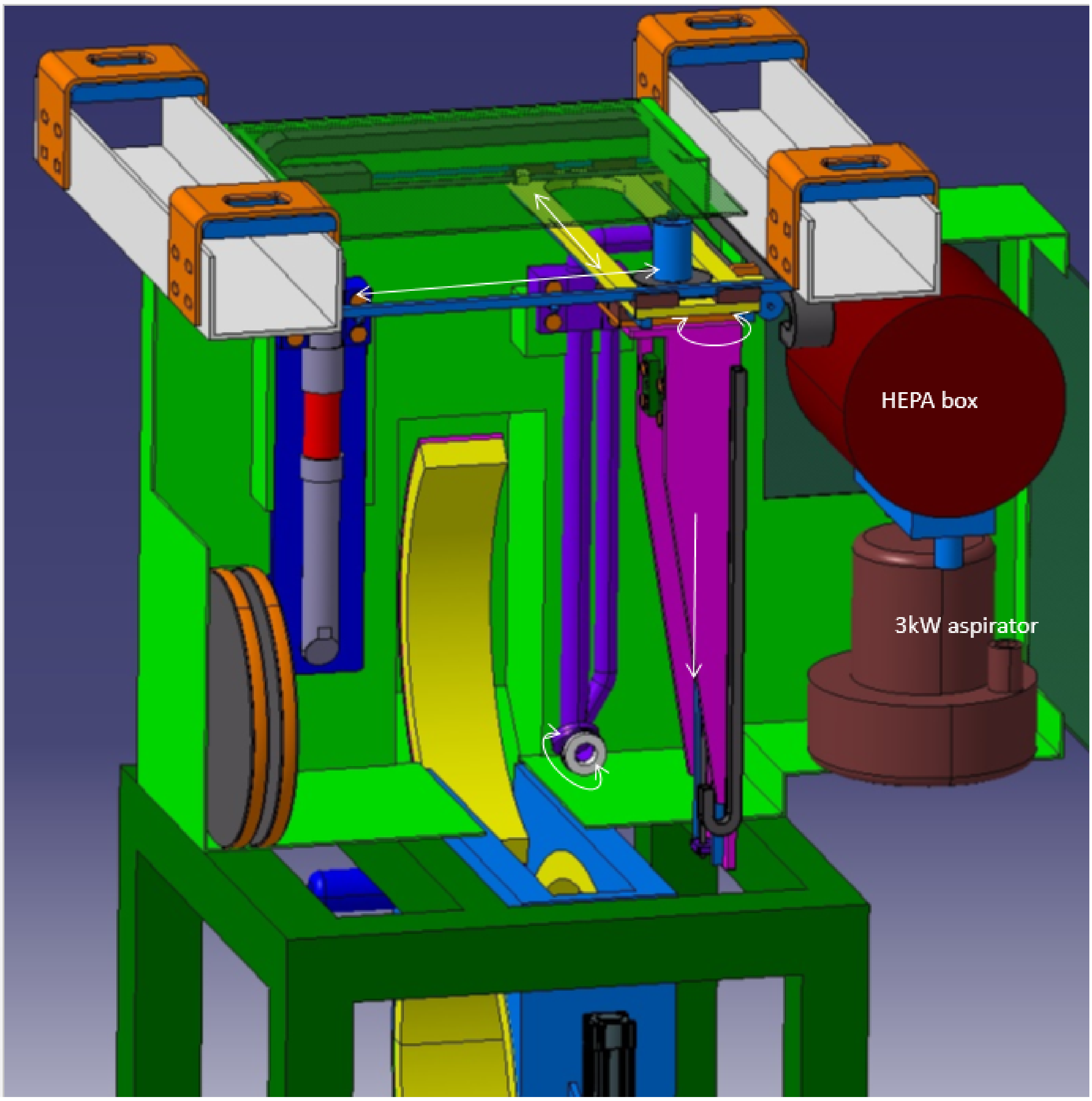


fig. 54 confinement box internal components

In the below reported close view the implementation of a standard mechanical/electrical interface between the manipulator interface and the two tools is visible (design based on standard industrial tool change solution). Internal cable management made with cable chain integrated in the layout is also part of the conceptual design.

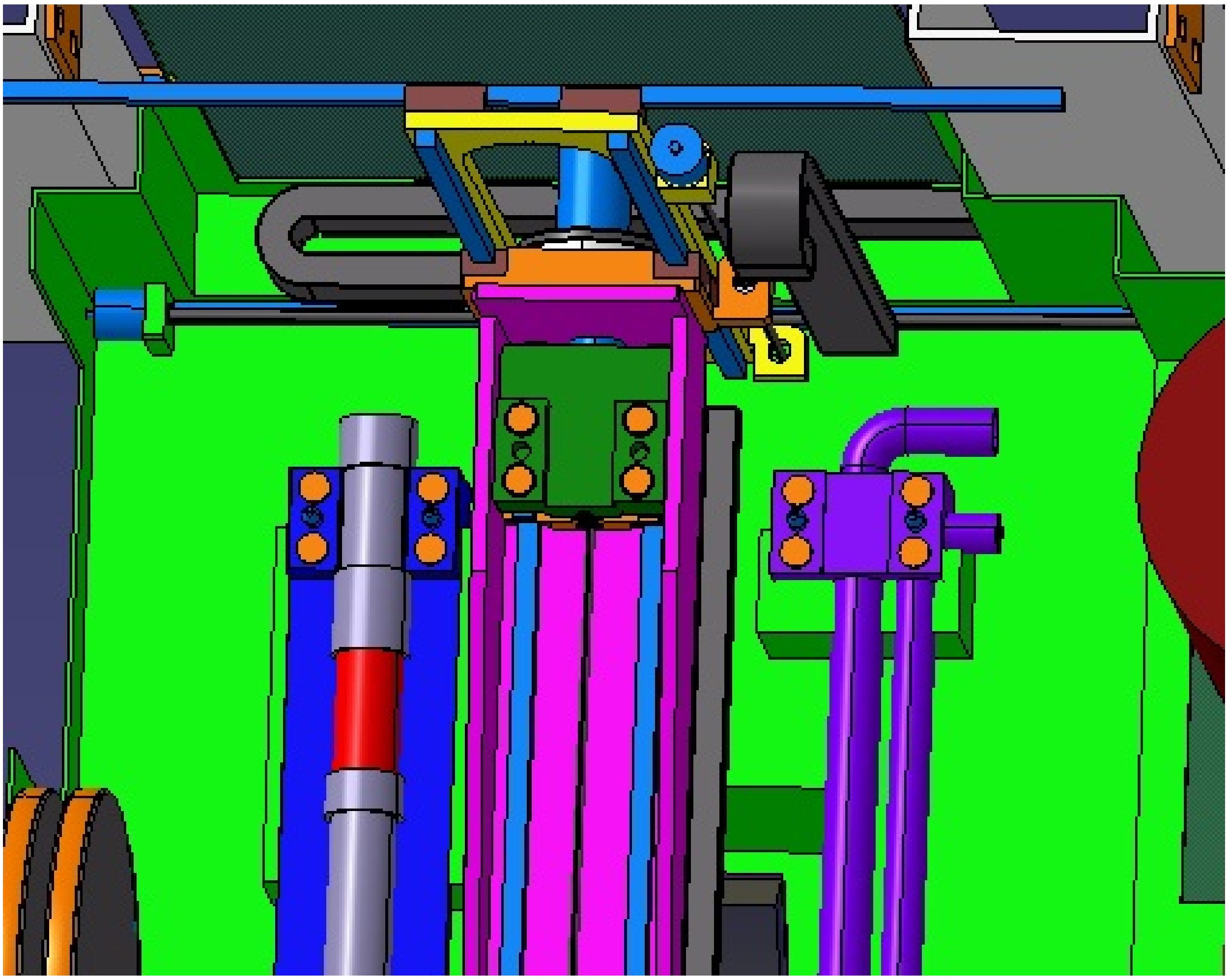


fig. 55 confinement box internal components

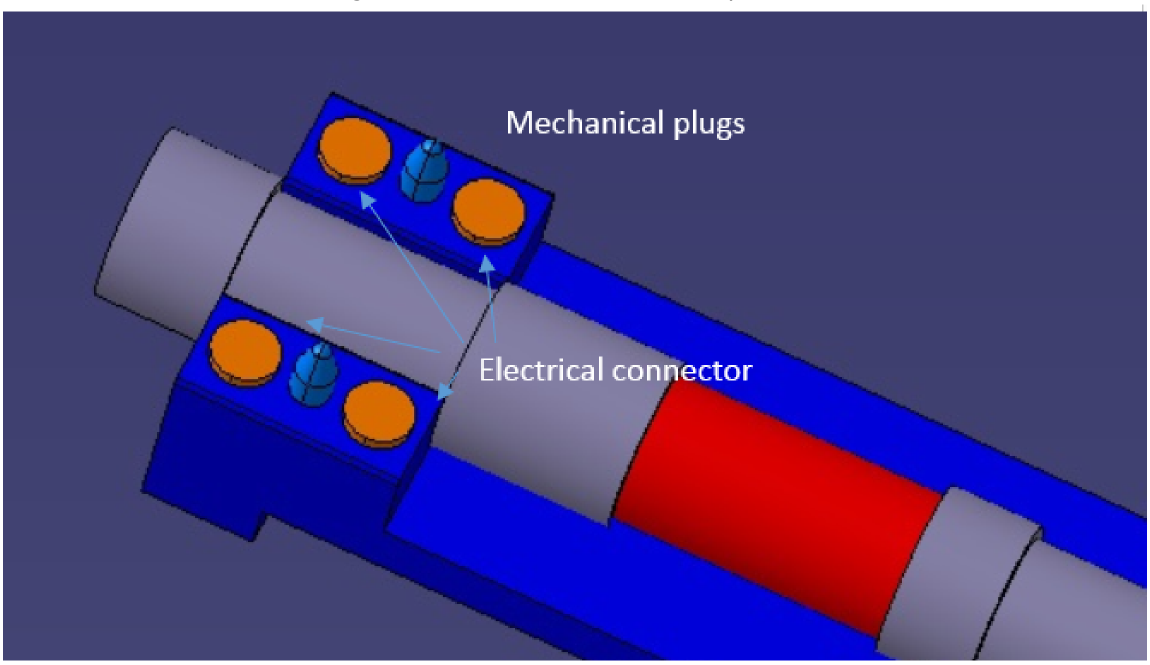


fig. 56 tool disconnection interface (detail)

DN 300 flange disconnection sequence will follow the same sequence and will require confinement box tool.
Two option are in this direction possible:

The same confinement box developed and discussed for DN 500 could be set-up for DN300 with dedicated clamshell adaptors as in the pictures that follow.

In this case the overall dimensions of the confinement box will not change but the same tool could be exploited for both diameters (less tools);

The alternative solution would be to optimize/scale the layout developed for DN500 for a DN300 diameter. The overall dimension of this second confinement box could be smaller but, as drawback, two tools are needed one per flange size.

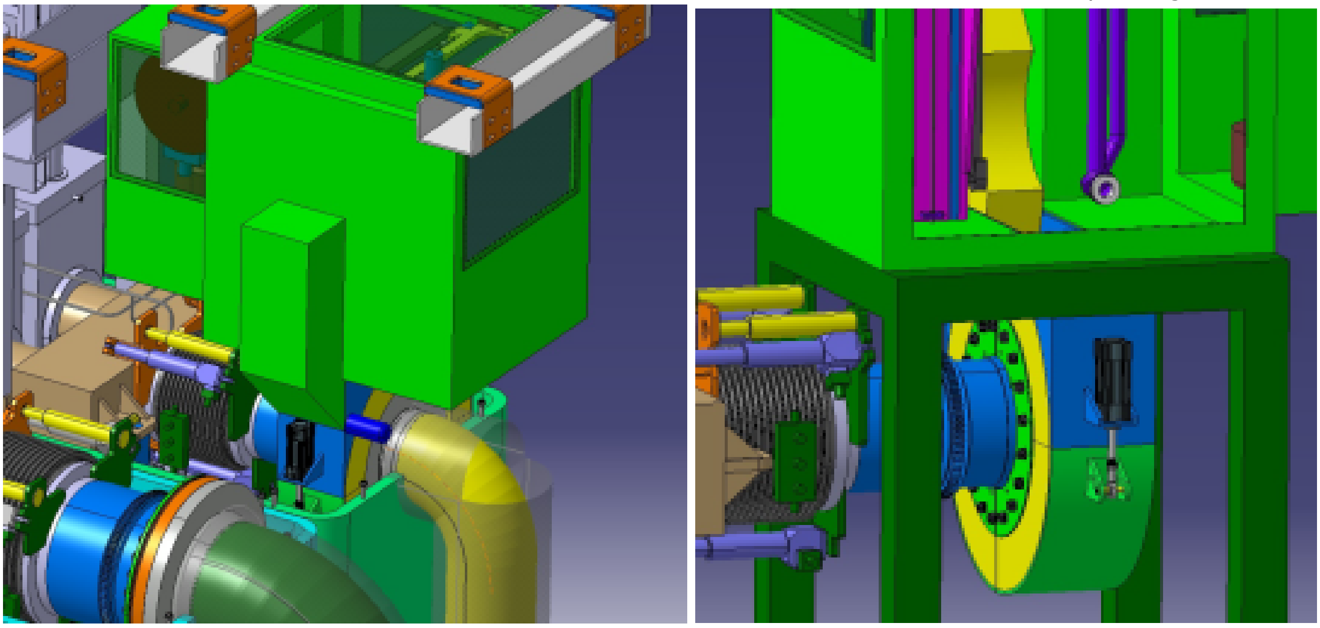


fig. 57 confinement box set-up for DN300 (support legs hidden)

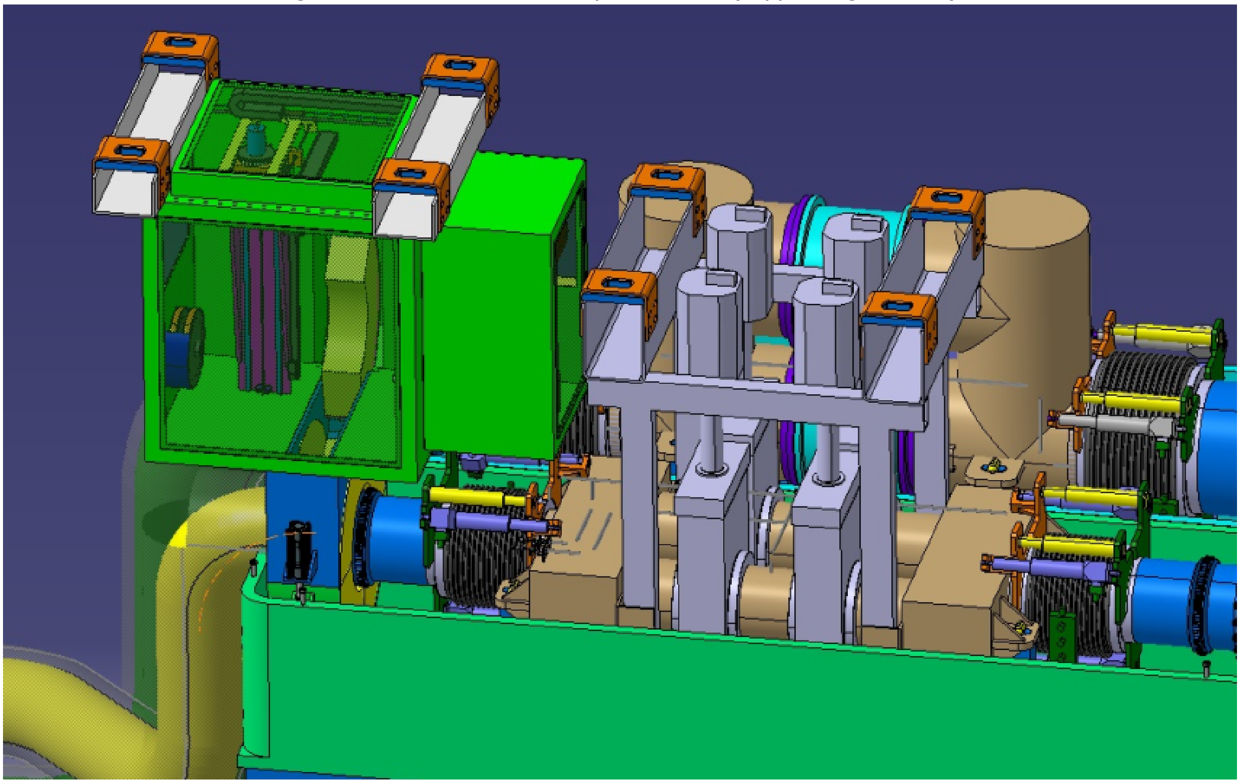


fig. 58 confinement box on BLV flange (support legs hidden)

As reference preliminary verification for the mechanical dimensions and general manipulator reservation spaces the vertical slider was dimensioned as follows.

Vertical slider is based on two stages linear actuation. The main translation is driven with a brushless motor connected to a ball screw and is position controlled with a net vertical stroke of 800 mm. The auxiliary vertical stage is actuated with a pneumatic cylinder and is used to offset the first slider workspace when used with the aspiration head. Failsafe brake on vertical slider should be considered in the detailed design phase to ensure the slider doesn't falls in any condition. The following table reports a first preliminary weight table.

closure plate configuration		
closure plate	20	kg
closure plate gripper	5	kg
closure plate boting head	10	kg
total	**35**	**kg**
dust aspiration configuration		
wrist articulation	5	kg
cleaning head	3	kg
structure+duct	10	kg
total	**18**	**kg**
auxiliary slider mass		
tool gripper interface	5	kg
main frame+sliders	5	kg
actuation (cylinder+ancilaries)	2	kg
total	**12**	**kg**
main slider mass		
cart frame	5	kg
carts	2	kg
actuation fixed screw rotating nut	6	kg
total	**13**	**kg**
TOTAL VERTICAL MOVING MASS	**60**	**kg**

tab. 12 confinement box vertical slider mass

Vertical slider rails loads are calculated based on max tentative tools interaction forces as follows.

INNER VERTICAL SLIDER verification			
auxiliary slider			
Lnozz	720	mm	distance btw nozzle head and carriages
Lcart main	170	mm	full cart legth
wcart main	140	mm	cart width
Lnozz_2ndry cart	820	mm	
l CP 2ndry cart	625	mm	
lcart 2ndry	77	mm	
lrail	20	mm	HGH20CA
Mrail	200	Nm	(from specification)
Mtot	400	Nm	2 in parallel
Fnoz	**200**	**N**	max contact force
Mmax noz	171.7	Nm	
fs	2.329645	OK	safety factor
FCP	**300**	**N**	max closure plate interaction force (axial)
Mmax noz	199.05	Nm	
fs	2.009545	OK	safety factor

tab. 13 confinement box vertical slider reference calculation

vertical electrical actuation			
ballscrew reference dimensions			
D	6		
p	2		
Fn (design load)	1000	N	
efficency	0.8		
Min (based on actuator design max loa	0.233958	Nm	
motor selection			
KOLLMORGEN RBE 01212			
Mn	0.3	Nm	ok

tab. 14 confinement box vertical electrical actuation reference calculation

The rotation of the vertical arm is ensured with an Harmonic Drive integrated gearhead with embedded crossed roller bearing. The harmonic drive gearbox is driven by another brushless motor. Critical verification in this case is the bending verification of the gearbox main unit.

YAW actuation main bearing verification			
LCP	760	mm	
Lnoz	956	mm	
2ndry slider stroke	100	mm	
LCP*	860		closureplate max offset
Lnoz*	1056		nozzle max offset
M_CP	258	**Nm**	
Mnoz	211.2	Nm	
Mref. HFUC32-2UH	313	Nm	ok

tab. 15 confinement box HD output bearing verification

The X and Y stages of the positioner are position controlled with a similar layout of recirculating ball rails and balls crew with brushless motor actuation (loads acting on X and Y stages are less critical than the vertical unit).

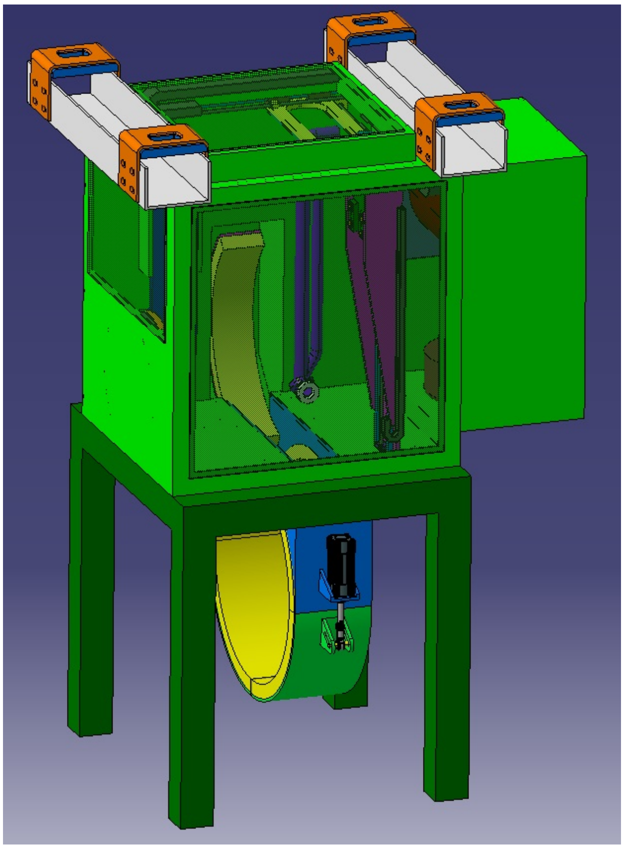


fig. 59 confinement box external removable covers

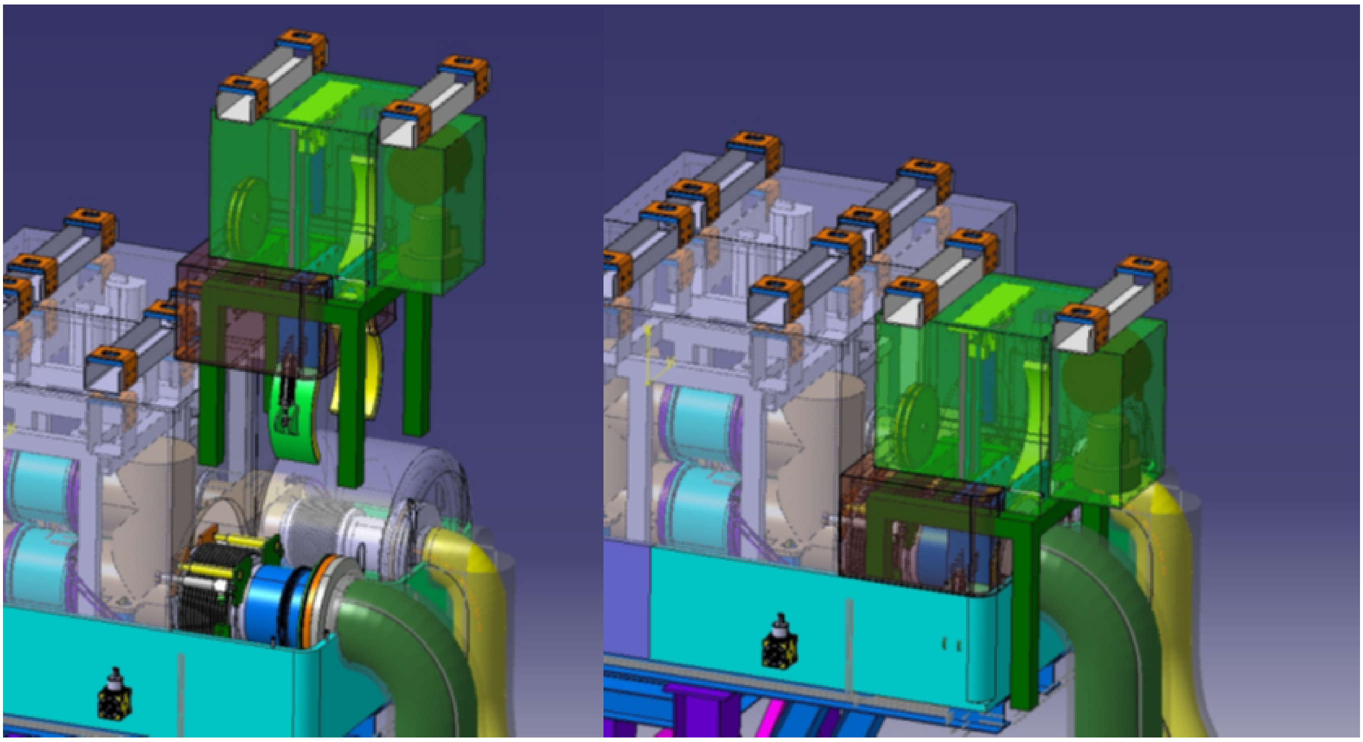


fig. 60 confinement box external support frame

Confinement box structure is provided with removable cover used to perform internal decontamination for maintenance.

To ensure the correct alignment of the confinement box with the flanges, four support legs engages dedicated receptacles integrated in the RD/BLV support structure.
The two outer support legs are supported outside the lower permanent fire insulation box so to provide a good alignment reference.
The same legs are used to ensure the needed stability in operation and storage conditions.
Confinement box confinement is achieved in two ways:
The system has airtight enclosures that ensure static confinement. When the tool is not in operation the clamshell internal lid is closed and keep confined the tool internals. When the tool is in operation (connected to the line) the adaptable seal inside clamshell connect the confinement box internal volume with the VVPSS line.

With the tool is connected to the VVPSS line, the line aspiration ensures dynamic confinement. Differential pressure sensor integrated in the confinement box monitors the confinement (tool connection with DS to further improve dynamic confinement could be evaluated).

Several failsafe features should be added in the confinement tool detailed design to ensure confinement also in case of failure: Clamshell failsafe locking should be added evaluating also the replacement of pneumatic actuation with electric actuation; redundant actuations should be also added on manipulator and tool to recover the system and, if needed, reposition closure plates and remove the tool.

5.3 closure plate

To ensure upstream and downstream as well as RD/BLV dust/contamination confinement a mechanical expansion cap was considered.
This kind of devices is broadly used in the offshore and onshore pipeline management.

REMARK: the mechanical expansion cap included in the conceptual design was derived by the conceptual implementation of a mechanical plug but should be dimensioned in a later design stage.
As alternative to a mechanical expansion cap a pneumatic expansion cap was also evaluated but then discarded for the lower reliability (a leak in the seal pressurization could compromise the confinement).

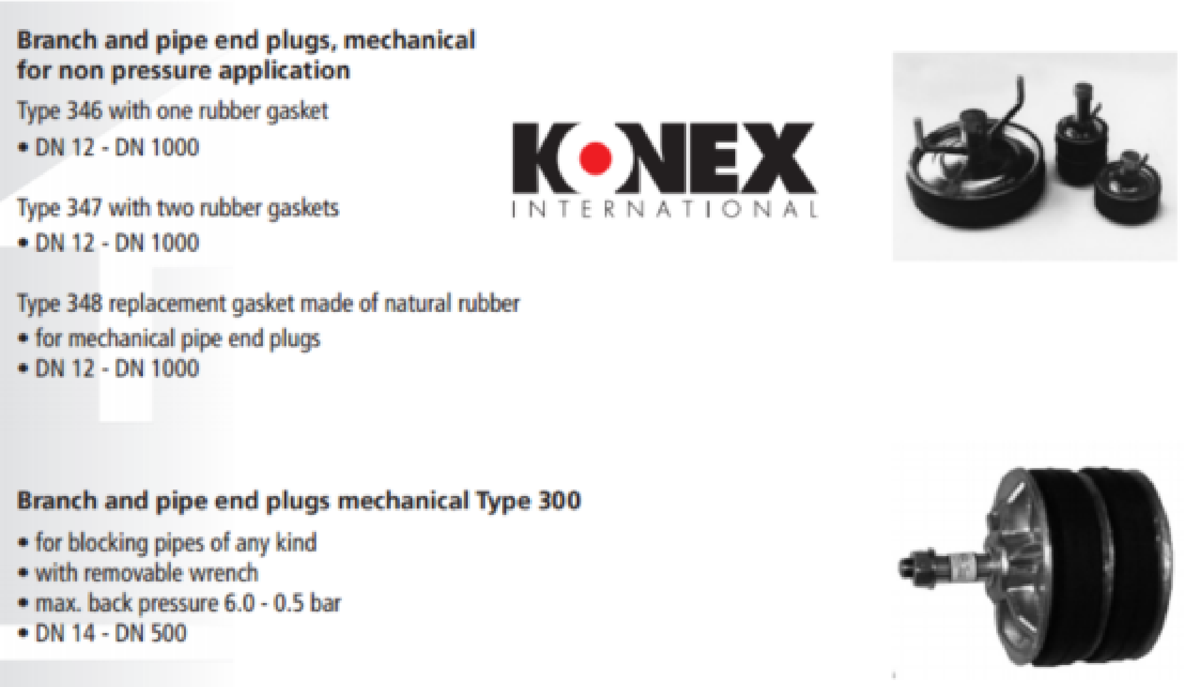


fig. 61 mechanical expansion cap commercial reference

5.4. cap insertion device

The cap insertion device is based on a standard 90° head bolting tool connected to the mechanical expansion cap and used to expand/compress the seal. The bolting tool is held by a deployment mast used to insert the cap inside each flange. As visible in the insertion tool the closure plate alignment reference is made directly with the tool support frame mating the flange (a softer interface plate will be evaluated and integrated if needed in the detailed design phase).

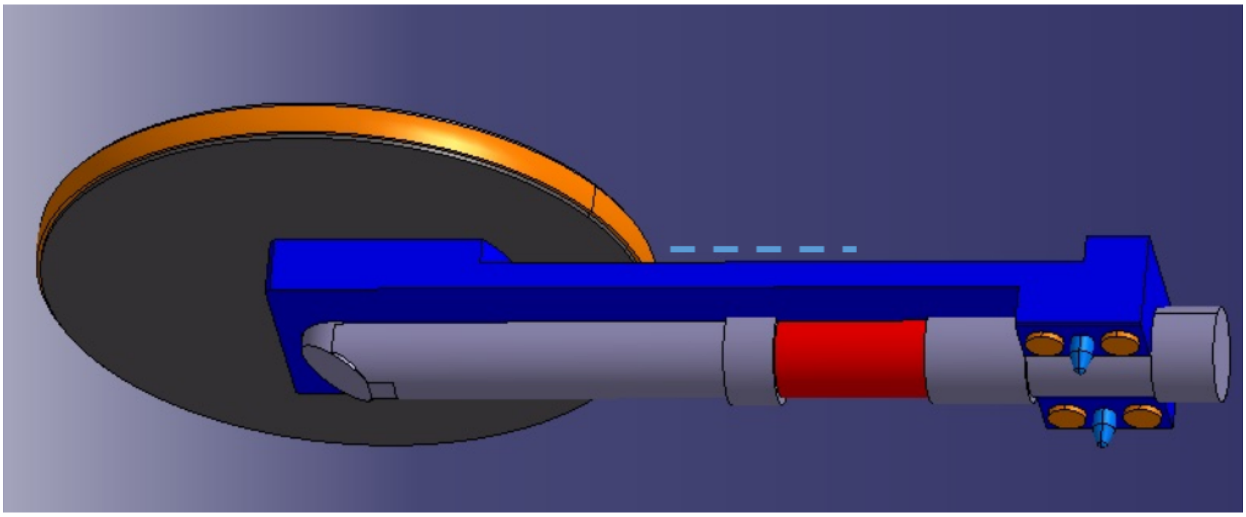


fig. 62 cap expansion head conceptual design

The following schematic sequences show the closure plate insertion sequence.

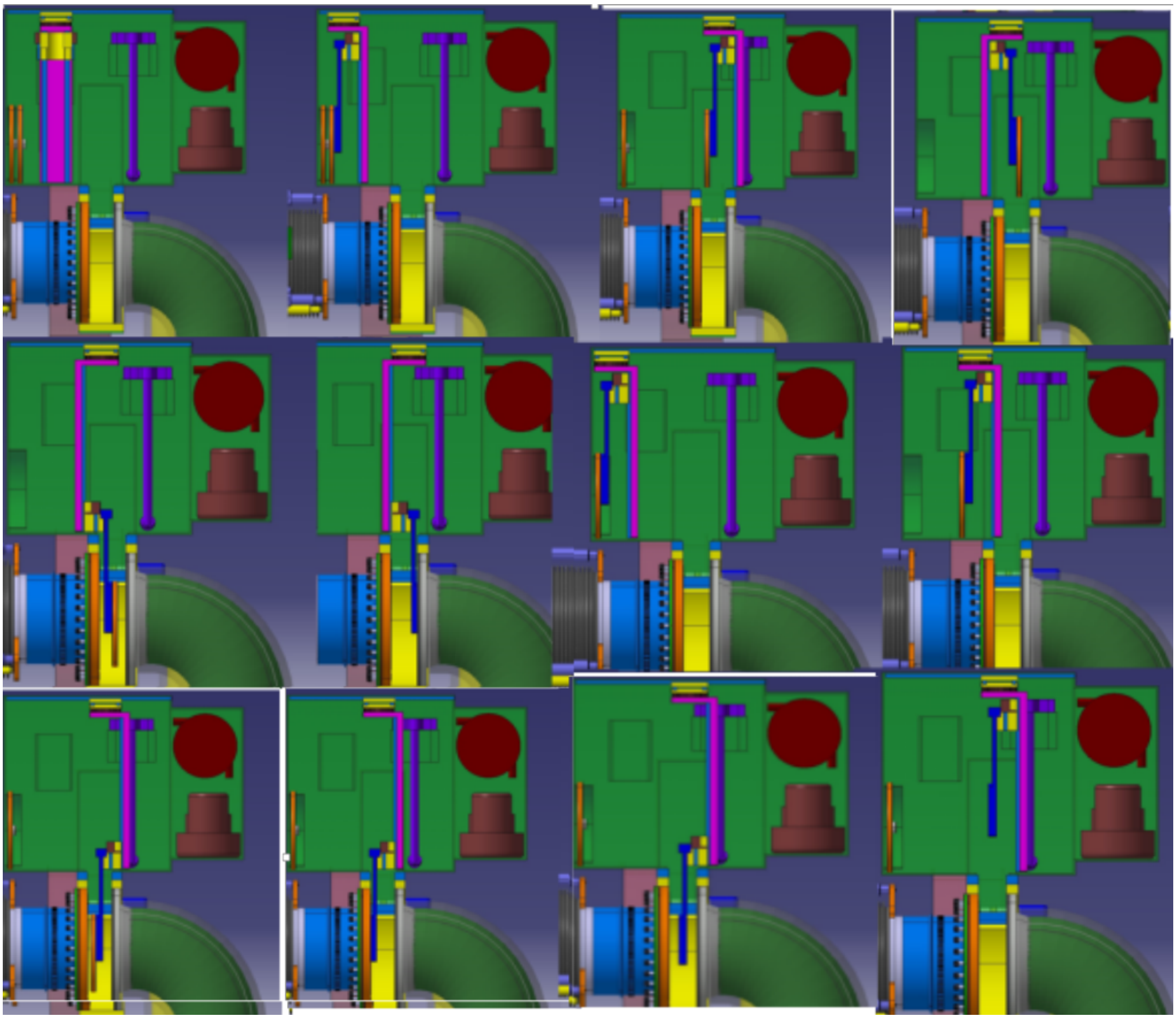


fig. 63 cap insertion sequence

5.5 cleaning device

A dedicated aspirator cleaning head is integrated Inside the confinement box supported by the main sliding frame. The cleaning head is positioned with the confinement box 4 dofs manipulator and is provided with an extra wrist rotational dof used to orient the suction cup inside the gap between the two flanges as needed to remove any dust residual. The aspiration head is connected to an on board aspiration unit based on a 3 kW blower and a HEPA filter used to trap the collected dust.

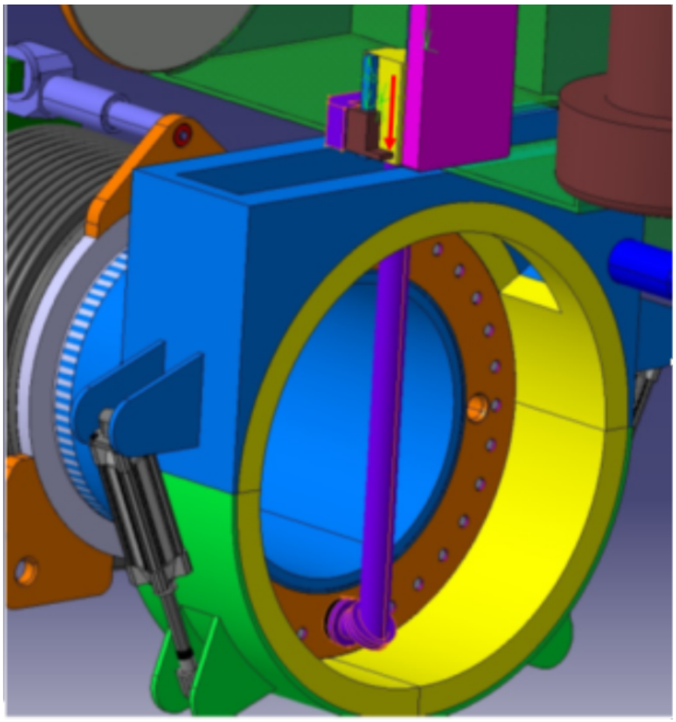


fig. 64 cleaning head

6 Concept design of the seal preparation tools

The following table reports the subtask requirements with some updates/comment based on the contract outcomes.

REQ	Concept design of the seal preparation tools	remarks/updates
2.3.01	Sealing preparation sequences shall be developed during the normal operation and accident cases. Note a survey study may be required to look for industry practices.	A consultation has been made with the IO Vacuum group concerning the hands-on sequence of the seal preparation such as cleaning and re-constructing the sealing surface. Reference inspection and cleaning procedure is defined. See sec. 6.1
2.3.02	The seal preparation tool shall be capable of being deployed remotely from the equatorial cask to the operating configuration.	deployment of tools from equatorial cask to working configuration is foreseen by NBRHS (see sec. 8)
2.3.03	The seal preparation tool shall be capable of accessing and cleaning the sealing tracks of the relief lines.	sealing track are exposed as 2.2.05.
2.3.04	The seal preparation tool shall be remote handling compatible for refurbishment and decontamination in the hot cell building. The decontamination means removal of any contamination in the tool so that maintenance by human worker is possible. The refurbishment means replacement of failed parts.	see S.1.08
2.3.05	The seal preparation operation during the regular maintenance of the rupture disk shall be RH class 1.	
2.3.06	The seal preparation operation after the accidents shall be RH class 2.	

tab. 16 seal preparation tool REQ

The following picture shows a RH developed in the past for seal surface preparation.

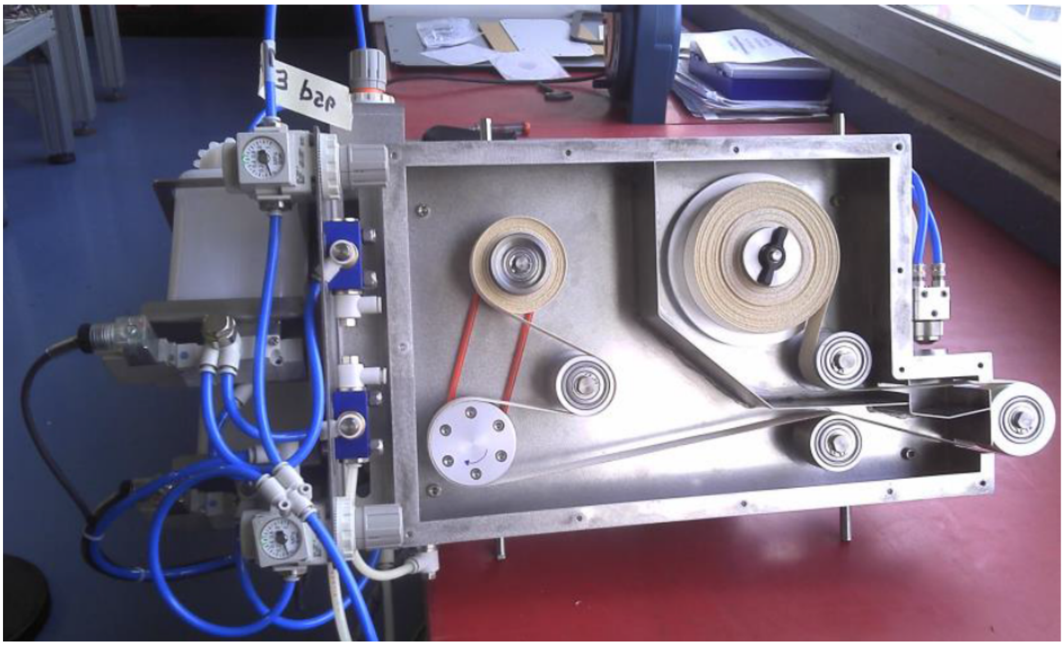


fig. 65 seal cleaning head for RH

Before the replacement of the double metallic seal of DN500 and DN300 flanges in the RD/BLV assembly a seal track inspection and preparation procedure is considered as mandatory.

The start condition has the flanges free to be accessed with the closure plate in position.

The RD/BLV assembly is already removed and the higher dust deposition already removed with the vacuum cleaning head integrated in the confinement box.

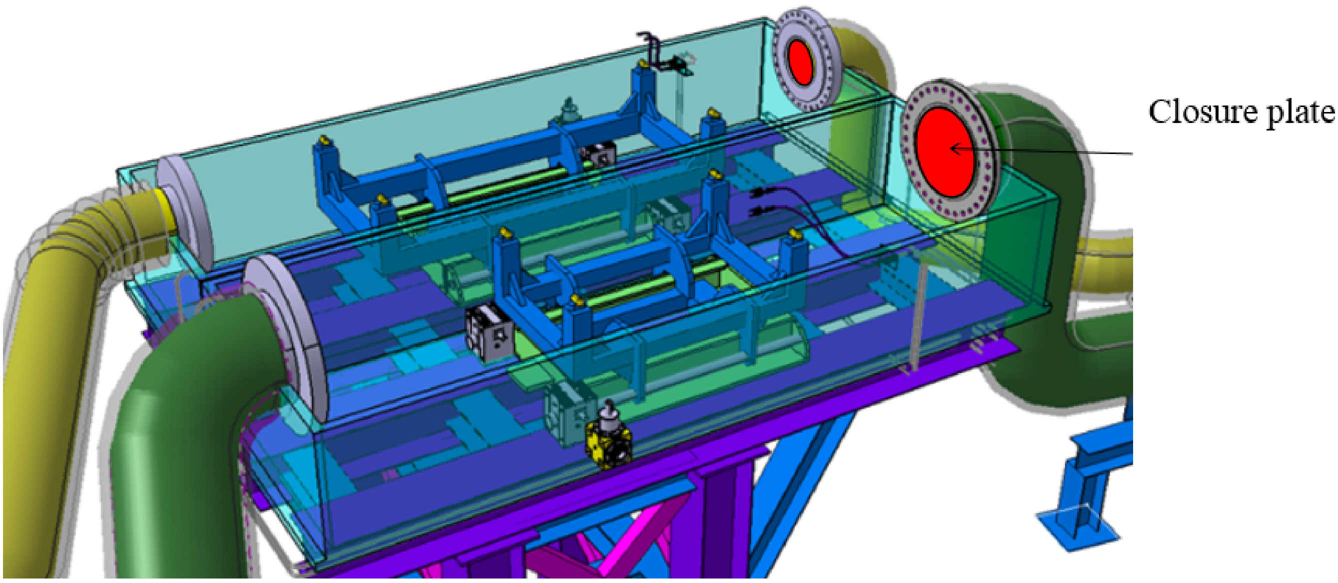


fig. 66 inspection cleaning sequence boundary conditions at start

for each fixed seal track the planned sequence of operation follows:

§	step	remarks

1	the initial status of the seal track is visually inspected with a PTZ optical zoom camera with integrated controllable lights and with the help of a second independent light source	Inspection camera could be fixed to the manipulator mast so to reduce the vibrations at minimum. the second light could be fixed to one of the arms of the same manipulator to orient freely the light beam to have for instance tangent light beam to outline surface scratches
2	an orbital cleaning machine is positioned and installed on the flange with the support of the manipulator	the machine is centred on the flange inner diameter left partially exposed by the closure plate: for such purpose the closure plate is inserted so to leave 10 mm of free internal flange surface
3	the cleaning machine is loaded by the manipulator with a disposable cleaning pad	lint free vacuum grade cloth pre-impregnated with a cleaning solution (alcohol and distilled water)
4	the machine performs first set of revolution with the cleaning pad on the track. the pad is then removed and visually inspected.	
5	a new (clean) path is loaded on the cleaning machine and a second cleaning cycle is performed. the cleaning pad is removed and visually inspected	if needed further cleaning cycle are performed until the cleaning pad is clean at the end of its cleaning cycle
6	the cleaning machine is then removed with the manipulator support and track surface re-inspected	

tab. 17 seal preparation sequence

In case any permanent radial scratch is detected on the surface, track surface re-construction would be required. In consideration of the planned flange disconnection sequence the occurrence of seal track damage is considered really low. Flanges are guided with dowel pin and mechanical actuator and bellow and rotating flange compensate as needed deformation/positioning errors.
Seal track reconstruction could be in case performed using the same concept of the cleaning machine where the cleaning path is replaced with a tangential polishing head.

The following picture introduces the conceptual design of the seal track inspection and cleaning machine.
The main frame of the machine is clamped on the outer diameter of the fixed flange with three fingers mechanically driven by a self-centring screw based device. The fingers shape should ensure a positioning accuracy in the range of +/-2 mm. Once the machine in place a rotating arm is engaged against the flange inner surface using a reference contact wheel pressed on the surface with a pressure controlled pneumatic actuator. A cleaning pad is then pressed axially on the seal track with a second and independent pressure controlled pneumatic actuator. The arm is then rotated with a central motor so to perform a full cleaning cycle. The cleaning head and the axial cylinder can be tilted by 90° so to move the pad in an easy to reach position where it can be inspected and if needed replaced. The same rotating unit embed also a PTZ inspection camera that can be efficiently used to monitor the seal track preparation (an Inuktun SP45 with HD sensor and 20 mm minimum focus distance is considered here as commercial reference).

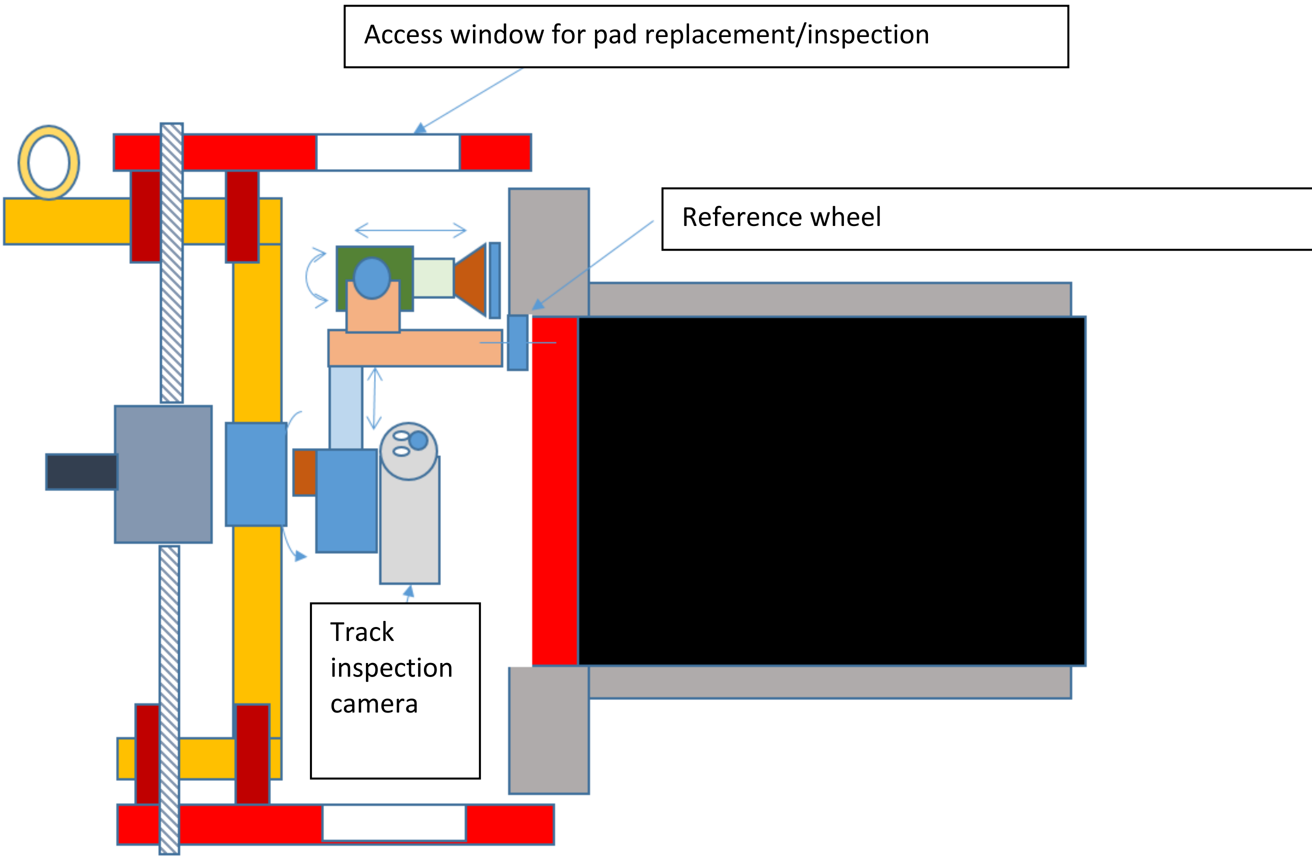


fig. 67 seal inspection and cleaning machine main functional items

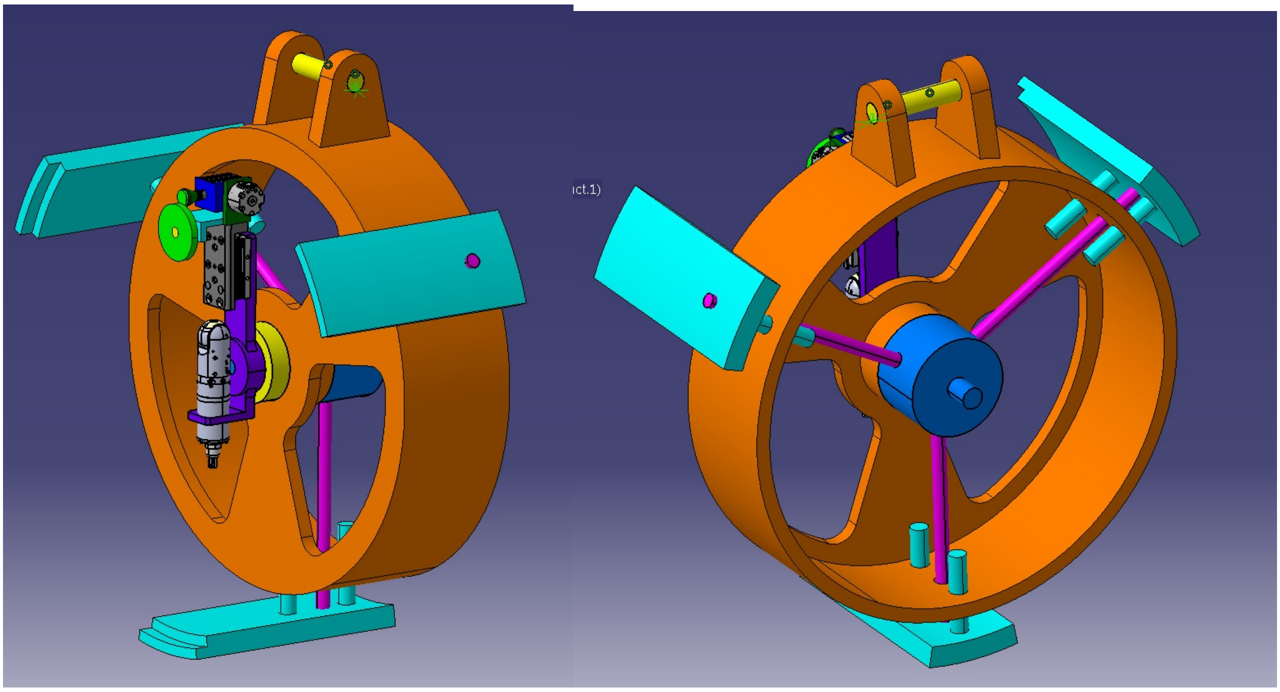


fig. 68 seal inspection and cleaning machine CAD conceptual design

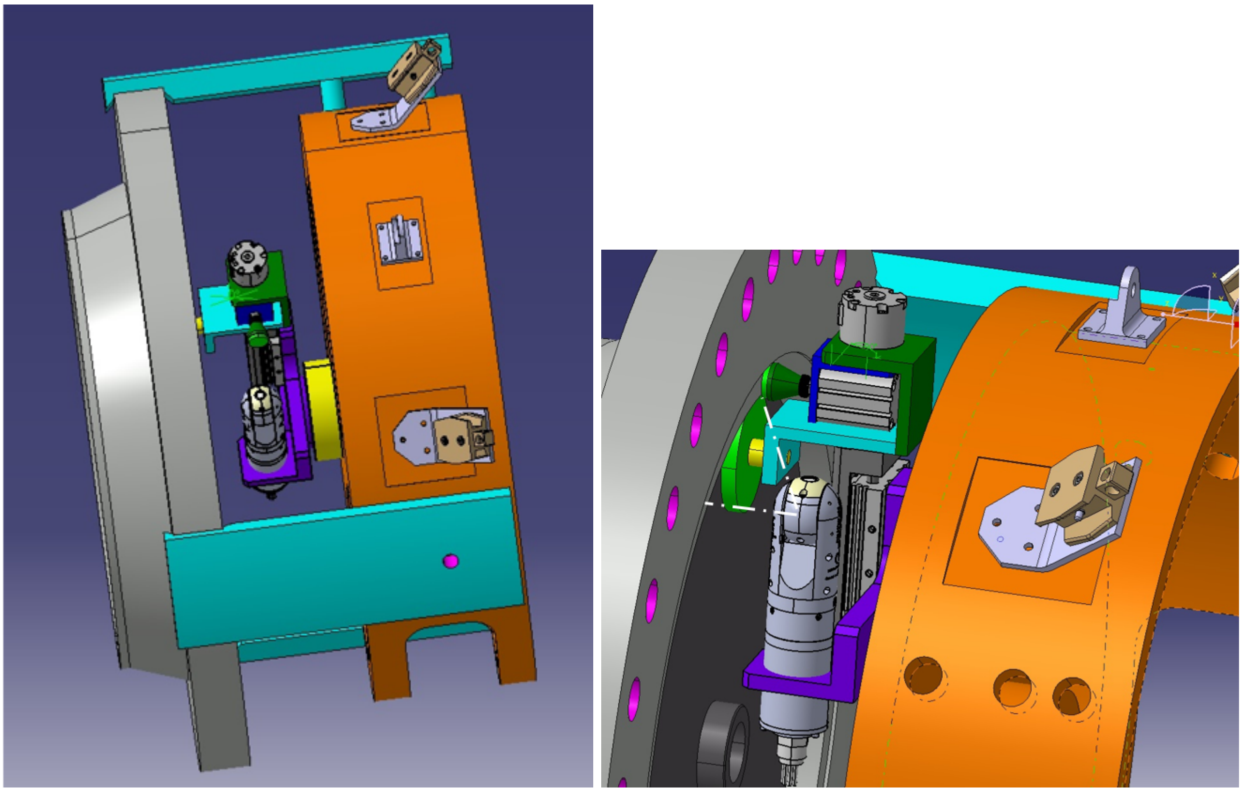


fig. 69 seal inspection and cleaning machine detail view in operation condition

7 Assessment of the contamination level and cleaning efficiency for the VVPSS

The following table reports the subtask requirements with some updates/comment based on the contract outcomes.

REQ	**Assessment of the contamination level and cleaning efficiency for the VVPSS components**	remarks/updates
3.1.01	The total in-vessel dust inventory from the vacuum vessel shall be assumed as 1000 kg.	
3.1.02	The reference characteristic of the dust is that the particle size is 0.1~100µm, median size of the dust is 1.6µm, main composition is Be (97%) and W (3%). A further test on sub-micron dust median size will also be considered.	
3.1.03	The contamination and cleaning testing shall be focused on separate effects testing to know the effect of each individual phenomenon as much as possible, for example, simple geometry, same material, and one physical phenomenon at a time.	two different dust deposition method are considered. Contamination/residual dependency on surface roughness is also assessed.
3.1.04	The contamination during the normal operation and after the accidental events shall be considered for any assessments. Reference dust concentration is above defined.	10g/l dust concentration in water suspension is considered as worst case reference 5g/l and 1g/l are also considered

3.1.05	The contamination testing shall be carried with both steam and water contamination.	steam and spray contamination shown little dust transport in lab scale experience for the purpose of this contract. The updated contamination tests are: quasi-static dust deposition on vertical and horizontal samples (tank sedimentation); dust deposition on vertical plate inside a dust suspension flow (0.2:0.4 m/s water speed)
3.1.06	The possible contaminated areas in each ITER VVPSS components shall be identified.	discussion on different dust distribution inside VVPSS was the focus of several meeting but nothing specific was finalized in this sense. Furthermore flow conditions and dust flow are not clearly stated in this stage. Dust deposition and flow condition before VVPSS line could affect dust concentration inside VVPSS. Dead pipe/line section as well as sharp flow transition could create local dust accumulation not verifiable with the current reduced scale lab simulations. For this reason reproducible reference conditions and statically relevant tests were performed
3.1.07	The amount of contamination in each ITER VVPSS components shall be estimated, eg. on the surfaces, inside discontinuity, dead zones, etc. based on the contamination results achieved.	see above
3.1.08	The contamination testing shall be established and justified in relation with the actual known contamination mechanism.	water suspension dust transportation was selected as reproducible contamination test.
3.1.09	Each contamination testing for each testing configuration shall be repeated at least twice to check no false reading/false results	a significant set of result is reported to have statistically relevant even if preliminary results
3.1.10	The cleaning during the normal operation and after the accidental events shall be considered for any assessments.	see 1.01.01/1.01.02
3.1.11	The applicability of various cleaning methods to the relief line, rupture disks and bleed line valves shall be assessed such as brushed vacuuming, air blasting, water jet (30 m/s water flow).	test are performed with updated DT waterjet cleaning conditions as reference: 20 m/s water flow. Cleaning head feed speed is set at speed in the range btw 10 and 30 mm/s Air blasting test were not included within the planned activities. Brush vacuuming is not compliant with internal VVPSS cleaning. In deep investigation on dust cleaning and dust residuals with SEM was included to support the planned experimental trials.
3.1.12	The applicability of various cleaning methods to the vapour suppression tank shall be assessed such as water jet etc.	water jet cleaning is considered the reference cleaning solution for the whole downstream VVPSS line including VST. The same solution being derived from DT decontamination.
3.1.13	The cleaning efficiency shall be assessed for each applicable cleaning method.	
3.1.14	The cleaning efficiency shall be assessed considering the various cleaning parameters, for example, pressure, pressure angle, shooting distance, velocity of the cleaning mediums, and cleaning time. The affected cleaning parameters shall be identified further when required.	reference cleaning condition above defined were kept constant. No further optimization was performed on those parameter. The next step to perform could be to scale test from sample plate size to real size mock-up. In this sense an iteration on cleaning parameter could be needed.

3.1.15	The amount of the required cleaning medium shall be assessed.	based on the above defined reference conditions the water flow in the lab test was 6.3 l/min reduced scale tests were focused in measuring the available cleaning efficiency. To asses correctly required cleaning medium for bigger surface specific tests on bigger scale are recommended.
3.1.16	The effect of the cleaning process to the ITER plant system shall be assessed from IO.	N.A.
3.1.17	The effect of the baking on the cleaning efficiency shall be assessed. The baking temperature is at least 180°C from [PR427-R]), for example, cleaning testing before baking and after baking.	all test performed on cleaning shows no difference on dust residual. 250 °C heating was included in a first set of tests. Sample heating after backing was hence suppressed
3.1.18	Each cleaning testing for each testing configuration shall be repeated at least twice to check no false reading/false results.	

tab. 18 contamination/cleaning REQ

7.1 Summary on previous dust related studies

At present the main concerns of ITER about dust are related to safety issues due to dust chemical activity and toxicity , tritium retention and radioactivity, which can complicate licensing process , and possible degradation of in-vessel diagnostics caused by the dust.

Maximum levels for mobilizable dust and T inventories have therefore been defined during the safety analysis of the ITER project:

-1 kg for the mobilizable T in vessel inventory, driven by the 'no evacuation' limit;
-1 ton of mobilizable dust in the vessel during the D–D and D– T phase, driven by estimate of the radioactive source term. No limit is foreseen during the H phase, as no significant activation/T inventory is expected;
-6 kg of C, 6kg of W, 6 kg of Be dust on hot surfaces, driven by the H2 production risk (this corresponds to the maximum allowable H2 quantity- 2.5 kg - for the vessel integrity to be guaranteed in case of explosion).

Administrative limits have been derived from these safety limits taking into account the uncertainties of the available measurement methods. However, both experimental results on dust generation, mobilization and transport in existing devices and theoretical predictions for ITER were defined as highly uncertain and requiring additional intensive study.

The issues of dust generation mechanisms in fusion devices and the rate of dust generation are the most important and, as yet, not completely understood. The reasons for that are the difficulties with dust generation diagnostics in the fusion environment and, more generally, poor understanding of plasma–surface interaction processes, evolution of surface morphology and the physics of near-surface material under large plasma heat and particle fluxes. Currently all conclusions on dust generation rate and generation mechanisms in fusion devices only can be made based on indirect evidence based on dust collection
As far as the mechanisms of dust generation are concerned, today it is widely believed that the main source of dust in magnetic fusion devices with carbon-based plasma facing components (PFCs) is due to the flaking of co-deposited films. However, analysis of the structure of dust collected from different devices indicates that other mechanisms, such as volumetric and surface growth of dust grains via nucleation, coagulation and condensation processes, hot spots and unipolar arcs, causing surface melting and producing droplets also, contribute and may even dominate in machines with all-metal PFCs.

After over two decades of JET operation with carbon walls, the ITER-Like Wall project at JET (JET-ILW) was initiated to explore plasma performance and plasma-wall interaction processes with a full metal wall: bulk beryllium (Be), Be-coated Inconel in the main chamber and bulk tungsten (W) or W-coated carbon fibre composites (CFC) in the divertor.

It is now recognized that dust will play an important role in determining the safety and operational performance of the next step devices because of its ability to retain Tritium during the D-T runs. Much greater plasma energies and subsequent material erosion rates will produce quantities of dust much greater than what is found in research machines today. Realization of the possible public safety consequences from accidental dust mobilization prompted greater attention to dust in the safety analyses of high energy density machines (e.g. ITER, FIRE, NIF). Dust's impact on the operation of such machines remains uncertain.

Safety concerns of dust in future machines include radiological hazard, chemical toxicity, and chemical reactivity.

Various materials needed in future fusion reactors contribute to activation, tritium retention, and chemical reactivity in varying degrees. For example, ITER will use differing amounts of tungsten, carbon, and beryllium in different regions as plasma facing components.

With tungsten dust, the greatest concern is its radiotoxicity because of the high activation of tungsten. For carbon dust, retention of large quantities of tritium is problematic. For beryllium dust, its chemical reactivity with steam leading to the production of hydrogen is of primary importance, followed by the chemical toxicity of beryllium oxide. The specific radiological hazard is determined by the amount of dust mobilized and transported from the facility in a given accident scenario. Mobilization and transport of the dust are determined by properties such as size and shape. Therefore, accurate safety analyses must reliably consider dust quantities and morphologies.

Dust is also chemically reactive if combustible gas is generated during interaction with coolants or air from a vacuum leak. Reaction rates are dependent on dust amount, size, exposed surface area, and temperature. Dust generation mechanisms in tokamaks give rise to particles of large surface area
Dusts from various size, shape and composition are expected to be produced in ITER. They are mainly foreseen on or under the divertor, at the bottom of the vacuum vessel, behind the PFCs, in tile gaps/castellation or between tiles, at the horizontal ports.

Knowing dust will exist in the ITER vacuum vessel, and recognizing the associated radiological and chemical hazards, safety analysts took an approach to ensure public safety by developing strategies to confine the dust and limit chemical reactions by limiting the total dust inventory. The safety approach developed for ITER is based on assigning administrative guidelines for the maximum tolerable amount of dust mass at locations inside the vacuum vessel.

The size of dusts is important for both chemical reaction analysis (surface/volume) and aerosol transport. Dust is defined by ITER as particles smaller than 100 µm in diameter. It is considered that particles larger than 100 µm will not be transported to the environment (out of the vessel).

Presence of very small (<0.01µm) carbon particles has been experimentally observed. This could mean that either there are not present individually (they always agglomerate) or the sampling method (mainly with a vacuum cleaner) is not appropriate for such small particles. However they contribute for a small percentage of the total mass and all dust on hot surfaces is assumed to react anyway. Nevertheless, these very small particles could represent an issue for the monitoring and removal because of very high trapping forces.

Only dust with a mobilization potential will be included in the assessment of dust inventories in ITER and 100% mobilization of dust is assumed for air or steam ingress events. The mobilization potential of dusts in remote areas (behind the blanket tiles for example) or in gaps still need to be addressed, even if in the ITER documentation, dusts in gaps are said to be less mobilizable (but they still can react in case of a steam ingress).

The actual dust inventory has to be maintained below 670 kg (administrative limit) taking into account measurement uncertainties, estimated to be 330 kg. In addition, smaller quantities of dust on hot surfaces are important in potential chemical reactions that could lead to vessel overpressure events. A 1000 kg inventory of dust inside the ITER vacuum vessel was fixed as a basis for safety assessments.

Collecting dust particles in the LHD using ex-situ and in-situ dust collection methods leads to classify three kinds of dust particles:

- small spherical dust particles from 1 nm to 1 µm in size;
- agglomerates of primary particles from 100 nm to few µm;
- large dust particles above 1 µm in size and irregular in shape.

This suggests that there are three formation mechanisms: CVD growth, agglomeration, and peeling from walls.

In ITER, it was foreseen the production of particles essentially made up of tungsten, which is the PFC selected for the divertor, and also of beryllium which is the main chamber PFC.

The studies in AUG tokamak suggest a number size distribution of tungsten particles potentially mobilizable by airflow between 0.1 and 5 µm with two particle populations: one of flaky particles (modal diameter at 0.6 µm) and a second composed of spherical particles (modal diameter at 1.8 µm).

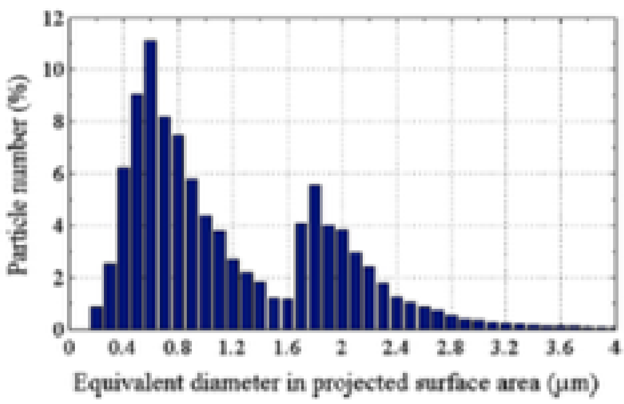


Fig. 5. Particles size distribution (in number) obtained by optical microscopy.

fig. 70 particle size distribution

In summary for what concern the dust dimensions all the studies converge on a bimodal distribution of diameters with three kinds of dust particles (small dust particles, agglomerates, and large dust particles) suggest three formation mechanisms: chemical vapour deposition (CVD) growth, agglomeration, and peeling from walls. The size ranges of these dust particles are 1 nm to 1 µm for small dust particles, 100 nm to a few µm for agglomerates and over 1 µm for large dust particles. In terms of number of particles almost 90 % is under 5 µm for Be . Also for W was demonstrated a bi- modal particle size distribution with a mode composed of flakes at 0.6 µm and a mode composed of spherical particles at 1.8 µm.

In summary it was stated that at the moment , on the basis of the results on the ILW in Jet and other full metal Tokamak, dust is a recognized safety concern on ITER but a factor of 10 more dust was expected in the past than in current devices. Largest source is expected to be due to disruption and for this reason development of effective mitigation/avoidance will be a priority. Operations in non-active phases must develop highly reliable disruption avoidance and mitigation

About 100 kg of Be dust formation per high power DT campaign is predicted (worst case with fd=1) so well below the authorized safety limit of 1000 kg. Only small W dust source expected because no melt destabilization and no steady state W deposition source was demonstrated.

Currently expecting ~100 unmitigated MD+VDE in first DT phase; but it is the worst case as disruption specifications for ITER are conservative. Most disruptions will not be worse case so the Be dust generation maybe on average ~1 kg per event Potentially only 100 kg of transient driven dust can be produced before first major intervention which will permit large scale clean-up with all divertors change-out.

In the very last scientific papers published in 2015 (144) a set of Be and W tiles removed after the first ITER-like wall campaigns (JET-ILW) from 2011 to 2012 has been analysed. The results indicate that the primary erosion site is in the main chamber (Be) as in previous carbon campaigns (JET-C). In particular the limiters tiles near the mid-plane are eroded probably during the limiter phases of discharges. W is found at low concentrations on all plasma-facing surfaces of the vessel indicating deposition via plasma transport initially from the W divertor and from main chamber W- coated tiles; there are also traces of Mo (used as an interlayer for these coatings). Deposited films in the inner divertor have a layered structure, and every layer is dominated by Be with some W and O content. Up to now the composition of the contaminated dust is defined as 97% Be and 3% W.

Events	# of events	Dust/event	Total dust	Limit
Steady-state	6000	3-19g Be	<50kg Be	
Unmitigated disruptions (MD/VDE)	~100	~1kg Be	~100kg Be	
Unmitigated RE	<1-2	~4 Kg Be/W	<8kg Be/W	
Total			~150kg Be	1000 kg
			~4 kg W	

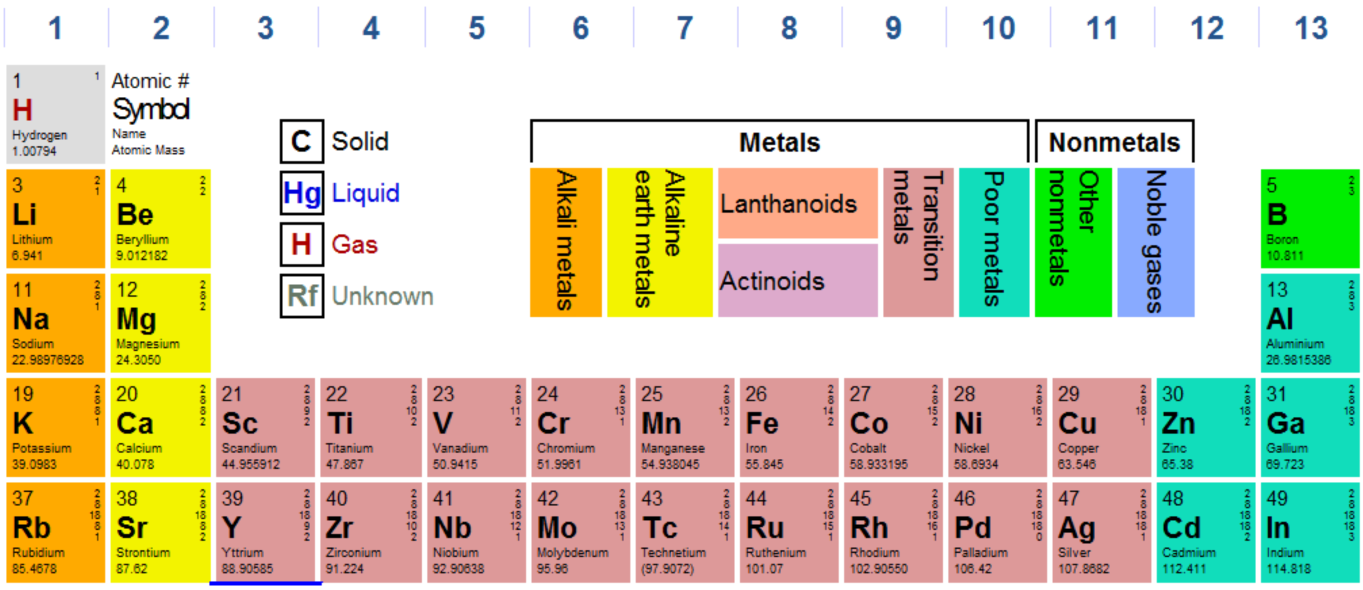
fig. 71 dust composition

7.2 dust equivalent identification

As discussed ITER dust reference composition is based by 97% Be and 3% W.
Tungsten is directly available as 2-3 um grain size well in line with ITER dust known specifications (a reworked fraction of this W down to 0.45 um was used to measure dust dependency on particle size).
To perform contamination and cleaning tests different materials was used as alternative Be because 2 um sized Be metal powder is not commercially available, as the standard dimension is 44 um , and for safety reasons it is not recommended to grind:
-Aluminium oxide (particle size <1 um) and Magnesium oxide (particle size < .1 um) were selected as best available equivalent of Beryllium Oxide where particle size of MgO was one order of magnitude less than dust reference specification;
-Pure magnesium was also used as Be equivalent belonging to the same chemical group with the same density (the main limitation in this case being the particle size one order of magnitude bigger than ITER specification).
- Zinc stannate is a commercially available plastic additives that was used as first dimensional and density “best equivalent” for Be.

Sample	Dimension	Density (g/cm^3)
Be		1.85
W	<3 µm	19.3
W	<450 nm	19.3
Al2O3	<1 µm	3.5:3.9
MgO	100 nm	3.58
Mg	63-100 µm	1.73
ZnS	>53 µm	4:5

tab. 19 material table



tab. 20 periodic table extract

As better discussed in the following sections the selected materials showed different behaviours not simply related to density and particle size. The influence of different chemical and electro-magnetic behaviour influences the dust deposition.

7.3 sample plate specifications

After a preliminary set of test done on different shapes/material plates, a "standardized" 20x50 aisi 316 sample plate was defined as reference. Three different surface finishes were considered to asses dust contamination/residual sensitivity on surface roughness. Average measured sample plate roughness in the three cases is below reported for reference.

SAMPLE ROUGHENSS							
SANDBLASTED			POLISHED			GRINDED	
Ra (um)	Rz (um)		Ra (um)	Rz (um)		Ra (um)	Rz (um)
1.06	6.32		0.512	3.62		0.82	0.95
0.95	6.9		0.497	3.527		0.226	2.083
0.77	5.11		0.385	3.457		0.23	2.45
1.019	7.04		0.656	5.47		0.132	1.036
			0.271	2.53		0.12	1.8
			0.105	1.3		0.13	1.15
Average			Average			Average	
Ra (um)	Rz (um)		Ra (um)	Rz (um)		Ra (um)	Rz (um)
0.94975	**6.3425**		**0.404333**	**3.317333**		**0.276333**	**1.578167**

tab. 21 sample plate average roughness

In the following the “Standard “ sample plate correspond to Sandblasted with Rz = 6.3 um , Polished to Rz 3.3 um and Grinded to Rz 1.6 um

7.4 contamination procedures

Two different contamination procedures below presented were used.

7.4.1 Dynamic contamination by mechanical stirring

A known concentration and composition is prepared (V= 500 ml) and was kept stirred by means of a mechanical stirrer (v= 60 rpm). A set of known weight sample plates fixed on pliers remained underwater for 5 min then stirring was stopped and the steel plates simply drained were placed in the oven for 15 min (105°C). The samples were cooled in a lab dryer for 15 min then weighed to measure dust deposition. Some samples were heated in a muffle furnace to 250°C and weighed again after cooling.

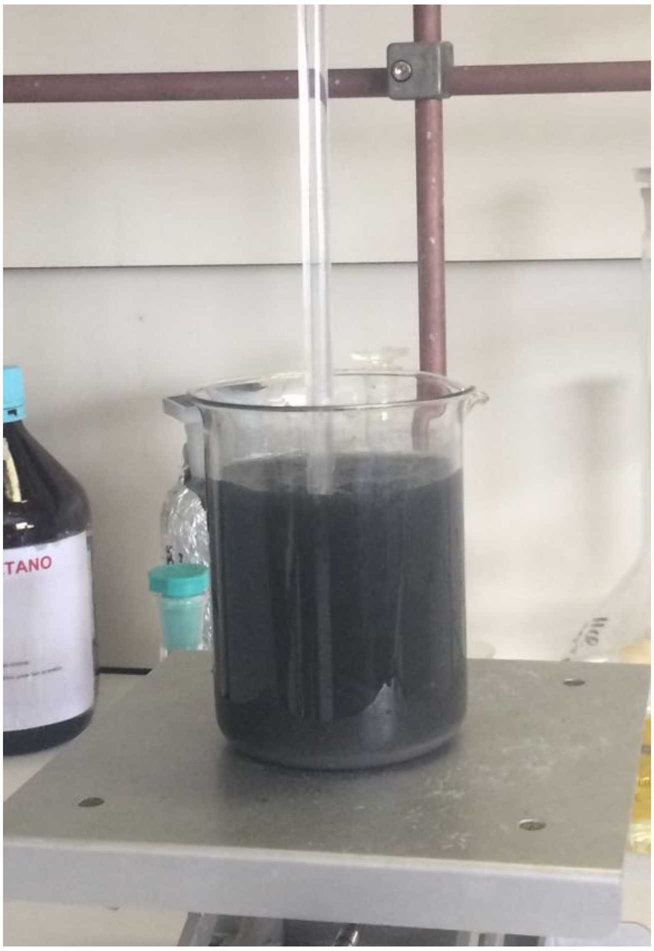


fig. 72 stirring setup

7.4.2 Static contamination by immersion

The solutions of known concentration and composition were prepared in the 5L flask and maintained stirred both with magnetic and mechanical stirrer. In a 5 L glass reactor connected to the flask by means of silicone tube the sample plates were vertically fixed on a sample holder. Four more plates were positioned horizontally on the bottom of the reactor to simulate the deposition in low flow areas.
The flask was stirred for 5 min to homogenize the solution, then the reactor was filled in about 1 min with the flask still stirred.
When the level of the liquid covered the plates the connection was closed and the reactor remains in a static situation for 5 min , then the reactor was emptied. The sample plates simply drained were placed in the oven for 15 min at 105°C . The samples were cooled in lab dryer for 15 min then weighed. Some samples were heated in a muffle furnace to 250°C and weighed again after cooling.

As added test reference condition, a set of test considers reactor cleaning with clean water after dust deposition.

The full test sequence in this case is:
The solutions of known concentration and composition is prepared in the 5L flask and maintained stirred both with magnetic and mechanical stirrer. In a 5 L glass reactor connected to the flask by means of silicone tube the sample plates are positioned horizontally on the bottom of the reactor to simulate the deposition in low flow areas. The flask is stirred for 5 min to homogenize the solution , then the reactor is filled in about 1 min with the

flask still stirred up to 3 l filling. The connection is then closed and the reactor remains in a static situation for 5 min .
Drain valve is opened and an equivalent flow of clean water is fed to the reactor to flush it with constant filling level for 5 m (total flow 9 l). Then clean water stops and the reactor is fully drained. The sample plates are placed in the oven for 15 min at 105°C, then cooled in lab dryer for 15 min and weighed.
Some plates are then cleaned with waterjet to measure cleaning efficiency on these samples. A second test is done with the same setup but with a sample inclination of 2.5°

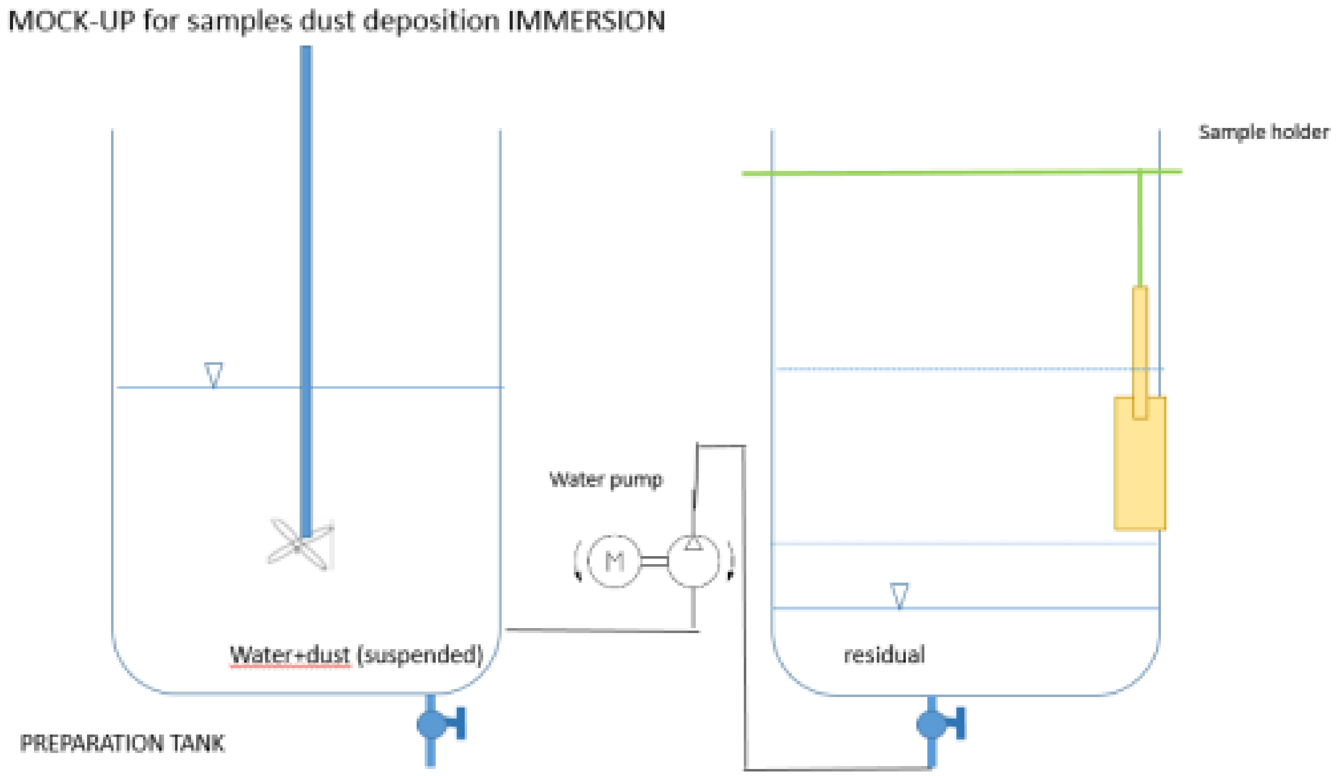


fig. 73 immersion setup

7.5 waterjet cleaning test setup

To perform reproducible cleaning test a setup with a high pressure waterjet head moved by a motorized axis travels with fixed distance and inclination along the contaminated sample plate.
The reference parameters adopted are:
Nozzle diameter: 2.5 mm
Water speed: 20 m/s
Distance between nozzle and sample: 400 mm;
Angle between sample and water: 45°.
Nozzle feed speed: 15 mm/s
These parameters are representative of the water nozzles in the drain tanks.

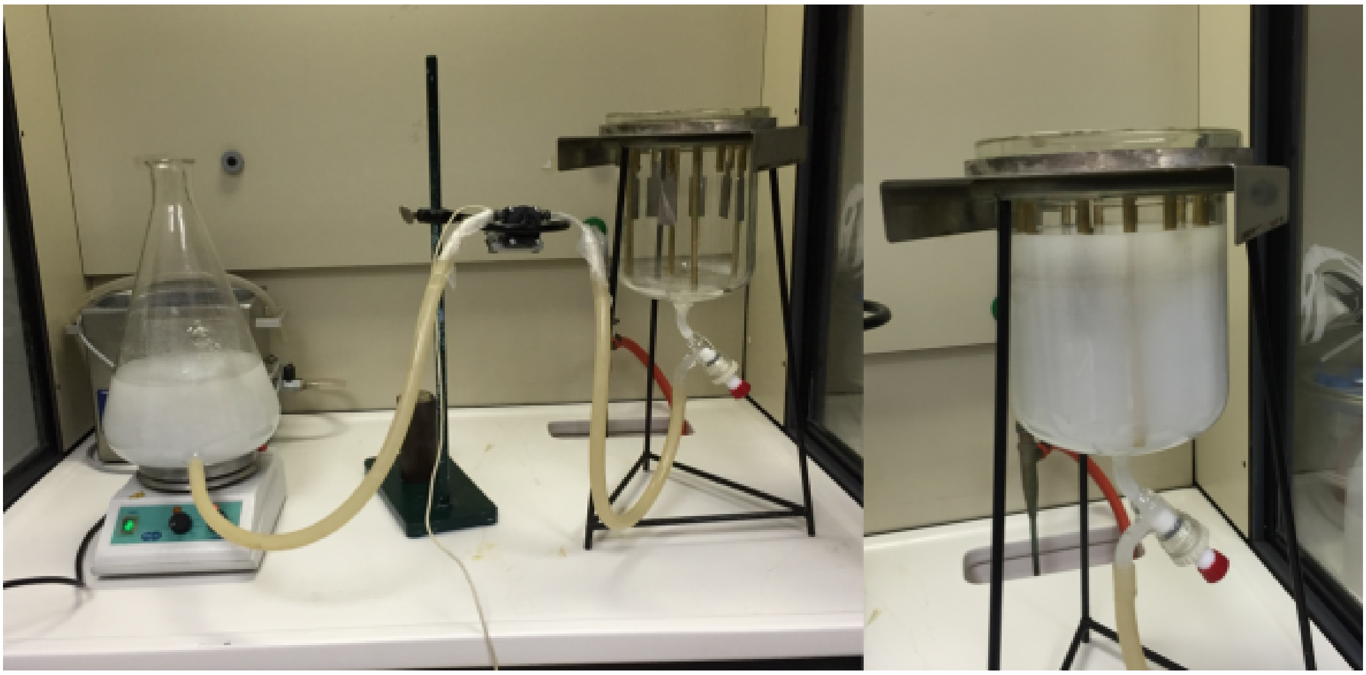


fig. 74 immersion setup

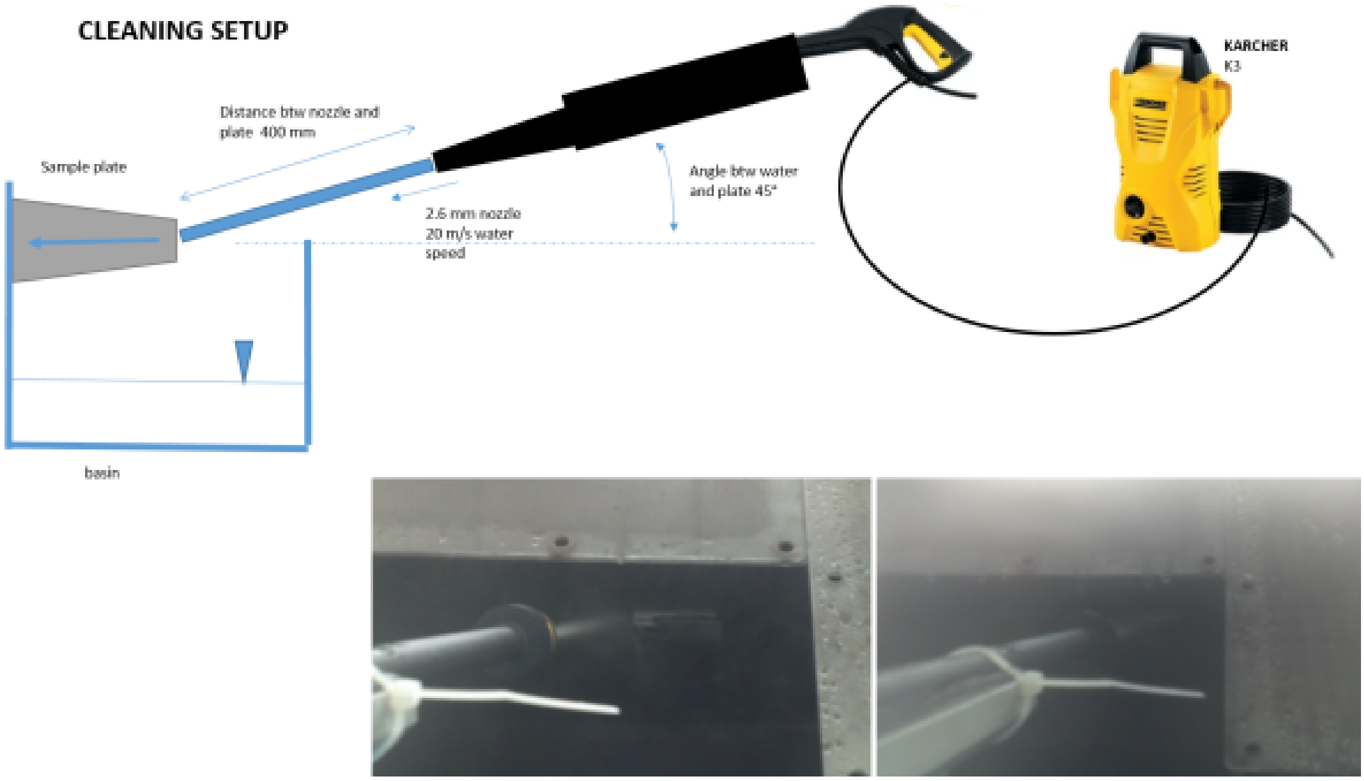


fig. 75 cleaning setup

All the samples were washed on both sides and then heated to 105°C, cooled in dryer and weighed to measure dust residuals.

7.6 contamination and cleaning results

The following tables resume all relevant results for the tests performed.
Each table reports the following data/fields grouped per columns:

- test identifier/material used as dust equivalent;
- dust suspension concentration (in g/l);
- test ID (for the defined test/material and concentration);
- sample plate initial (clean) weight (in g);
- sample plate weight after dust deposition (in g);
- sample plate weight after dust cleaning (in g).

From the last three column (experimental data) the following results are calculated:

- dust deposition (sediment) on the sample plate (in mg);
- dust removed from the sample plate by cleaning (in mg);
- dust residual on the sample plate after cleaning (in mg).

The last four column report for each test:

- average dust deposition (sediment) on sample plate (in mg);
- average dust residual on sample plate after cleaning (in mg);
- average dust deposition (sediment) on sample plate (in g/m2);
- average dust residual on sample plate after cleaning (in g/m2);

at the end of each test some further statistical data are added:

- average dust deposition standard deviation (and standard deviation over average value in percentage);
- average dust residual (sediment) standard deviation (and standard deviation over average value in percentage);

7.6.1 Static vertical/horizontal different materials

mix	concentration (g/l)	#	sample ID	initial weight (g)	weight after sedimentation (g) and 15' @105°C	weight after cleaning (g)	sedment (mg)	removed (mg	residual (mg)	average sediment (mg)	average residual (mg)	average sediment (g/m2)	average residual (g/m2)		
10g/l vertical wall															
97%ZnS e 3% W (3 um)	10 vertical wall	1	14	18.609	18.612	18.610	3	1.9	1.1	2.469	1.306	1.234	0.653	dep.dev.st	0.516
		2	15	18.604	18.607	18.606	2.8	1.3	1.5					dep. Dev st.%	20.9%
		3	16	18.613	18.616	18.615	2.5	1.2	1.3					RES. DEV. ST	0.567
		4	18	18.627	18.629	18.628	2.4	1.1	1.3					RES.DEV. ST.%	43.4%
		5	T6	18.795	18.797	18.795	1.8	1.4	0.4						
		6	7	18.614	18.616	18.614	1.7	1.2	0.5						
		7	C5	18.788	18.790	18.790	2.2	0.2	2						
		8	A4	18.775	18.777	18.777	2.4	0	2.4						
		9	18	18.626	18.629	18.628	2.7	1	1.7						
		10	12	18.603	18.607	18.605	3.4	2.1	1.3						
		11	A2	18.782	18.784	18.783	1.8	1	0.8						
		12	A3	18.766	18.769	18.767	2.8	1.9	0.9						
		13	A4	18.775	18.777	18.777	2.6	0.8	1.8						
		14	C2	18.796	18.798	18.797	1.8	1	0.8						
		15	C3	18.779	18.782	18.781	3.2	1.2	2						
		16	C4	18.792	18.795	18.793	2.4	1.3	1.1						
Al2O3 (1 um)	vertical wall	1	26	18.739	18.740	18.739	1.3	0.8	0.5	1.575	0.55	0.787	0.275	dep.dev.st	0.250
		2	2	18.586	18.588	18.587	1.6	1	0.6					dep. Dev st.%	15.9%
		3	8	18.722	18.723	18.722	1.5	1.1	0.4					RES. DEV. ST	0.129
		4	27	18.633	18.635	18.634	1.9	1.2	0.7					RES.DEV. ST.%	23.5%
MgO (0.1 um)	vertical wall	1	28	18.754	18.755	18.755	1.2	0.7	0.5	1.375	0.525	0.687	0.262	dep.dev.st	0.171
		2	25	18.605	18.606	18.606	1.3	0.8	0.5					dep. Dev st.%	12.4%
		3	10	18.630	18.632	18.631	1.4	0.8	0.6					RES. DEV. ST	0.050
		4	14	18.608	18.610	18.608	1.6	1.1	0.5					RES.DEV. ST.%	9.5%

tab. 22 Vertical wall static dust deposition with 10g/l concentration and different “dust equivalent” material

mix	concentration (g/l)	#	sample ID	initial weight (g)	weight after sedimentation (g) and 15' @105°C	weight after cleaning (g)	sedment (mg)	removed (mg	residual (mg)	average sediment (mg)	average residual (mg)	average sediment (g/m2)	average residual (g/m2)		
10g/l bottom tank															
97%ZnS e 3%W	10 tank bottom 0°	1	24	18.749	19.174	18.753	425.3	421	4.3	415.825	4.55	415.825	4.55	dep.dev.st	31.800
		2	A10	18.794	19.193	18.799	399.4	394.3	5.1					dep. Dev st.%	7.6%
		3	T5	18.798	19.181	18.803	382.9	377.5	5.4					RES. DEV. ST	0.896
		4	A8	18.728	19.183	18.731	455.7	452.3	3.4					RES.DEV. ST.%	19.7%
Al2O3 (1 um)	tank bottom 0°	1	18	18.626	18.742	18.627	115.3	106.3	23.2	119.73	20.57	119.73	20.57	dep.dev.st	8.470
		2	12	18.604	18.733	18.622	129.5	107.3	18.3					dep. Dev st.%	7.1%
		3	7	18.615	18.729	18.635	114.4	942	20.2					RES. DEV. ST	2.470
MgO (0.1 um)	tank bottom 0°	1	24	18.749	18.842	18.773	93.4	69.1	24.3	99.775	27.7	99.775	27.7	dep.dev.st	7.502
		2	1	18.740	18.850	18.770	110	80.2	29.8					dep. Dev st.%	7.5%
		3	9	18.698	18.799	18.726	100.7	73.2	27.5					RES. DEV. ST	2.467
		4	23	18.734	18.829	18.763	95	65.8	29.2					RES.DEV. ST.%	8.9%

tab. 23 Horizontal wall static dust deposition with 10g/l concentration and different "dust equivalent" material

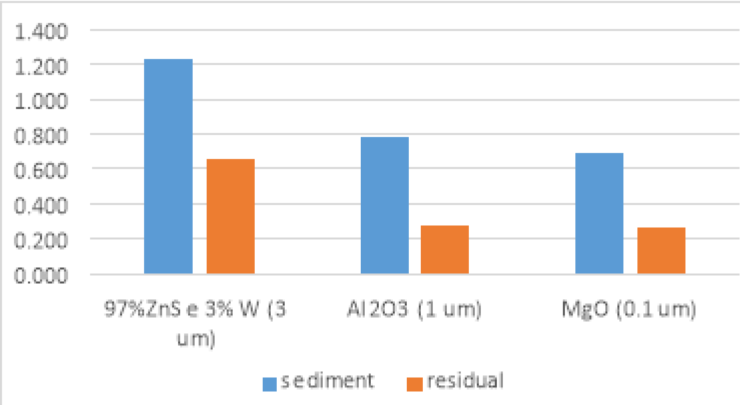


fig. 76 static vertical wall deposition and residual (g/m2) of different materials (10g/l dilution)

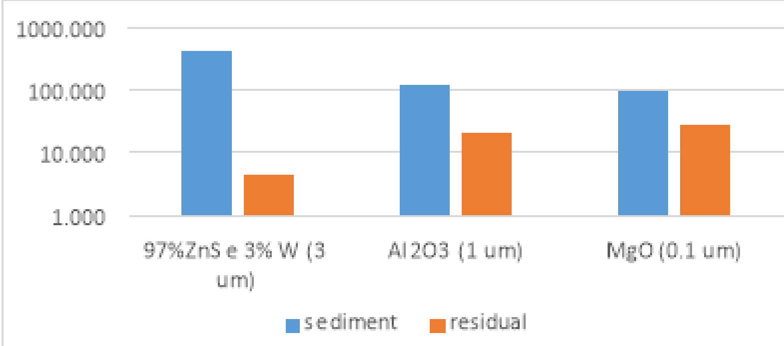


fig. 77 static horizontal wall deposition and residual (g/m2) of different materials (10g/l dilution

From the above results the suspension ZnS/W shows higher average sediment both in horizontal and vertical static test while shows lower residual in horizontal tests. In general values of residuals in vertical tests are significantly lower than in horizontal ones.

7.6.2 Static vertical/horizontal different concentration

mix	concentration (g/l)	#	sample ID	initial weight (g)	weight after sedimentation (g) and 15' @105°C	weight after cleaning (g)	sedment (mg)	removed (mg	residual (mg)	average sediment (mg)	average residual (mg)	average sediment (g/m2)	average residual (g/m2)		
10g/l vertical wall															
97%ZnS e 3% W (3 um)	10 vertical wall	1	14	18.609	18.612	18.610	3	1.9	1.1	2.469	1.306	1.234	0.653	dep.dev.st	0.516
		2	15	18.604	18.607	18.606	2.8	1.3	1.5					dep. Dev st.%	20.9%
		3	16	18.613	18.616	18.615	2.5	1.2	1.3					RES. DEV. ST	0.567
		4	18	18.627	18.629	18.628	2.4	1.1	1.3					RES.DEV. ST.%	43.4%
		5	T6	18.795	18.797	18.795	1.8	1.4	0.4						
		6	7	18.614	18.616	18.614	1.7	1.2	0.5						
		7	C5	18.788	18.790	18.790	2.2	0.2	2						
		8	A4	18.775	18.777	18.777	2.4	0	2.4						
		9	18	18.626	18.629	18.628	2.7	1	1.7						
		10	12	18.603	18.607	18.605	3.4	2.1	1.3						
		11	A2	18.782	18.784	18.783	1.8	1	0.8						
		12	A3	18.766	18.769	18.767	2.8	1.9	0.9						
		13	A4	18.775	18.777	18.777	2.6	0.8	1.8						
		14	C2	18.796	18.798	18.797	1.8	1	0.8						
		15	C3	18.779	18.782	18.781	3.2	1.2	2						
		16	C4	18.792	18.795	18.793	2.4	1.3	1.1						
5g/l and 1g/l vertical wall															
97%ZnS e 3%W	5 vertical wall	1	C1	18.798	18.798	18.798	0.8	0.3	0.5	1.412	0.687	0.706	0.344	dep.dev.st	0.567
		2	C2	18.796	18.797	18.797	1.1	0.2	0.9					dep. Dev st.%	40.1%
		3	C3	18.779	18.781	18.781	1.8	0.2	1.6					RES. DEV. ST	0.445
		4	C4	18.792	18.793	18.793	0.9	0.2	0.7					RES.DEV. ST.%	64.8%
		5	8	18.722	18.724	18.722	2.5	2.3	0.2						
		6	9	18.699	18.701	18.700	1.7	1	0.7						
		7	10	18.632	18.634	18.633	1.4	0.7	0.7						
		8	11	18.741	18.742	18.741	1.1	0.9	0.2						
	1 vertical wall	1	A5	18.762	18.762	18.762	0.3	0.1	0.2	0.475	0.325	0.238	0.163	dep.dev.st	0.287
		2	18	18.626	18.626	18.626	0.3	0.2	0.1					dep. Dev st.%	60.5%
		3	12	18.604	18.605	18.605	0.9	0	0.9					RES. DEV. ST	0.386
		4	17	18.726	18.726	18.726	0.4	0.3	0.1					RES.DEV. ST.%	118.8%

tab. 24 Vertical wall static dust deposition concentration sensitivity (test performed with ZnSn 97%+W3%)

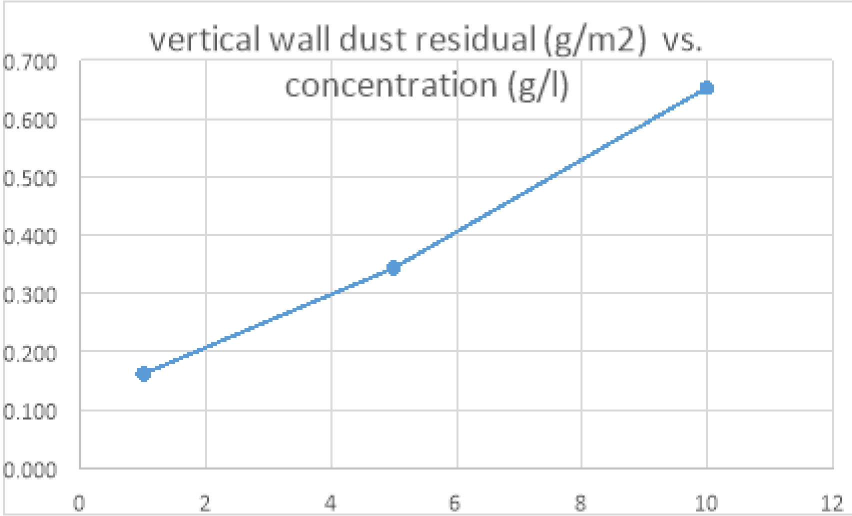


fig. 78 residual vs. concentration (vertical)

mix	concentration (g/l)	#	sample ID	initial weight (g)	weight after sedimentation (g) and 15' @105°C	weight after cleaning (g)	sedment (mg)	removed (mg	residual (mg)	average sediment (mg)	average residual (mg)	average sediment (g/m2)	average residual (g/m2)		
10g/l bottom tank															
97%ZnS e 3%W	10 tank bottom 0°	1	24	18.749	19.174	18.753	425.3	421	4.3	415.825	4.55	415.825	4.55	dep.dev.st	31.800
		2	A10	18.794	19.193	18.799	399.4	394.3	5.1					dep. Dev st.%	7.6%
		3	T5	18.798	19.181	18.803	382.9	377.5	5.4					RES. DEV. ST	0.896
		4	A8	18.728	19.183	18.731	455.7	452.3	3.4					RES.DEV. ST.%	19.7%
5g/l and 1g/l bottom tank															
97%ZnS e 3%W	5 tank bottom 0°	1	C8	18.792	18.878	18.794	86	83.4	2.6	88.5	2.175	88.5	2.175	dep.dev.st	2.426
		2	A12	18.820	18.909	18.822	89.1	87.2	1.9					dep. Dev st.%	2.7%
		3	A6	18.750	18.842	18.752	91.6	90	1.6					RES. DEV. ST	0.506
		4	16	18.612	18.699	18.614	87.3	84.7	2.6					RES.DEV. ST.%	23.3%
	1 tank bottom 0°	1	C6	18.801	18.807	18.803	6.1	4.4	1.7	6.25	1.675	6.25	1.675	dep.dev.st	1.377
		2	A2	18.781	18.788	18.783	6.9	5	1.9					dep. Dev st.%	22.0%
		3	C7	18.786	18.791	18.788	4.4	2.9	1.5					RES. DEV. ST	0.171
		4	A3	18.7649	18.7725	18.7665	7.6	6	1.6					RES.DEV. ST.%	10.2%

tab. 25 horizontal wall static dust deposition concentration sensitivity (test performed with ZnSn 97%+W3%)

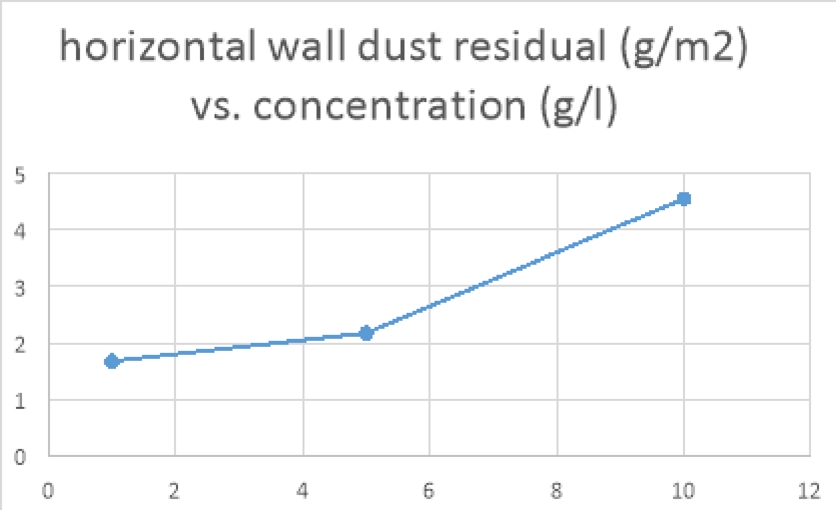


fig. 79 residual vs. concentration (horizontal)

Higher concentration of the suspension leads to higher deposition, but no linear correlation was found between the concentration of the suspension and the deposit weight on the plates. On the contrary a quasi-linear correlation between dust concentration and residual was shown both for vertical and horizontal static dust deposition tests.

7.6.3 Flush tests

mix	concentration (g/l)	#	sample ID	initial weight (g)	weight after sedimentation (g) and 15' @105°C	weight after cleaning (g)	sedment (mg)	removed	residual (mg)	average sediment (mg)	average residual (mg)	average sediment (g/m2)	average residual (g/m2)
97%ZnS e 3%W	10 tank bottom 0° (residual are also cleaned)	1	17	18.726	18.751	18.728	25.3	23.6	1.7	22.875	1.225	22.875	1.225
		2	24	18.748	18.780	18.750	31.4	30.1	1.3				
		3	A8	18.728	18.743	18.729	15.4	14.1	1.3				
		4	A10	18.797	18.816	18.798	19.4	18.8	0.6				
	10 tank bottom 2.5°	1	8	18.721	18.726		5.5			4.9	-	4.9	-
		2	9	18.698	18.702		3.4						
		3	10	18.630	18.637		6.7						
		4	19	18.616	18.620		4						

tab. 26 flush contamination/cleaning results

Flush tests show significantly lower residual than static deposition (95% of the dust is removed by reactor flushing).

7.6.4 Dynamic different materials

mix	concentration (g/l)	#	sample ID	initial weight (g)	weight after sedimentation (g) and 15' @105°C	weight after cleaning (g)	sedment (	removed (mg)	residual (	average sediment (mg)	average residual (mg)	average sediment (g/m2)	average residual (g/m2)		
100% W (3 um)	10	1	T1	18.790	18.795	18.790	5.100	4.900	0.200	3.220	0.471	1.61	0.236	dep.dev.st	1.009
		2	T2	18.779	18.782	18.779	3.400	3.100	0.300					dep. Dev st.%	31.3%
		3	T1	18.790	18.793		2.800							RES. DEV. ST	0.180
		4	T2	18.779	18.780		1.600							RES.DEV. ST.%	38.2%
		5	T3	18.790	18.792		2.300								
		6	19	18.616	18.619	18.616	3.300	2.800	0.500						
		7	15	18.603	18.607	18.604	3.800	3.200	0.600						
		8	14	18.607	18.612	18.608	4.300	3.700	0.600						
		9	12	18.602	18.605	18.603	3.000	2.600	0.400						
		10	10	18.629	18.632	18.630	2.600	1.900	0.700						
100% W (0.45 um)	10	1	7	18.612	18.619	18.614	6.600	5.000	1.600	4.900	1.500	2.45	0.75	dep.dev.st	0.913
		2	8	18.719	18.725	18.721	5.900	3.800	2.100					dep. Dev st.%	18.6%
		3	9	18.696	18.700		4.100							RES. DEV. ST	0.269
		4	10	18.628	18.632	18.630	4.000	2.600	1.400					RES.DEV. ST.%	18.0%
		5	1	18.739	18.744	18.740	5.500	4.300	1.200						
		6	2	18.585	18.590	18.586	4.900	3.300	1.600						
		7	3	18.614	18.618	18.615	4.600	3.100	1.500						
		8	7	18.613	18.618	18.614	4.800	3.600	1.200						
		9	8	18.720	18.725	18.721	5.000	3.500	1.500						
		10	9	18.697	18.701	18.699	3.600	2.200	1.400						
MgO (0.1 um)	10	1	C5	18.789	18.917	18.791	128.200	126.400	1.800	105.833	1.883	52.917	0.942	dep.dev.st	16.893
		2	7	18.615	18.738	18.616	123.400	122.000	1.400					dep. Dev st.%	16.0%
		3	19	18.614	18.699	18.615	85.400	83.600	1.800					RES. DEV. ST	0.286
		4	24	18.742	18.848	18.744	105.700	103.600	2.100					RES.DEV. ST.%	15.2%
		5	25	18.600	18.699	18.602	98.700	96.500	2.200						
		6	26	18.706	18.800	18.708	93.600	91.600	2.000						
Al2O3 (1 um)	10	1	12	18.601	18.726	18.603	124.700	122.900	1.800	113.925	2.543	56.963	1.271	dep.dev.st	8.752
		2	14	18.588	18.701	18.600	113.000	100.300						dep. Dev st.%	7.7%
		3	18	18.622	18.740	18.626	118.100	114.700	3.400					RES. DEV. ST	0.735
		4	27	18.629	18.750	18.632	120.500	117.700	2.800					RES.DEV. ST.%	28.9%
		5	22	18.724	18.820	18.725	95.900	94.600	1.300						
		6	23	18.733	18.842	18.736	109.300	106.300	3.000						
		7	24	18.747	18.860	18.750	112.700	109.800	2.900						
		8	27	18.632	18.749	18.635	117.200	114.600	2.600						
ZnS97%- W3% (3um)	10	1	1	18.740	18.749	18.740	9.900	9.400	0.500	8.517	0.400	4.258	0.2	dep.dev.st	1.242
		2	3	18.614	18.621	18.614	7.400	7.000	0.400					dep. Dev st.%	14.6%
		3	15	18.731	18.740	18.732	8.500	8.200	0.300					RES. DEV. ST	0.089
		4	19	18.6039	18.6139	18.6044	10.000	9.500	0.500					RES.DEV. ST.%	22.4%
		5	23	18.7336	18.7419	18.7339	8.300	8.000	0.300						
		6	24	18.7498	18.7568	18.7502	7.000	6.600	0.400						

tab. 27 dynamic contamination/cleaning results

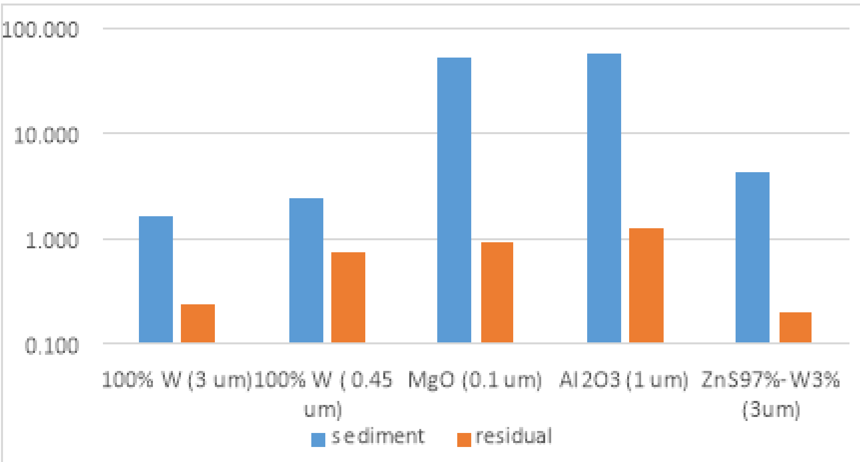


fig. 80 dynamic deposition and residual (g/m2) of different materials (10g/l dilution)

It is clear that the Al and Mg oxides show a different behaviour for what concerns average sediment while the results after cleaning appear to be closer. The different behaviour is probably due to the different chemical characteristics.

7.6.5 Dynamic roughness sensitivity

															dep.dev.st
Al2O3 (1 um)	10	1	12	18.601	18.726	18.603	124.700	122.900	1.800	113.925	2.543	56.963	1.271	sample 2 cleaning result discarded	dep. Dev st.%
		2	14	18.588	18.701	18.600	113.000	100.300							RES. DEV. ST
		3	18	18.622	18.740	18.626	118.100	114.700	3.400						RES.DEV. ST.%
		4	27	18.629	18.750	18.632	120.500	117.700	2.800						
		5	22	18.724	18.820	18.725	95.900	94.600	1.300						
		6	23	18.733	18.842	18.736	109.300	106.300	3.000						
		7	24	18.747	18.860	18.750	112.700	109.800	2.900						dep.dev.st
		8	27	18.632	18.749	18.635	117.200	114.600	2.600						dep. Dev st.%
polished sample															
Al2O3 (1 um)	10	1	S1	18.780	18.824	18.781	44.100	43.100	1.000	92.888	1.575	46.444	0.787		dep.dev.st
		2	S2	18.780	18.882	18.781	102.100	101.000	1.100						dep. Dev st.%
		3	S3	18.774	18.878	18.775	104.200	102.900	1.300						
		4	S4	18.760	18.875	18.762	114.600	112.800	1.800						RES. DEV. ST
		5	S5	18.775	18.876	18.776	101.500	100.400	1.100						RES.DEV. ST.%
		6	S6	18.759	18.826	18.760	67.500	66.200	1.300						
		7	S7	18.746	18.847	18.749	101.200	98.000	3.200						
		8	S8	18.769	18.877	18.771	107.900	106.100	1.800						
grinded sample															
Al2O3 (1 um)	10	1	G1	18.717	18.717	18.717	0.400	0.300	0.100	0.887	0.238	0.444	0.119	8 samples with high result deviation	
		2	G2	18.763	18.764	18.763	0.700	0.400	0.300						dep.dev.st
		3	G3	18.777	18.778	18.777	0.900	0.600	0.300						dep. Dev st.%
		4	G4	18.775	18.776	18.775	0.900	0.800	0.100						RES. DEV. ST
		5	G5	18.763	18.764	18.763	1.100	0.800	0.300						RES.DEV. ST.%
		6	G6	18.776	18.777	18.776	1.500	1.200	0.300						
		7	G7	18.768	18.769	18.768	1.100	0.900	0.200						
		8	G8	18.730	18.731	18.730	0.500	0.200	0.300						

tab. 28 Sample plate roughness sensitivity on dynamic dust deposition test

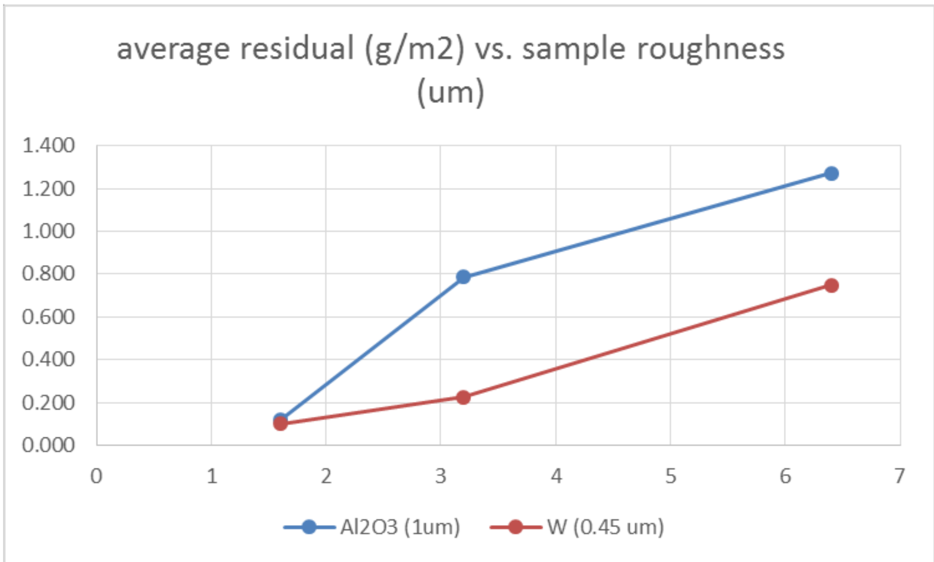


fig. 81 Sample plate roughness sensitivity on dynamic dust deposition test

It is assessed that dust deposition residual increases with the roughness of the plate. While 0.45 micron W dust shows a quasi linear correlation between roughness and residual Al2O3 show a steep transition between 0.8 um and 1.6 um. The reasons for this are discussed in the next section.

7.6.6 SEM analysis on dust deposition

Dust deposition SEM view with different materials on standard sample plate:

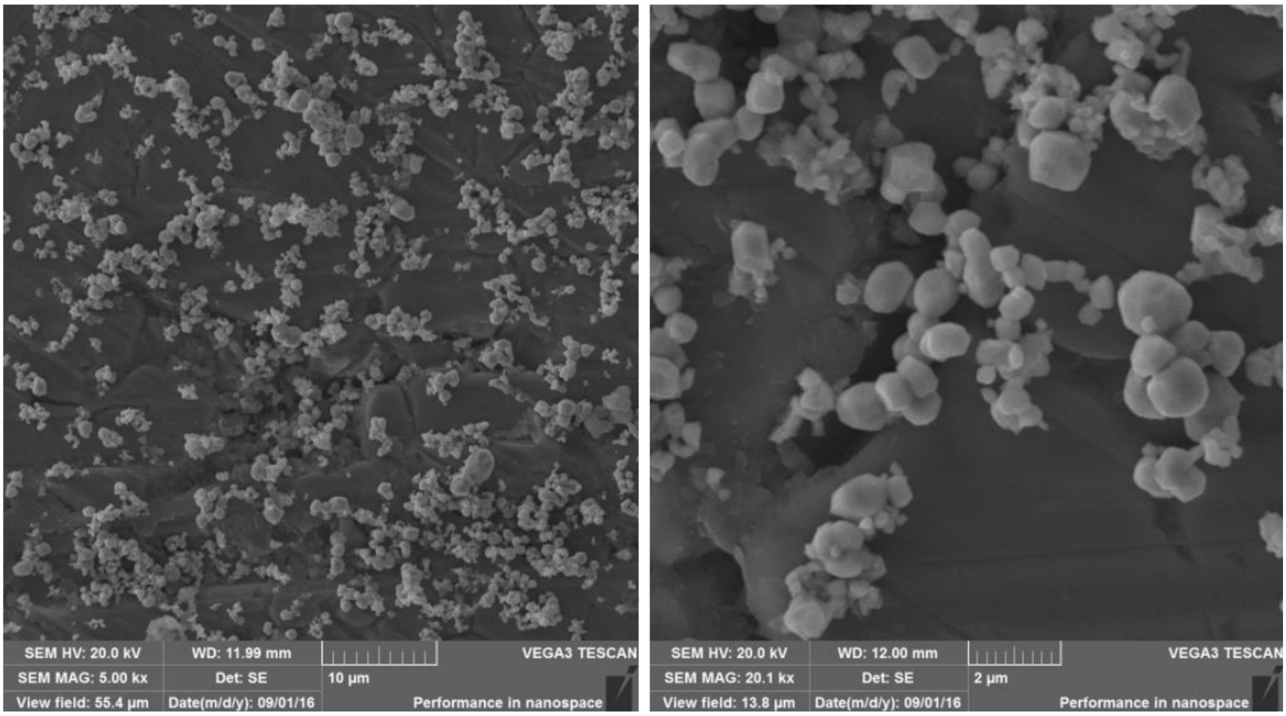


fig. 82 W 3 um

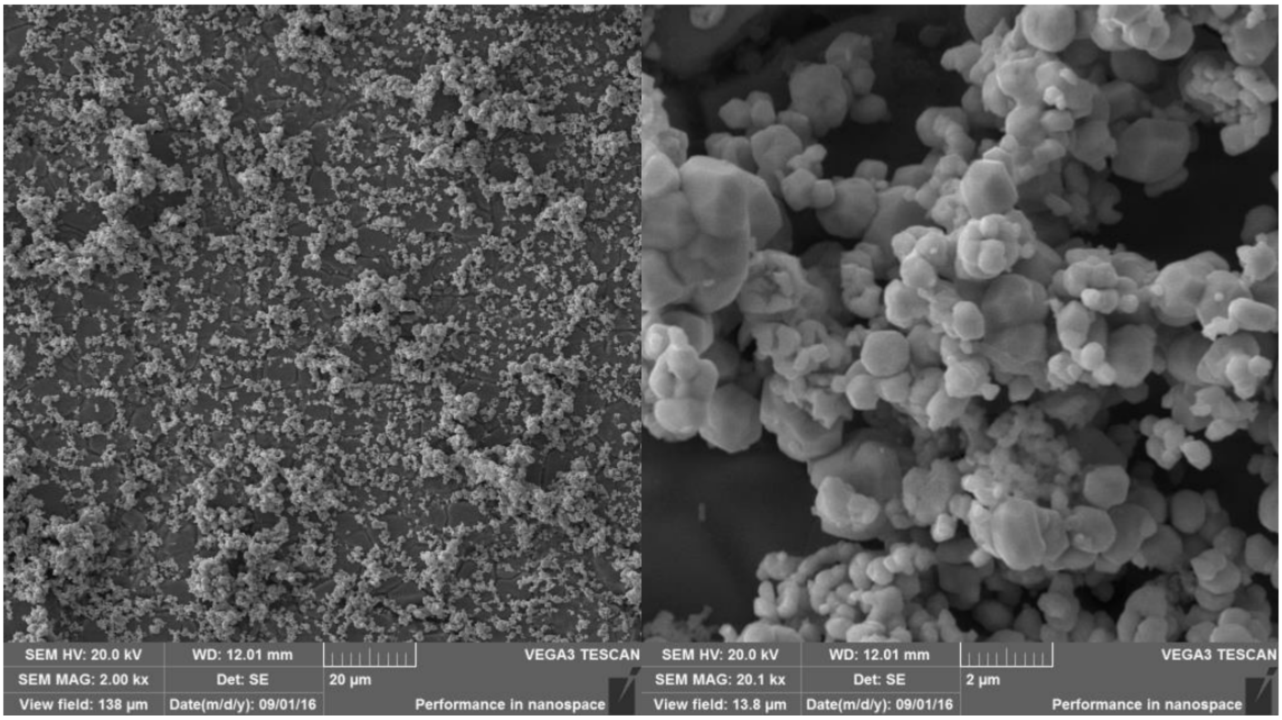


fig. 83 W .45 um

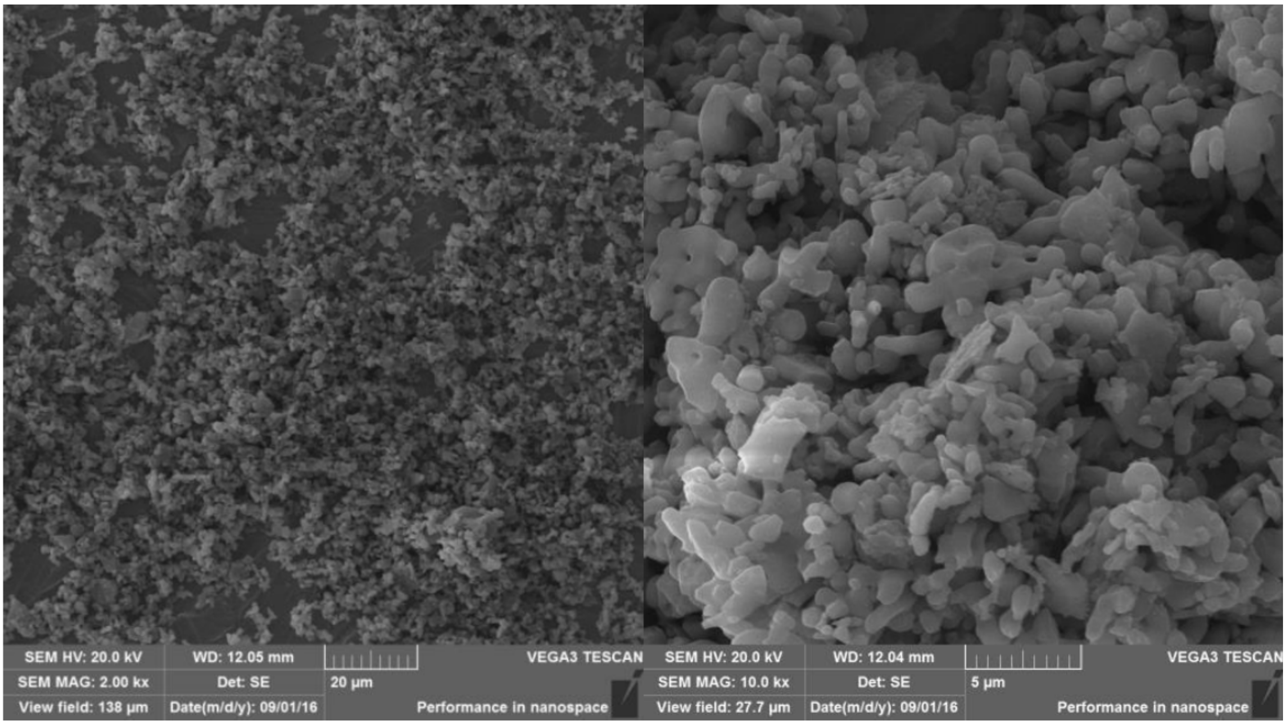
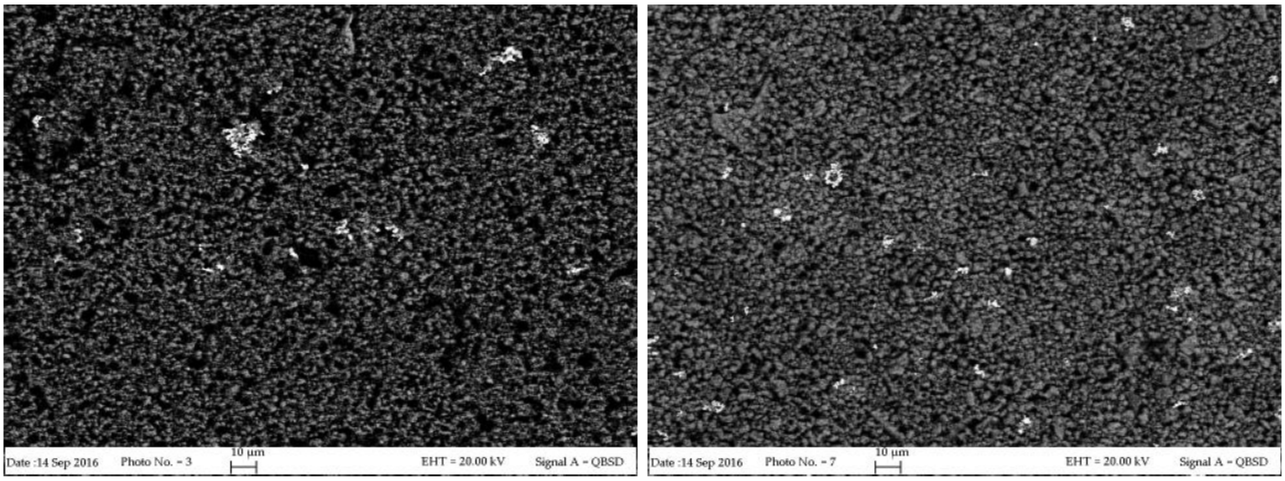


fig. 84 Al2O3 1 um

The previous pictures clarify the different behaviours of materials with different density and size. In general we can say that smaller particles means more particles per volume. This leads to a bigger Ratio surface/mass with more particle aggregation. Lighter material (density 1/5) means more particles per volume, with a bigger ratio surface/mass and more particles layered.



backscattering signal contribution		
	Weight%	
Element	VERTICAL	HORIZONTAL
Zn	30.5	30.8
Sn	66.1	64.1
W	3.4	5.1

fig. 85 W fraction on 97%ZnSn 3% W deposition (SEM backscattering)

The previous two slides demonstrate the presence of W (white particles) in the deposition sediment.

7.6.7 SEM analysis on dust RESIDUALS

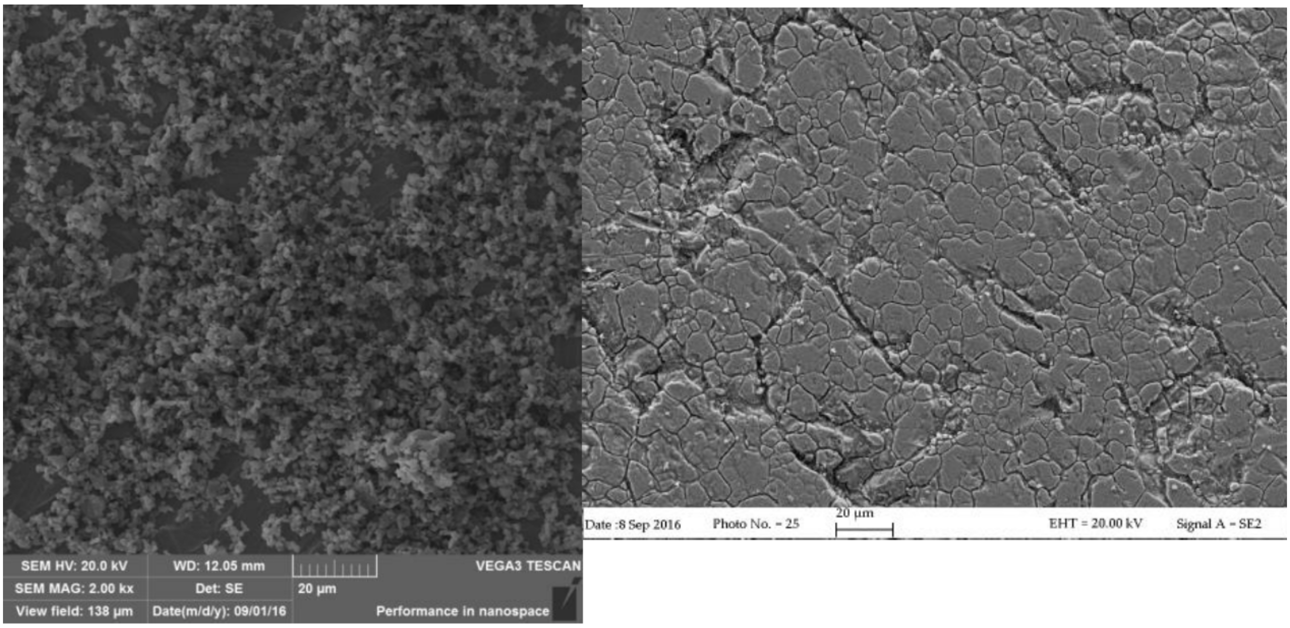


fig. 86 Al2O3 dust deposition vs. residuals on standard plate

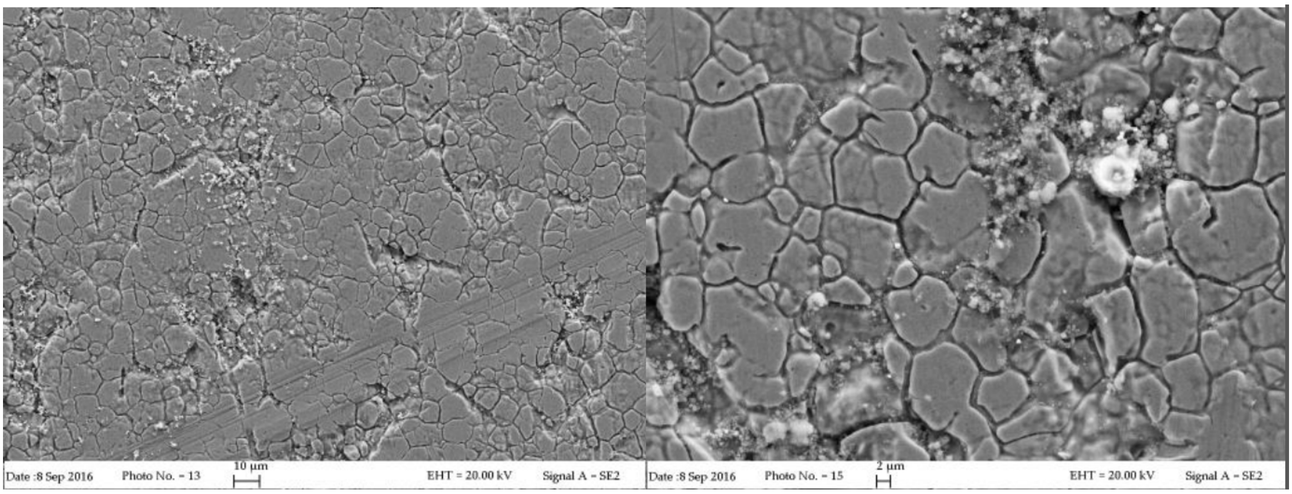


fig. 87 W 3 um residuals on standard plate

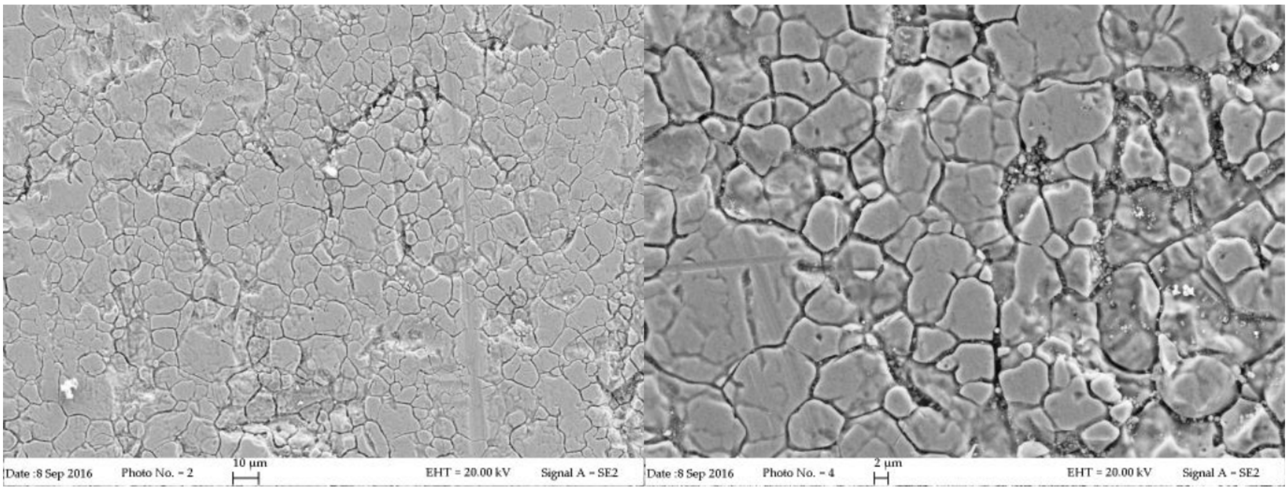


fig. 88 W .45 um residuals on standard plate

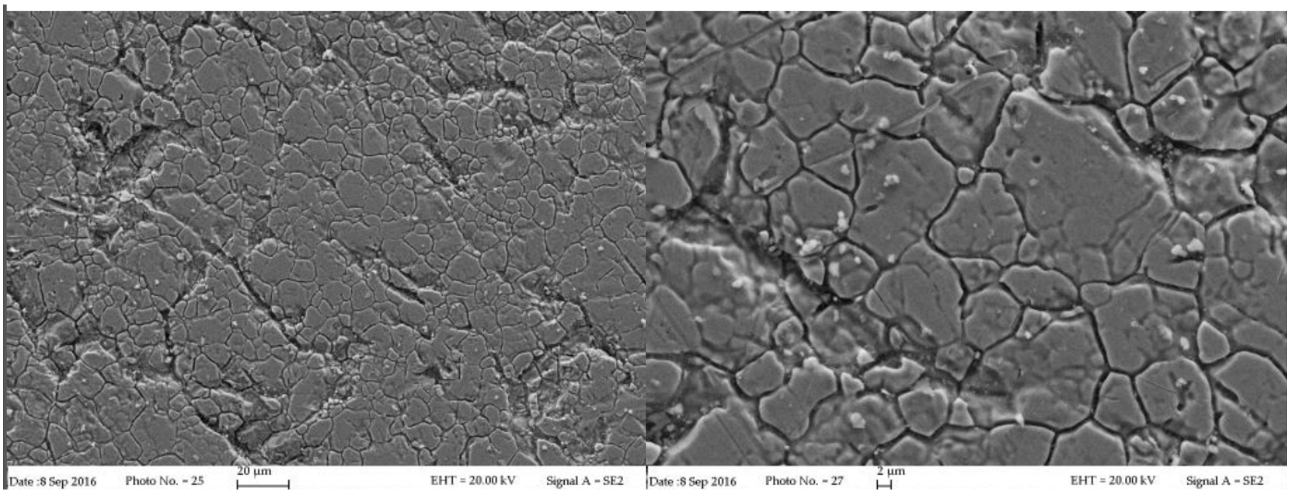


fig. 89 Al2O3 1 um residuals on standard plate

A direct quantitative correlation between the SEM pictures and the measured dust seems not obvious (at least within the limit of the test performed). In general some particles are still on the surface with more residuals inside gap and surface defects . Locally some particles appear still grouped at least for W 3um.

7.6.8 **SEM analysis on dust** RESIDUALS ROUGHNESS SENSITIVIY

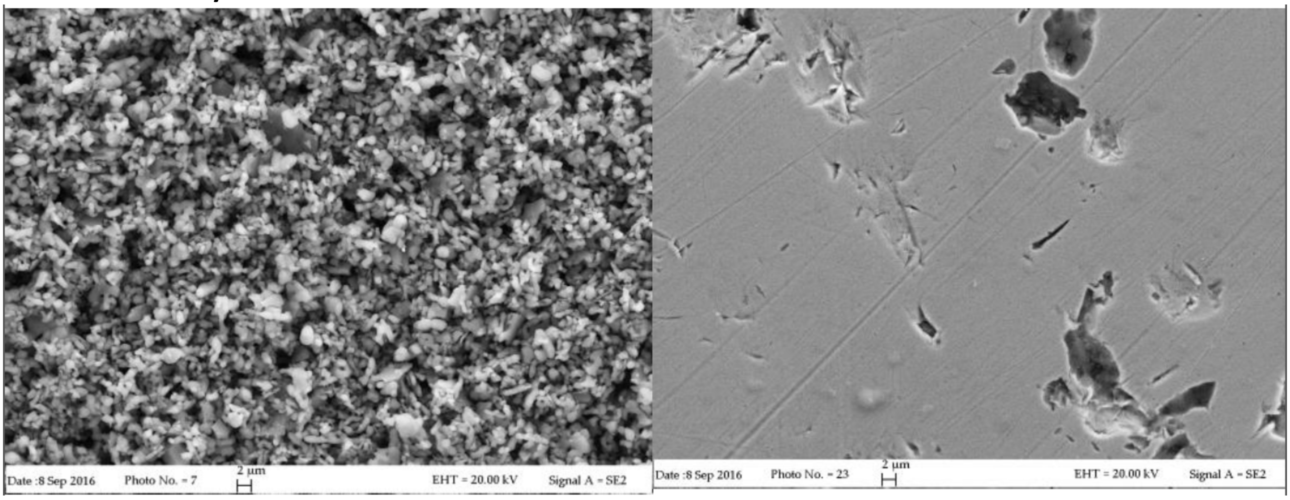


fig. 90 Al2O3 depositions vs. residuals on 1.6 um roughness plate

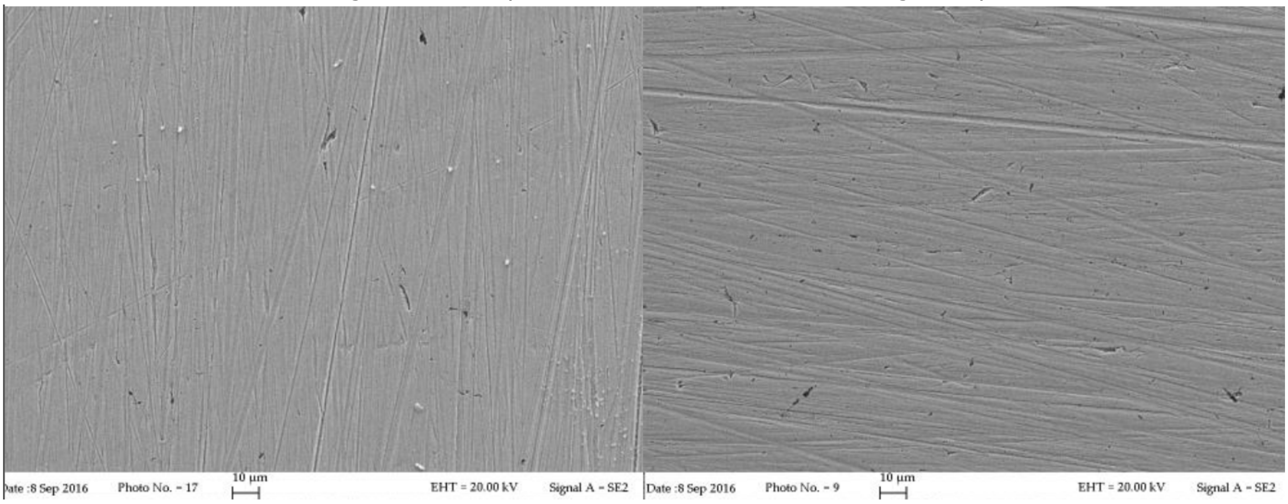


fig. 91 Al2O3 depositions vs. residuals on 0.8 um roughness plate

The pictures of the polished plate surface show the residual dust particles mostly blocked inside defects while the grinded plate surface picture show the few residual dust particles scattered on the surface.

The following schematic drawings explain the cleaning process model as interaction between particle size and surface defects size.

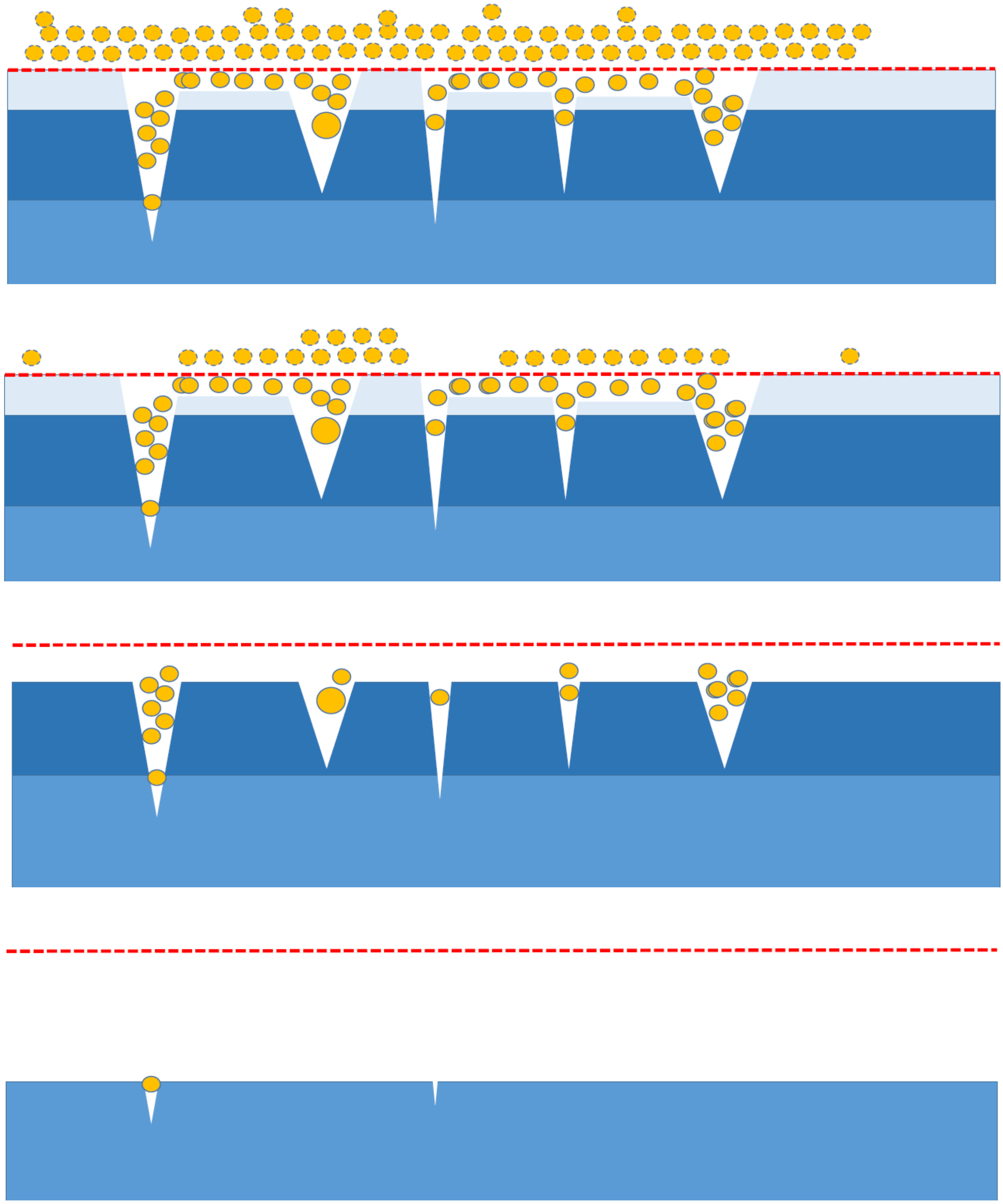


fig. 92 roughness geometric model based on SEM results

The model shows that layered particles are easily removed while particles more or less blocked in the defects and gaps are removed with increased difficulty bounded to the ratio particle size/ gap size.

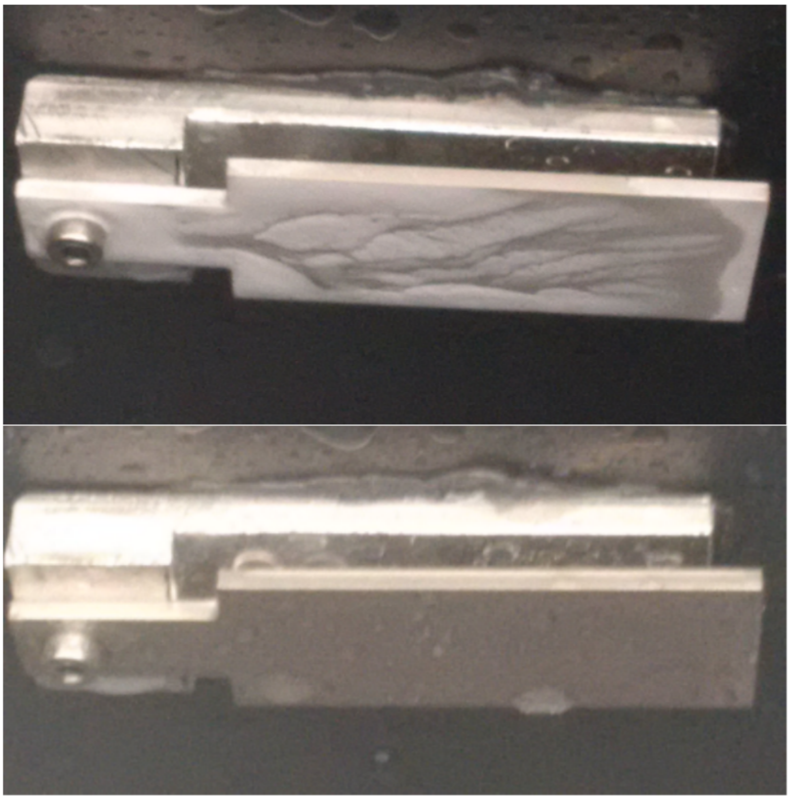


fig. 93 sample plate cleaning (before/after)

fig. 94 reactor bottom samples without and with flush cleaning

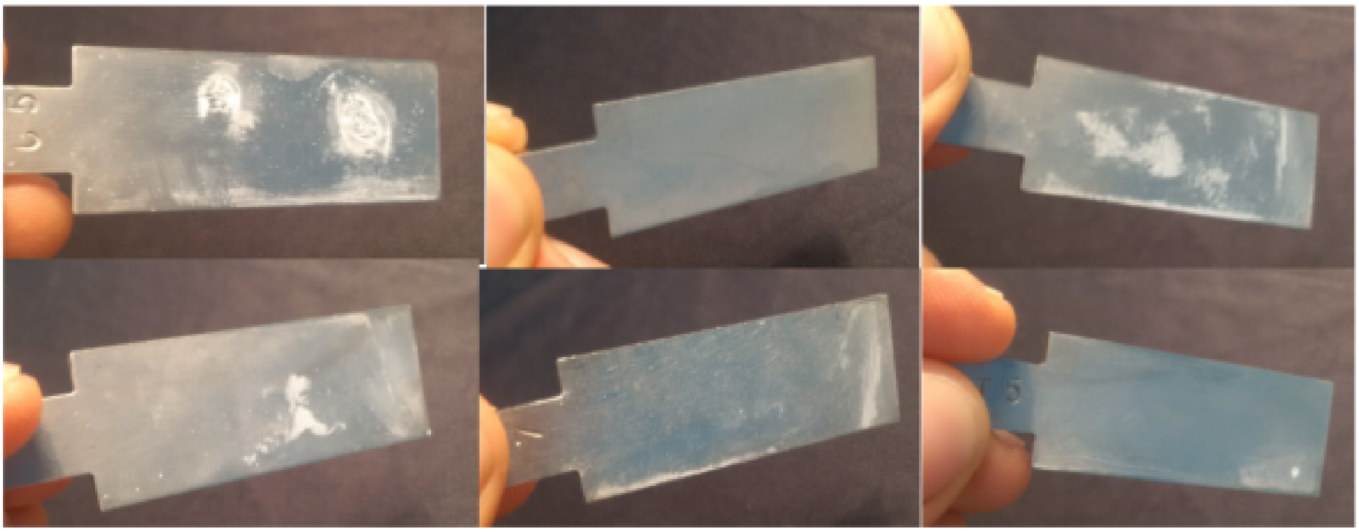


fig. 95 dust traces on sample plate after cleaning (visible residuals)

7.7 comments on contamination cleaning tests

Tests performed with mechanical stirring show a systematically higher deposit in comparison with the immersion tests with same material and orientation of the steel plates (vertical). This may depend from the greater turbulence obtained with the mechanical stirring which could promote the adhesion of the powders.

- Al and Mg oxides show a different behaviour probably due to the different chemical characteristics.
- Tests with the horizontal plates show a much higher deposition than vertical ones due to sedimentation.

- Heat treatment does not influence the adhesion of dust to the plates as the efficiency of the cleaning operation remains the same at the 2 different temperatures 105/250°C (test performed with heat treatment are not included in this final report)
- Flush tests show significantly lower residual than static deposition (95% of the dust is removed by reactor flushing).
- Samples with carbonyl Iron are systematically higher than other materials probably but this is the only tested magnetic material hence and higher particle to particle adhesion could be expect.
- In static contamination tests higher deposition leads to higher residual.
- In flow contamination residual are mostly constant even with a wide range of different depositions and materials.
- Higher concentration of the suspension leads to higher deposition, but no linear correlation was found between the concentration of the suspension and the deposit weight on the plates.
- The dust deposition residual both for vertical and horizontal plates shows a quasi linear correlation with concentration .
- The dust deposition residual increases with the roughness of the plate with a quasi linear correlation at least for W 0.45 microns. To reduce residual dust grinded surface should be used .
- SEM pictures of the standard plate surface after deposition show that in case of smaller particles there are more particles per volume with a Ratio surface/mass bigger, consequently with more particle aggregation. In case of lighter material(density 1/5) there are more particles per volume with a ratio surface/mass bigger. Consequently more particles layered.
- A direct quantitative correlation between the SEM pictures and the measured dust seems not obvious (at least within the limit of the test performed).
- In general, pictures of the standard sample plates after cleaning show that some particles remain on the surface with more residuals inside gap and surface defects . Locally some particles appear still grouped .

- SEM pictures of the polished plate surface show the residual dust particles mostly blocked inside gap while pictures of the grinded plate surface show the few residual dust particles scattered on the surface. This result outline that the industrial process of surface finish may affect significantly dust residuals after cleaning.
- In all the tested conditions dust residuals could be removed by soft cloth dry wiping.
- A simple model was developed just to show that layered particles are easily removed while particles more or less blocked in the defects and gaps are removed with increased difficulty bounded to the ratio particle size/ gap size.
- Water jet cleaning shows a general high cleaning efficiency in all the tested conditions. Also the reduced number of tests on flush cleaning shows a good cleaning efficiency.

8 VVPSS tools operational sequence

8.1 HBC-NB cell deployment sequence

The following sequence focus on the tools and component flow between the HCB and the NB Cell to define how tools are grouped and handled.

BT/STP tools rack and confinement box are loaded inside the transfer cask from HCB and moved to NB cell with a dedicated stillage that holds a VVPSS dedicated task module and the confinement box with its support frame.

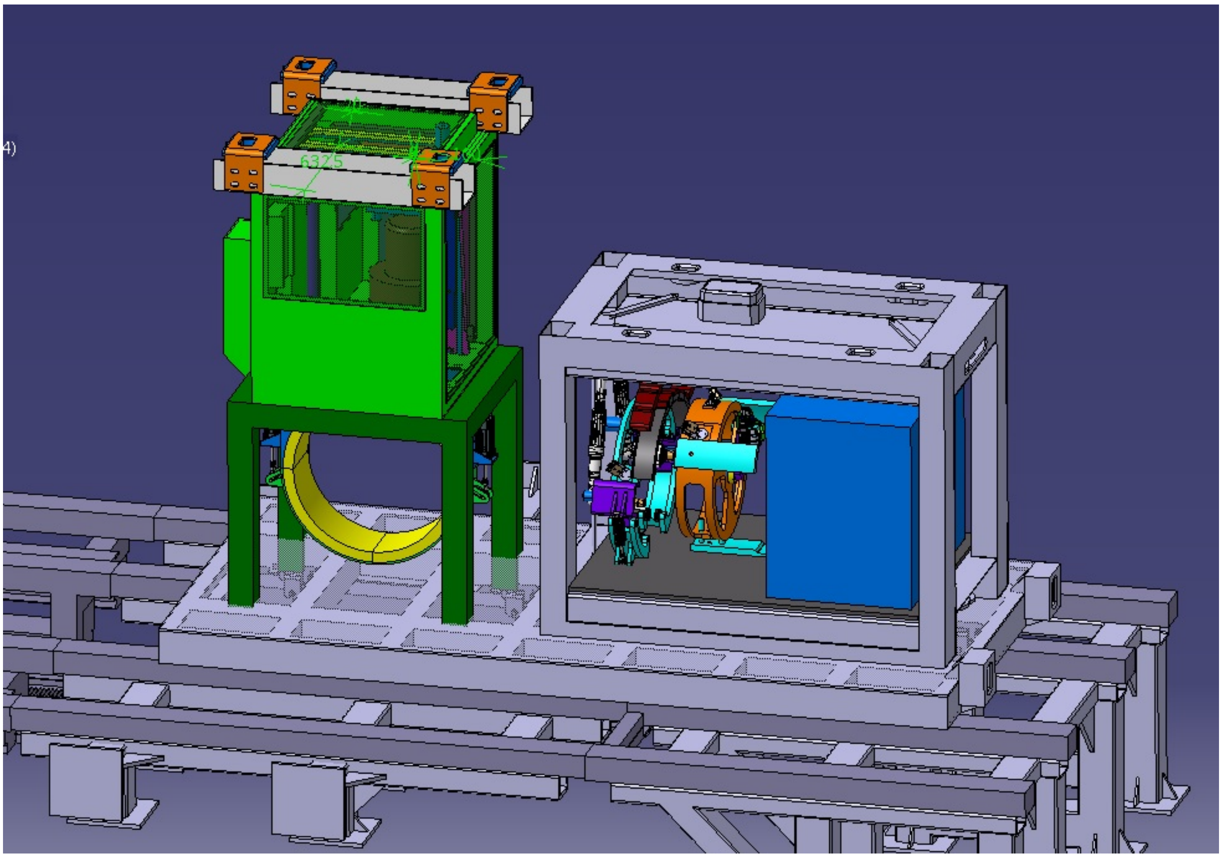


fig. 96 VVPSS task module and confinement box dedicated stillage

VVPSS task module is moved near the RD on top of the tool box shelf which can be mounted on the PMS support structure of the NBI.

Confinement box is stored in a temporary storage area located in the NB cell (Beam Source RHE location). The transfer cask moves back to HCB (empty) unload VVPSS tools stillage and loads RD stillage.

RD assembly is loaded from NB cell and moved to HCB where is unloaded at L1 (to be processed as rad waste down to B2). The cask loads the cleaning tool loaded on the same stillage and moves back to NB Cell. Once completed the cleaning sequence the cleaning tool is moved back to HCB. This time cleaning toll is unloaded to IRMS remote decontamination system (21-B2-11C) to be then serviced. A new RD assembly is loaded on the cask and moved to NB Cell.

The transfer cask moves back to HCB to release the RD stillage and to load the VVPSS tools stillage.

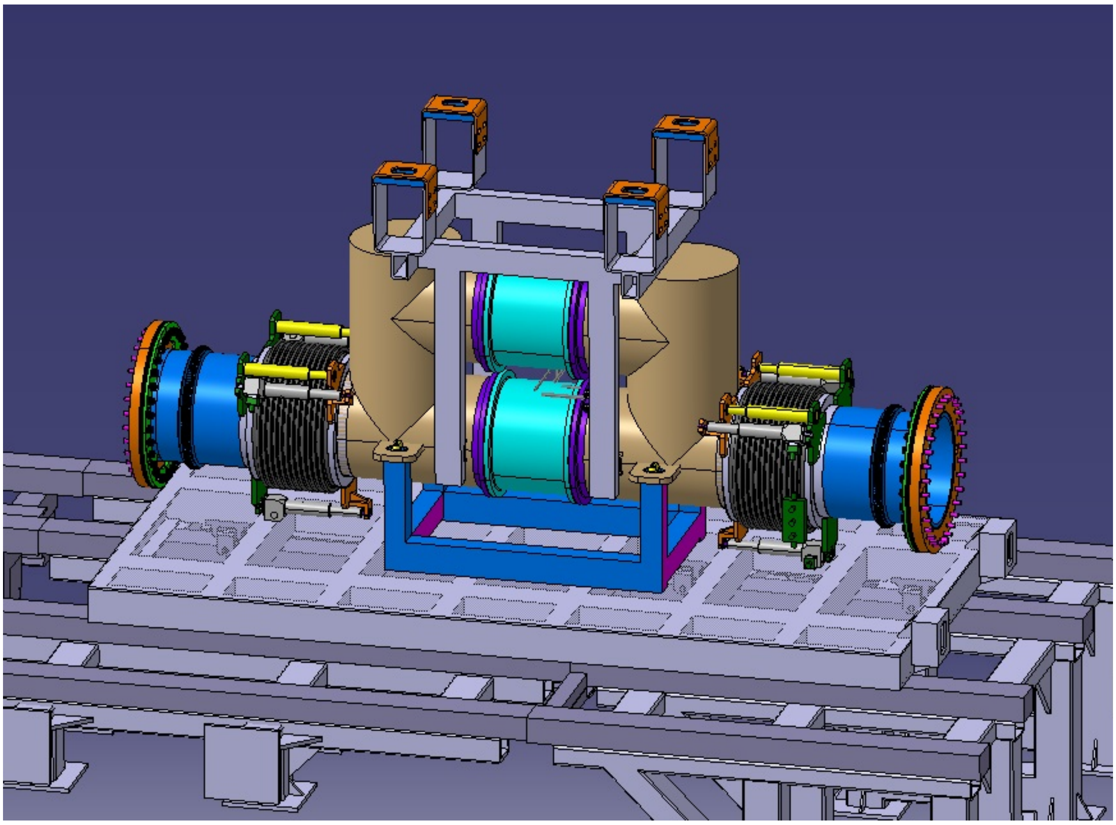


fig. 97 RD assembly on dedicated stillage

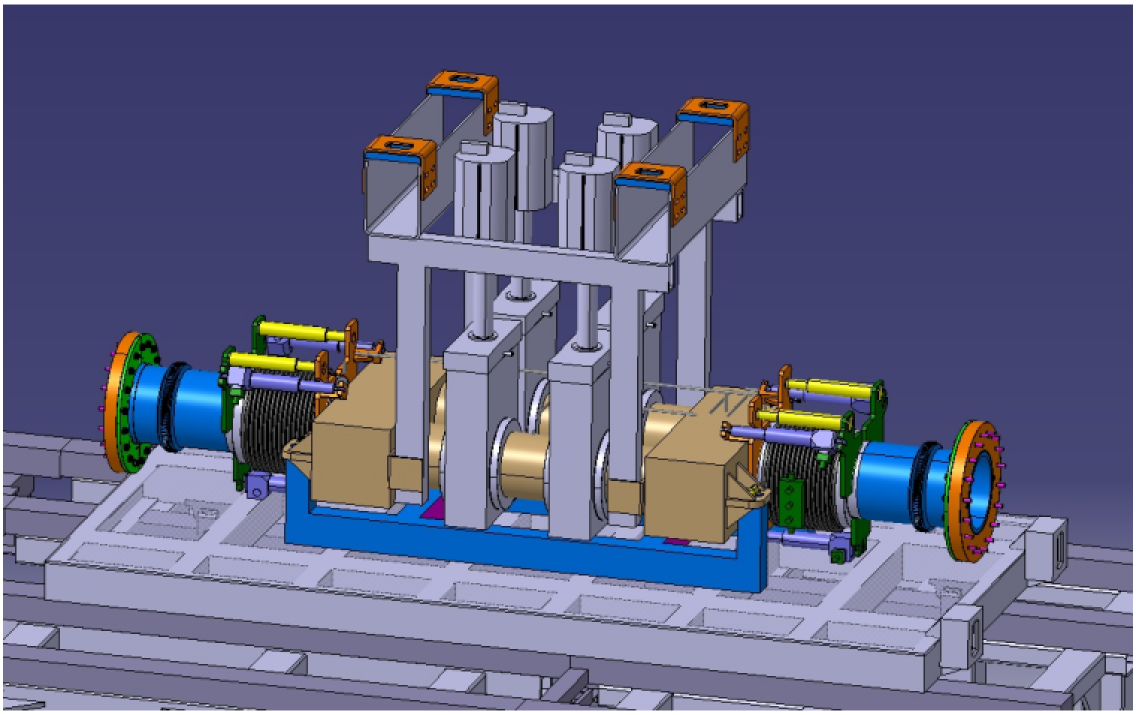


fig. 98 BLV assy on dedicated stillage

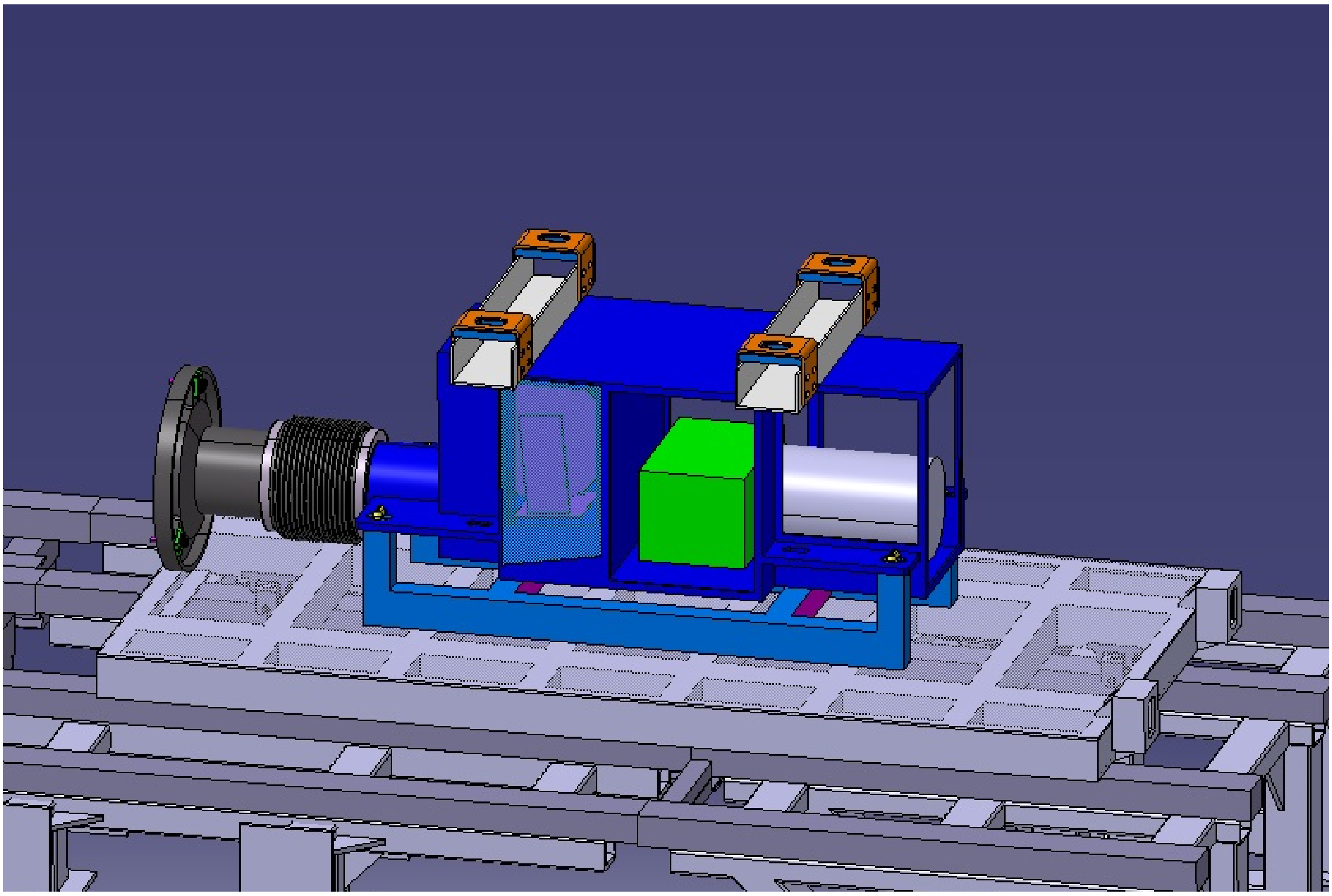


fig. 99 water jet cleaning tool on RD/BLV dedicated stillage

VVPSS task modules and confinement box are moved from NBC to HCB so to be decontaminated and serviced and sequence ends. (the same/similar sequence is implemented for BLV replacement)

Detailed local sequence for RD replacement with some comments follows:

§	TASK	TOOLS	DEPLOYMENT/TRANSFER NEEDED
0	VVPSS tools deployment		VVPSS BT and STP tools as well as confinement box are moved to NB cell and stored (task module near RD on the PMI structure of the NBI and confinement box in the beam source RHE location)
1	upper thermal insulation box removal	monorail crane	upper thermal insulation are temporarily stored by mean of monorail crane in the NB cell north wall area
2	SVS disconnection	NB manipulator	
3	Bellow extension	NB manipulator	
4	Flanges unbolting	bolting tool+manipulator	bolting tool is already positioned near the RD inside the task module
5	closure plate insertion	confinement box	confinement box is moved from its temporary storage to flange by mean of monorail with generic interface adaptor and docked to the flange. At the end of the closure plate insertion the confinement box is moved back to its temporary storage
6	RD assy removal	monorail crane	RD assembly is loaded to a transfer cask and moved to HCB

7	VVPSS line cleaning tool positioning	monorail crane	cleaning tool is deployed from transfer cask to RD support frame following the same path of the RD assembly backward
8	cleaning tool docking/line cleaning	cleaning tool+confinement box	confinement box is positioned to perform cleaning tool docking. Once completed the cleaning tool docking sequence the confinement box is removed and is repositioned only at the end of the cleaning cycle. confinement box reset local confinement, perform local cleaning and is removed.
9	cleaning tool removal	monorail crane	cleaning tool at the end of the sequence is moved back to HCB
10	seal track inspection and preparation	seal preparation tool+ manipulator	the seal preparation track is positioned on the flange the deployment and the sequence is performed with the support of the manipulator (e.g.. Pad replacement)
11	RD assy replacement	monorail crane	the new RD assy is took from the monorail from the transfer cask and positioned on the VVPSS support
			the confinement box and bolting tools are used for the RD assembly assembling sequence. At the end of the sequence VVPSS specific tools are moved back to HCB.

tab. 29 RD replacement tools deployment sequence

9 Requirement compliance matrix

This section groups all contract relevant general requirement included in the reference technical specification. For tool specific requirement please ref. sec.2:6.

REQ	**General design requirements**	remarks/updates
G.1.01	The RH operation shall utilize the NBRHS as much as applicable in order to be cost effective.	the deployment and handling of RH tools is fully based on existing NB RHS (see sec.8 for further details)
G.1.02	Number and size of the RHS shall be minimized to reduce the space occupancy in the hot cell building for its storage.	where possible the same tool is used in different tasks (see sec.3.3 as example)
G.1.03	The RHS shall be modular for its maintenance and transportation.	the RHS is made of different tools that are deployed in sequence (see sec.8) in order to limit the number of tools required and the number of spare parts the same technical solution are implemented in different tools. Bolting tools for DN 300 and DN500 adopt the same control cabinet while confinement box and cleaning tools change only flange interface to adapt to the two pipe sizes. As discussed also in sec. 8 each tool handling is already discussed.
G.1.04	The RHS shall have handling features to allow handling within the NB cell, Hot Cell building, and the Test Facility.	preliminary identification of devices lifting points is included within the scope of the conceptual design. Standard interfaces for monorail crane and manipulator are where needed included I the design (see sec. 3.1,3.2 and 4.4,..)

G.1.05	The RHS shall be compliant with its interfacing systems as specified in P-ICD of the NBRHS [18].	VVPSS RHS interfaces with VVPSS components were discussed within the scope of the contract where needed specific VVPSS design review were agreed. RD/BLV flange design as well as thermal insulation box and main support frame were reviewed to ensure correct interfaces. The bellow compression tool was also directly integrated on RD/BLV assembly.
G.1.06	The RHS shall be failure-tolerant.	all actuators are provided by a failsafe actuation for system recovery redundant actuation will be included in the next detailed design phase
G.1.07	The RHS design shall avoid common failure occurrences.	
G.1.08	The RHS design shall avoid any single failure of components resulting in significant consequences to the personnel, public and/or environment.	safety relevant tools actuations will be provided by redundant control or failsafe actuation (see sec.5.2)
G.1.09	The RHS shall have fail-safe features against the loss of power.	See sec 4.4 and 5.2 as example
G.1.10	The RHE shall be recoverable in the event of failure, either by self-recovery techniques (that is, not involving additional systems like rescue equipment or a rescue cask) or by rescue (involving the deployment of additional systems like the rescue equipment or the rescue cask).	all actuators are provided by a failsafe actuation for system recovery. See as example protruding rear motor shaft visible in bolting tool actuation sec. 4.4.
G.1.11	Required interface features in the components to support the RH operations shall be defined. The interface features shall be reported in a form of updated component CAD model or interface drawings. It is recommended to fix these interfaces in the early stage of the task.	interfaces on existing components are defined and required modification/integration discussed (see sec. 3.1,3.2 and 4.4,..)

tab. 30 generic requirement compliance matrix

REQ	**Safety requirements**	remarks/updates
S.1.01	The RHS shall be designed such that operation, inadvertent actuation, failure or damage shall not prevent Safety Importance Class (SIC) equipment from performing its safety functions when required.	SIC relevant RHS are cleaning tools and confinement box. See sec. 3.2,3.3 and 5.4 for specific comments on this topic
S.1.02	Following system failure, or activation of an emergency stop, the system shall enter a safe state, whereby the motion is stopped, and the equipment is holding load.	all actuations subjected to lifting loads are provided by releasable failsafe brake or non-reversible actuation (see sec. 4.4 and 5.4 for further detail)
S.1.03	Two confinement systems shall be provided for each principal inventory of radioactive or hazardous material unless formal project approval for a single confinement system is given. Each confinement system shall include one or more static barriers or dynamic components to confine the inventory at risk. (Static barriers require no moving parts to fulfil their confinement function (such as vacuum vessel, process piping). Dynamic components require moving parts in order to fulfil their confinement function (such as isolation devices or detritiation systems).	this requirements apply to confinement box and cleaning tools that are provided with sealed enclosure to provide static confinement. Once connected to VV dynamic confinement is also in place.
S.1.04	The RHS shall provide means to limit the spread of contamination inside the NB cell during maintenance of the components inside the NB vessel and maintenance of confinement boundary.	confinement tool and cleaning tools are all provided with specific confinement to avoid any contamination spread. (see sec. 3.1,3.2 and 5.2)

S.1.05	The confinement systems in the RHS shall provide means to maintain its internal pressure below the NB cell atmospheric pressure, generally ranges from 200Pa to 500Pa during normal operation and incident. (ref. NF ISO 11933-4).	confinement systems will be connected to DS before operation (see sec. 5.2)
S.1.06	Normal safety flow rate shall be no less than 0.5 m/s, to avoid the spread of contamination and 1.5 m/s when tritium is involved (ref. NF ISO 11933-4).	static confinement is always ensured for RHS as cleaning tool and confinement tool. (see sec. 3.1,3.2 and 5.2)
S.1.07	The safety-specific instrumentation for the confinement system in the RHS shall monitor the performance of the confinement system and provide signal to the high level control system to trigger any safety actions, e.g.. detritiation system during normal and accidental situations.	confinement tool is provided by a differential pressure sensor used to check correct confinement.
S.1.08	As far as practically possible, exposed surfaces of the RHS shall be covered by disposable gaiters which shall be removed and disposed of by remote means prior to hands-on maintenance.	Internals of cleaning tool and confinement tool can be contaminated. as discussed in sec. 3.1,3.2 and 5.2 all confinement boxes are provided with specific removable covers used to perform decontamination before hands/on maintenance. Internal decontamination should be performed, as already foreseen for other similar RH tools, inside IRMS decontamination facility. Bolting tool is not contaminate, seal track preparation could be should be easier to be decontaminate as also less exposed to contamination
S.1.09	Surfaces that cannot be protected by disposable gaiters shall be designed in such a way as to minimize the trapping of dust, and be manufactured from materials that lend themselves to decontamination.	
S.1.10	Confinement shall be kept during the maintenance operations. Note that detritiation system (DS) is working in the VV and in the drain tank providing the dynamic confinement. The DS system can provide 1.5m/s2 air flow for the 0.02m2 breach of confinement.	

tab. 31 safety requirement compliance matrix

REQ	Loading conditions and operation environment	remarks/updates
L.1.01	The RHS shall satisfy the loading conditions specified in the Load Specification of the NBRHS [19].	static equivalent seismic load are: 4.8m/s^2 in X and Y direction and 34.5+9.8 m/s2 in Z (vertical). Cleaning tools share the same mechanical interfaces of RD and BLV. Structural frames of cleaning tool will be finalized in detailed design to comply reference seismic loads. Confinement tool is directly supported by main RD/BLV support frame. Support legs and docking interfaces will be finalized in consideration of specified accelerations. seal track preparation tool clamp is based on mechanical self centring actuation and should consider as survival load 4.5 g. bolting tool support wheels should consider the same peak load. locking clamp should consider as worst case opening force 2.5 g (the bolting tool has nominal working range of +/-90° and peak acceleration is hence vertical upward)
L.1.02	The design process for the RHS shall take into consideration the loading values that result from SL-1, SMHV, and SL-2 seismic events.	preliminary consideration on reference accelerations are introduced in L.1.01. Direct calculation on seismic induced stresses should be considered in the detailed design phase

L.1.03	Radiation sensitive items in the RHS shall have a minimum radiation lifetime of 20 kGy (which roughly equates to 104 weeks, 7 days/week, 24 hours/day operation within the NB vessel at 1 Gy/hour).	Available ORE assumption gives total RD/BLV replacement time of 200h. With a reference dose rate of 1 Gy/h the integral dose for VVPSS RHS is 200 Gy. Even considering a safety factor 4 to take in account system failures or unexpected stop the integral dose is always below 1kGy. Some local shielding could be considered for electronics integrated in the RHS.
L.1.04	Components of the RHS that have a shorter radiation lifetime than 50 kGy shall be designed for easy replacement during scheduled maintenance operations	see previous comment
L.1.05	Components of the RH equipment that remain permanently inside the NB cell shall withstand the radiation condition during the machine operation (20Gy/h), and shall be easy to replace in case of failure to reduce the worker dose uptake.	the only permanent RH equipment is bellow compression tool that is integrated in the RD and BLV assembly. Bellow compression tool has no active component. A correct selection of critical components as lubricants, polymers or seals is enough in this case.
L.1.06	Failure and/or recovery of RHS after a SL-2 event shall not result in contamination release beyond the primary confinement barrier that is established for the maintenance activity, or cause damage to SIC components performing the confinement function during the maintenance operation.	confinement box and cleaning tool detailed design should keep this requirement in consideration.
L.1.07	The RHS shall operate in a dry air or nitrogen.	operational condition compliant with the conceptual design developed within this contract
L.1.08	The RHS shall operate under an absolute pressure of 1 bar.	operational condition compliant with the conceptual design developed within this contract
L.1.09	The RHS shall operate at environmental temperatures between 20°C and 50°C.	operational condition compliant with the conceptual design developed within this contract
L.1.10	The RHS shall operate with gamma radiation dose rate of up to 1 Gy/h during maintenance operation (12 days after the machine shutdown).	see above
L.1.11	The parts of the NB RH system that remain permanently inside the NB cell shall be exposed to the radiation condition during the machine operation up to 20 Gy/h.	see L.1.05
L.1.12	The RHS shall be capable of operating in an environment that is contaminated with tritium and activated dust (Be and W).	operational condition compliant with the conceptual design developed within this contract
L.1.13	The RHS shall operate with a residual magnetic field of up to 1 mT during maintenance.	operational condition compliant with the conceptual design developed within this contract

tab. 32 loading requirement compliance matrix

REQ	**General statement of work requirements**	
W.1.01	The quality plan shall include the justification plan of the requirements specified in this document.	requirement compliance check is implemented as part of the interim and final report
W.1.02	The final reports shall include all source files that has been produced or used to write the final reports such as the excel sheets, calculation notes, datasheets, any source file of the software used, etc.	
W.1.03	The report shall be prepared and submitted in Microsoft Word format.	
W.1.04	The report shall be written in English.	
W.1.05	The figures, tables, and equations in the report shall be numbered and referred automatically.	

W.1.06	The original editable figures in the report shall be provided. It is recommended to add texts or legends directly in the word file. The figures should be within a “Drawing Canvas”.	
W.1.07	The CAD models shall be CATIA V5 models/drawings (see §14 requirements).	CAD models developed within the contract are part of the contract deliverables.
W.1.08	The CAD models shall be reintegrated to the ENOVIA database.	integration performed from IO (no teradici configuration was possible within the scope of the contract.

tab. 33 general requirement compliance matrix

10 Main system interfaces

This section groups the relevant system interface modification considered in the development of the VVPSS RHS.

10.1 RD and BLV assembly

As widely discussed bellow compression tool and bolting tool require the integration of dedicated mechanical interfaces on RD assembly and BLV assembly. Furthermore docking flange design should be updated to integrate the needed alignment features above introduced.

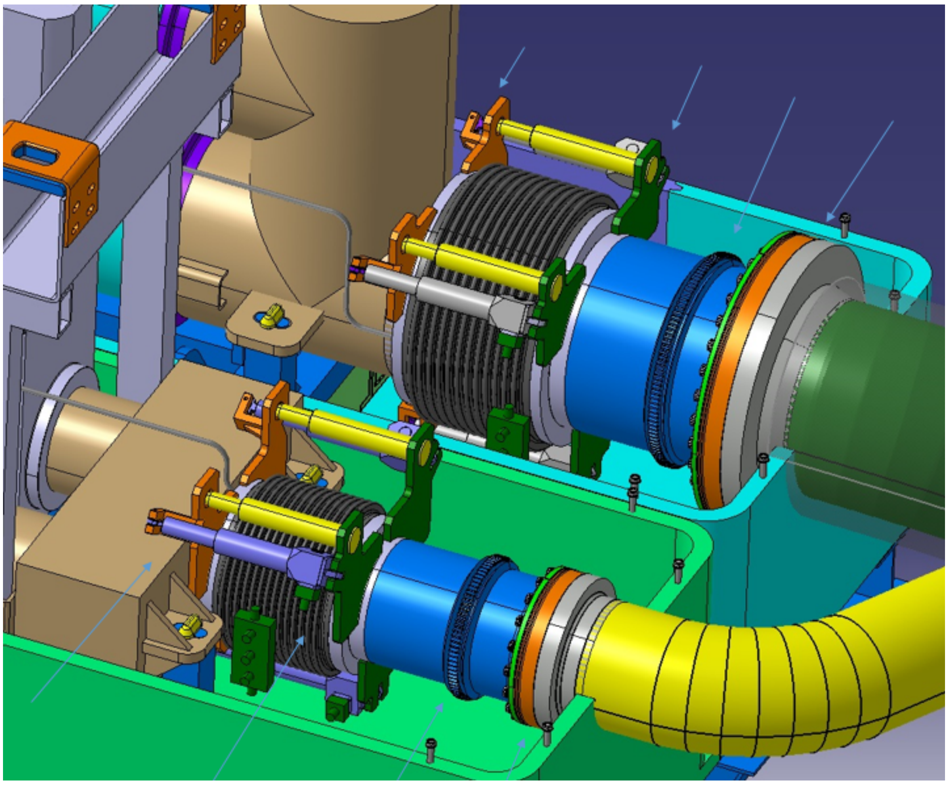


fig. 100 mechanical interfaces on RD and BLV assy

10.2 Alignment frame

To integrate bellow compensation screw jack on BLV assembly a little alignment frame review is also required to avoid interferences (compare BLV alignment frame in the two following pictures).
The width between BLV and RD support frame locking pin should also standardized (now the width is 900 mm for RD and 935 mm for BLV) to simplify cleaning tool docking.

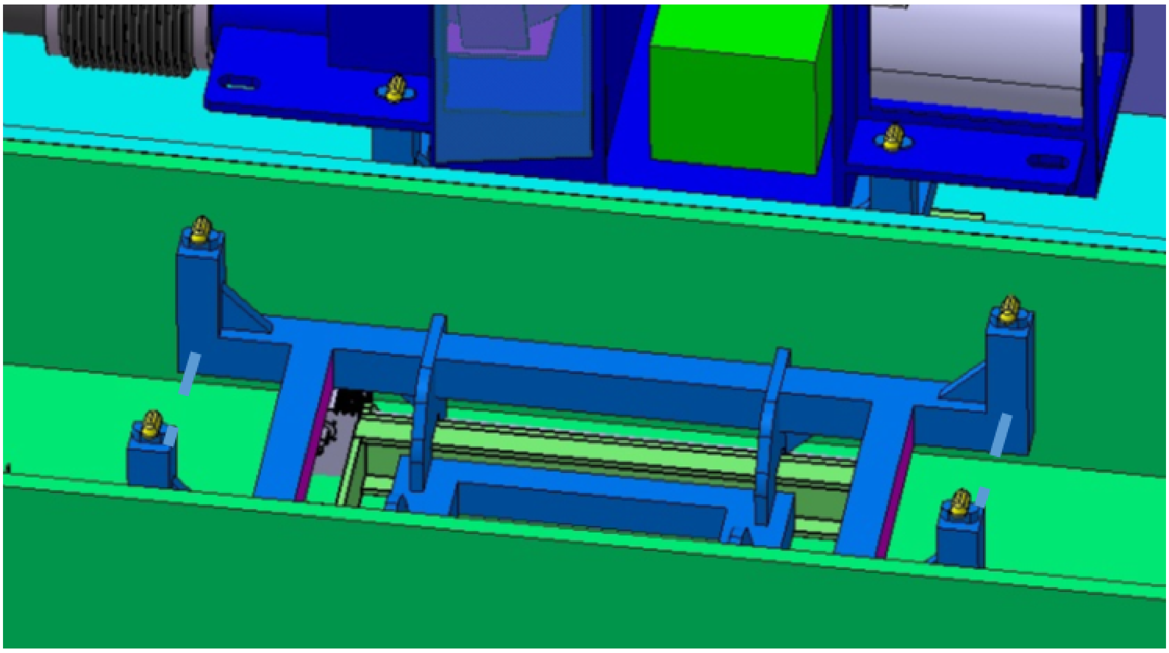


fig. 101 BLV alignment frame (updated)

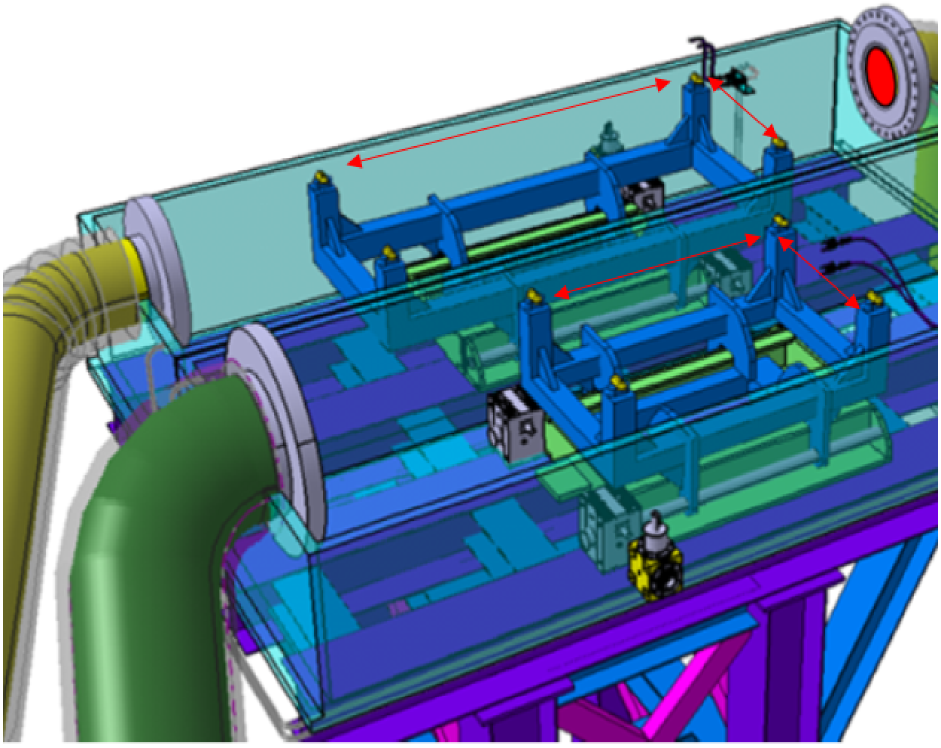


fig. 102 different width of RD and BLV alignment frame

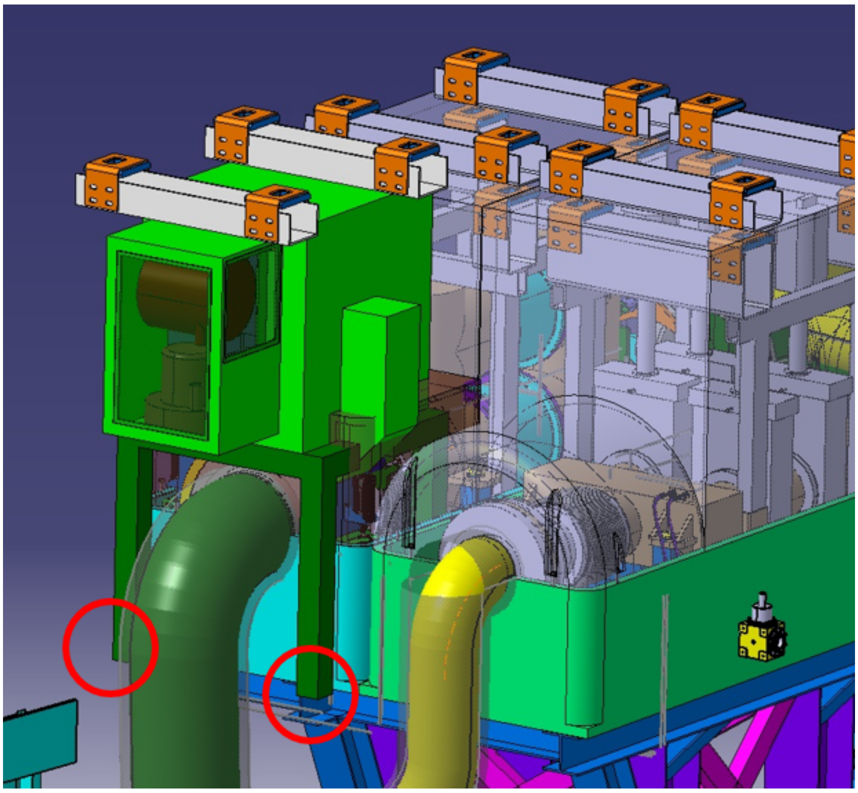


fig. 103 main frame review

10.3 RD and BLV support frame

Main RD/BLV support frame should be reviewed to integrate two relevant features:

- Support for external confinement box legs;
- Machined references for confinement box alignment.