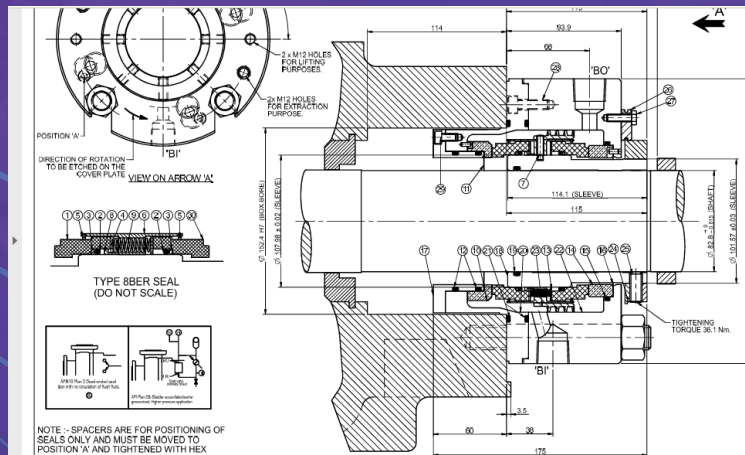




3rd Annual PLANT RELIABILITY EXCELLENCE CONFERENCE 2023

Reliability improvements for new offshore pump projects

By *SERGIO VIDAL*



***3rd Annual Plant Reliability Excellence Conference – Dubai,
2023***

Reliability improvements for new offshore pump projects

by

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(Pump maintenance specialist)***

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Reliability improvements for new offshore pump projects - *Introduction*



“The devil is on the details”

*“The devil is in the details” is an idiom alluding to a catch or mysterious element hidden in the details; it indicates that “something may seem simple, but in fact the details are complicated and likely to cause problems”. It comes from the earlier phrase “God is in the details”, expressing the idea that whatever one does should be done thoroughly; that is, details are important – **source Wikipedia.***



Reliability improvements for new offshore pump projects - *Introduction*

- **Some Oil & gas companies, don't plan and execute major projects of their facilities (major existing facilities upgrades, existing facilities capacity increase, new installations, etc) every year.** Some time they only execute major projects every 5 or 10 years. As a result, they don't have a properly sized (in terms of human resource number and/or the human resources skills/knowledge) Major Project or Engineering depart for new installations. **They depend almost completely on the EPC companies;**
- **There is a knowledge and generation gap on the Oil & Gas industry,** with a lot of older and experience Oil & Gas professionals retiring;
- Upstream offshore facilities are unique facilities in the Oil & Gas industry, **the assets are in remote locations in the middle of the sea, logistics (boats, helicopters, etc), bed space, sea state, etc are serious constraint to offshore facilities maintenance** and by consequence to the offshore equipment maintenance;

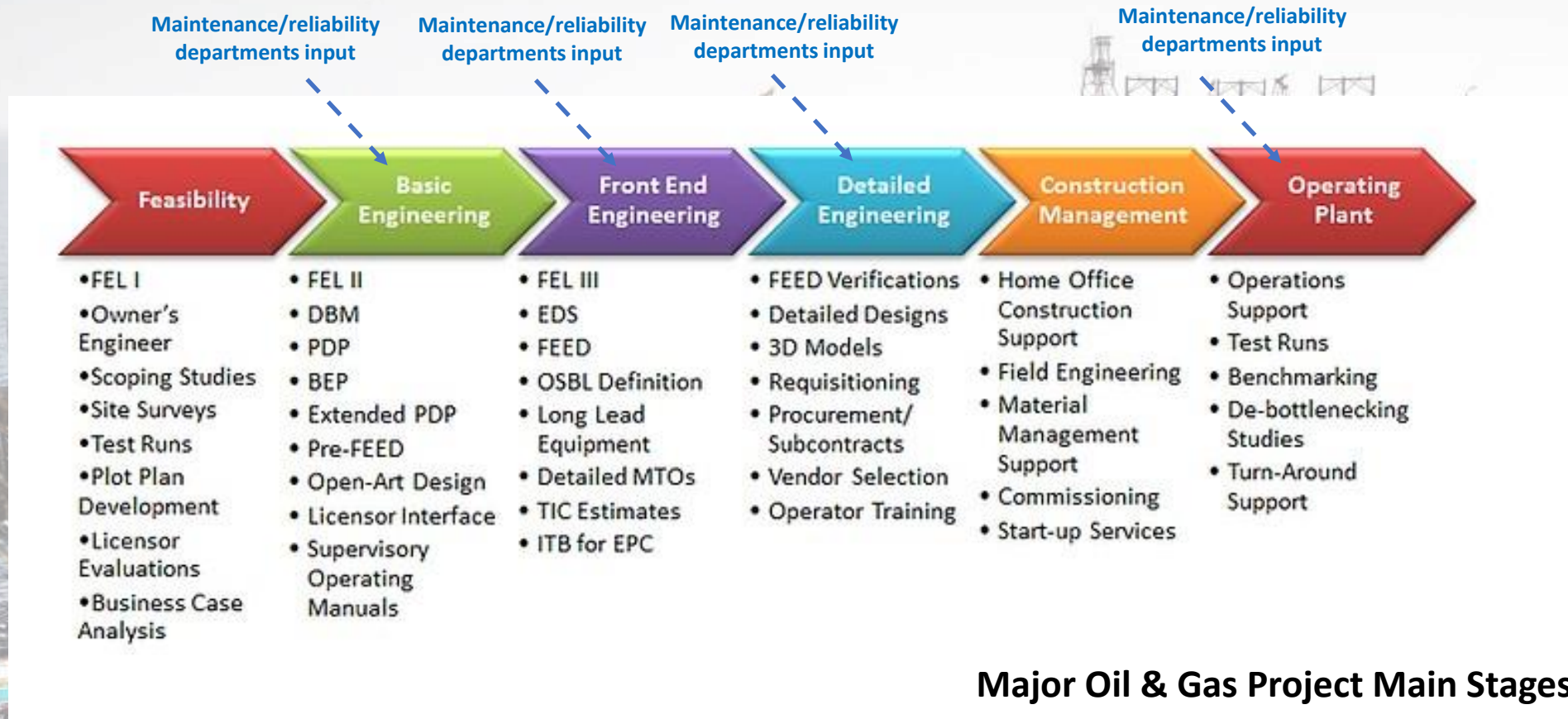
Reliability improvements for new offshore pump projects - *Introduction*

- Time and time again, we have seen some major Oil & Gas companies awarding new projects contract to **EPC companies solely based on the lowest cost bid**. As result, some EPC companies use mainly engineers with no or only 1 – 5 years experience on this project. Basically, **some EPC companies thrown numbers and not quality into the new projects design, specification and execution**;



Reliability improvements for new offshore pump projects - *Introduction*

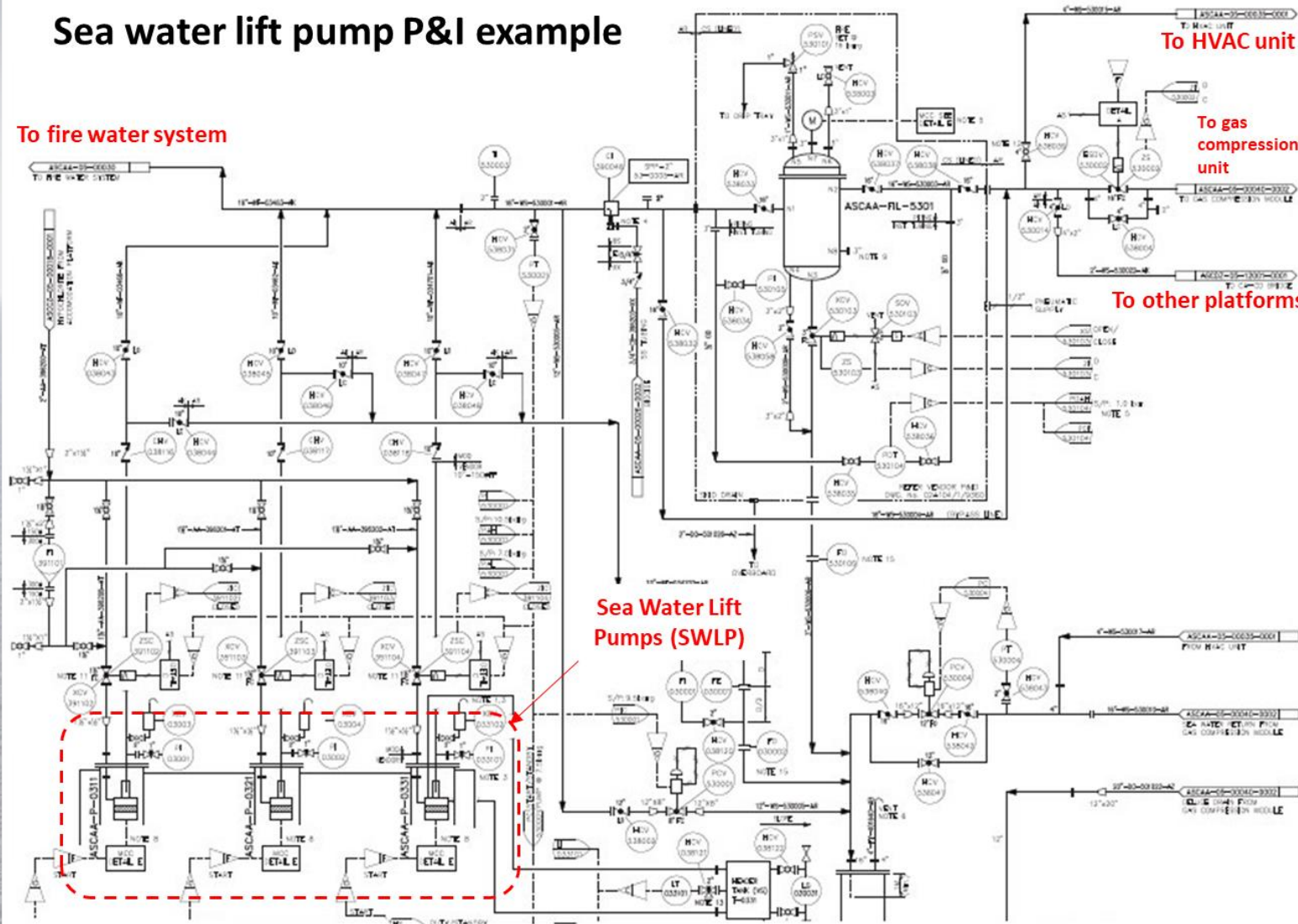
- As part of the reliability improvement and life cycle cost reduction of new projects, the **maintenance/reliability departments lessons learn, improvements and best practices should be introduced on the new projects at the early stage of the project design and project specification;**



- Even during the new projects major equipment first run and site acceptance tests, the maintenance and/or reliability departments should be involved with the commissioning team;**

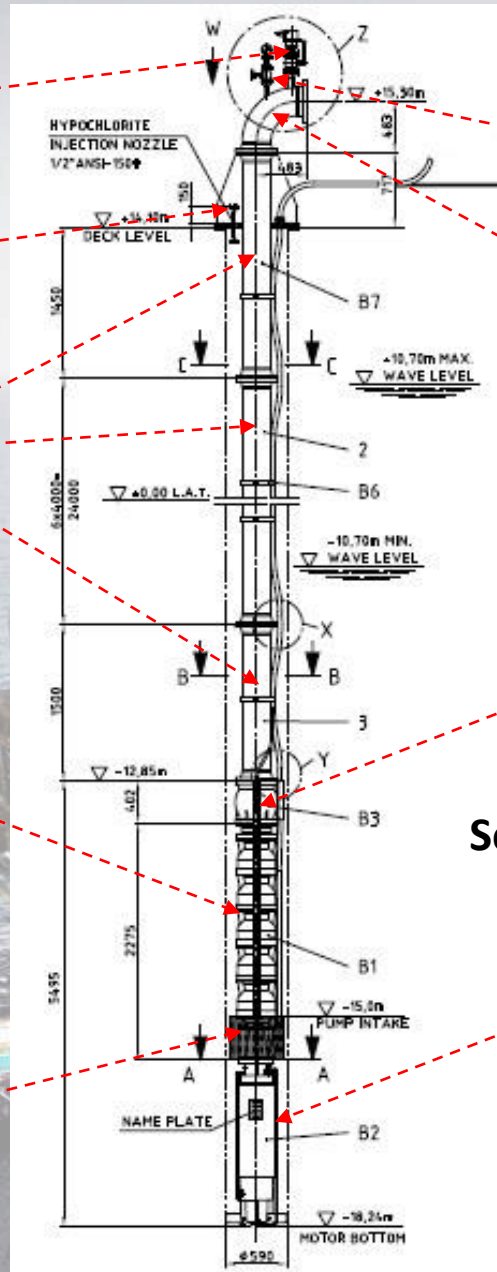
Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

Sea water lift pump P&I example



- Offshore sea water lift pumps (SWLP) are critical pumps on offshore Oil & Gas Upstream producing facilities;
- Offshore sea water lift pumps (SWLP) are responsible for pumping sea water for process cooling (gas compression, etc), HVAC units cooling and safety critical fire water system;
- Main maintenance and reliability challenge with SWLP pumps:
 1. The equipment is under sea water between 5 to 25 meter depth, there is no easy access, you cannot see it, you cannot touch it, you cannot monitor every day;
 2. The unit (pump and electrical motor) is completely submergent under sea water, so always under corrosion attack and subject to marine growth and fouling;

Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*



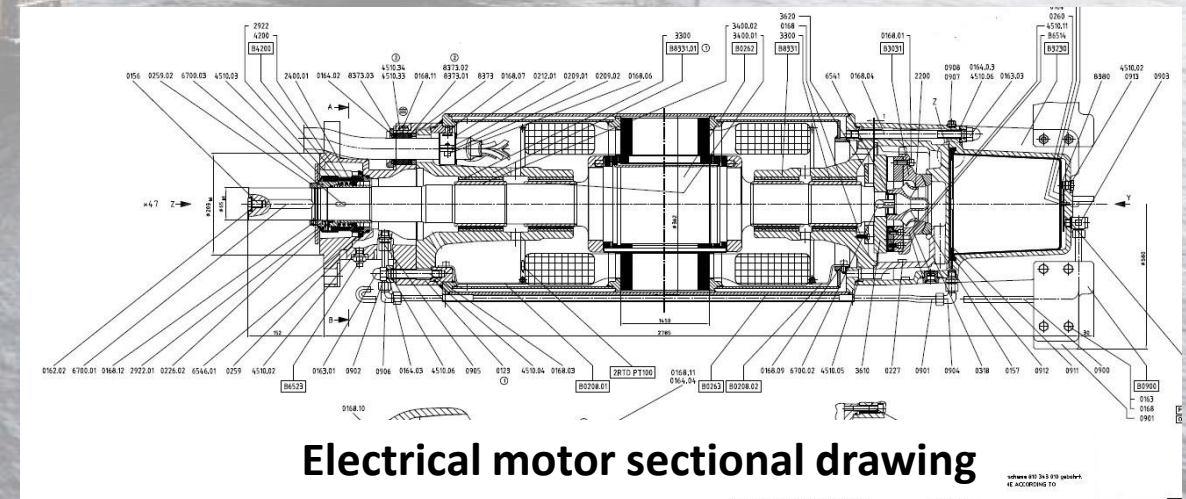
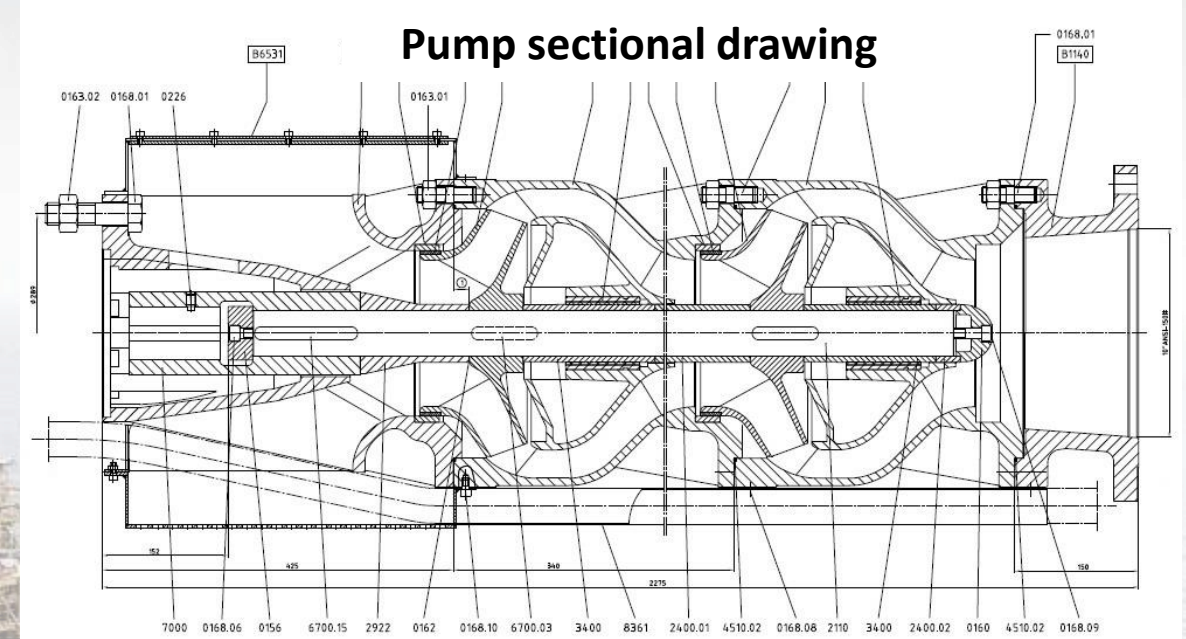
**Pump discharge
local pressure gage**

Pump discharge bend

Pump non-return valve

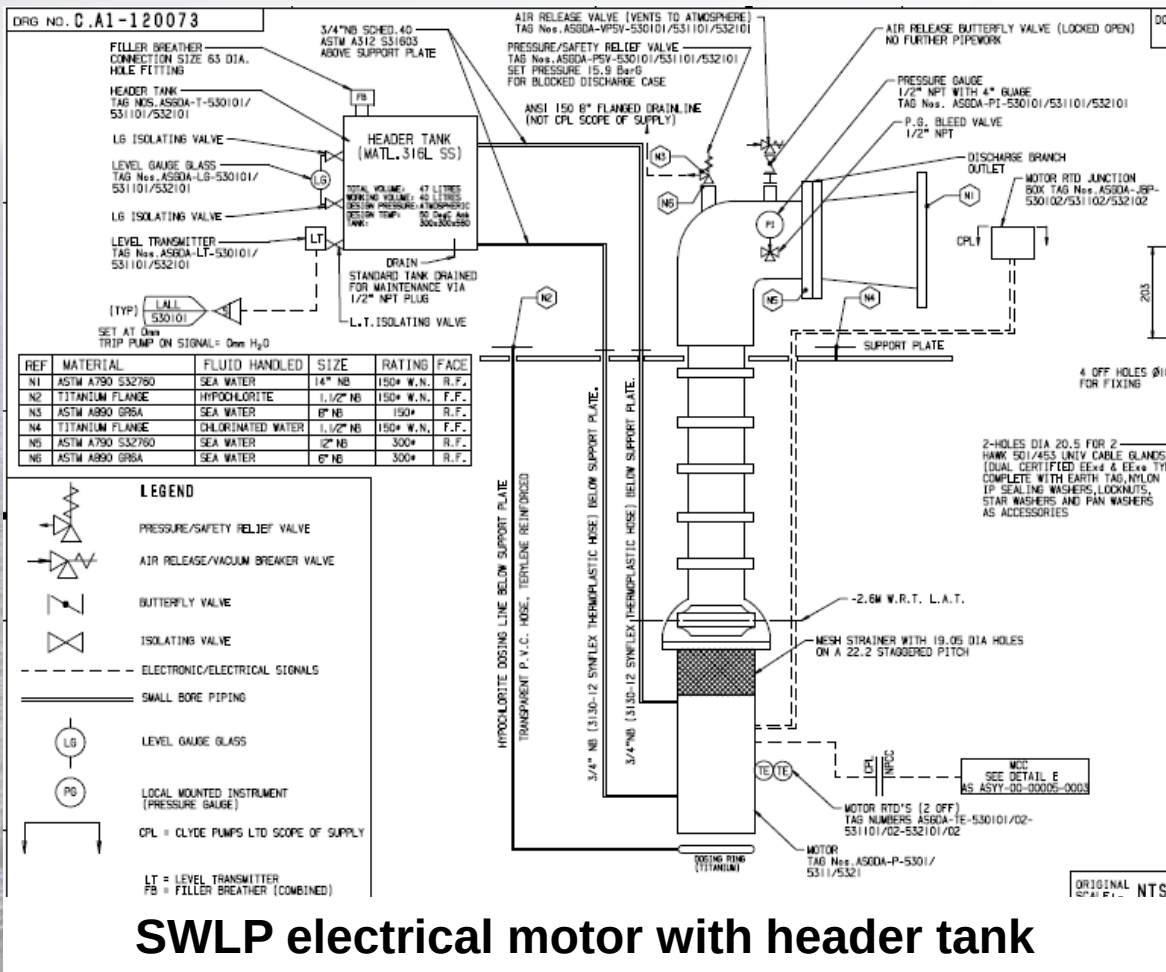
Sea water lift pump layout example

Electric motor



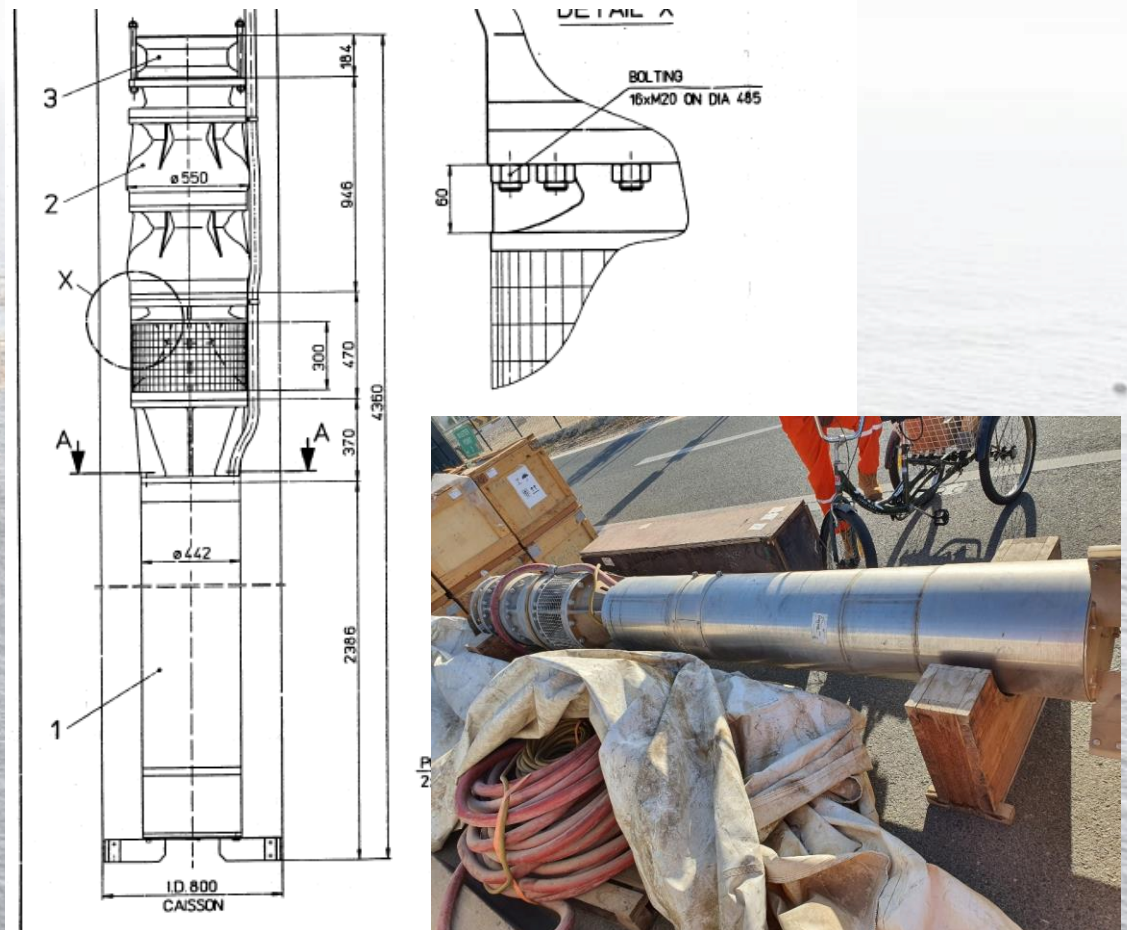
Reliability improvements for new offshore pump projects – Sea Water Lift Pumps

- There are basically two designs for SWLP electrical motors: header tank and non-header tank (sealed electrical motor);
- The advantage of the header tank design is that you can monitor if the electrical motor mechanical seal starts leaking (your header tank level will drop) and you can top up the mechanical seal losses at the header tank;



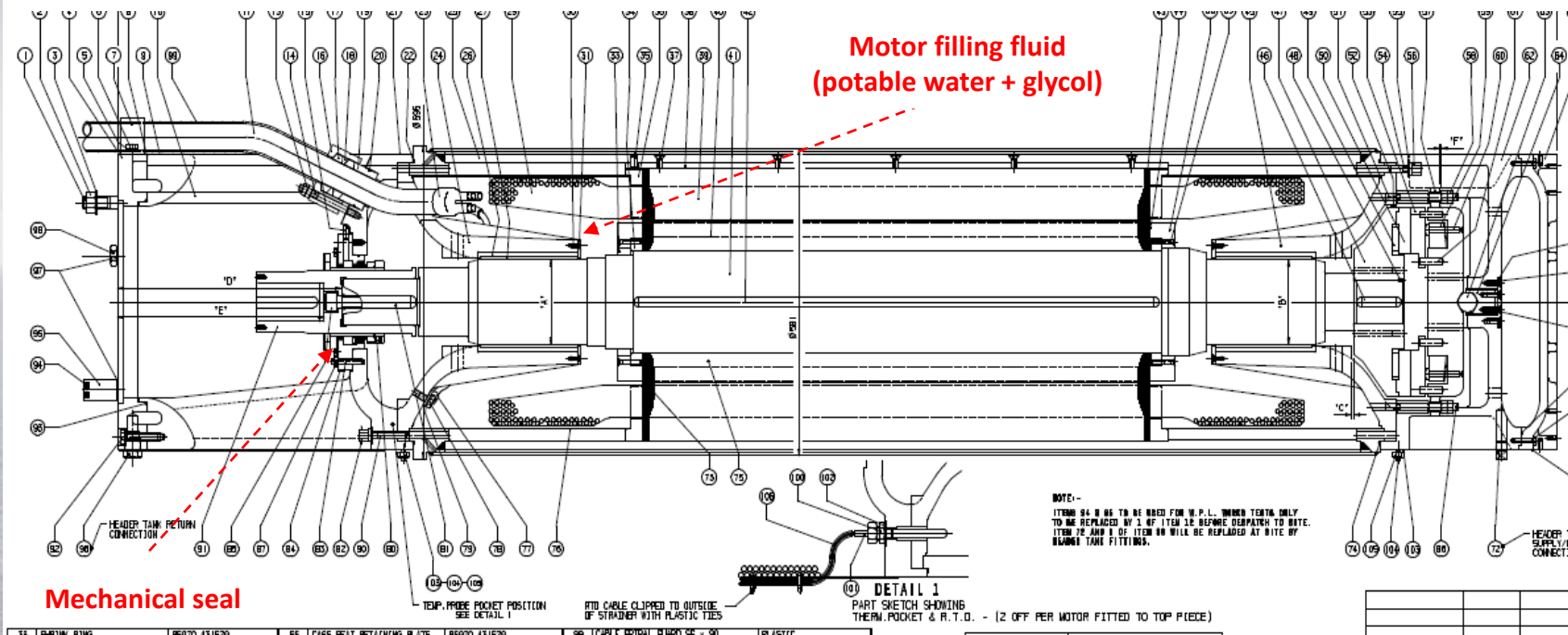
SWLP electrical motor with header tank

SWLP electrical motor without header tank

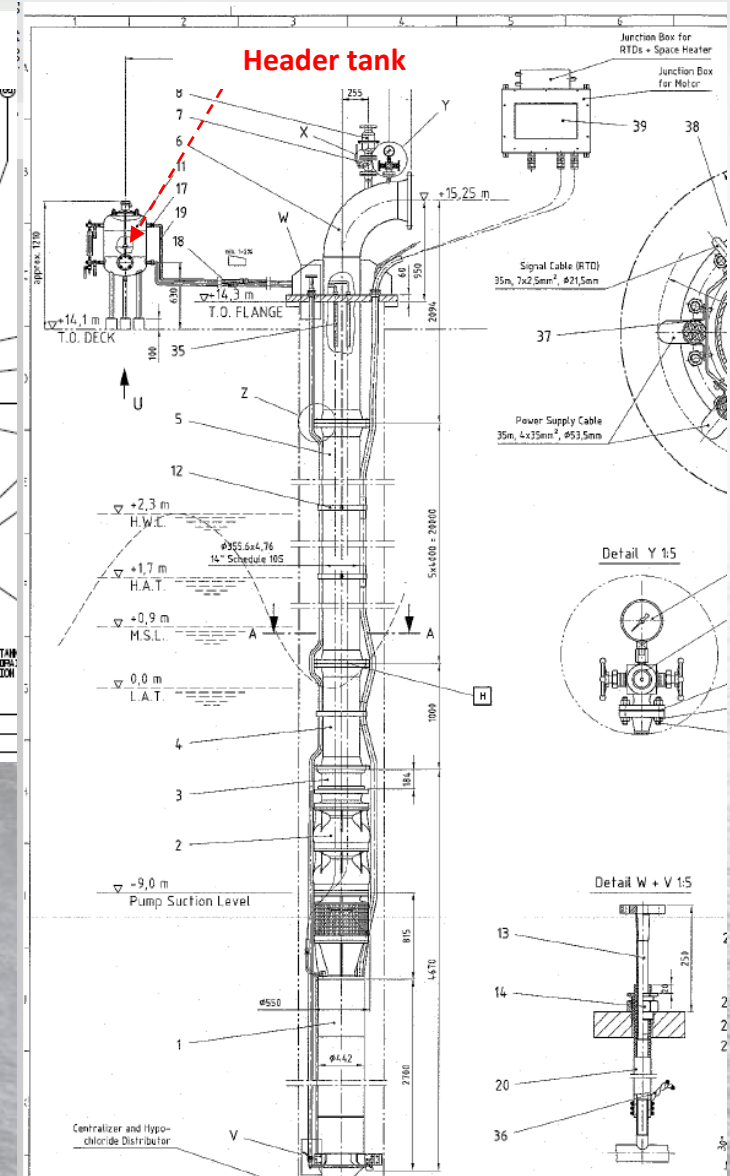


Reliability improvements for new offshore pump projects – Sea Water Lift Pumps

Non header tank SWLP electrical motor details



- The SWLP electrical motor are filled with proper cooling and lubrication fluid (potable water + glycol mixture) to guarantee the lubrication on the radial and thrust bearing and protect the motor windings;
- The weakest link on this type SWLP electrical motor are the electrical motor mechanical seal that in same design and pump models only last 1-3 years and on other designs and pump models last 3-6 years;



SWLP header tank design

Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*



Sea water lift pump picture



Sea water lift pump picture



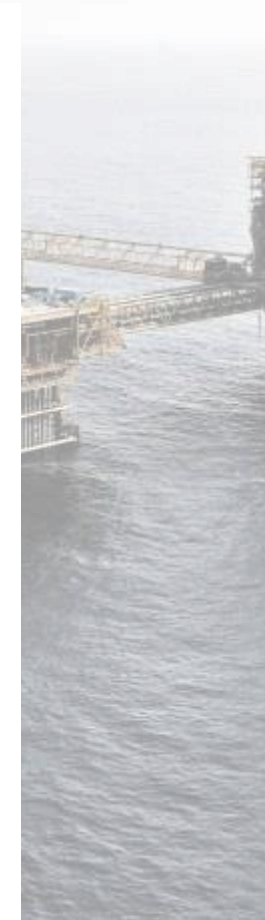
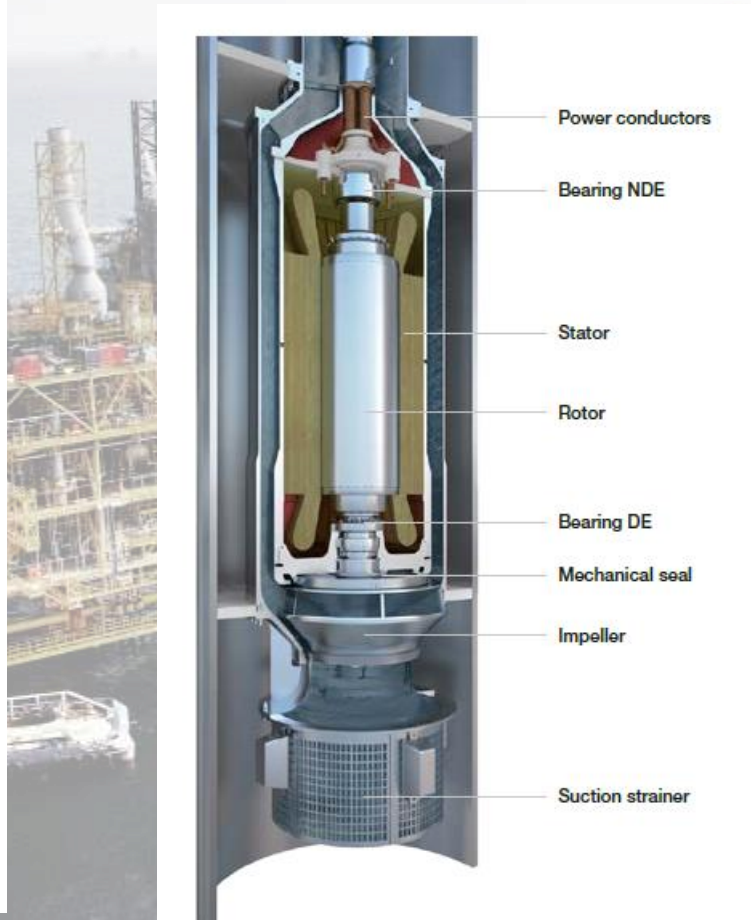
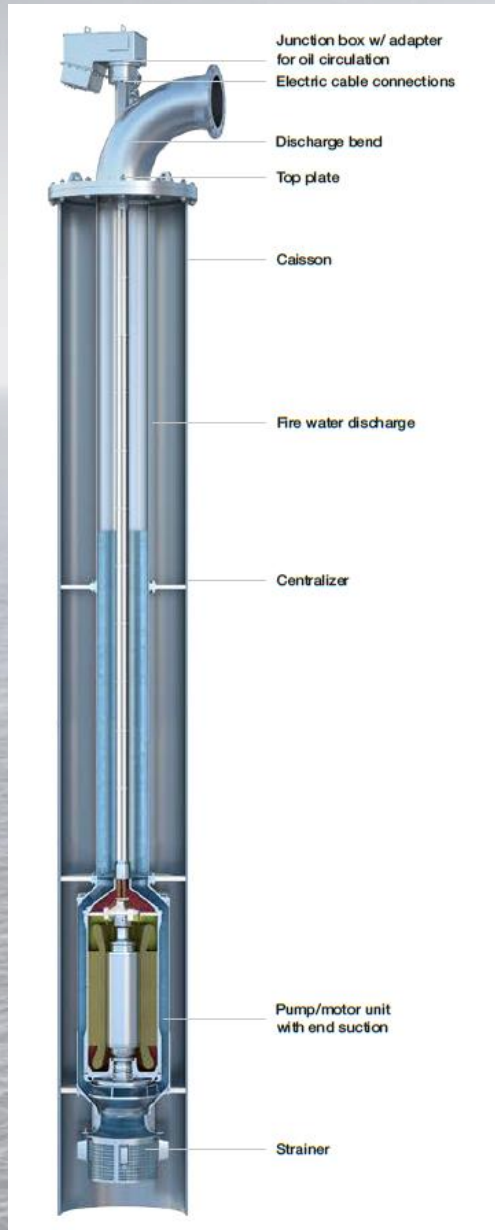
Sea water lift pump picture



Sea water lift pump picture

Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

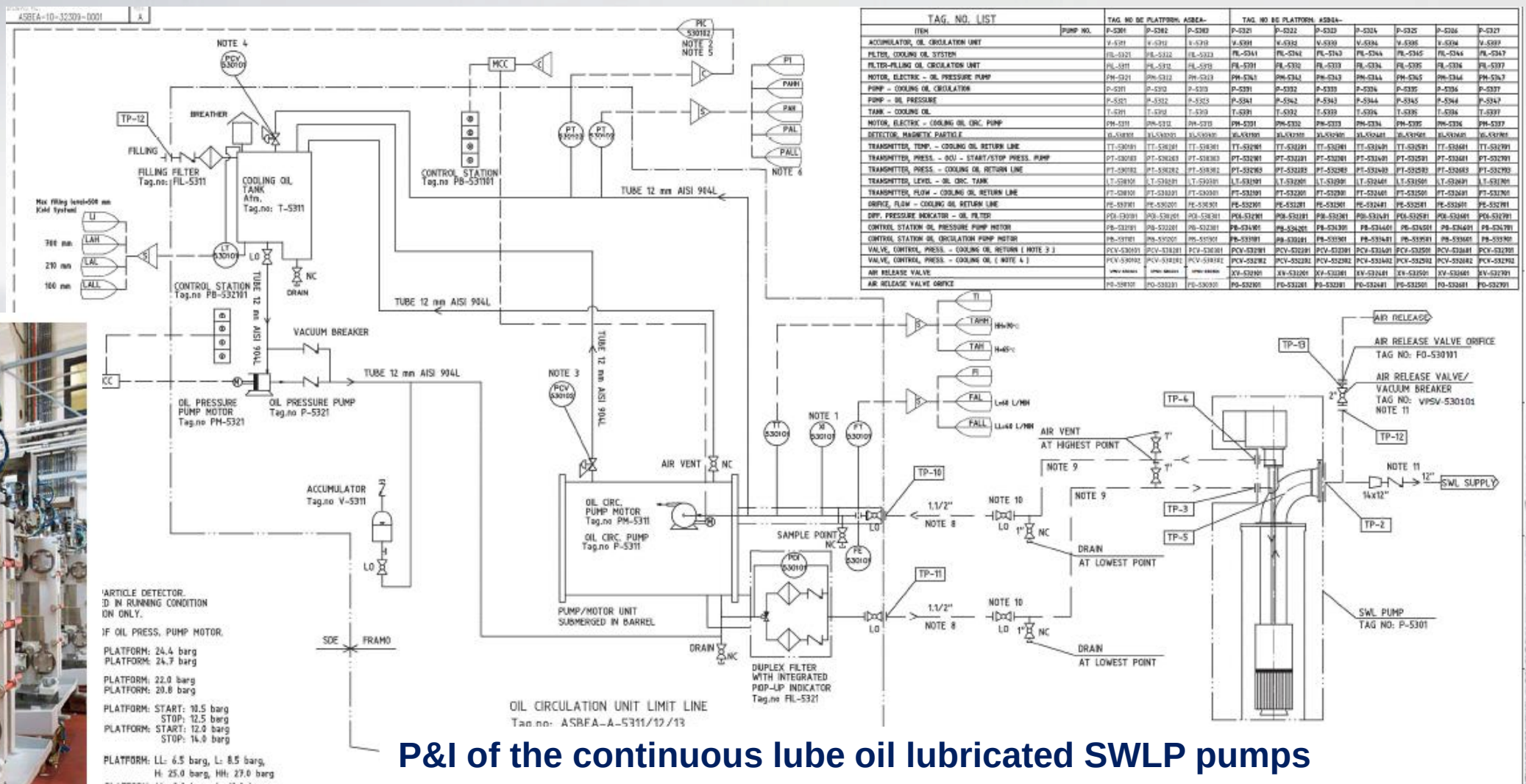
- There is another type design for SWLP in which a dedicated lube oil system is always cooling and lubrication the motor bearing with clean oil system and in which the electrical motor power is send inside the pump discharge pipe;
- This continuous lube oil lubricated SWLP pump initial cost is around 150-170% of the other SWLP type with or without header tank, but the MTBF of this units is 10-12 years;



Reliability improvements for new offshore pump projects – Sea Water Lift Pumps

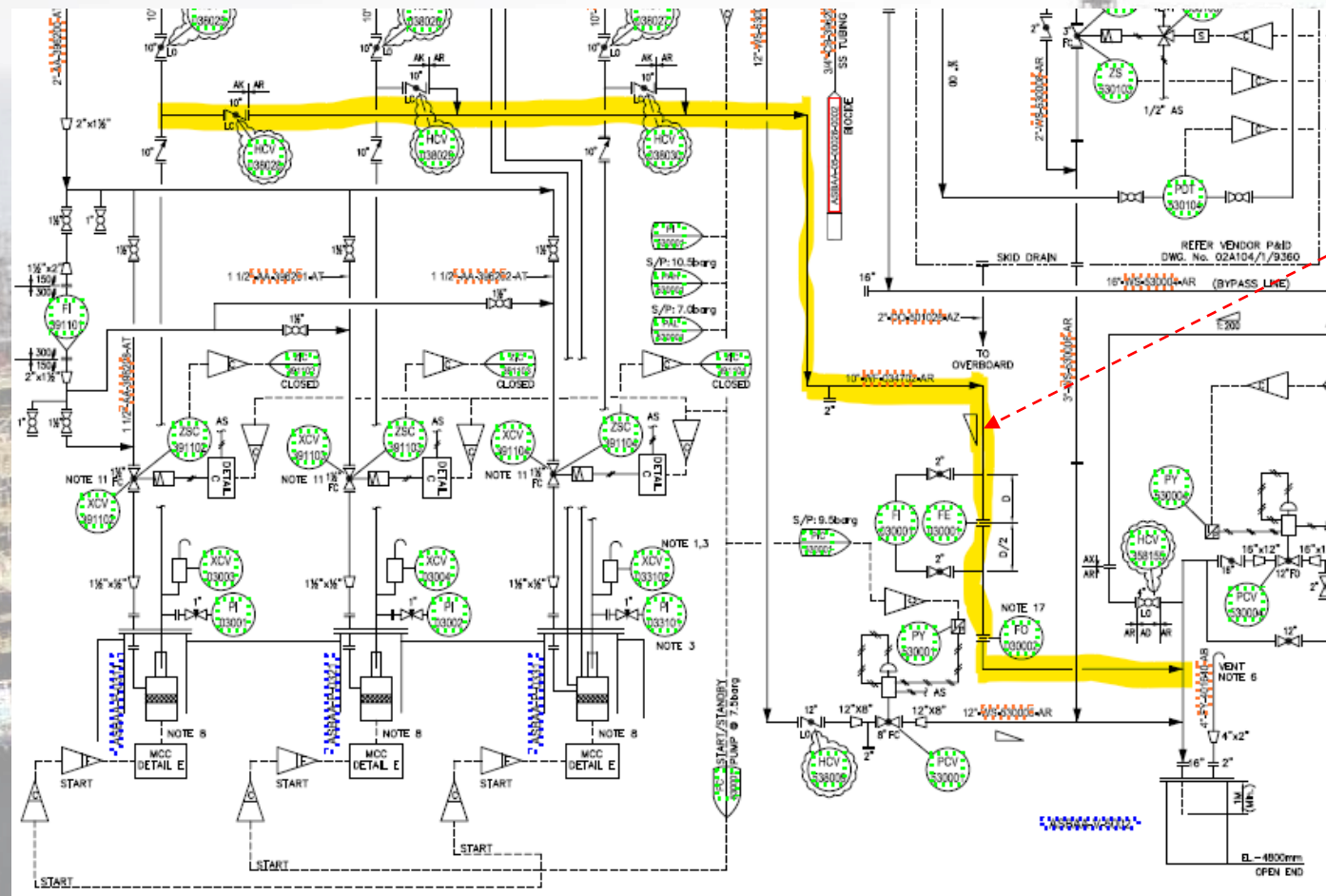


Lube oil circulation unit (OCU)
Sergio Vidal



Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

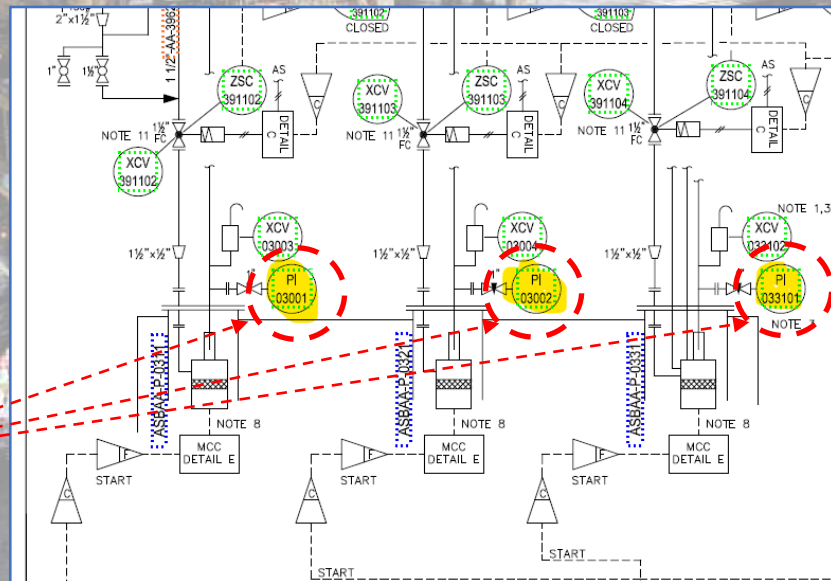
- SWLP pumps casing, pumps shaft and pumps impellers material should be in **duplex stainless steel (UNS S31803)** instead of the **NI-Al-Bz alloy (C95800)** used in the past (1970-1990). The casing/impeller wear rings should be duplex stainless steel (J93404 / UNS J93254);
- **SWLP pumps should have a dedicated performance test line to sea with manual control valve and flowmeter.** This will allow to conduct pump performance testing at site at different flow points (yearly mandatory for SWLP fire water pumps as per NFPA 20 and 25);



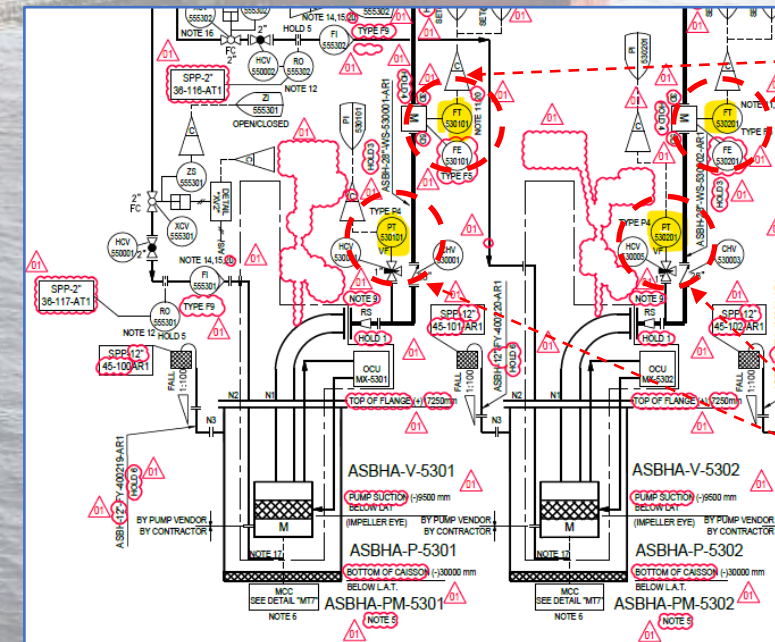
Dedicated test line
overboard to sea

Reliability improvements for new offshore pump projects – Sea Water Lift Pumps

- SWP pumps minimum field instrumentation should be:
 - pressure transmitter (PT) with local indication (PI) at pump discharge flange, connected to control room DCS;
 - discharge flowmeter (FT) connected to the control room DCS;
 - electrical motor current consumption (amps) connected to the control room DCS;
 - electrical motor sealing/cooling liquid temperature probes or electrical motor winding temperatures connected to the control room DCS;
 - electrical motor mechanical seal leak detection system for sealed non-header tank submerged electrical motors connected to the control room DCS;
- The SWLP pumps should have a low flow alarm (FAL) and low flow trip (FALL) to protect the pump from running dry and overheating;
- The SWLP pumps should have a high flow alarm (FAH) to protect the pump from high flow cavitation and/or running the pump above pump allowable operating range;



Only local
pressure
gages

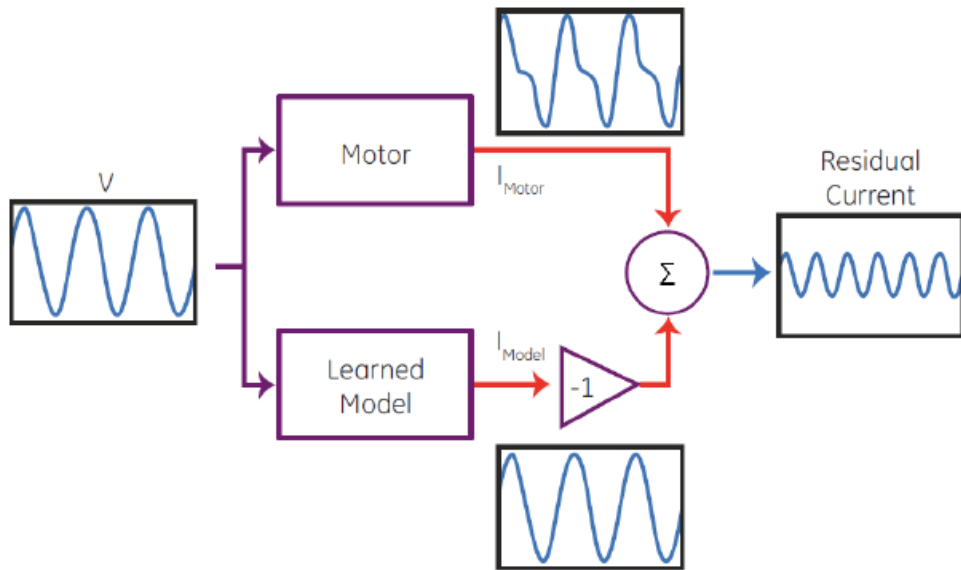


Flow
transmitters

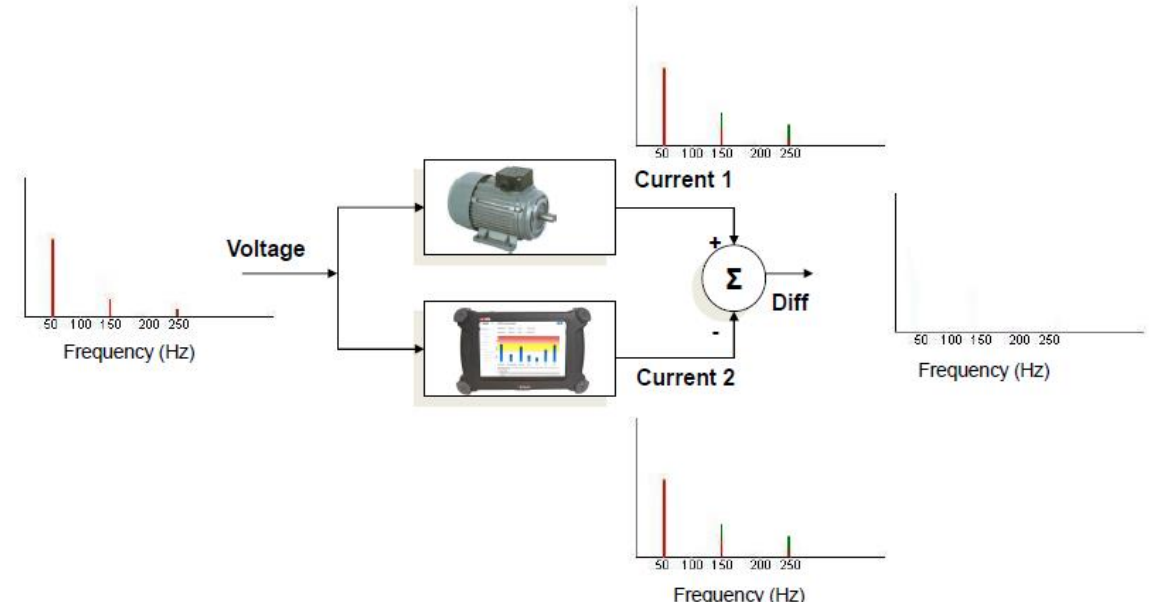
Pressure
transmitters

Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

- SWLP pumps should have an on-line protections and condition monitor system using either:
 - **electrical motor voltage and current analyze system like the GE Artesis or similar system**, with information available on the control room DCS;
 - **permanent vibration and temperature probes for the pump and electrical motor bearings**, with information available on the control room DCS;
- The electrical motor voltage and current analyze system have the advantage **that they don't need installed vibration probes on the pump and electrical motor casing that are permanently under sea water (subjected to corrosive sea water, waves and under water currents) and installed at distance from around 10-40 meters below the sea water level (long length cables);**



Electrical motor voltage and current analyze system



Electrical motor voltage and current analyze system

Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

Electrical motor voltage and current analyze system



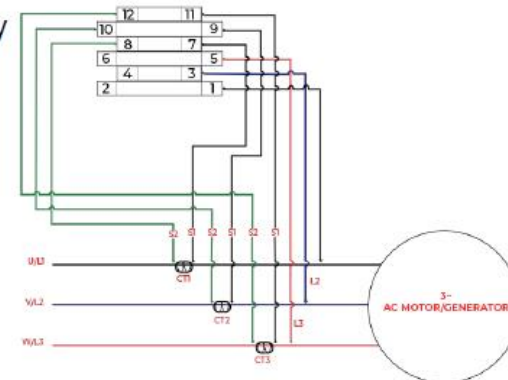
- Most of the on-line electrical motor voltage and current analyze system available on the market, give a continuous health check of the SWLP pumps detecting both mechanical and electrical problems;



Electrical motor voltage and current analyze system

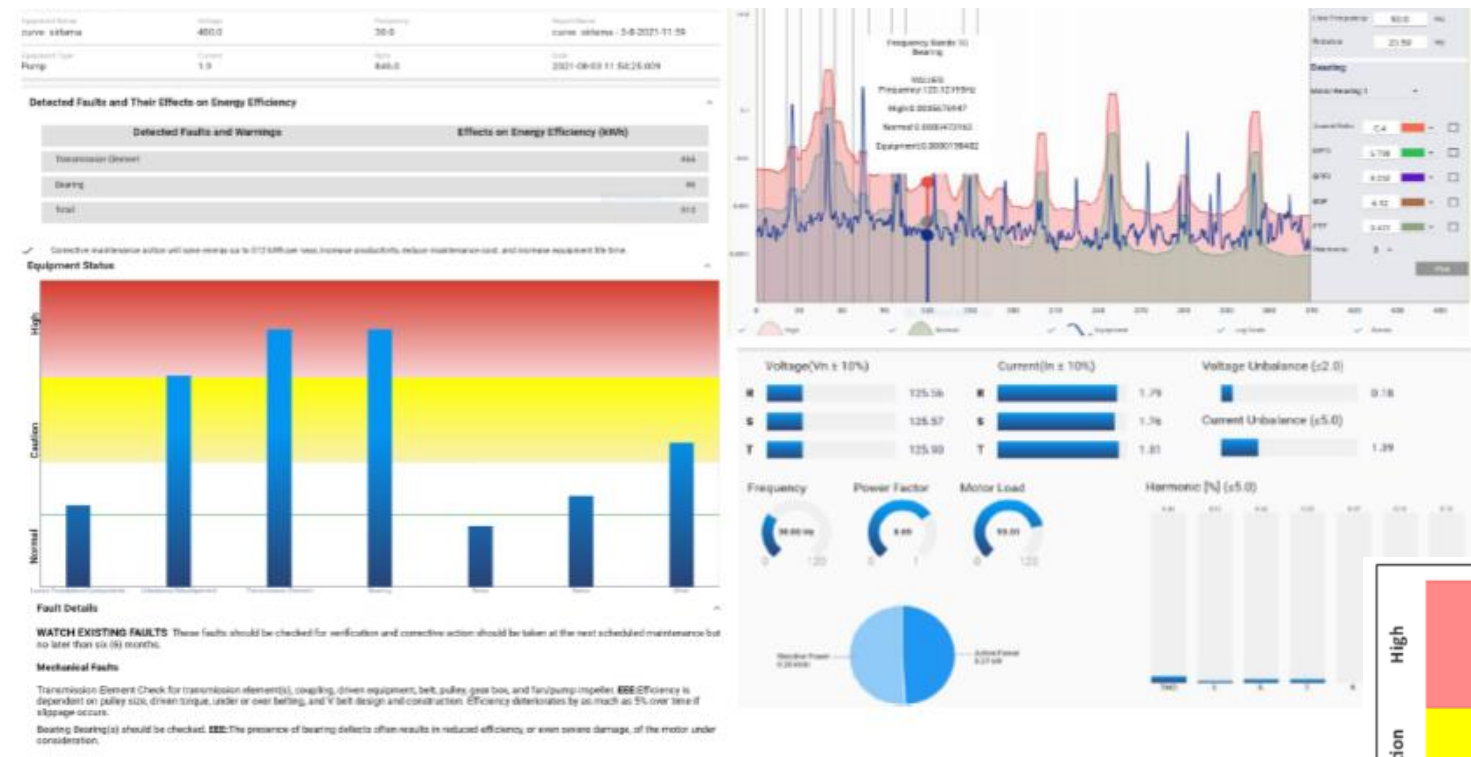
- The on-line electrical motor voltage and current analyze system available on the market, only need connection on the Motor Control Room (MCC) for the SWLP electrical motor power cables or the SWLP electrical motor power cables current measuring transformers;

The test can be started quickly by making a contactless and safe connection to current transformers and voltage points while the motor is running.

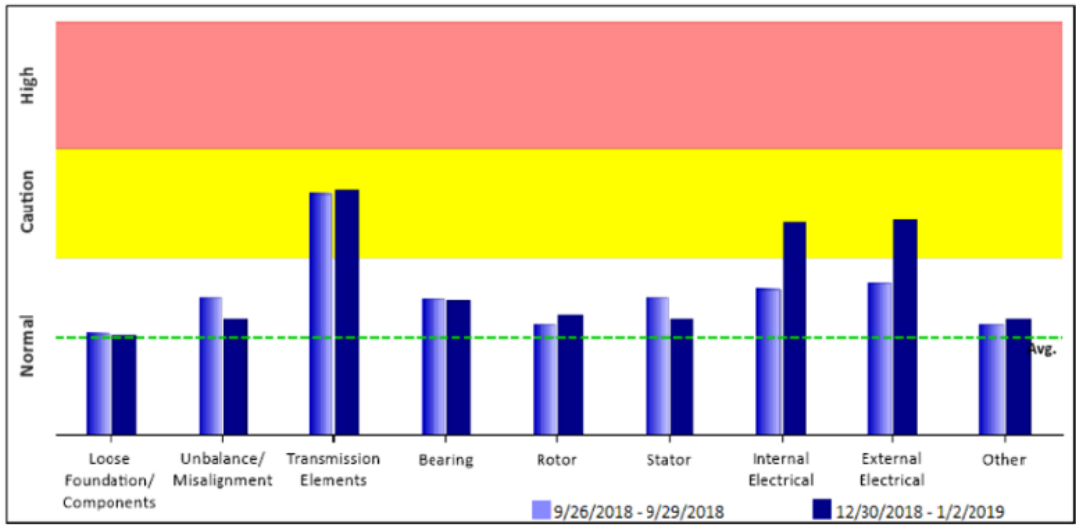


Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

Electrical motor voltage and current analyze system



- The on-line electrical motor voltage and current analyze system available on the market, **can detect problems like unbalance, misalignment's, bearing issues , rotor and stator electrical issues, etc;**



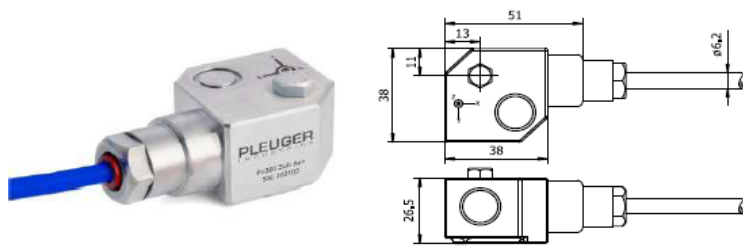
Electrical motor voltage and current analyze system

Reliability improvements for new offshore pump projects – Sea Water Lift Pumps

Permanent on-line vibration monitoring systems

PI-300 Sub Acc

Triaxial AC accelerometer for vibration measurement on submersible motor pumps



- Features
- Triaxial acceleration measurements
 - For all PLEUGER® units
 - Waterproof up to 10 bar
 - Oil-resistant

Description	Mechanical data	
The PI-300 Sub Acc sensor is designed for the special operating conditions on a PLEUGER® submersible motor pump. The vibration measurement method uses piezoelectric ceramic (PZT).	Housing material	Stainless steel / Super Duplex
	Sensor element	Piezoresistive
A sensor measures the vibrations in three axes (X, Y and Z) simultaneously. All measured values are transferred to the surface by a sturdy multi-core cable.	Tightening torque	8 Nm
	Mounting screw incl.	M8 x 1.25 mm
	Mounting screw material	Stainless steel / titanium
	Cable material	Blue; oil- and water-resistant
	Cable properties	Armored; filled PUR
	Maximum cable length	1000 m
	Weight without cable	235 g

- 4-20 mA output vibration module to be installed on the top deck above sea water level, to allow vibration reading and DCS connections for the SWLP pumps permanent on-line vibration monitoring system;

- Triaxial AC accelerometer to be used on permanent vibration on-line monitoring for the SWLP pump and electrical motor, to detect mainly mechanical issues: unbalance, looseness, bearing defects, etc;



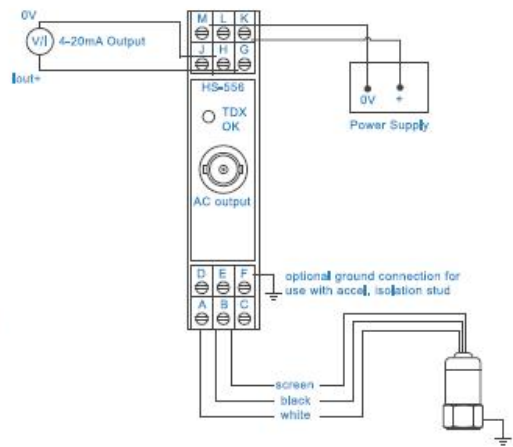
Permanent on-line vibration monitoring systems

HS-556 Vibration Module

4-20mA output

Key Features

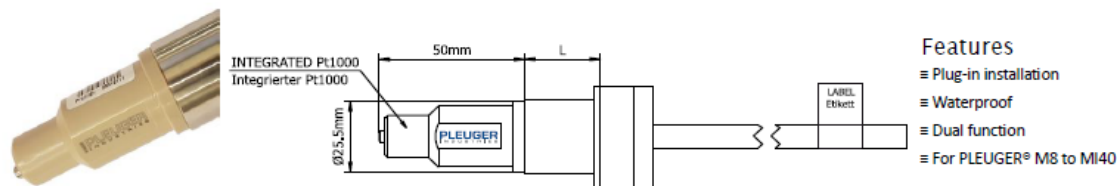
- Industrial Accelerometer input
- 4-20mA Velocity or 'g' output
- TDX OK Function
- Low pass filter
- Din Rail Mounted
- Buffered Accelerometer output (for data collection) via BNC



Reliability improvements for new offshore pump projects – Sea Water Lift Pumps

SWLP electrical motor filling sensor (for non-header tank SWLP electrical motor design)

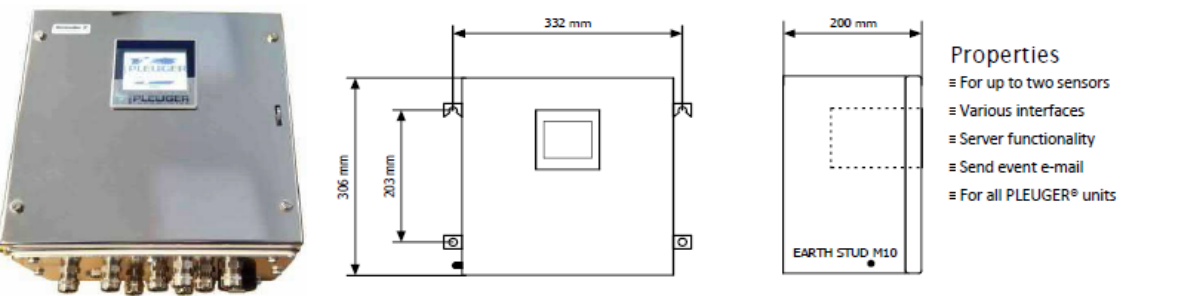
PI-100 Sub Con Plug-in Motor Fill Monitoring Sensor



Description	Mechanical Data
The PI-100 Sub Con detects an incorrect or contaminated fill of the PLEUGER® motor.	Housing material stainless steel 1.4571/PEEK
The system consists of the sensor, a cable and the monitoring controller. The sensor measures the conductivity of the motor fill and its temperature. The monitoring controller compensates the purity measurement over the full temperature range of motor operation.	Construction plug-in, integrated cable, moulded
The PI-100 Sub Con is a plug-in sensor intended to be installed in your PLEUGER® Industries submersible motor with an applicable interface (adaptor and seal).	Mounting with a type specific adaptor
	Cable material special elastomer
	Outer sheath black; oil & water resistant
	Conductor finely stranded, tinned copper
	Conductor size 4 x 2 x 0.22 mm ² , twisted pair
	Cable diameter 9...10 mm
	Min. bending radius (fixed) 60 mm
	Approx. net weight 90 kg/km
	Permitted pulling force max. 100 N

- On-line SWLP electrical motor filling sensor (for non-header tank SWLP electrical motor design) to detect if there is any leak on the SWLP electrical motor cooling fluid, which means there is a deterioration of the electrical motor mechanical seal;

PI-MOON Motor fill monitoring - signal analyzer and converter with recording function

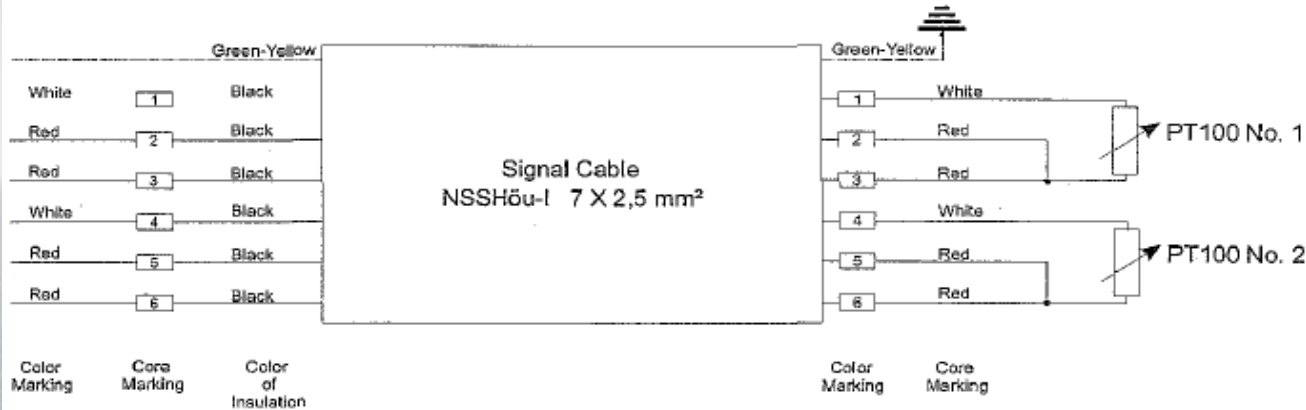


Description	Mechanical data
The PI-MOON is a multi-channel measuring device, designed for up to two PI-100 Sub Con sensors for monitoring the PLEUGER® motor fill. The housing is made of high-quality stainless steel with a high IP class.	Housing material Stainless steel 1.4404 (316L) 1.5 mm
In addition to the raw measured values from the PLEUGER® submersible motors, ON- and OFF-states of the motor starters can also be recorded.	Flange plate 3 mm
The recorded data is written to a ring buffer. Access to the	Design Wall mounting
	Cable glands Bottom
	Cover mounting Hinge (std. flex left) screwed
	Seal Silicone

SWLP electrical motor filling sensor (for non-header tank SWLP electrical motor design)

Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

SWLP electrical motor temperature sensor



Settings for Motorprotection

Overtemperature pre-alarm setting : 70 °C

Overtemperature switch off setting : 75 °C

Technical data

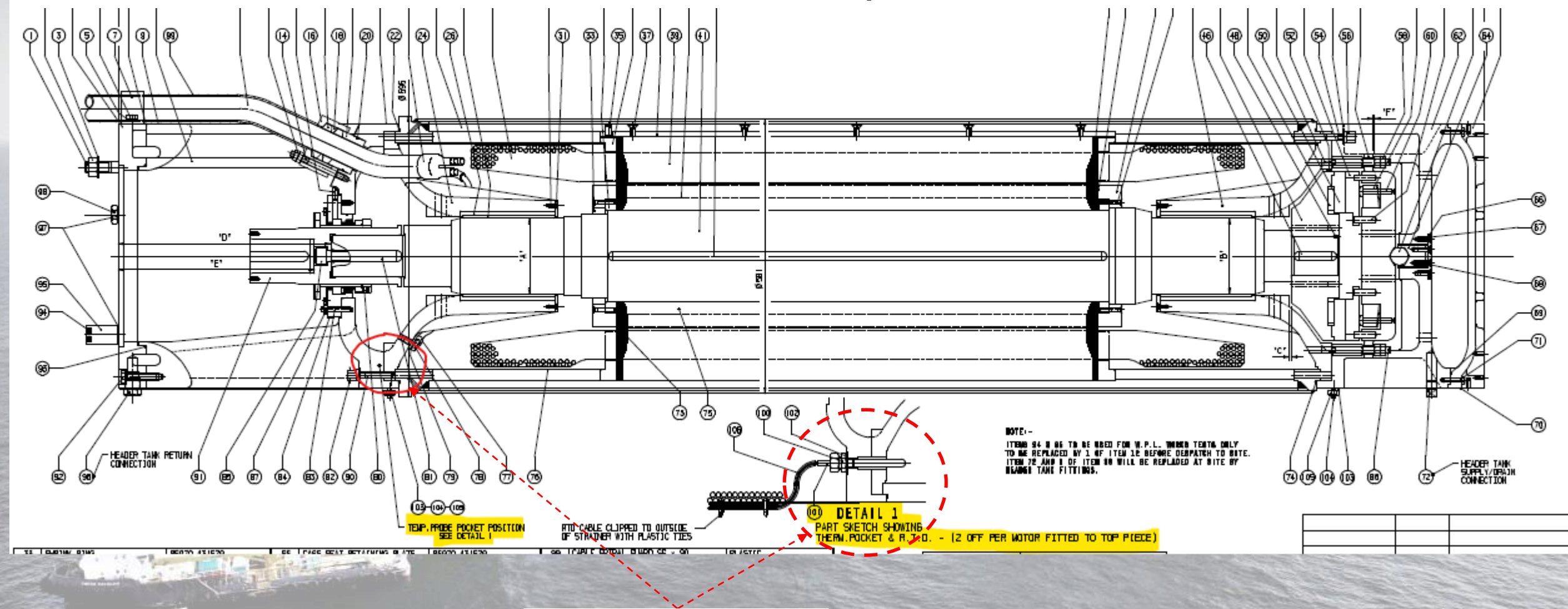
Measurement resistance PT100 according DIN IEC 751/B

Basic resistance value	100 Ohm bei 0 °C
Mean change of resistance	0,385 Ohm/K
Allowable measure current	5 mA, heating up error < 0,2 °C
Pressure water proof	50 bar
Temperature range	-15 °C to 95 °C

- The on-line SWLP temperature sensor PT100 is inserted on the electrical motor to monitor the filling medium temperature. The resistance transmit a signal which is proportional to the filling liquid temperature;
- The on-line SWLP electrical motor temperature sensor alarm values is normally around 70°C and shutdown value is normally around 75°C;

Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

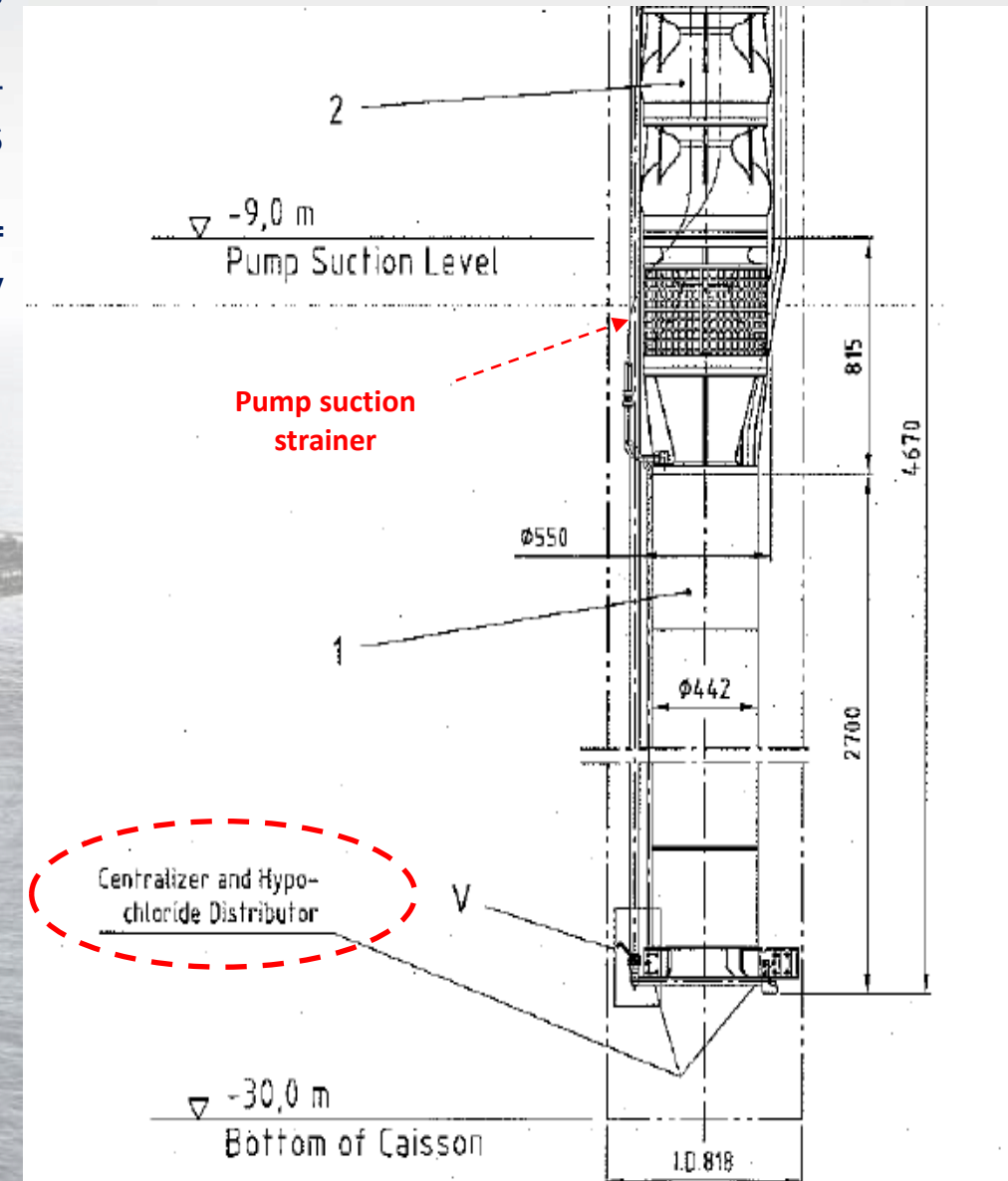
SWLP electrical motor temperature sensor



On-line SWLP electrical motor temperature sensor

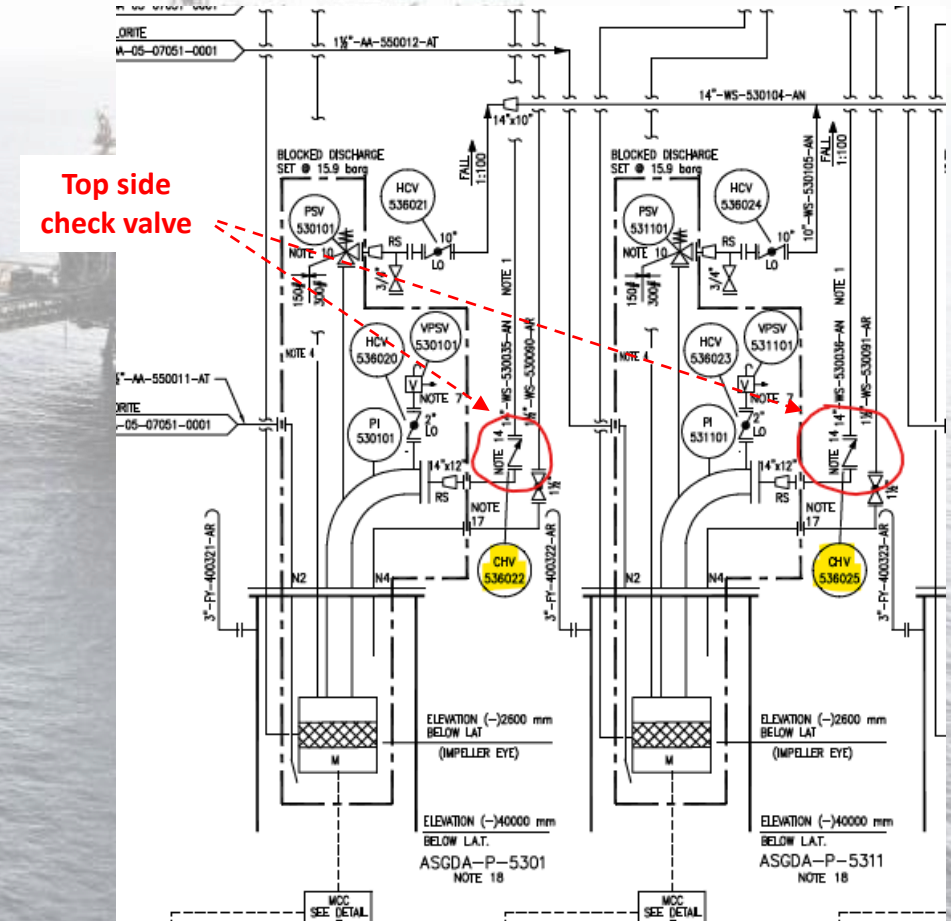
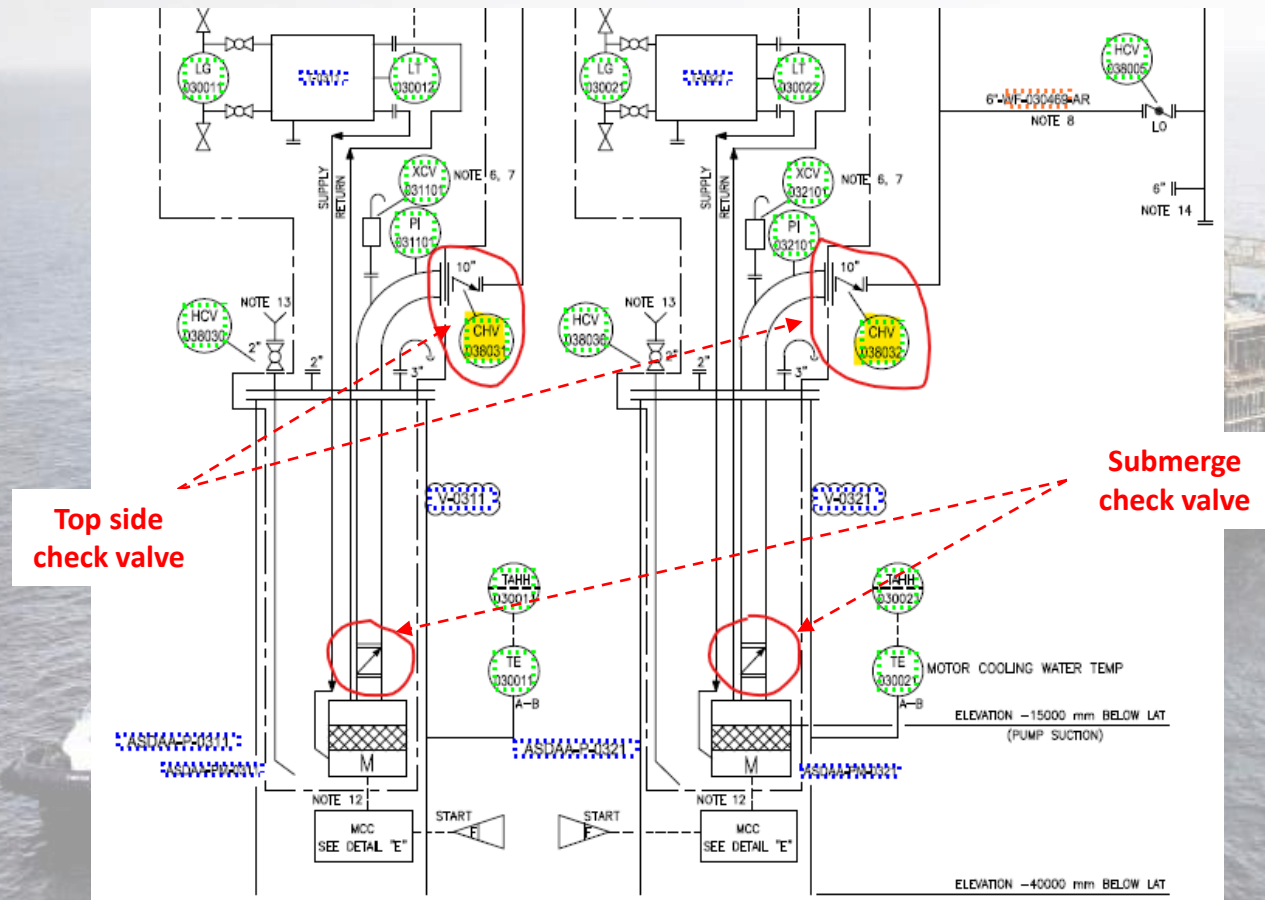
Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

- All SWLP pumps should have a **hypochlorite injection system** to prevent marine growth and blockage of the pump suction strainer;
- The hypochlorite injection ring should be in titanium and the hypochlorite under water connections should be either in **rubber flexible hoses with reinforce duplex SS mesh/coating (hydraulic hose type specification)** or duplex SS rigid tubing;
- Due to easy of field replacement/installation and duration, **we recommend the use of flexible hoses. We don't recommend PVC tubing** due to its lack of durability under sea water and sea wave conditions;

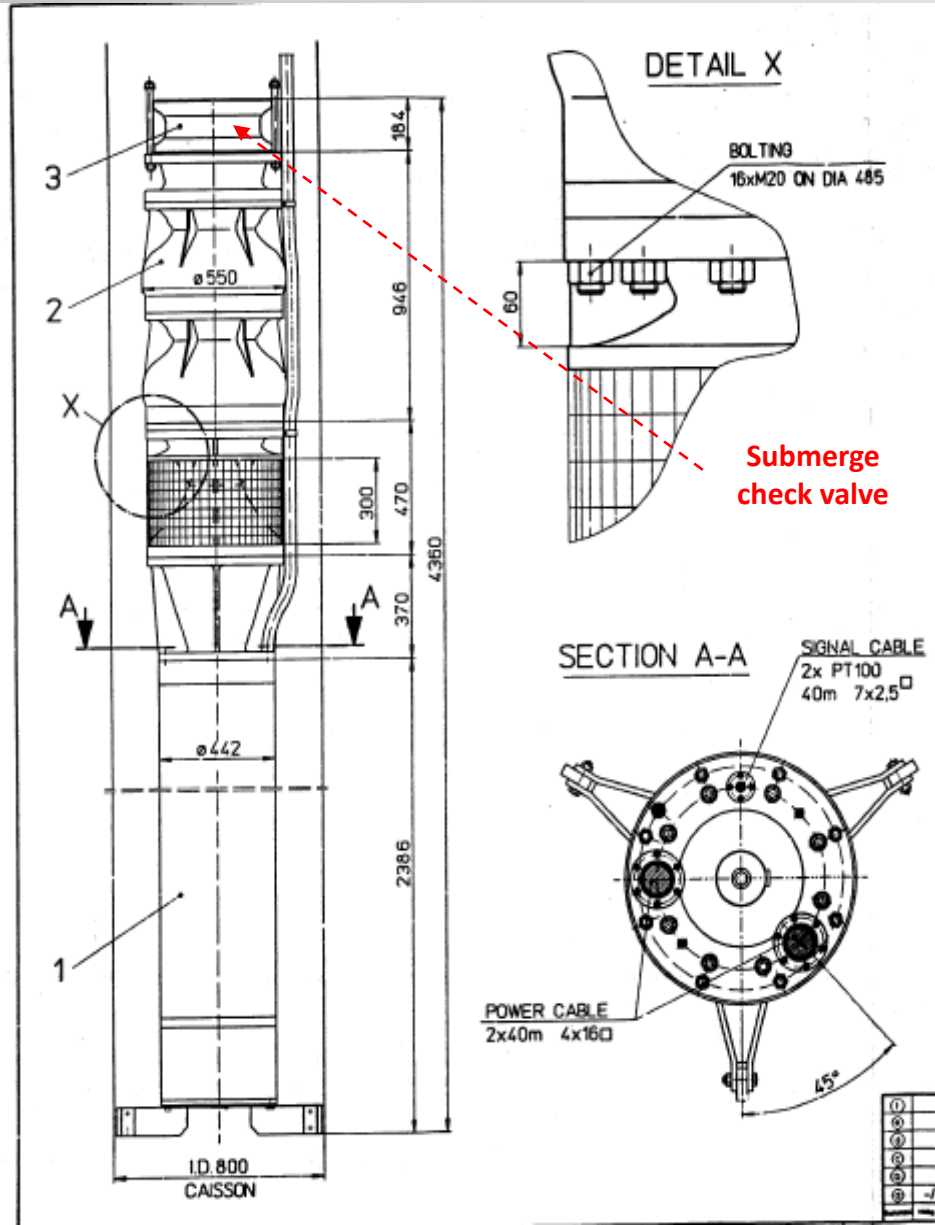


Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

- For the SWLP pumps have two different design in terms of check valve position:
 - one check valve immediately after the pump discharge flange under water and another check valve on the pump top side piping, besides an air release valve and PSV valve on the pump top discharge bend curve above water;
 - other, only a check valve on the pump top side discharge piping, besides an air release valve and PSV valve on the pump top discharge bend curve above water;



Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*



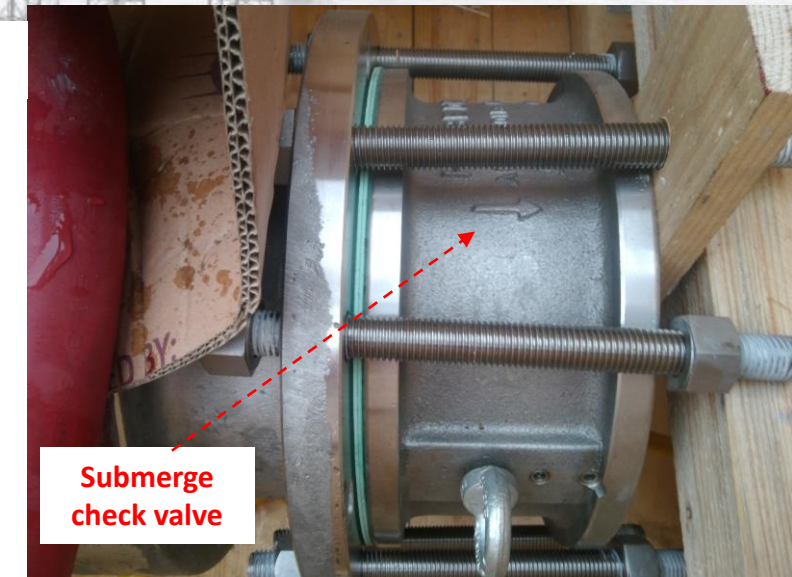
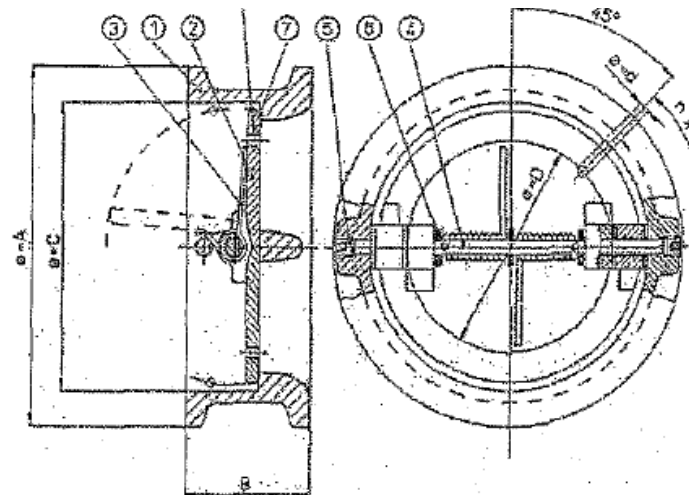
- The reasons for the two different design philosophies on the SWLP pumps check valve position are:

1. Control of the water hammer during the SWLP pump start up/shutdown;
2. Prevent the SWLP pump to rotate when the pump is stooped;
3. Hydraulic axial loads of the SWLP electrical motor thrust bearing during the SWLP pumps start-up and shutdown situations;

This design choice and associated calculations must be discussed with the SWLP OEM and be reported on the pump project documentation;

- Based on our experience, we recommend the design with one check valve immediately after the pump discharge flange under water and another check valve on the pump top side;

Submerged check valve



Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

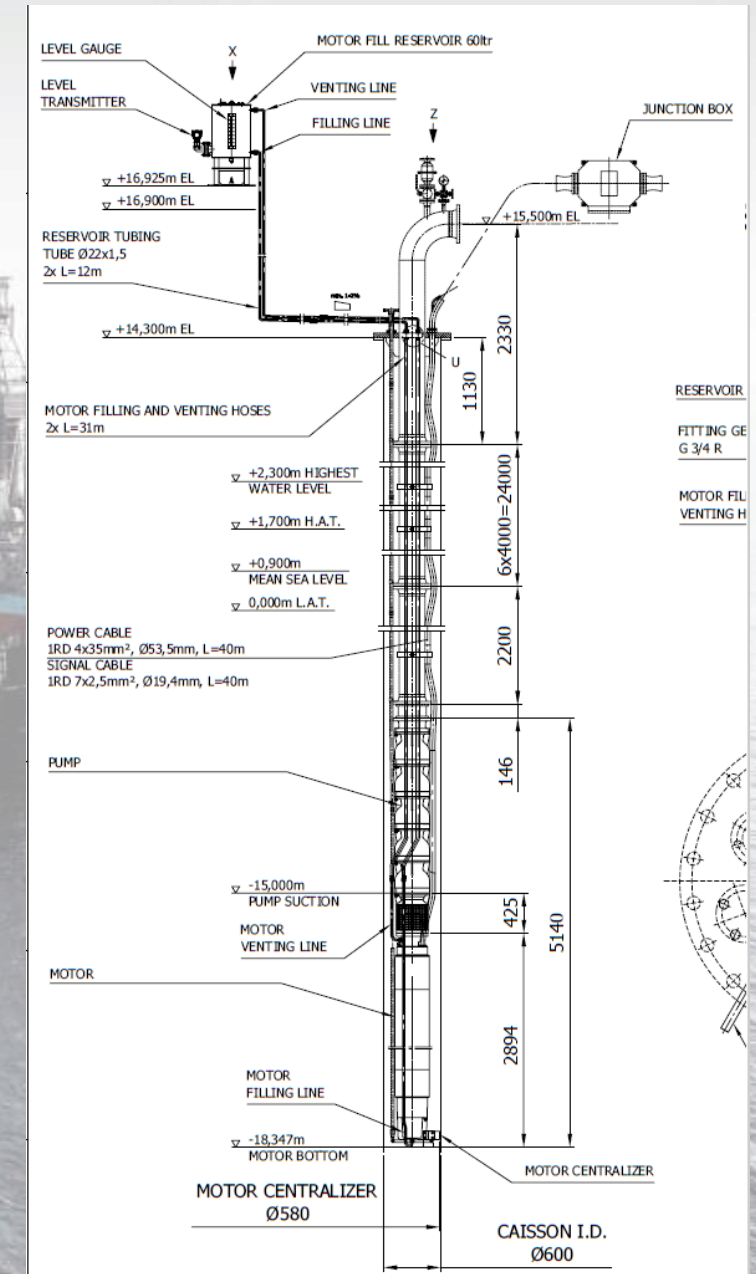
- For SWLP pumps with electrical motor cooling by dedicated tank header, the cooling medium tubing under water should be either in rubber flexible hoses with reinforce duplex SS mesh/coating (hydraulic hose type specification) or duplex SS rigid tubing;
- Due to easy of field replacement/installation and duration, we recommend the use of flexible hoses. We don't recommend PVC tubing due to its lack of durability under sea water and sea wave conditions;



Flexible hoses



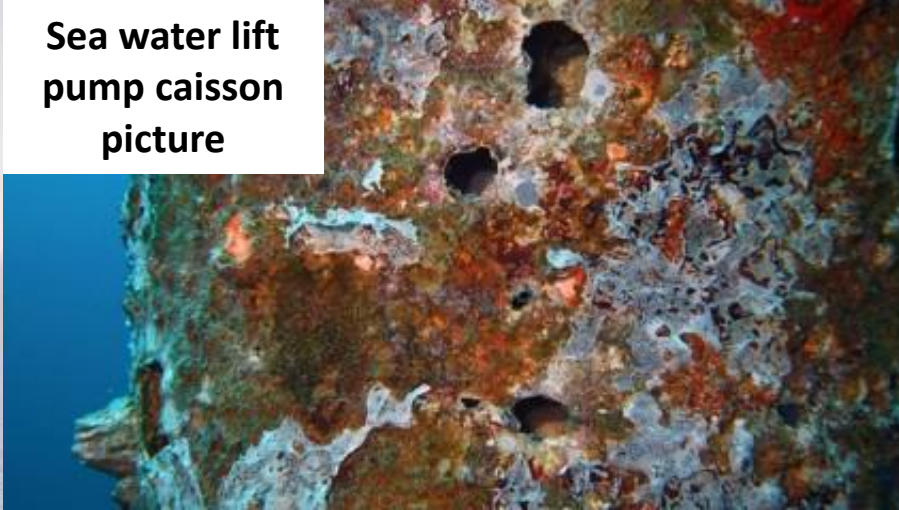
Duplex SS rigid tubing



Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

Some historic findings on SWLP caisson following ROV/diver inspection

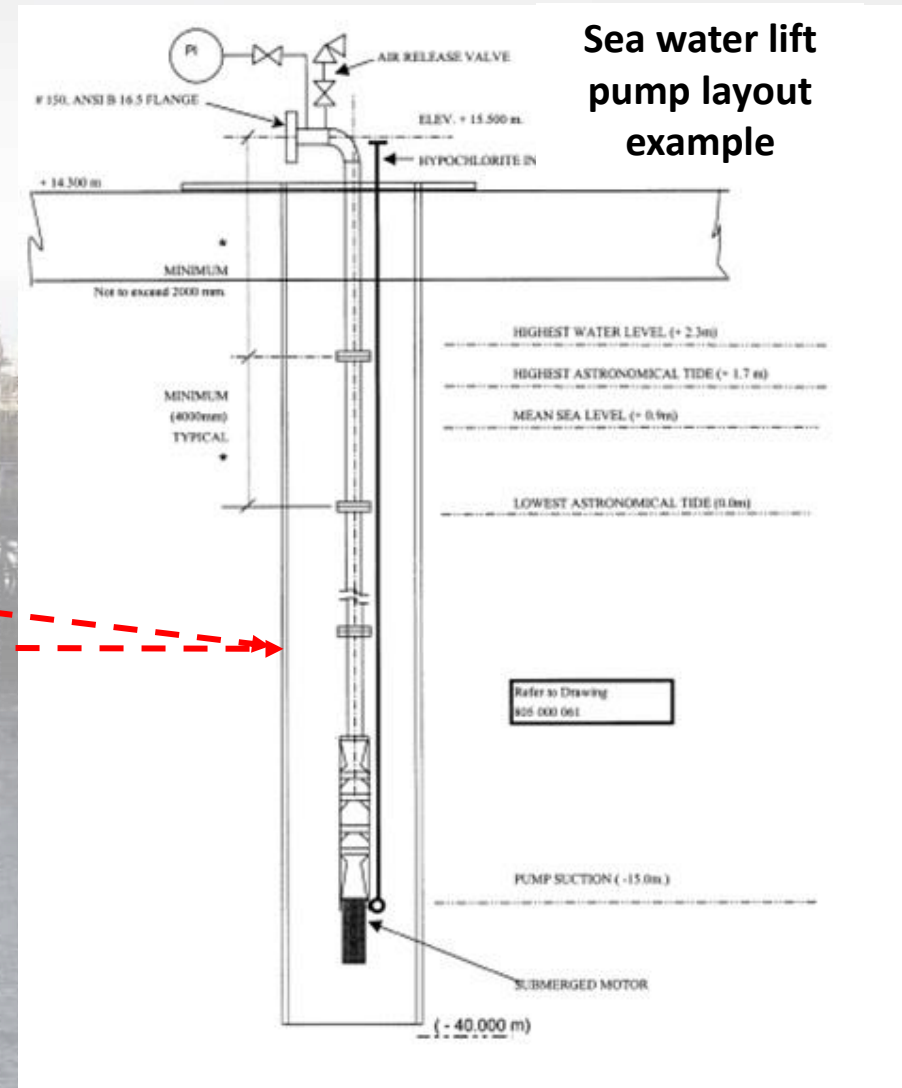
Sea water lift
pump caisson
picture



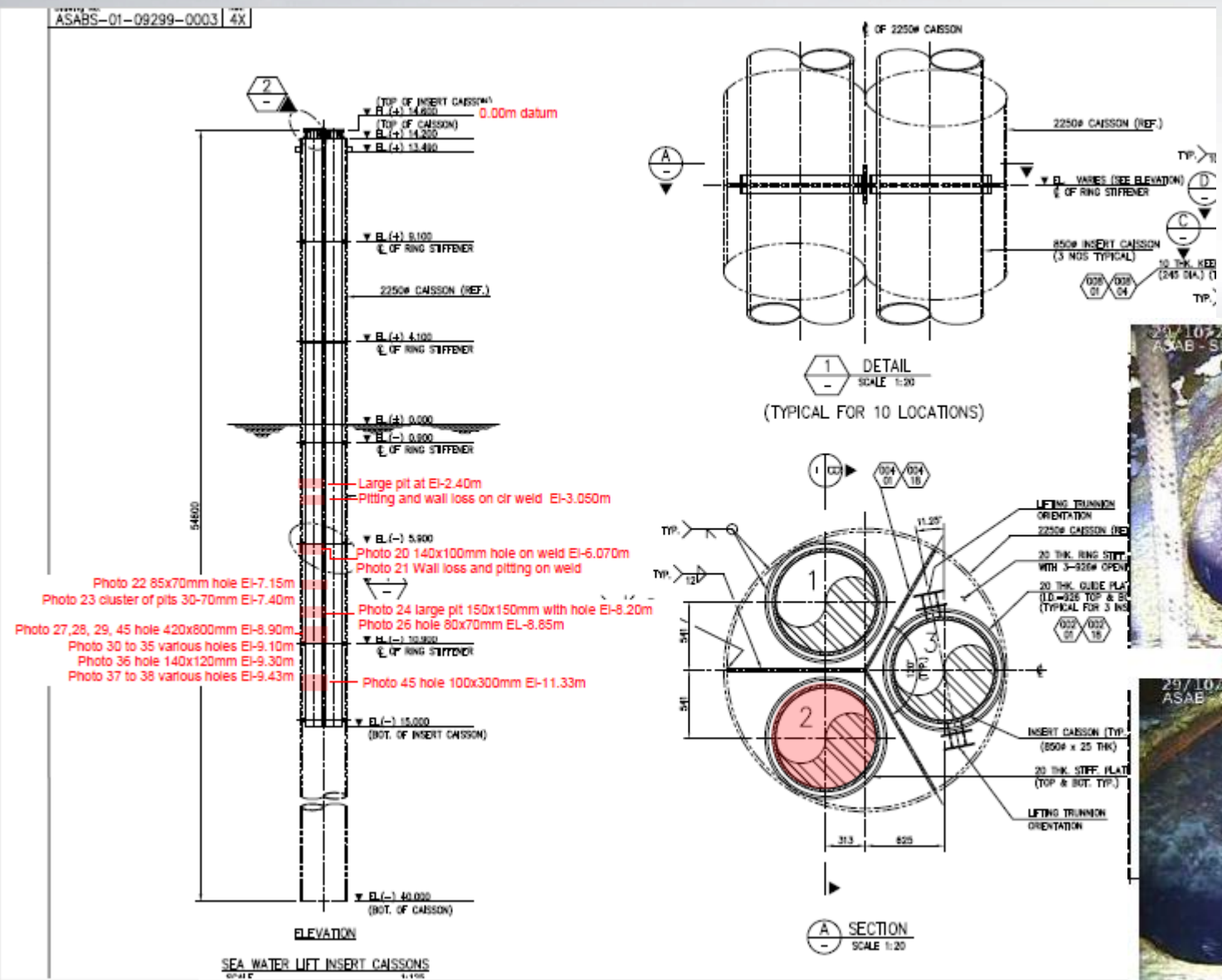
Sea water lift pump caisson picture

- During the ROV/diver inspection of the SWL pumps caissons sometimes have found severe caisson holes that can affect the entire caisson structural integrity (in same cases, the caissons have failed and drop down to bottom of the sea, after 10-14 year, taking the SWLP with them);

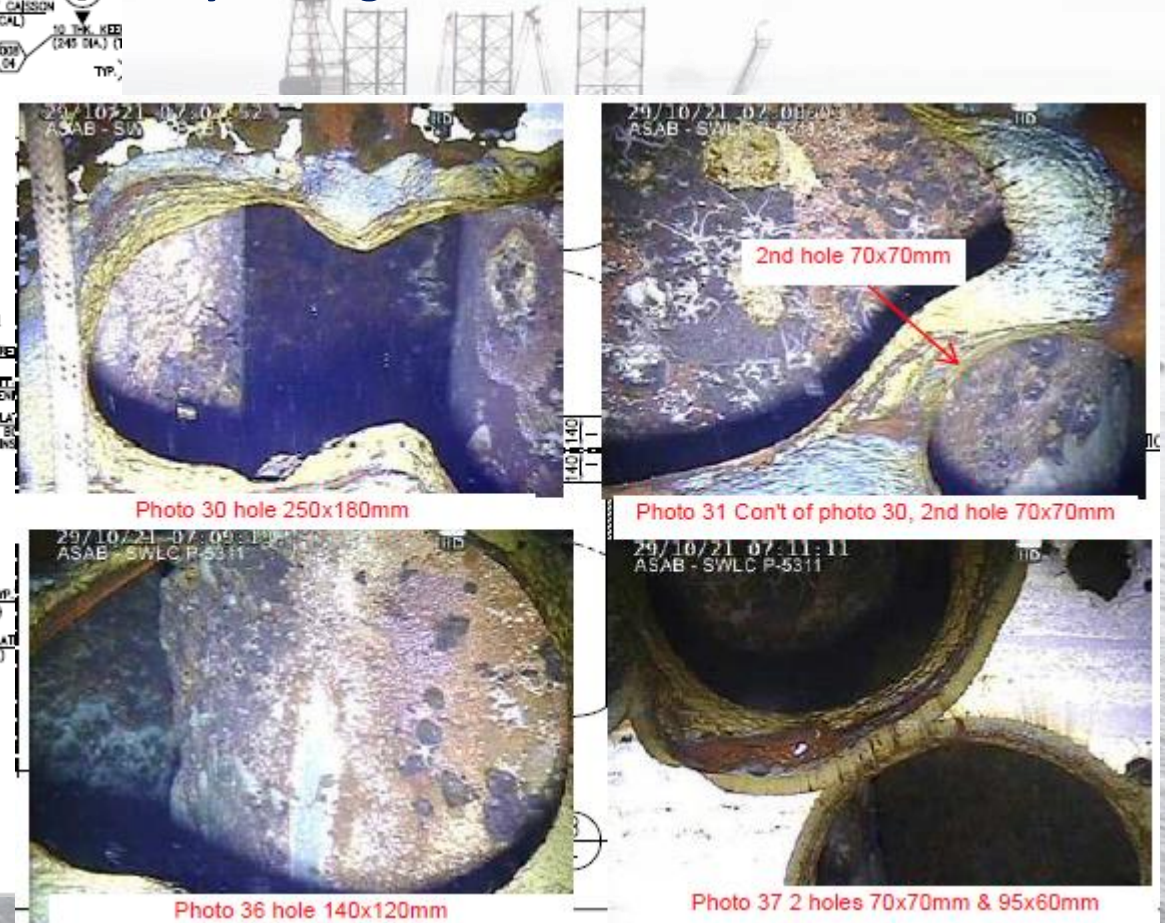
- The recommended best practice is to perform a complete SWL pump caisson inspection by ROV/Diver and nondestructive testing (NDT) methods every 5-7 years or based on Risk Based Inspection (RBI) criteria. For the caisson NDT inspection, the SWL pump must be removed;



Reliability improvements for new offshore pump projects – Sea Water Lift Pumps



- Another example of the damage found in the SWLP caissons, during ROV inspection for caissons installed at least around 9-12 years ago;



Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*



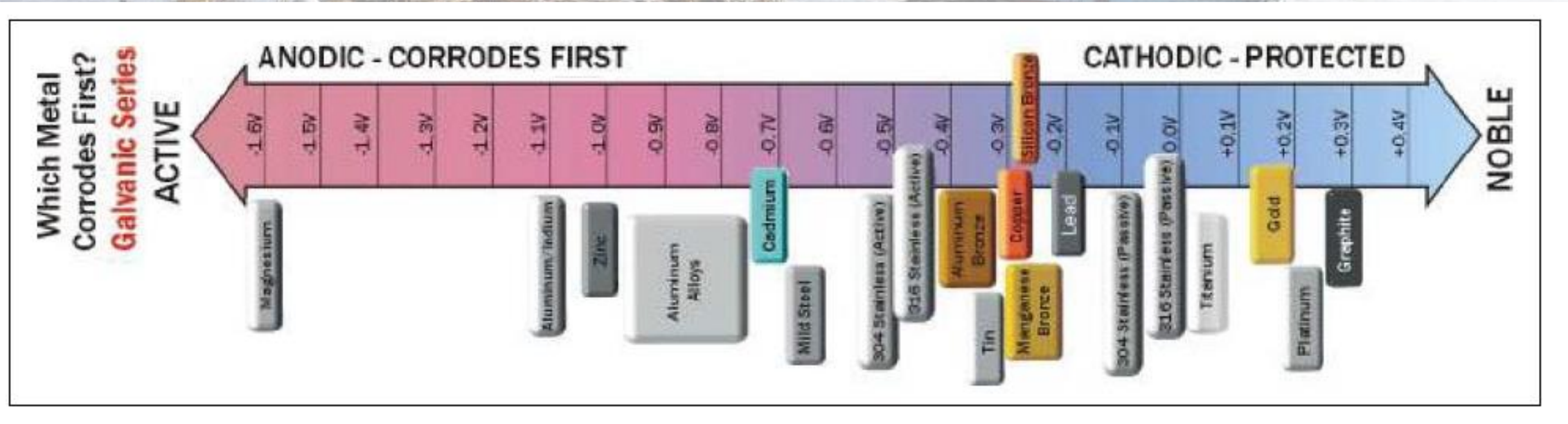
- Some SWLP have sacrificial anodes and others don't have;



- The SWLP sacrificial anodes, are there not to protect the pump from sea water corrosion (because the pumps are in duplex stainless steel, so they will never corrode) but to protect the pump caisson that are made in plain carbon steel, coated or not;

Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

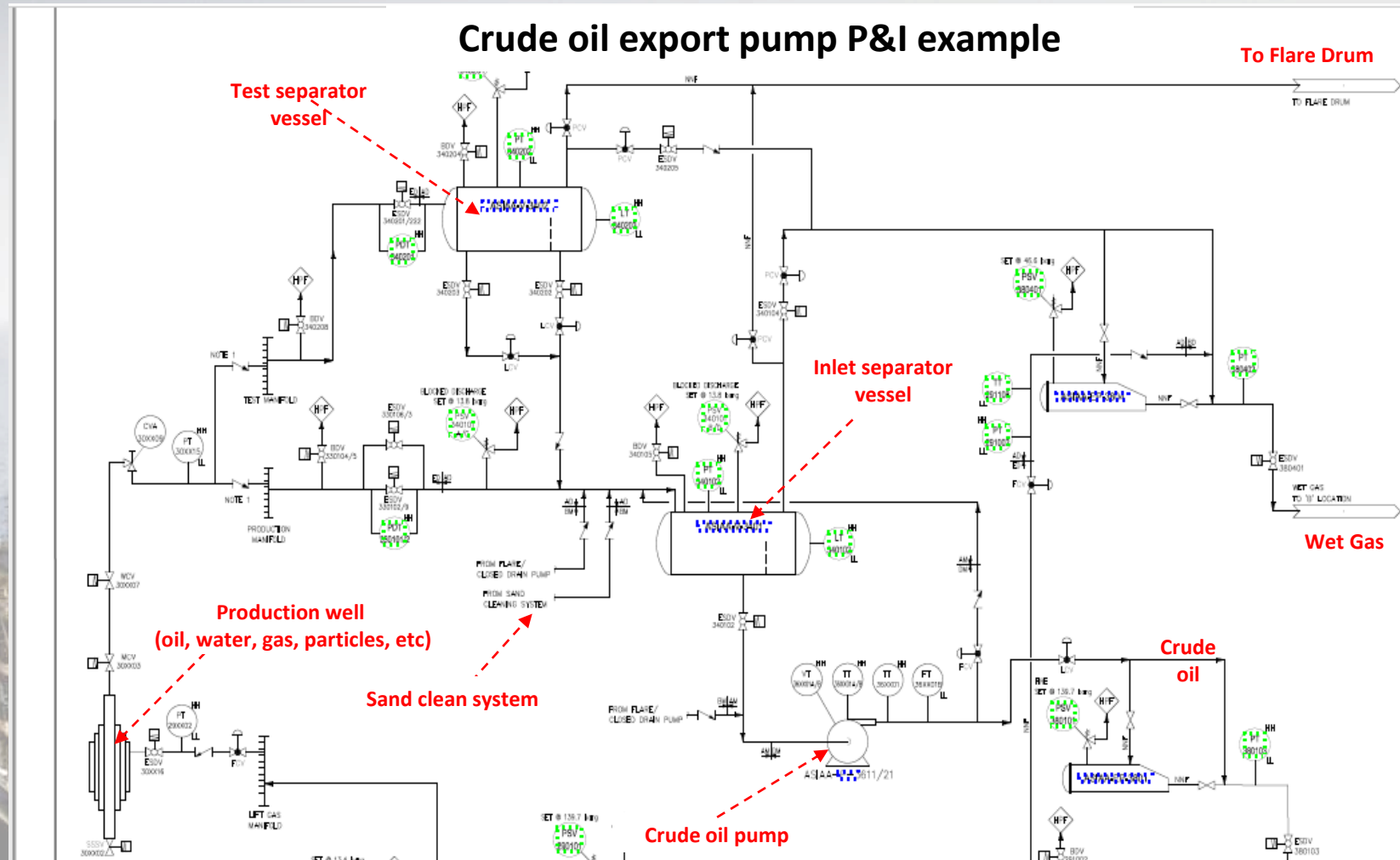
- Some SWLP pumps are supplied with anodes in order to protect the inside surface area of Carbon Steel (CS) Caisson Pipes;
- **Cathodic Protection (CP)** can be defined as e.g. “electrochemical protection by decreasing the corrosion potential to a level at which the corrosion rate of the metal is significantly reduced” (ISO 8044) or “a technique to reduce corrosion of a metal surface by making that surface the cathode of an electrochemical cell” (NACE RP0176). The process of suppressing the corrosion potential to a more negative potential (100 mV) than the native generated potential for Carbon Steel, i.e. -600 to -700 mV, is referred to as "cathodic polarization" where protective calcareous films are built up on the cathode surface;



Reliability improvements for new offshore pump projects – *Sea Water Lift Pumps*

- **Assumptions Concerning Use of Anode Type:**
 - **Al-0.1%Ga anodes** may be used for coated surfaces where the initial current demand can normally be omitted since this will not be a critical constraint in the design. This anode type will reduce the risk of Hydrogen Induced Stress Cracking (HISC) in Duplex SS since the anode potential is closer to -800 mV, where HISC normally will be suppressed (Ref.: ISO 15589-2). Furthermore, when the CP system is located in a protected environment away from heavy storms and removal of marine growth inside the Caisson Pipe, depolarization has been found to have a minor effect. The required Number of Al-0.1%Ga anodes are therefore normally chosen based on the mean current demand.
 - **Al-In-Zn anodes with a potential of -1050 mV, where Duplex SS can be susceptible to HISC**, are used when low potential Al-0.1%Ga anodes are not allowed by customer or cannot be used due to unpainted CS Caisson Pipe. For this case the Pump Pipe stack will in addition to paint have wrapping in the critical flange neck areas in order to suppress hydrogen ingress, hydrogen embrittlement and development of HISC.
 - **Splash zone will only be partly (1/3 of fully) protected by a CP system, and should not be relied upon alone. DNV-RP-C302 recommends epoxy polyester coating type with DFT 600 μm in Minimum of 3 coats in splash zone.**

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*



- Offshore crude oil export pumps are **critical pumps** on offshore Oil & Gas Upstream producing facilities;
- Offshore crude oil export pumps send “**crude oil**” to other offshore platforms, FPSOs, onshore storage/processing facilities, etc;
- Offshore crude oil export pumps are subject to **severe corrosion and erosion** due to their closeness to the production wells, they pump a mixture of crude oil, water, sand particles, H₂S, chemical injected products to boost well production, etc;

Pump arrangement drawing

110

685

475.25

821.75

TP1

TP2

TPZ

TPZ 9

TP10 150

TP4

TP5

340

210

1390

610

1420

850

2621.5 C of G

100 TYP

SEE SOLEPLATE DETAIL

WINDING RTD'S TERMINAL BOX

BEARING RTD'S TERMINAL BOX

2000 MAX. HOOR HEIGHT

8 x 330 Holes For M24 Foundation Bolts by others

8 x M20 Jacking Sc

921.01

940.01

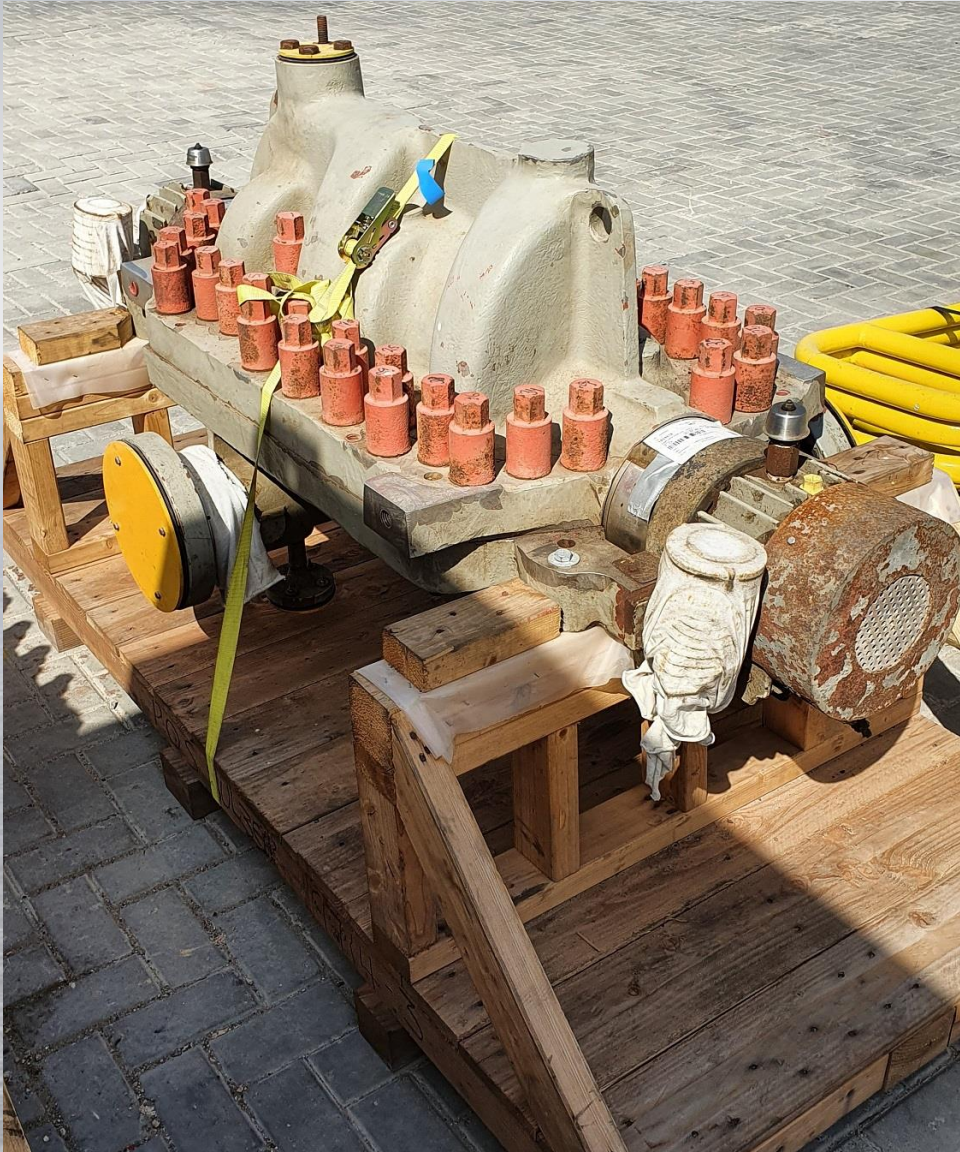
210.01

ELEVATION

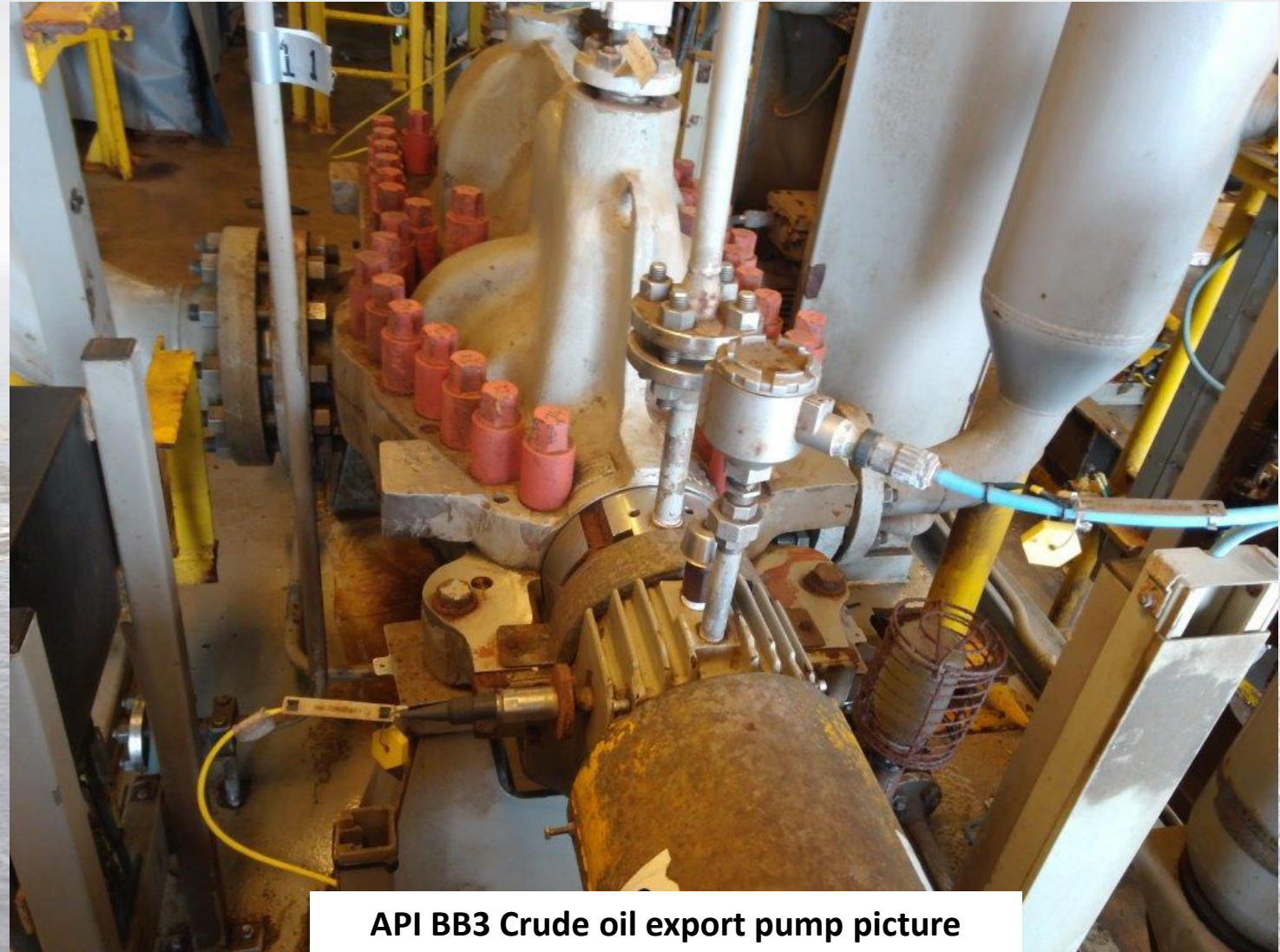
Shaft



Reliability improvements for new offshore pump projects - *Crude Oil Pumps API BB3*

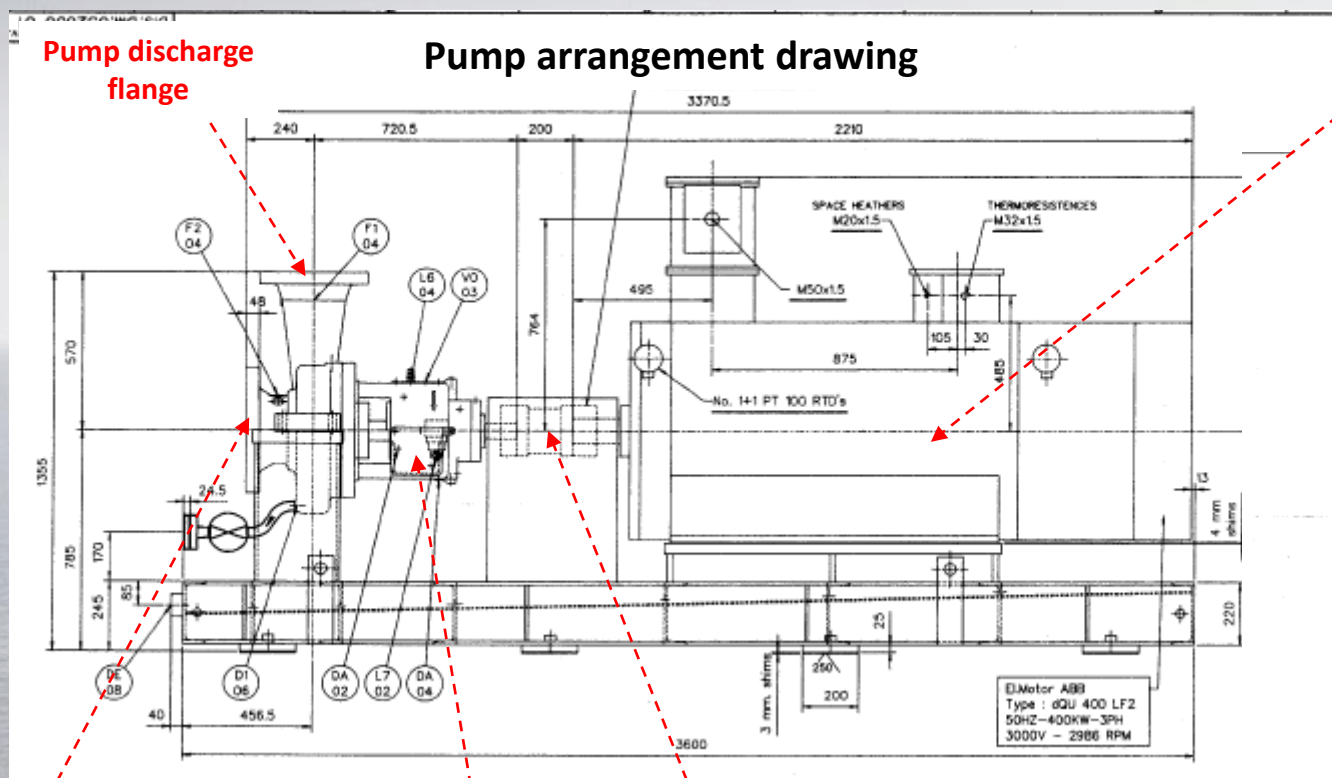


API BB3 Crude oil export pump picture

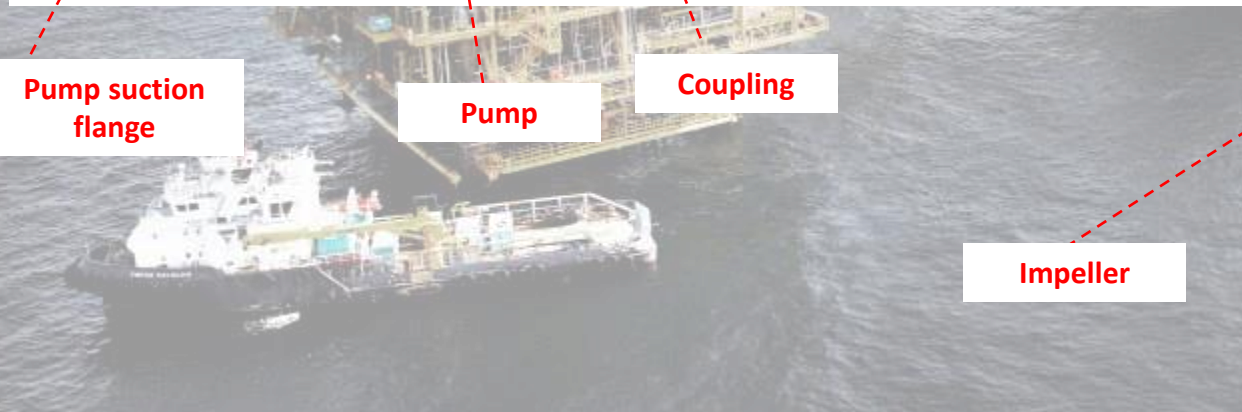


API BB3 Crude oil export pump picture

Reliability improvements for new offshore pump projects - *Crude Oil Pumps API OH2*



Electrical motor

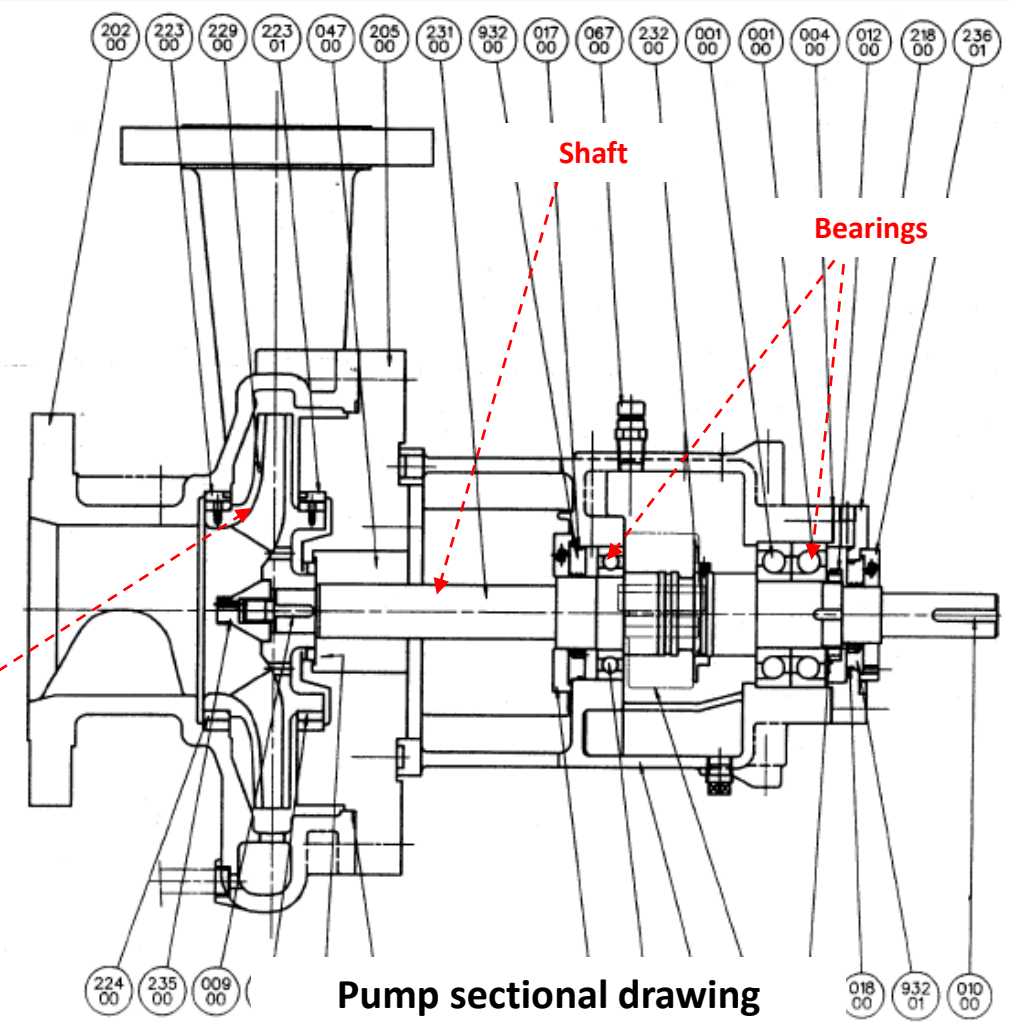


Pump suction flange

Pump

Coupling

Impeller



Shaft

Bearings

Pump sectional drawing

Reliability improvements for new offshore pump projects - *Crude Oil Pumps API OH2*



API OH2 Crude oil export pump picture

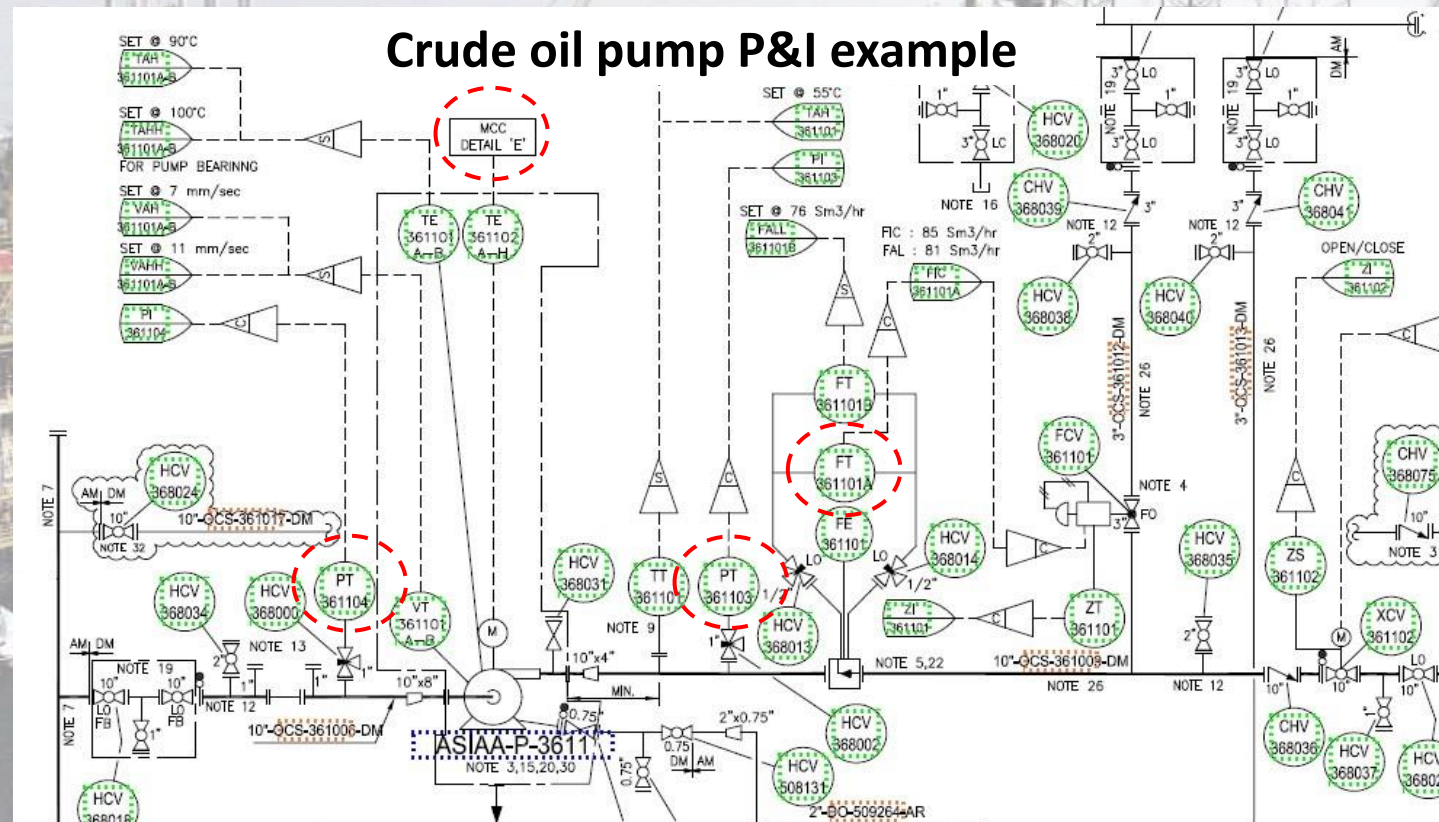


API OH2 Crude oil export pump picture

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- Crude oil export pumps (COE) minimum field instrumentation should be:
 - **suction and discharge pressure transmitter (PT) with local indication (PI) at pump suction/discharge flange**, connected to control room DCS;
 - **discharge flowmeter (FT)**, connected to the control room DCS;
 - **electrical motor current consumption (amps)**, connected to the control room DCS;
 - **on-line vibration protection and monitoring system**, connected to the control room DCS;

In order to guarantee that we have pump full monitoring for low suction pressure issues, enable pump performance continuous monitoring, etc;



Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- The recommend COE pump materials are:

Option 1 (*initial cost: 120 - 150%, estimated MTBF: 6-10 years*)

- Casing/cover/seal housing – Super duplex steel ASTM A890 Gr.1C with a SUME SA coating on all the wetted parts;
- Impeller - Super duplex steel ASTM A890 Gr.1C with a SUME HVOF coating (tungsten carbide);
- Shaft - Super duplex steel (UNS S32760) or similar material;
- Shaft sleeve - Super duplex steel ASTM A890 Gr.1C or similar material with a SUME HVOF coating (tungsten carbide);
- Casing and impeller rings - Super duplex steel ASTM A890 Gr.1C or similar material with a SUME HVOF coating (tungsten carbide);
- Interstage bushes and sleeves - Super duplex steel ASTM A890 Gr.1C or similar material with a SUME HVOF coating (tungsten carbide);

Option 2 (*initial cost: 100%, estimated MTBF: 4-7 years*)

- Casing - ASTM A487 CA6NM/B with HVOF coating (tungsten carbide);
- Cover/Seal Housing- ASTM A487 CA6NM/B with HVOF coating (tungsten carbide);
- Impeller - ASTM A487 CA6NM/B with TMT hardening;
- Casing Wear Ring - ASTM A351 CA15 with HVOF coating (tungsten carbide);
- Impeller Wear Ring - ASTM 426 CPCA15 Annealed with HVOF coating (tungsten carbide);
- Pump Shaft - ASTM A276-410-DT with no coating or AISI 4140 Alloy Steel (chromium, molybdenum and manganese-containing low alloy steel) with no coating;

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- **HVOF (High Velocity Oxygen Fuel) Coating :**

- The process is one of injecting a powder into a high velocity flame and spraying the particles onto the base material to form a dense uniform coating. The base material is not heated sufficiently to melt it, and its properties are not affected by the application of the coating.
- Even though the powder can be composed of a wide variety of materials, for COE pumps we prefer the powders consisting primarily of **tungsten carbide** with various metallic binders. HVOF coatings are proven to be more resistant to erosion than are overlays.

Many powders are available but the three listed below are considered industry standards:

Coating Material Trademark	SUME®Pump SA (1)			JK 112 (2)			TAF A 1350 VM (3)		
HVOF Spray System	Diamond Jet 2600			JKII or JKIIA			JP-5000		
Coating Hardness (Rc)	68-70			66			68		
Coating Thickness:	Std.	X Thick	Max	Std.	X Thick	Max	Std.	X Thick	Max
(millimeters)	0.305	0.610	1.27 ⁽⁴⁾	0.305	0.610 ⁽⁵⁾	1.27 ⁽⁵⁾	0.305	0.610 ⁽⁵⁾	1.27
(inches)	0.012	0.024	0.050 ⁽⁴⁾	0.012	0.024 ⁽⁵⁾	0.050 ⁽⁵⁾	0.012	0.024 ⁽⁵⁾	0.050 ⁽⁵⁾
Coating Binder (Tungsten Carbide balance)	14% CoCr			12% Co			10% Co, 4% Cr		

- The primary recommendation for the COE pumps is the **SUME®Pump SA (1)**. It is proven to have up to **two (2) times more wear resistance plus better bond strength** than the **JK 112 (2)**. The third, TAF A 1350 VM (3), is also commonly requested by customers and rates midway between the other two.

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- TMT hardening for impellers:

- On some COE pumps we also use impellers fabricated in A487-CA6NM/B + TMT601. This impellers are in CA6NM material, and they are hardened using a TMT-601 boron diffusion alloying process (final coating end thickness of around 0.0015" and a final coating end hardness of around 1554 khn).
- **TMT-601 boron diffusion alloy specifications** : following diffusion process heat impellers to 1250 Degrees Fahrenheit with cover gas and hold for 2 hours per inch followed with air cool to less than 90 Degrees Fahrenheit. Reheat part to 1125 Degrees Fahrenheit with cover gas and hold for a minimum of 6 hours or 2 hours per inch (whichever is greater) followed with air cool to ambient temperature;



- **TMT coating for impellers:**

HARDNESS TESTS CERTIFICATE					
CERTIFICATO PROVA DI DUREZZA					
H.T. No.				Mocq 2029-13	
Shop Order Commessa		Customer Cliente		Purchase Order Ordine Cliente	
20121016884401		Maersk Oil Qatar		SO-21901	
Type of Machine Tipo di Macchina		Serial Matricola		Item N. Item Nr.	
6 HED 16 DS		D 61128		ASFAA-P-3621	
N. Pieces N. Pezzi	Subject Oggetto	Drawing Disegno	Material Materiale		
2	IMPELLERS	DBM727841 / 2	A743 - CA6NM/B		
☐ HEAT TREATMENT / TIPO TRATTAMENTO TERMICO			MATERIAL / MATERIALE		
			SHAFTWEAR RING		
☐ Precipitation Hardening Indurimento Adfocale			☐ A 276 - 410		
☐ Normalizing Normalizzazione			☐ A 276 - 420		
☐ PWHT Estensione Solitudine			☐ A 473 - 410		
			☐ A 473 - 420		
			☐ A 426 CPCA 15		
DESCRIPTION / DESCRIZIONE		REQUIRED / RICHIESTA	HB / HRC	OBTAINED / OTTENUTA	HB / HRC
☐ IMPELLER RINGS ANELLI DI USURA			☐ HB ☐ HRC		☐ HB ☐ HRC
☐ CASING RINGS ANELLI DI TENUTA			☐ HB ☐ HRC		☐ HB ☐ HRC
☐ SHAFT ALBERO			☐ HB ☐ HRC		☐ HB ☐ HRC
☐ CASING CORPS CORPO			☐ HB ☐ HRC		☐ HB ☐ HRC
☐ COVER / STUFFING BOX COPRICHIO			☐ HB ☐ HRC		☐ HB ☐ HRC
☐ DRAIN WELDS SALDATURE DRENAGGIO			☐ HB ☐ HRC		☐ HB ☐ HRC
☐ FLUSHING WELDS SALDATURE FLUSSAGGIO			☐ HB ☐ HRC		☐ HB ☐ HRC
☐ VENT WELDS SALDATURE VENT			☐ HB ☐ HRC		☐ HB ☐ HRC
☒ IMPELLER GRANZE		22 max (255 HB max)	☐ HB ☒ HRC	248 max	☒ HB ☐ HRC
EQUIPMENT TYPE TIPO DI STRUMENTO		SERIAL No.		309509	
☐ GALILEO D 2003		SERIAL No.		E301-005-1506	
☒ EQUOTIP 3		SERIAL No.		2306	
☐ SPINA TARATA (ERNST)					
SPECIFICATION SPECIFICA		RESULTS - RISULTATI			
DE 3511.006		☒ ACC. TO SPECIFICATION CONFORME ALLA SPECIFICA			
		☐ NON ACC. TO SPECIFICATION NON CONFORME ALLA SPECIFICA			
		☐ REJECTION SCARTO			
☒ NACE MR 0175		NOTES NOTE			

Impeller made of CA6NM/B base material in addition to TMT surface treatment (coating thickness: 0.0015" and coating hardness: 1554 khn)

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- TMT coating for impellers example:

- Example of crude oil pump 1st stage impeller (ASTM A487 CA6NM/B with TMT hardening) that has been running for more than 5-6 years without any major problem;



ASxxx-P-3621 1st stage impeller (March 2021)



ASxxx-P-3621 1st stage impeller (March 2021)

- No significant signs chemical attack or corrosion was found on the 1st stage impeller. The impeller the coating was gone due to erosion in some areas but no chemical attack signs;

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- TMT coating for impellers example:

- Crude oil pump 2nd stage impeller (ASTM A487 CA6NM/B with TMT hardening) that has been running for more than 5-6 years without any major problem;
- As you can see on the below pictures, we don't have any relevant signs of chemical attack on the 2nd stage impeller. We have **some erosion on the impellers, casing, wear rings**. On the impellers the coating was gone due to erosion but no chemical attack signs;



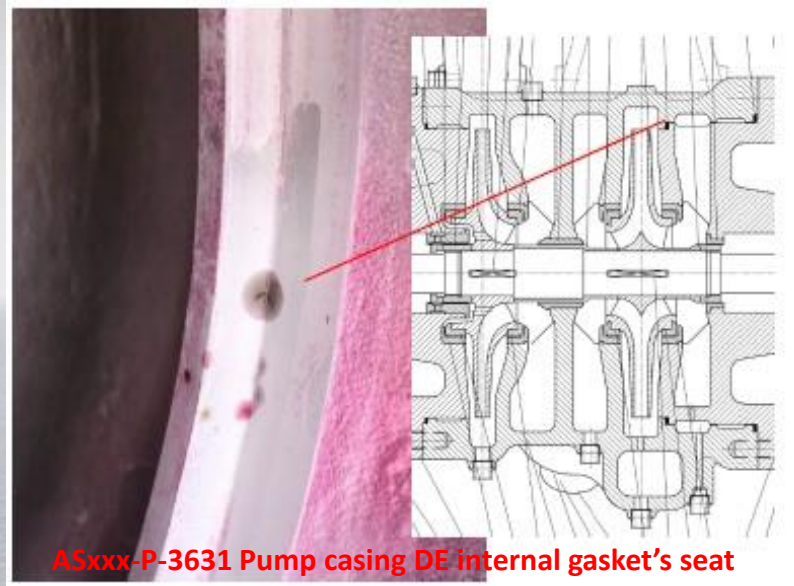
ASxxx-P-3621 2nd stage impeller (March 2021)



ASxxx-P-3621 2nd stage impeller

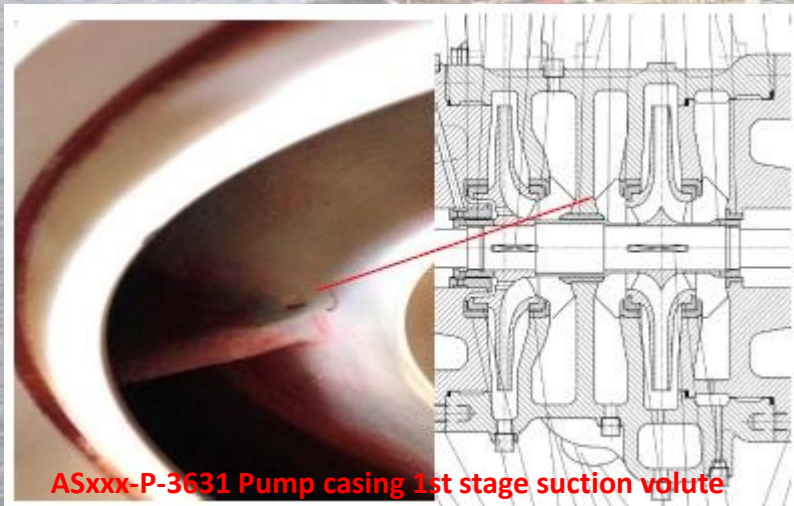
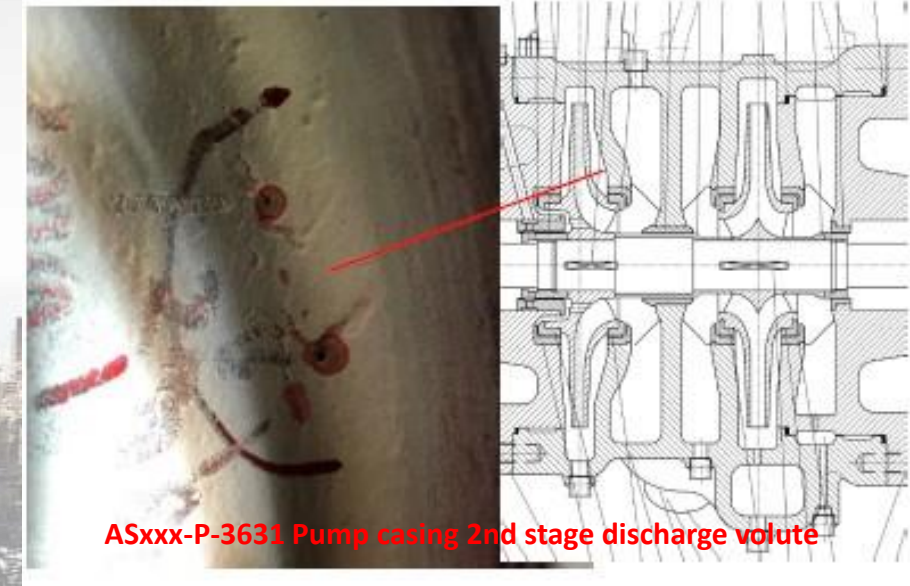
Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- New crude oil pump casing concerns:



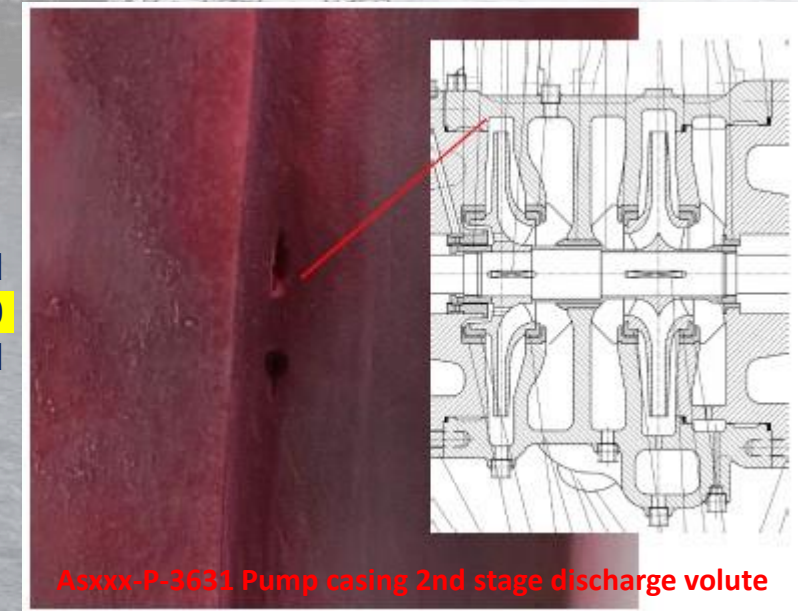
- ASxxx-P-3631 Pump casing DE internal gasket's seat - observed a 3 mm linear indication by LPs on the machined surface where gasket seats;

- ASxxx-P-3631 Pump casing 2nd stage discharge volute - 1 mm and 2 mm round indications revealed on raw and coated surface;



- ASxxx-P-3631 Pump casing 1st stage suction volute – 6 to 8 mm linear indication in raw and coated material;

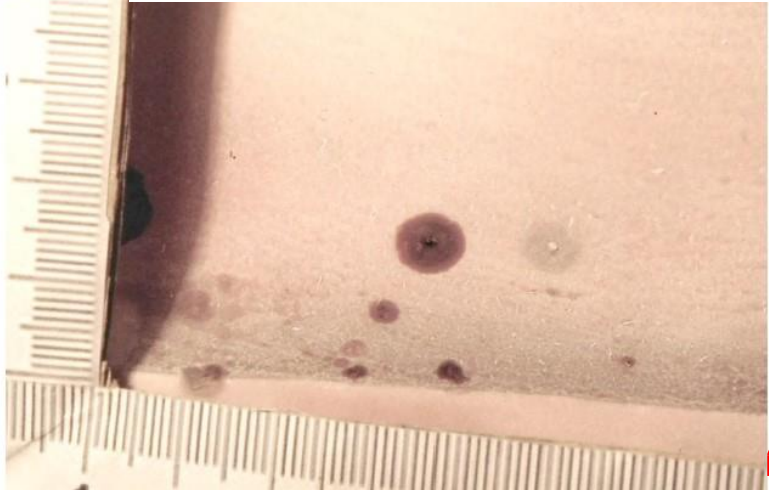
- ASxxx-P-3631 Pump casing 2nd stage discharge volute - 8 to 10 mm linear indication on raw and coated material;



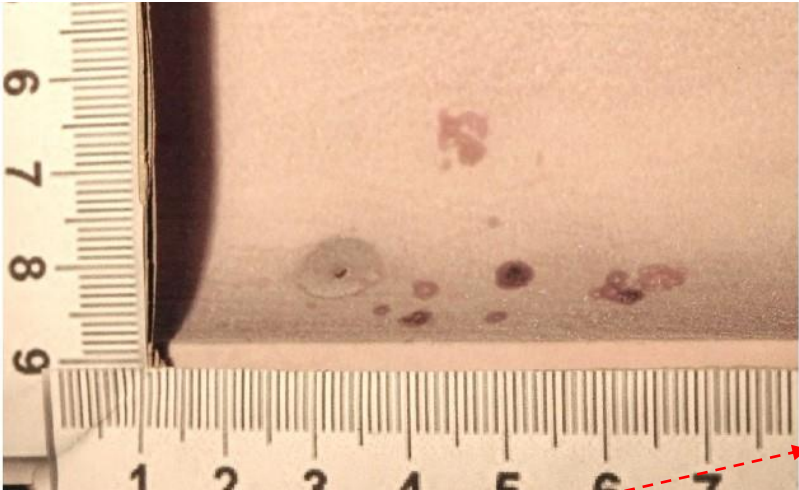
Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- New crude oil pump casing concerns:

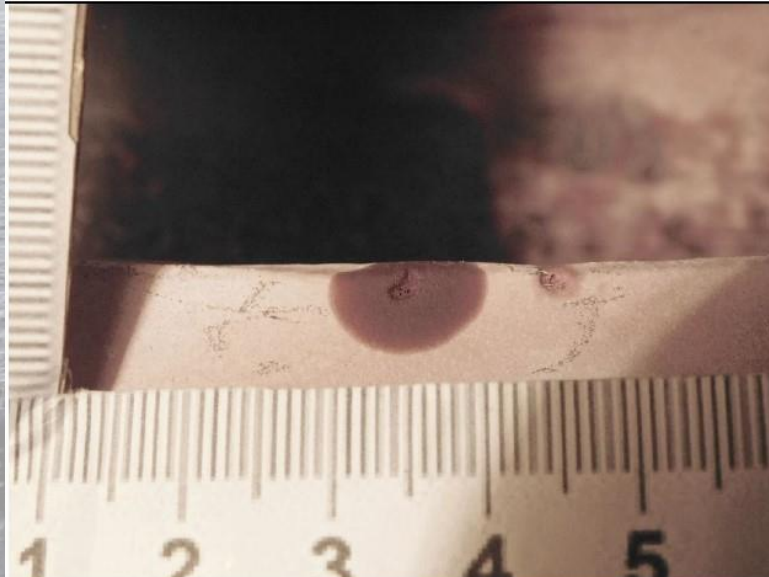
ASxxx-P-3631 Pump casing exterior area, dye penetrant inspection as per ASME V ARTICLE 6 : 2019
Acceptance criteria: ASME B16.34:2013 App. III – 2.2



Indication 1
Rounded Indications
NON Accettable



Indication 2
Rounded Indications
NON Accettable



Indication 3
Rounded Indications
Accettable



Indication 4
Linear Indications
NON ACCEPTABLE

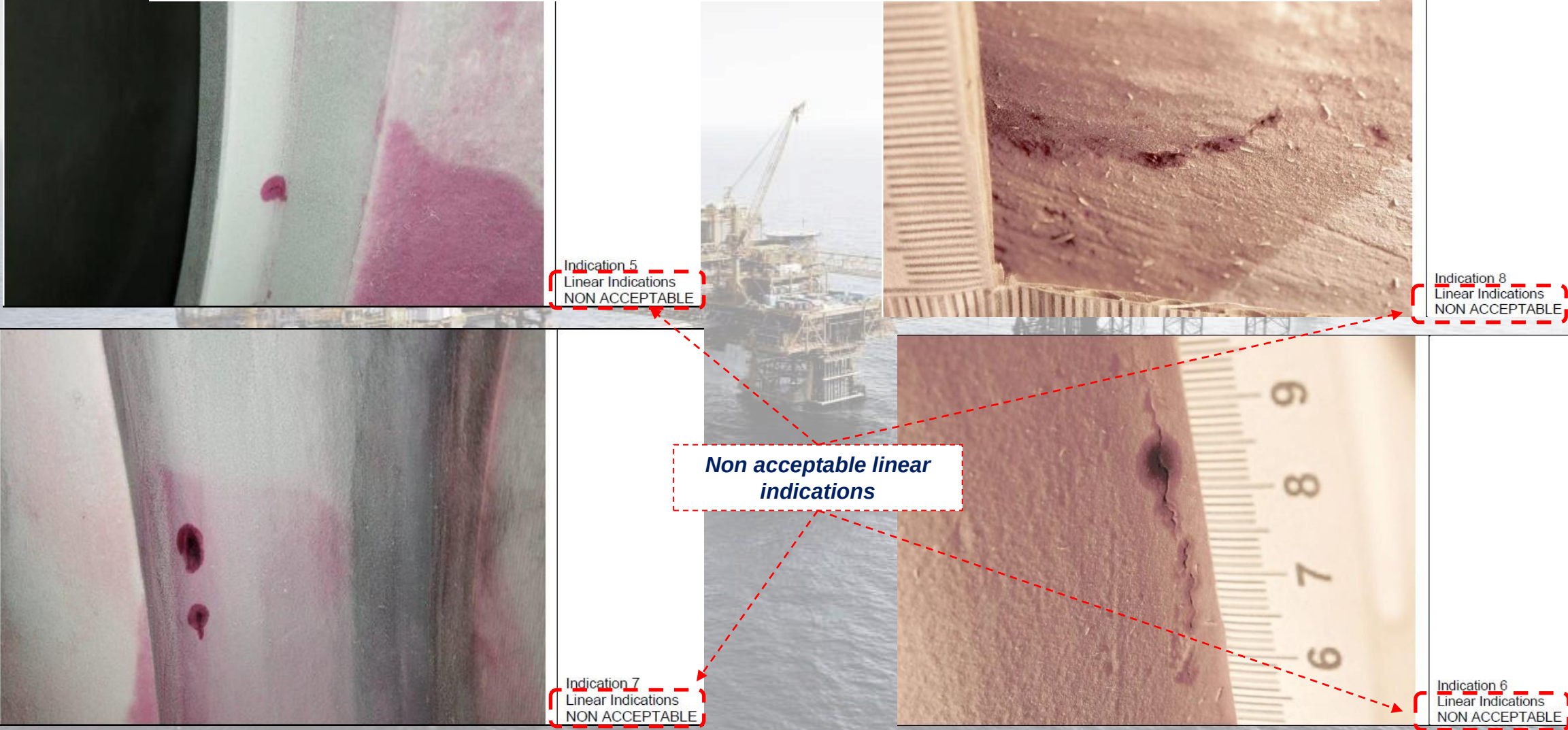
Non acceptable rounded indications

Non acceptable linear indications

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- New crude oil pump casing concerns:

ASxxx-P-3631 Pump casing interior area, dye penetrant inspection as per ASME V ARTICLE 6 : 2019
Acceptance criteria: ASME B16.34:2013 App. III – 2.2



Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- New crude oil pump casing concerns:

ASxxx-P-3631 Pump casing exterior area, magnetic particle inspection as per ASME V ARTICLE 7 : 2019
Acceptance criteria: ASME B16.34:2013 App. II – 2.1



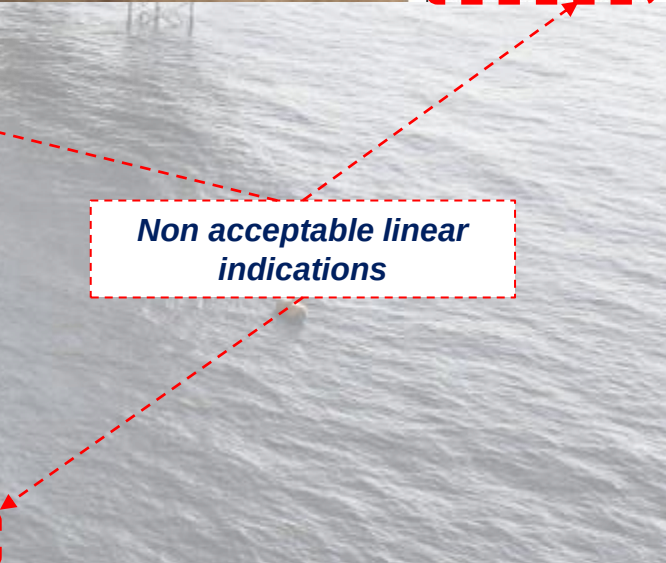
Indication 1
Linear Indications
NON ACCEPTABLE



Indication 3
Linear Indications
NON ACCEPTABLE



Indication 5
Linear Indications
NON ACCEPTABLE



Non acceptable linear indications



Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- New crude oil pump casing concerns:

- For COE pumps casing the standard OEM inspection testing plan (ITP plan), recommends the below the following application of RTs, MTs, LPs:
 - RT: only critical areas;
 - MT: 100% casting;
 - LP: only machined surfaces;
- RTs are mainly used to guarantee reliability of heavily loaded areas, such as nozzles, feet and mail bolts' seat;
- MTs and LPs, instead, are applied to casing and internal wet parts, to found defects during manufacturing and machining;
- Normally the COE pump casing are manufactured by casting process by a sub-supplier to the pump OEM. The casing are them delivered to the pump OEM shop to be machined;
- The pump casing are normally subject to RT, MT and LP inspection as per own pump OEM procedure and acceptance criteria (FPD Procedure) at the pump OEM sub-supplier facility;

Casing ASTM A487-CA6NM/B	6	Material Certificate	R	SUPP	ASTM	ASTM Material Spec.	3.2	H	H	R	R	R	NACE MR0175/ISO15156
	7	Visual Inspection	R	SUPP	ASME V	MSS-SP-55	Int	H	R	-	-	-	
	8	Identification Check	R	FPDD	FPD Standard	FPD Standard	Int	-	H	-	-	-	
	9	Hardness Test	R	SUPP	ASTM A 370	NACE - 23 HRC Max	3.1	-	H	R	R	R	
	10	REV (RT) Radiographic Inspection	R	SUPP	FPD Procedure	FPD Procedure	3.1	H	H	R	R	R	only critical areas
	11	REV (MT) Magnetic Particle Inspection	R	SUPP	FPD Procedure	FPD Procedure	3.1	H	H	R	R	R	100% castings
	12	REV (LP) Liquid Penetrant Inspection	M	FPDD	FPD Procedure	FPD Procedure	3.1	-	H	R	R	R	only machined surfaces

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- COE pumps should have a commissioning suction strainer of determinate mesh size (Mesh 80) with:
 - PDT across strainer: to monitor strainer performances and clogging level. PDT not higher than 500 mbar (or any value suggested by supplier as clogged Δp), connected to the control room DCS;
 - PT downstream the strainer at the pump suction flange: to monitor real pump's suction pressure value. PT with at least 0.5/1 bar as margin on vapor pressure, connected to the control room DCS;

Suction pressure is crucial considering the application (wet crude oil and high vapor pressure). Strainer is crucial as well, because it must protect pump from debris while ensuring the lowest possible pressure drop

- If we have only local suction pressure gages at the pump suction flange or pump suction pressure transmitter far from the pump suction flange (like for example, on the common pump suction header), **we will never have a proper continuous protection for low pump suction pressure (especially on remote operated pumps that don't have 24h/7 day human presence)**;
- We could **not find API pump standards like API 610, API 670, API Recommended Practice 686, etc that makes it mandatory to have installed suction local pressure gage and pressure transmitter at the pump suction flange or mandatory to have any low pump suction alarm/trip**;
 - “API Standard 610, Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries” only states:

7.4 Instrumentation

7.4.1 Gauges

- If furnished, temperature indicators and pressure gauges shall be in accordance with ISO 10438 (all parts).

NOTE For the purpose of this provision, API Std 614 is equivalent to ISO 10438 (all parts).

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- Considering the nature of the fluid and the application (low suction pressure), **it is suggested to vent pump's casing and suction line any time the pump is prepared for start-up**. Fluctuation in suction pressure (considering the suction valve kept always open – as a good practice) could cause gas release and gas pockets formation inside the pump, potentially dangerous for operation;
- Start-up procedures:** When priming and venting is completed, valves must be prepared for start-up: as per IO&M Manual, discharge valve must be crack-open (15÷30 % opening), to ensure adequate control of flowrate and pressure. **It is mandatory to avoid starting the pump with opening grater than 30%**

On the new pump project installation and commissioning documents **there were no clear and details instructions in how to start the pump: no reference to pump casing drain checks, pump casing purging, status of the main discharge valves status during start up, etc;**

The pump project installation and commissioning documents must be reviewed either by the pump OEM or the company mechanical team;

ASFAA-P-3631 EMERGENCY STOP TEST				
<i>Note: During the Emergency Stop Test and Shutdown Test (Steps 13 – 99) Pump ASFAA-P-3631 discharge is closed by HCV-368120/368121. Pump operated in a closed loop discharging back to Inlet Separator V-3401 though the mini-flow line via FCV-363101</i>				
13.	Ensure Blowers ASFAA-B-3631 is ready to start			
14.	Push Local emergency button ASFYY-PB-363100. Attempt to start Pump ASFAA-P-3631 from the local control station, confirm pump cannot be started due to emergency button activated.			
15.	Release the local emergency stop push button ASFYY-PB-363100.			
16.	Confirm FCV-363101 is fully closed and FIC-363101A is set with 100% output before pump ASFAA-P-3631 is started.			
17.	Ensure Crude Export Pump ASFAA-P-3631 ready to start. Start the pump ASFAA-P-3631 from local control station. and confirm local Running light is "ON" on the local control station			
18.	Confirm Blower ASFAA-B-3631 is started automatically			
19.	Locally on site Confirm Pump ASFAA-P-3631 direction of rotation and running status.			
20.	Stop the Pump ASFAA-P-3631 by using Local emergency button ASFYY-PB-363100. Confirm that Pump ASFAA-P-3631 is stopped. Attempt to start Pump ASFAA-P-3631 from the ICSS HMI confirm Pump cannot be started due to emergency button activated. Attempt to start Blower ASFAA-B-3631 from the Local control station confirm Pump cannot be started due to emergency button activated.			

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- As per API 670 - Machinery Protection Systems, **the vibration time delay we can put in a vibration protection and monitoring system is between 1 to 3 seconds;**

7.1.5 A monitor system shall include the following alarm and integrity comparison functions.

a) Fixed time delays for shutdown (danger) relay activation that are field changeable (via controlled access) to require from 1 to 3 seconds sustained violation. A delay of 1 second shall be standard.

b) Alarm (alert) indication for each channel or axial position channel pair.

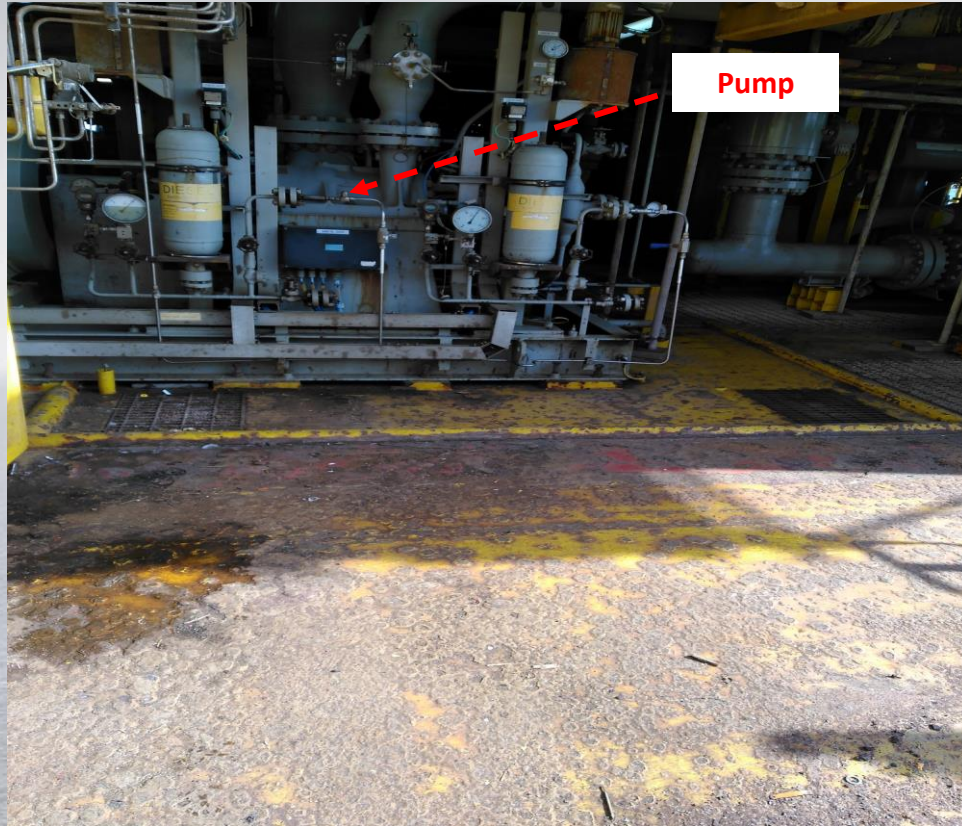
7.1.6 A monitor system shall include an integral, dedicated display capable of indicating the following:

a) all measured variables used in the protection function;

Accessed by account: North Oil | Date: Mon Jun 1 05:25:54 2020 | IP address: 78.100.159.43

- For COE pumps with maximum speeds of 3600 rpm, power ranges of around 300-500 kW and operating on offshore platforms (not high energy pumps like: boiler feed water pumps, water injection pumps), **we recommend to put the maximum allowable trip delay of 3 seconds.** This will prevent un-planned machine trips due to platform movement due to crane operation, boats docking, etc while still providing an effective machine mechanical protection;
- Operating offshore COE pumps with **0 time delay on their vibration protection and monitoring system will can cause operation upsets due to sporadic machine trips that will affect the plant production and reliability;**

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

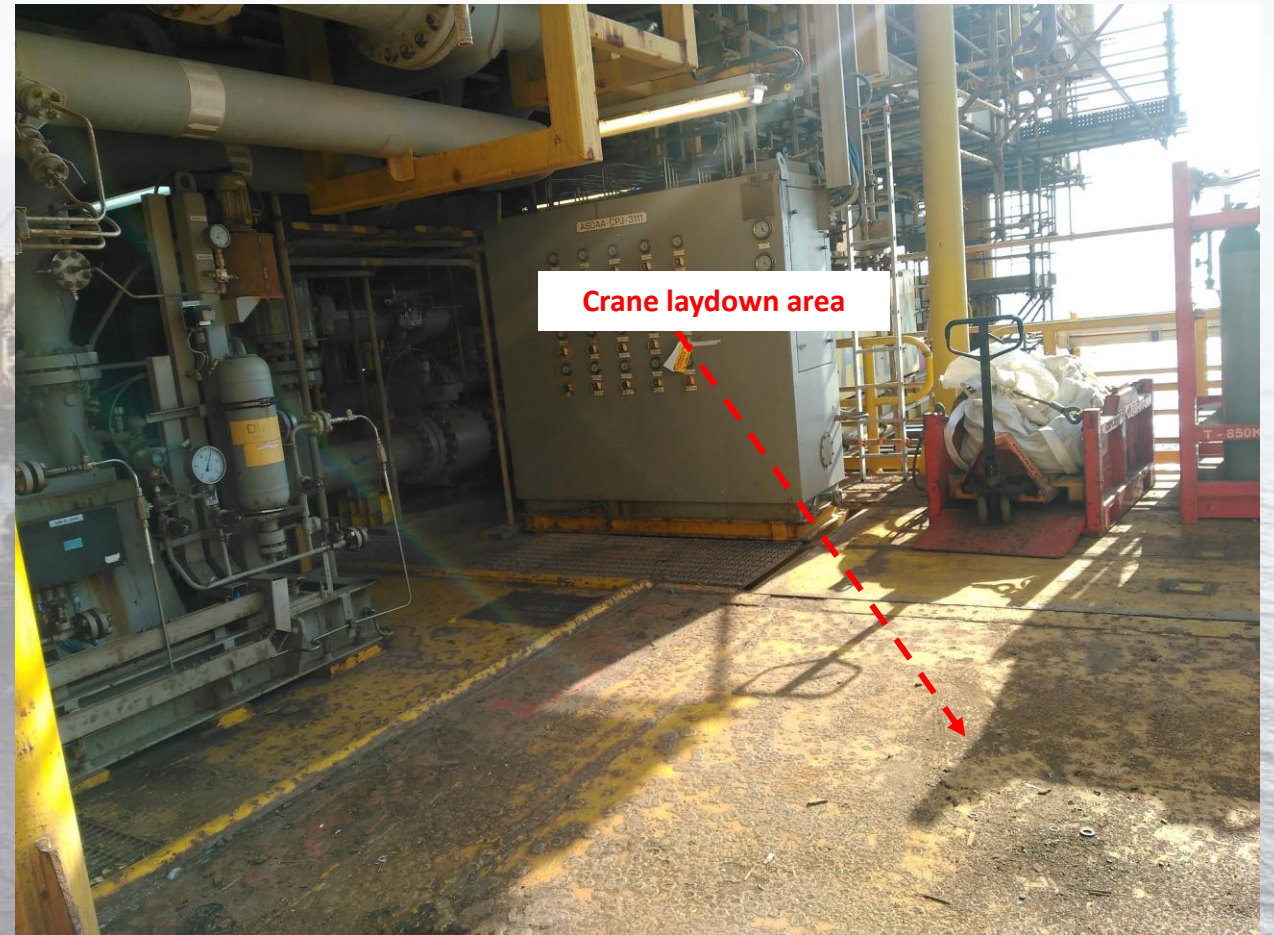


Pump

Cellar deck crane laydown area near a COE pump

- Under normal operations there are not a lot of lifting operation down to on the Cellar deck area **however during offshore campaigns periods, the COE pump was tripping often;**

- The loading/offloading of good at the landing place using the crane near the COE pump was causing COE pump trips;



Crane laydown area

Cellar deck crane laydown area near a COE pump

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

VIBRATION TRANSMITTER & ELEMENT DATA SHEET - INSTRUMENT							REQ./P.O NO.	QPO 131979
							PROJECT	DDAE01
							PLATFORM	DA
							AREA	
	4		CC	AM	AC	15/05/12	TAG NO.	ASDAA-VT-363101 A/B & ASDAA-VT-364101 A/B
	3		CC	AM	AC	21/12/11	MESC. NO.	
	2		CC	AM	AC	28/11/11	MANUFACTURER	METRIX INSTRUMENT CO
LI. NO.	REV.	DESCRIPTION	PREP	CHK	APP	DATE	MODEL NO.	ST5484E-121-232-00
PLANT SPECIFIC DATA								
DESCRIPTION						SPECIFIED		VENDOR DATA
1	AMBIENT TEMPERATURE					0 / 50 °C		0/ 50°C
2	HUMIDITY					100 % R.H.		100% R.H.
3	ENVIRONMENT					EXPOSED, SALIFEROUS		
4	AREA CLASSIFICATION					ZONE1, IIB, T3		ZONE 1, IIB, T3
EQUIPMENT SPECIFIC DATA								
5	SERVICE (Located at)							Pump vibration
6	TYPE							Velocity sensor
7	BEARING TYPE							ROLLING BEARING
8	DESIGN							
9	QUANTITY							2
10								
11	TEMPERATURE							-40 / 100°C
12	ELEMENT TYPE							Piezoelectric
13	SPAN							
14	CALIBRATED RANGE							25 mm/s pk
15	ACCURACY							
16	AXIS ORIENTATION							ANY
17	HEIGHT							130 mm
18	DIAMETER							38 mm
19	FREQUENCY RESONSE							2Hz to 1500Hz
20	ALARM VALUE							5 mm/s
21	TRIP VALUE							7 mm/s
22								
23	MATERIAL							

**Vibration velocity sensor
frequency range 2Hz to
1500 Hz**

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- As per API 670 - Machinery Protection Systems, this COE pumps vibration tags should have the default filtered velocity range of 10 Hz to 1000 Hz. This will make sure that low structural frequencies below 10Hz (like the ones generated by crane operations, boat landing, etc) will not trip the machine;

7.4.4 Casing Vibration Monitoring

7.4.4.1 Requirements in this section apply to monitoring casing vibration utilizing acceleration transducers on machines such as gears, pumps, fans, and motors equipped with rolling element bearings. Unless otherwise specified, machines with fluid film bearings that are designated for monitoring shall be equipped with shaft displacement monitoring in accordance with the system arrangements in Annex H.

NOTE 1 When casing vibration is used for machine protection, velocity measurements are recommended (see Annex E). Acceleration measurements should be used to indicate condition and not for machine protection.

NOTE 2 While unfiltered overall vibration is necessary for test stand acceptance measurements (such as outlined in API 610), it is generally not recommended for machinery protection or continuous monitoring applications. Experience has shown that the default filtered velocity range in 7.4.4.5 b) is generally desirable for eliminating spurious noise sources and potential false alarms.

7.4.4.2 The monitored frequency range of each casing vibration channel shall be fixed with two field-changeable filters, high and low pass, or equivalent. Filters, or equivalent, used to set the frequency range shall have the following characteristics.

- a) Unity gain and no loss in the passband greater than 0.5 dB, referenced to the input signal level.
- b) A minimum roll-off rate of 24 dB per octave at the high and low cutoff frequency (–3 dB).
- c) Filtering shall be accomplished prior to integration.
- d) Unless otherwise specified, casing velocity shall be monitored within a filter passband from 10 Hz to 1000 Hz.

7.4.4.3 The casing vibration circuit fault system shall activate whenever an open circuit or short circuit exists between the monitor system and accelerometer. The circuit fault system shall be latching and shall inhibit the operation of the affected channel until the fault is cleared and the channel reset.

- **7.4.4.4** If specified, a controlled-access setpoint multiplier function shall be provided with the following capabilities:

- So, we can either:
 - Install/define a filter on the vibration monitoring system to provide a filtered velocity range of 10 Hz to 1000 Hz filter (as per API 670);
 - install a new pump vibration transmitter with a filtered velocity range of 10 Hz to 1000 Hz (as per API 670);

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- Considering the most offshore COE pumps run at around 2970 rpm (around 50 Hz) and that normally the important mechanical related vibration issues generated low frequencies of $1/2 \times$ running speed and some time $1/3 \times$ running speed, **if the standard 10Hz low pass filter doesn't work, the maximum low pass filter we can put will be around 12.5 to 15 Hz;**

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API STANDARD 670

7.4.4.5 Unless otherwise specified, casing vibration on gears, pumps, fans, and motors equipped with rolling element bearings shall be monitored as follows.

- a) Gear casing vibration shall be monitored in acceleration and velocity modes from a single accelerometer.
 - i) Acceleration shall be monitored in a frequency range between 1000 Hz and 10 kHz from 0 to 500 m/s² true peak (0 to 50 g true peak).
 - ii) Velocity shall be monitored in a frequency range between 10 Hz and 1000 Hz; amplitude from 0 to 25 mm/s rms (0 to 1 ips rms).
- b) Pumps, fans, and motors with rolling element bearings (see Notes following 7.4.4.1).
 - i) Velocity shall be monitored in a frequency range from 10 Hz to 1000 Hz; amplitude from 0 to 25 mm/s rms (0 to 1 ips rms).
 - ii) If specified, acceleration shall be monitored from the same transducer in a frequency range from 10 Hz to 5 kHz; amplitude from 0 to 100 m/s² true peak (0 to 10 g true peak). Root mean square (rms) values factored from any other intermediate value or calculated measurement other than the transducer or signal interface are not acceptable.
 - iii) Equipment operating at shaft speeds from 750 rpm down to 300 rpm should be monitored in a frequency range from 5 Hz to 1000 Hz.

NOTE If the gear mesh frequency is greater than 5 kHz, then an extended frequency range accelerometer may be required.

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- As per API 670 - Machinery Protection Systems **doesn't** forces any specific radial casing accelerometer location/direction on the equipment's bearing housing like: all in vertical direction, all in the horizontal directions, etc.

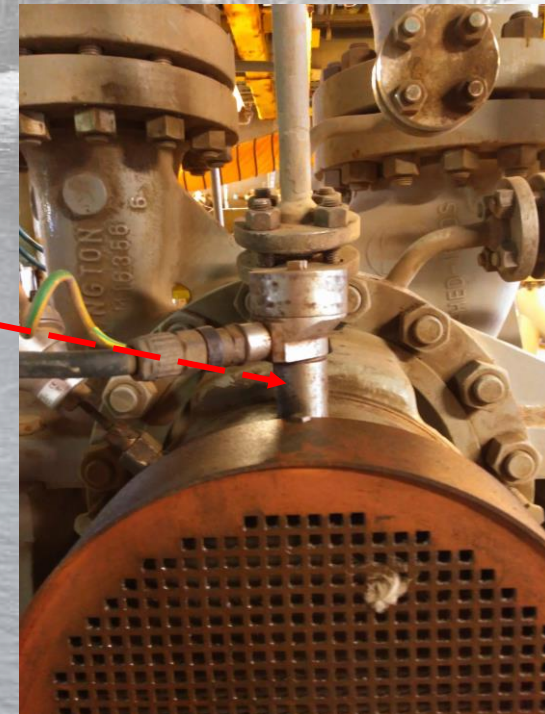
6.1.8 Accelerometers and Velocity Sensors

6.1.8.1 Accelerometers intended to monitor radial casing vibration shall be located on the radial bearing housing. Location and number of accelerometers shall be jointly developed by the machinery vendor and the owner. In some applications, field determination of the optimum mounting location may be required.

6.1.8.2 Accelerometers intended to monitor axial casing vibration shall be oriented axially located on or as near as possible to the thrust bearing housing.

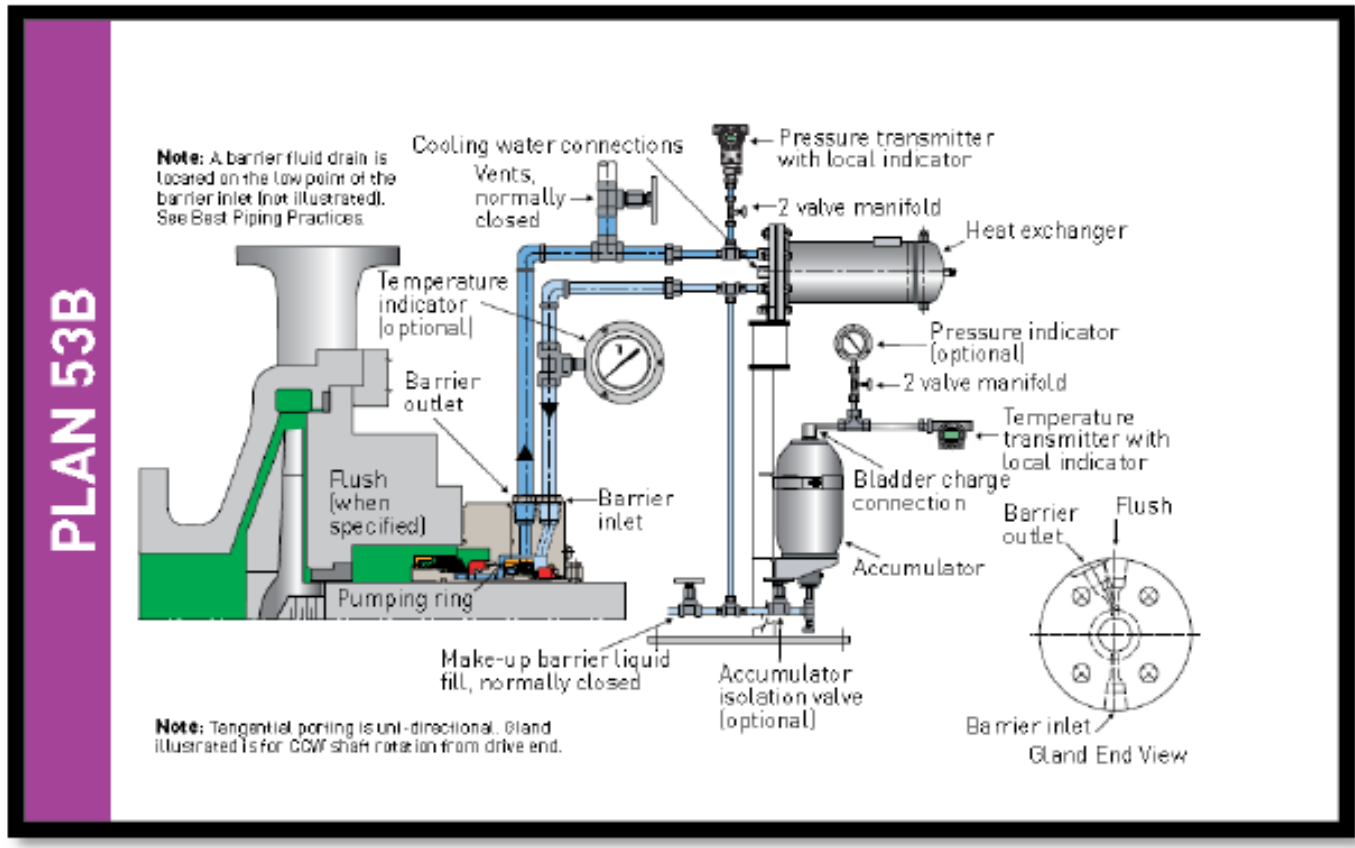


Normally the vibration probes on the COE pumps are installed vertically



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➤ COE pumps mechanical seal plan

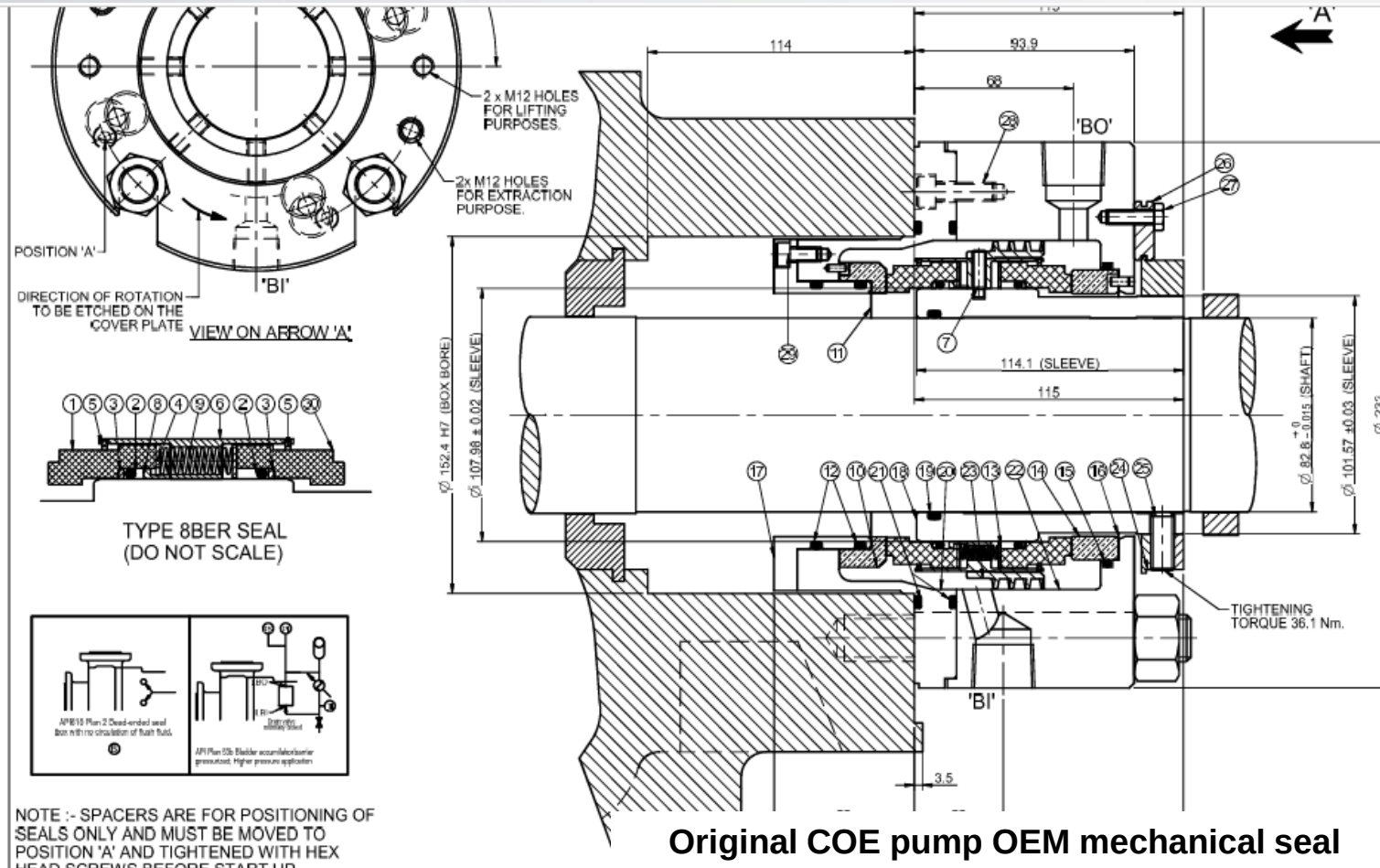


- For COE pumps, mechanical seals with **API auxiliary seal plan using the pumped liquid as cooling / lubrication to mechanical seal are not recommended;**
- COE Pumps to be **supply with double mechanical seals API plan 53 B with liquid barrier and on-line top-up/filing system** (manual, pneumatic or hydraulic);
- We prefer the seal barrier fluid to be a **commercially available seal circulation oil, with low viscosity (normal ISO VG 10) and with good heat transfer properties** to diesel fuel due better lubrication properties and less probabilities for solid contaminates, liquid contaminate like water, etc to be present;

- For API53B mechanical seal plan, a low pressure on the barrier fluid should be a PL (alarm) not PLL (trip);

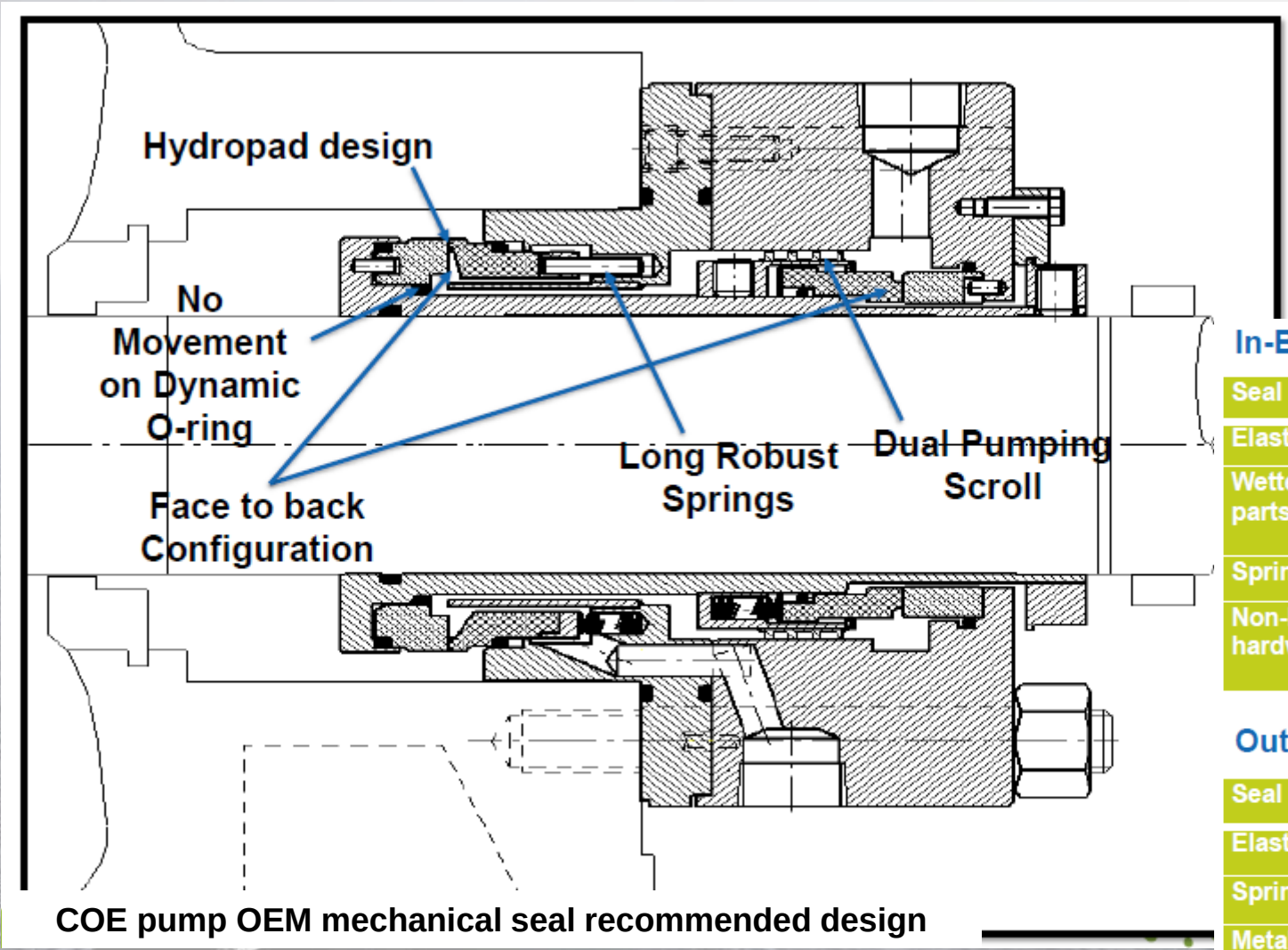
Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

➤ COE pumps API 53 plan B mechanical seal design



- Original pump OEM double mechanical seal, plan API 53B (MTBF: 1 - 2 years):
 - Frequent top-up – More than 5 times within a month;
 - O-Ring Hung up;
 - Sleeve erosion under the dynamic o-ring sealing area;

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- COE pumps API 53 plan B mechanical seal recommend design (*MTBF: 2 – 4 years*)



In-Board Seal

Seal Faces	Graphite-Loaded Silicon Carbide vs Silicon Carbide
Elastomers	Perfluoroelastomer
Wetted metal parts	Super Duplex Stainless Steel
Springs	Inconel X750
Non-Metal hardware	316 SS

Out-Board Seal

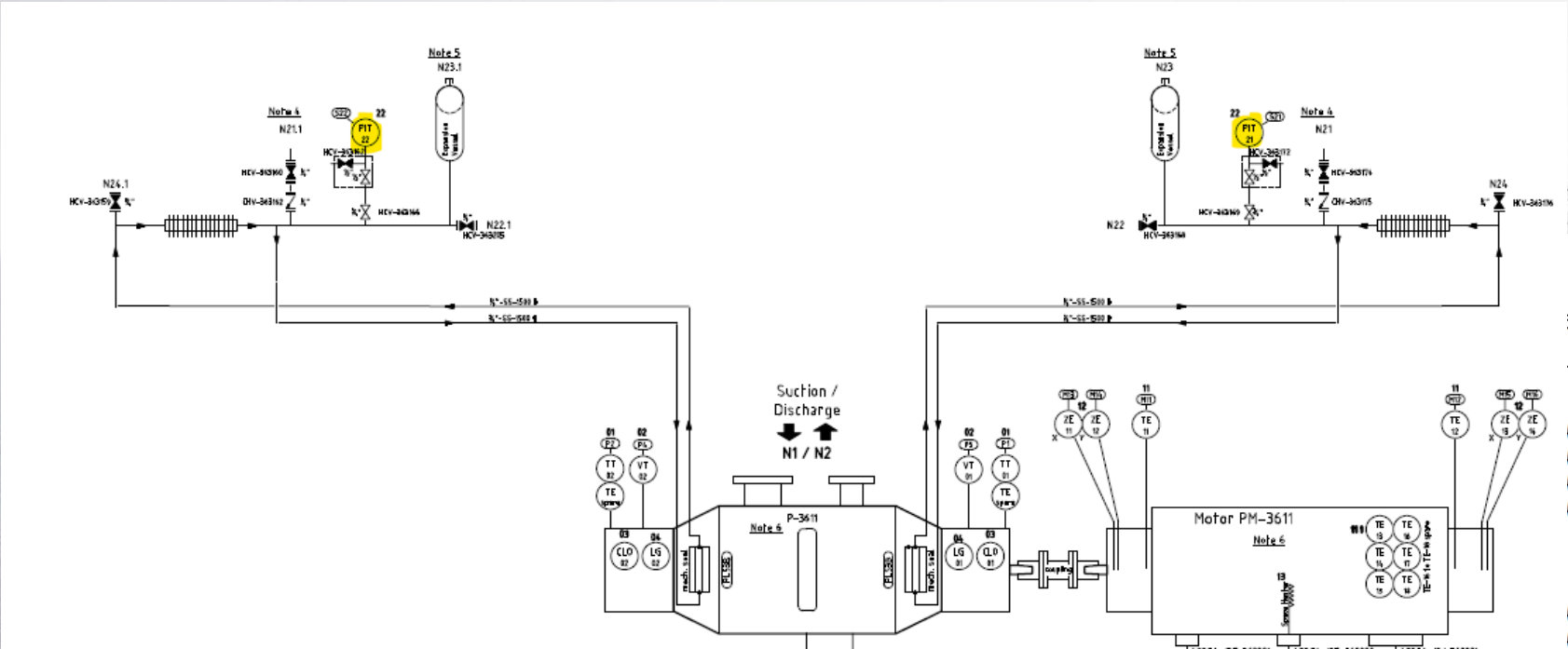
Seal Faces	Carbon vs Silicon Carbide
Elastomers	Perfluoroelastomer
Springs	Inconel X750
Metal hardware	316SS

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- COE pumps API 53 plan B recommend mechanical seal design specifications:
 - **Process fluid at OD of seal faces** -centrifugal forces keep solids away from the inner faces and dynamic components.
 - Stationary multiple spring configuration with springs located in barrier fluid –prevents spring clogging, less sensitive to shaft deflection.
 - **Double balanced inner seal – ability to tolerate reverse pressure condition that may occur due to process upsets or loss of barrier fluid pressure providing greater seal integrity. Without this feature, failure of the outer seal will create reverse pressure of inner seal, opening of seal faces and product leakage to the environment.**
 - **Bidirectional pumping ring – single seal for both DE & NDE, reduces inventory requirements.**
 - Dynamic o-ring and sliding surfaces to move to clean area as the faces wear –to prevent ‘hang-up’.
 - To achieve these features a dual cartridge seal with face to back layout and stationary flexible element is required.
 - **As per API 682 7.3.1.1 , Having -Note 1: “Liquid-barrier seal designs arranged such that the process fluid is on the OD of the seal faces help to minimize solids accumulation on the faces and minimize hang-up”**
 - As per API 682 7.3.1.2, “The inner seal shall have an internal (reverse) balance feature designed and constructed to withstand reverse pressure differentials without opening”.
 - **As per API 682 7.3.4.2.1: “Unless otherwise specified, the configuration shall have the inner and outer seals arranged in series (3CW-FB)”, having mechanical seals in Face to Back configuration;**

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

➤ COE pumps trip due to API Plan 53 B low barrier fluid pressure



New 2022 COE pump project seal system P&I

10	11.1	TE	- 16	TE-362111F	Temp. Element	Motor winding U spare	Pt100, 3-wire	0	120	°C	-	-	90	100	°C	
11	11.1	TE	- 17	TE-362111G	Temp. Element	Motor winding V spare	Pt100, 3-wire	0	120	°C	-	-	90	100	°C	
12	11.1	TE	- 18	TE-362111H	Temp. Element	Motor winding W spare	Pt100, 3-wire	0	25.4	mm/s	-	-	7	11	mm/s	
13	12.1	ZT	- 11	XT-362112A	Vibration Transmitter	Motor bearing DE	4 - 20 mA	0	25.4	mm/s	-	-	7	11	mm/s	
14	12.1	ZT	- 12	XT-362112B	Vibration Transmitter	Motor bearing DE	4 - 20 mA									
15	12.1	ZT	- 13	XT-362113A	Vibration Transmitter	Motor bearing NDE	4 - 20 mA									
16	12.1	ZT	- 14	XT-362113B	Vibration Transmitter	Motor bearing NDE	4 - 20 mA									
seal plan:																
17	22	PT	- 21	PT-362110A	Pressure Transmitter	Plan 53B DE	4 - 20 mA, LCD	0	33	barg	18	19	30	-	barg	
18	22	PT	- 22	PT-362110B	Pressure Transmitter	Plan 53B NDE	4 - 20 mA, LCD	0	33	barg	18	19	30	-	barg	



New 2022 COE pump project instrumentation set-points

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- It doesn't make sense to have a PLL (low value trip) on barrier fluid pressure, because as you can see on the below API 682 - Shaft sealing systems for centrifugal and rotary pumps, section 7.3.1.2 the pump can run for certain period with **loss of barrier fluid**. A low seal barrier fluid pressure doesn't mean the seal is running dry, it is still being lubricated/cooled by either the seal barrier fluid or by the crude oil;
- We should only have PL (low value alarm) on the barrier fluid pressure. Neither API 610, API 682 or API 670 call for a PLL (low trip) on the barrier fluid pressure, they just call for a low-pressure alarm (PL);

7.3.1 General

- 7.3.1.1 The barrier fluid shall be a liquid or gas, as specified.

NOTE 1 Barrier fluid pressure is usually regulated between a gauge pressure of 0.14 MPa (1.4 bar) (20 psi) and 0.41 MPa (4.1 bar) (60 psi) over the pressure in the seal chamber.

NOTE 2 Gas-barrier seal designs might not be appropriate for services in which dissolved or suspended solids in the pumped fluid tend to adhere to the seal faces or cause hang-up. This is especially true if the process fluid is on the ID of the inner gas-lubricated seal. Liquid-barrier seal designs arranged such that the process fluid is on the OD of the seal faces help to minimize solids accumulation on the faces and minimize hang-up.

NOTE 3 While stationary, capillary action of sticky or polymerizing fluids between gas-barrier-lubricated faces can cause torque failure upon start-up, even if the gas-barrier pressure is maintained while the pump is idle.

7.3.1.2 Unless otherwise specified:

The inner seal shall have an internal (reverse) balance feature designed and constructed to withstand reverse pressure differentials without opening. Refer to 6.1.1.11 and Figure 10.

- In static operation, the seal shall be able to contain the rated process pressure in the event that barrier fluid pressure is lost.
- In static operation, the seal shall be able to contain the rated barrier pressure in the event that process pressure is atmospheric. (This is a seal qualification test point.)
- In dynamic operation, the seal shall be capable of operation for a time period agreed between the purchaser and the vendor to allow orderly pump shutdown upon loss of gas or liquid barrier fluid pressure.
- In continuous dynamic operation, the purchaser shall inform the seal vendor if the seal shall be required to operate continuously under abnormal conditions such as at rated barrier pressure with atmospheric pressure in the pump (gas or liquid barrier) or at rated process pressure if barrier pressure is lost for gas barrier seals. The purchaser shall advise the vendor of these abnormal conditions.

Previous Next

PUMPS—SHAFT SEALING SYSTEMS FOR CENTRIFUGAL AND ROTARY PUMPS

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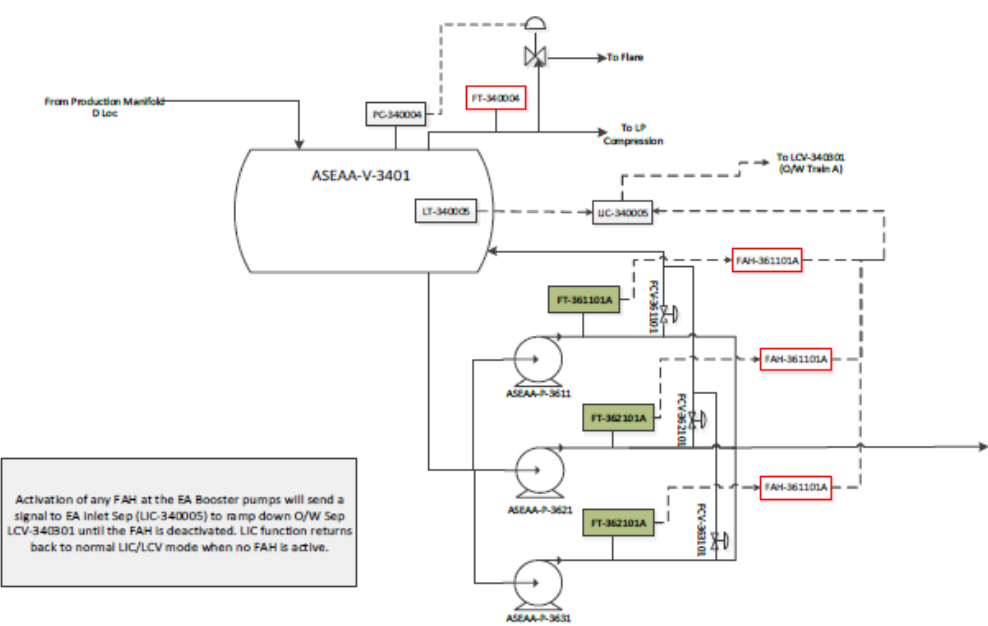
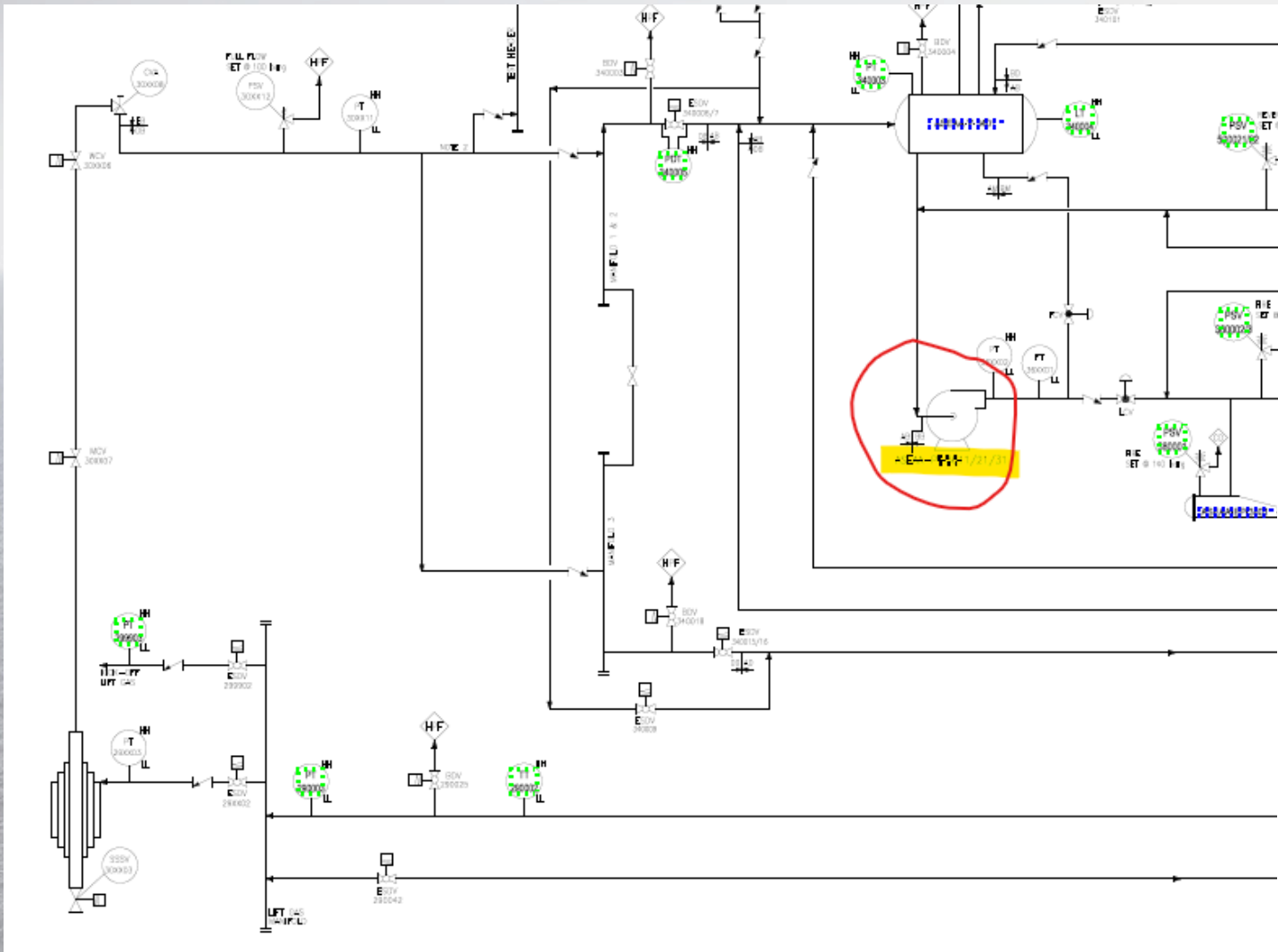
NOTE Arrangement 2 seals equipped with a buffer fluid reservoir normally utilize a high-pressure alarm to indicate if the primary seal has failed. Arrangement 3 seals equipped with a barrier fluid reservoir normally utilize a low-pressure alarm to indicate a drop or loss of barrier fluid pressure.

- 8.3.6.2.4 Unless otherwise specified, the reservoir shall be equipped with a level transmitter and low-level alarm (LLA). When specified, a high-level alarm (HLA) shall be provided.

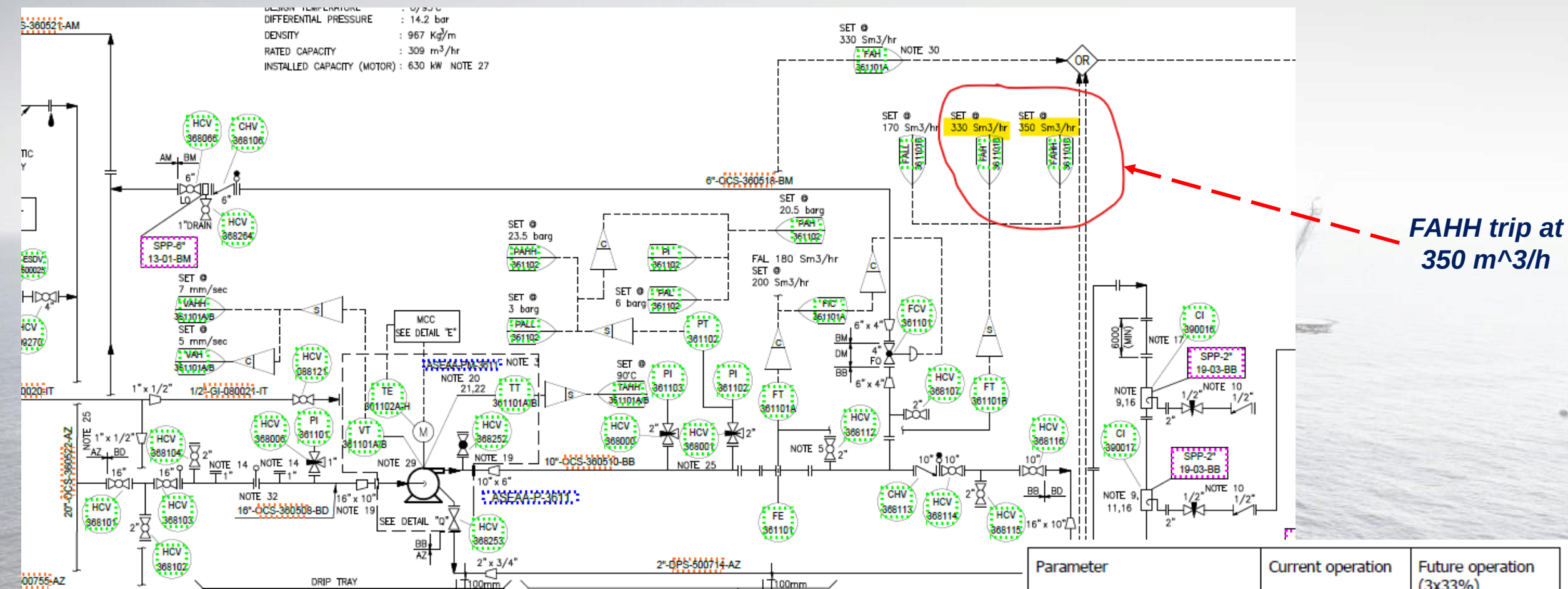
- Pump OEM response to PLL removed for pumps trip due to API Plan 53 B low barrier fluid pressure:
 - “We recommend original alarm and trip set-points”;
 - “For safe operation certain parameters shall not be violated. But of course it is in end-user possibility AND responsibility to decide if trips will not be performed. In case of critical process, it is common practice to avoid any trips as the commercial impact of this trips is higher than any broken mechanical seal. But it has to be pointed out, that all warranty aspects lose their relevance in this case;”

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- 3 x Fixed speed COE pumps with FAHH (High flow) alarm



Reliability improvements for new offshore pump projects - Crude Oil Pumps



- As part of a production increase, it was expected that the current 3 x COE pumps flow of around 309 m³/h per pump to be increase to around 3 x 340 m³/h per pump;
- So, the 3 x COE pumps FAHH at 350 m³/h that was never an issue now become one on the new operation regime;

Parameter	Current operation	Future operation (3x33%)
Rated flow per pump (Sm ³ /h)	309	344
NPSHa (m)	6.64	6.54
NPSHr (m)	4.74	5.42
Absorbed Power	158	159

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- The reasons for the installation of the FAHH at the discharge of the COE pumps are un-known. It is suspected that FAHHs were installed to protect the pump from cavitation at high flows;

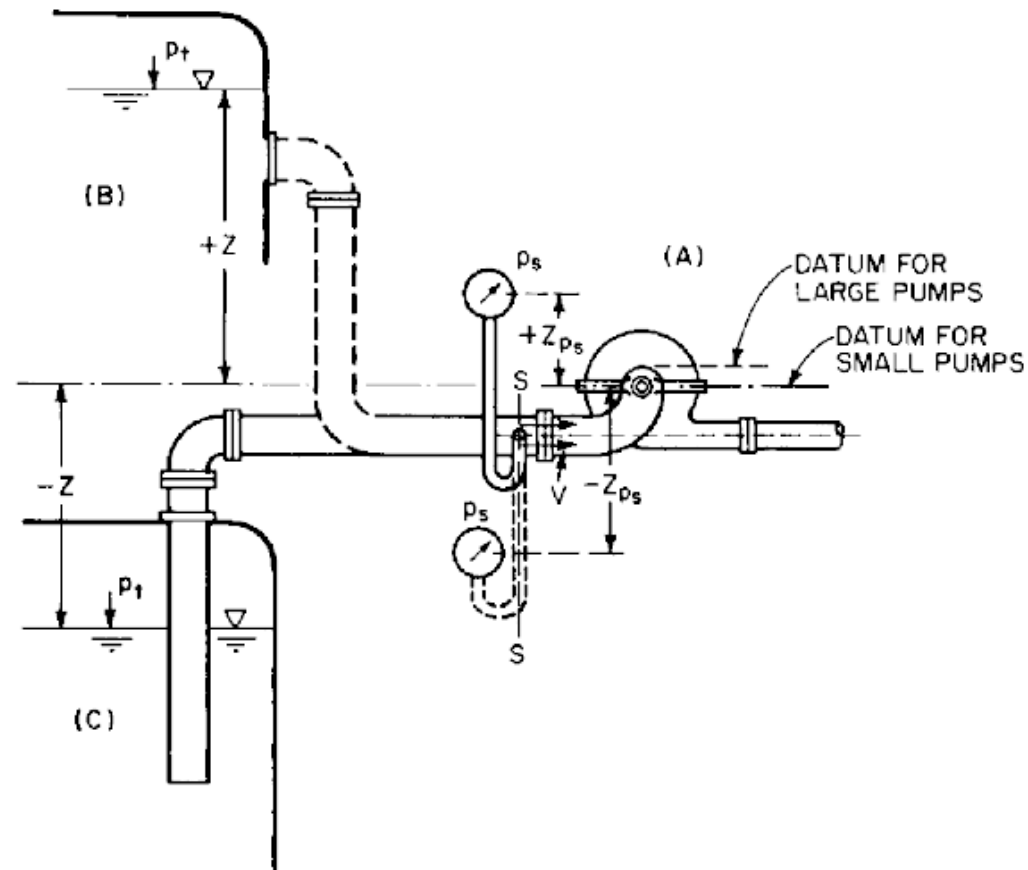


FIGURE 22 Definition sketch for computing NPSH

NPSH available formula

$$h_{sv} = \frac{p_a - p_{vp}}{\gamma} + \frac{p_s}{\gamma} + Z_{ps} + \frac{V^2}{2g}$$

$$h_{sv} = \frac{p_t - p_{vp}}{\gamma} + Z - h_f$$

p_a = absolute pressure in atmosphere surrounding gage, Figure 22

p_s = gage pressure indicated by gage or manometer connected to pump suction at section s-s; may be positive or negative

p_t = absolute pressure on free surface of liquid in closed tank connected to pump suction

p_{vp} = vapor pressure of liquid being pumped corresponding to the temperature at section s-s (if liquid is a mixture of hydrocarbons, p_{vp} must be measured by the *bubble point* method)

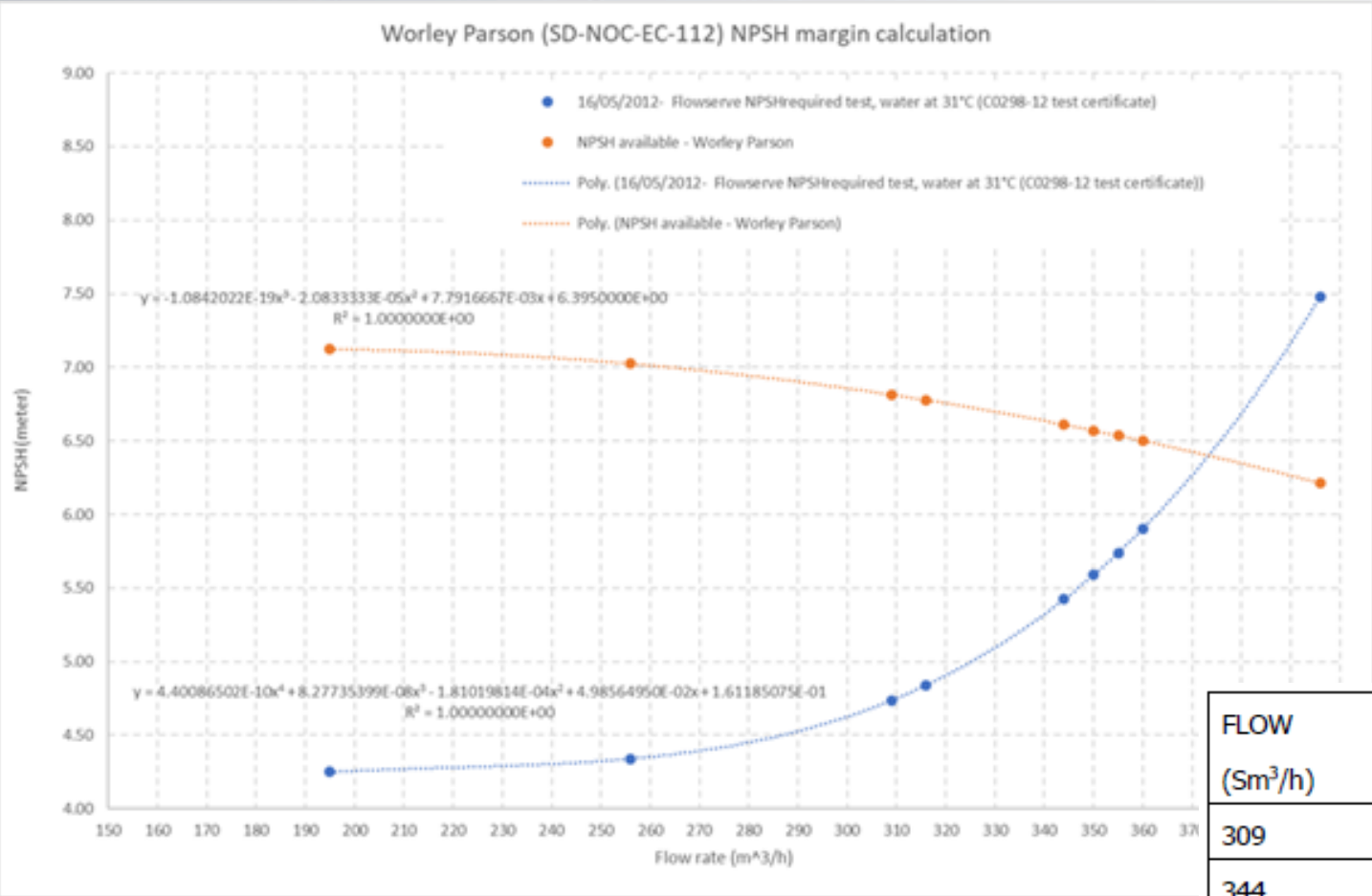
h_f = lost head due to friction in suction line between tank and section s-s

V = average velocity at section s-s

Z, Z_{ps} = vertical distances defined by Figure 22; may be positive or negative

γ = specific weight of liquid at pumping temperature

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*



- NSPH calculation shows that the NPSH margin is zero at 375 m³/h. **Therefore, pump cavitation may be expected at flows higher than 375 m³/h;**
- **NPSH available will be above the NPSH required by the pump for the expected 344 m³/h flow rates and new proposed set point for the FAH 360 m³/h;**



- Furthermore, pump allowable flow range is 200 to 391 Sm³/h as stated on the vendor datasheet. **Therefore, future operating conditions at 344 m³/h would be within the pump allowable flow range;**

FLOW (Sm ³ /h)	NPSHr (m)	NSPHa (m)	NPSH margin (m)	Comment
309	4.74	6.64	1.90	Current rated flow
344	5.42	6.54	1.12	Future max operating flow
350	5.59	6.52	0.93	Current high flow trip set point
360	5.90	6.49	0.59	Proposed alarm set point (FAH)
375	6.40	6.40	0	Zero margin point

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- The API 610 “Centrifugal pumps” and the offshore Oil & Gas operating company internal standards stated that:
 - The difference between the required NPSH (NPSHR) and the available NPSH (NPSHA) at rated point **shall be greater than 20% of the available NPSH (NPSHA)**;
 - The difference between the NPSHA at pump inlet and NPSHR **shall not be less than 0.5 m throughout the allowable operating region of flow**;
- So, as per API 610 the COE pump should be able to operate through its entire pump allowable flow range is 200 - 391 m³/h with enough NPSH margin so it will never cavitate;
- The NPSH available calculations show that at 350 m³/h the NPSH margin is 0.98 meter and at 360 m³/h is 0.60 meter;

Flow (m ³ /h)	NPSH required as per 16/05/2012 Flowserve NPSH required test, water at 31°C (C0298- 12 test certificate)	NPSH available as per Worley Parson (SD-NOC-EC-112 (m))	NPSH margin (m)	NPSH margin (%)	SD-NOC-MEC- 271 NPSH margin limit (m)
0					
195	4.25	7.12	2.87	67.58	0.50
256	4.34	7.02	2.68	61.85	0.50
309	4.74	6.81	2.08	43.83	0.50
316	4.84	6.78	1.94	40.02	0.50
344	5.42	6.61	1.19	21.89	0.50
350	5.59	6.57	0.98	17.55	0.50
355	5.74	6.54	0.80	13.86	0.50
360	5.90	6.50	0.60	10.11	0.50
396	7.48	6.21	-1.27	-16.93	0.50

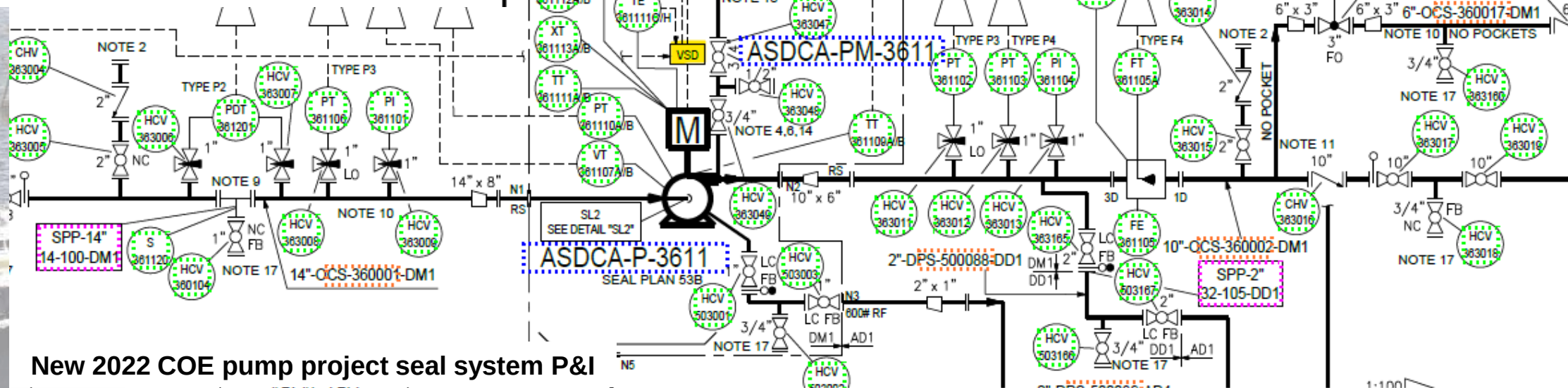
Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- Any possible cavitation issues due to operating at high flows will take time to cause damage and will not cause any immediate failure of the pump. **A FAH (High flow) alarm is enough for operation to recognize this situation and reduce the flow of the pump to avoid any possible cavitation issues;**
- Action plan to remove the FAHH (High flow) alarm:
 - Phase 1:
 - Increase the set point of the FAH high flow alarm from 330 m³/h to 360 m³/h;
 - Increase the FAHH high flow trip from 350 m³/h to 375 m³/h;
 - **Pumps vibration to be monitored for 4 weeks immediately after the implementation of the new operating mode as per above points, using “33rd Pump Symposia, Pump Cavitation Severity Evaluation Using Accelerometers and Dynamic Pressure Transducers” recommended procedures;**
 - Phase 2 to be executed after successful completion of Phase 1 above:
 - **Remove the FAHH high flow trip at 375 m³/h while keeping the FAH high flow alarm at 360 m³/h;**
 - **Keep 1 x spare COE pump at warehouse and 1 x complete spare rotor (shaft + impellers);**

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

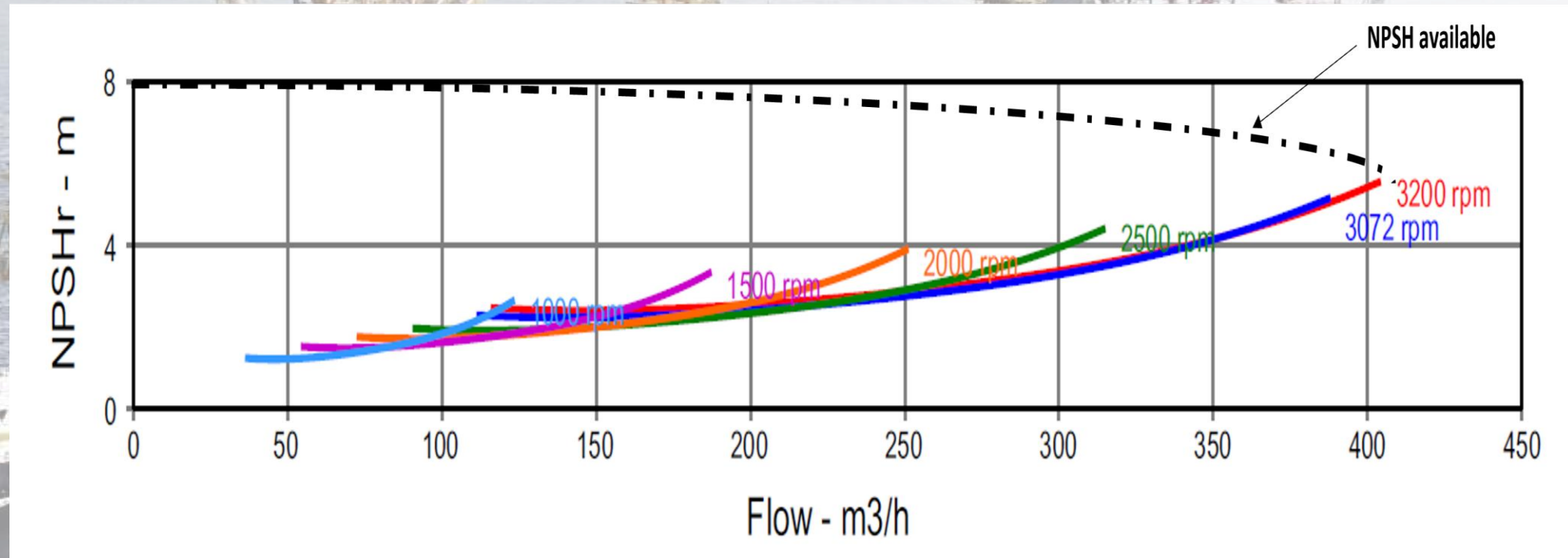
- **Variable speed COE pumps with FAHH (High flow) trip**

14. CRUDE EXPORT PUMPS CONFIGURATION IS 3 x 50%. (INITIALLY 2 PUMPS SHALL BE INSTALLED AND THE THIRD PUMP SHALL BE INSTALLED IN FUTURE.)
15. LC SHALL BE CHANGED TO LO AND SPECTACLE BLIND TO BE SWITCHED WHEN 3rd PUMP IS INSTALLED.
17. BLEEDED LIQUID IS ROUTED BY A HOSE TO THE CLOSEST HAZARDOUS OPEN DRAIN SYSTEM.
18. ~~VENT TO A SAFE LOCATION BY A HOSE.~~
19. TO ENSURE SUFFICIENT MARGIN BETWEEN NPSHa AND NPSHr AT EACH SPEED, PUMP SHALL BE TRIPPED WHEN THE FLOW REACHES THE RESPECTIVE MAXIMUM FLOW. MAXIMUM FLOW IS CALCULATED IN SCADA BASED ON THE FOLLOWING EQUATION :
- $$F(X) = 6.9354E-15x^5 - 8.6769E-11x^4 + 3.9478E-07x^3 - 8.3227E-04x^2 + 9.4719E-01x - 3.0699E+02$$
- WHERE:
- $F(X)$ = FLOWRATE (m3/hr)
 x = SPEED (rpm), x = [1000:3200]
20. BLIND FLANGE IS PROVIDED. WHEN 3rd PUMP IS INSTALLED, SPADE IS REPLACED BY SPACER.
21. SEAL PLAN AND OTHER PUMP DETAILS SHALL REFER TO VENDOR P&ID,
WHP01-PMC1-ASDCA-10-R02019-0001.
22. DELETED.



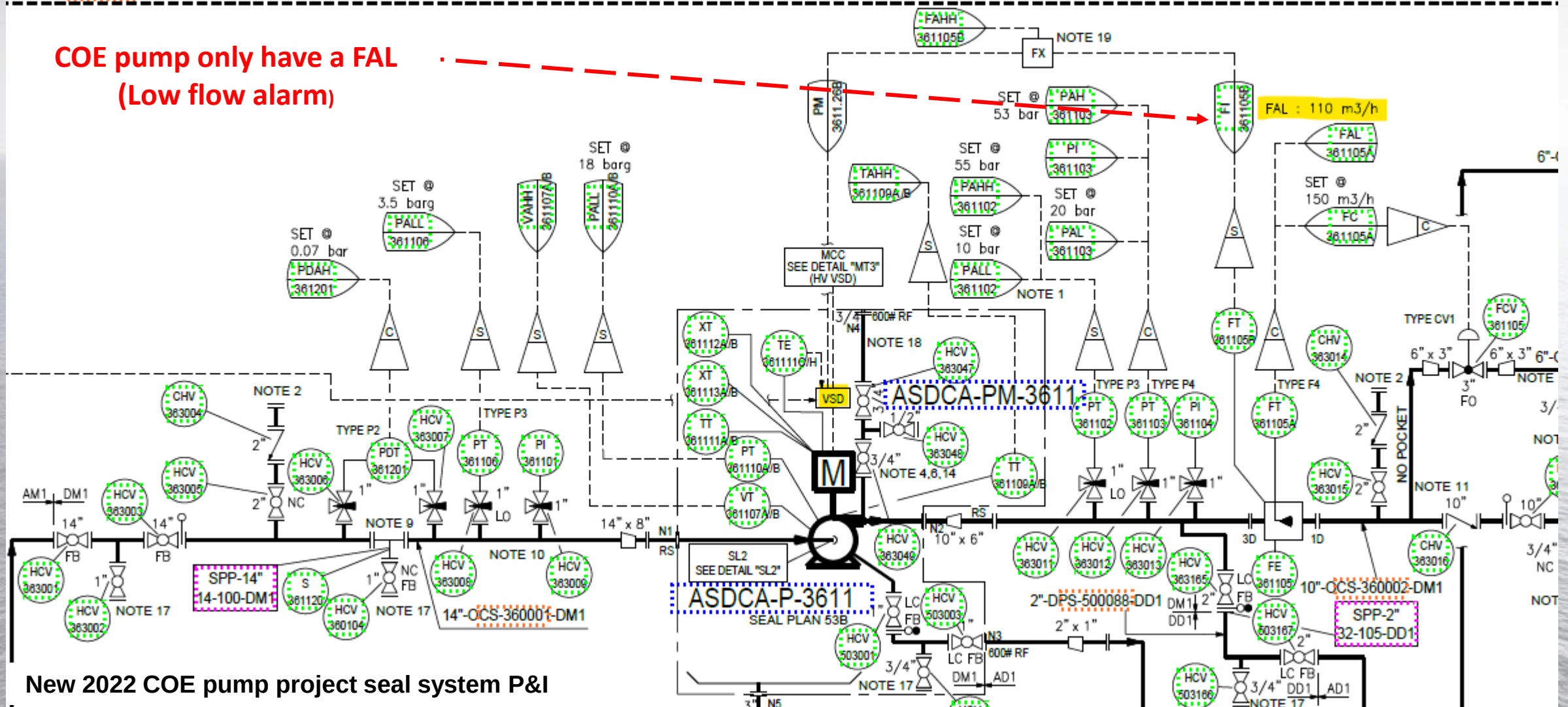
Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- The COE pump FAHH (High flow) trip should be removed and change to FAH (alarm only) at fix flow of 380 m³/hr (lowest NPSH margin is at 3200 rpm), because:
 - as per below NPSH available calculation, the NPSH margin (NPSH required – NPSH available) will only be 0 meter around 400 m³/h for 3200 rpm;
 - any possible cavitation issues due to operating at high flows (for each pump speed) will take time to cause damage and will not cause any immediate failure of the pump. A FAH (High flow) alarm is enough for operation to recognize this situation and reduce the flow of the pump to avoid any possible cavitation issues;



➤ **Variable speed COE pumps with only FAL alarm**

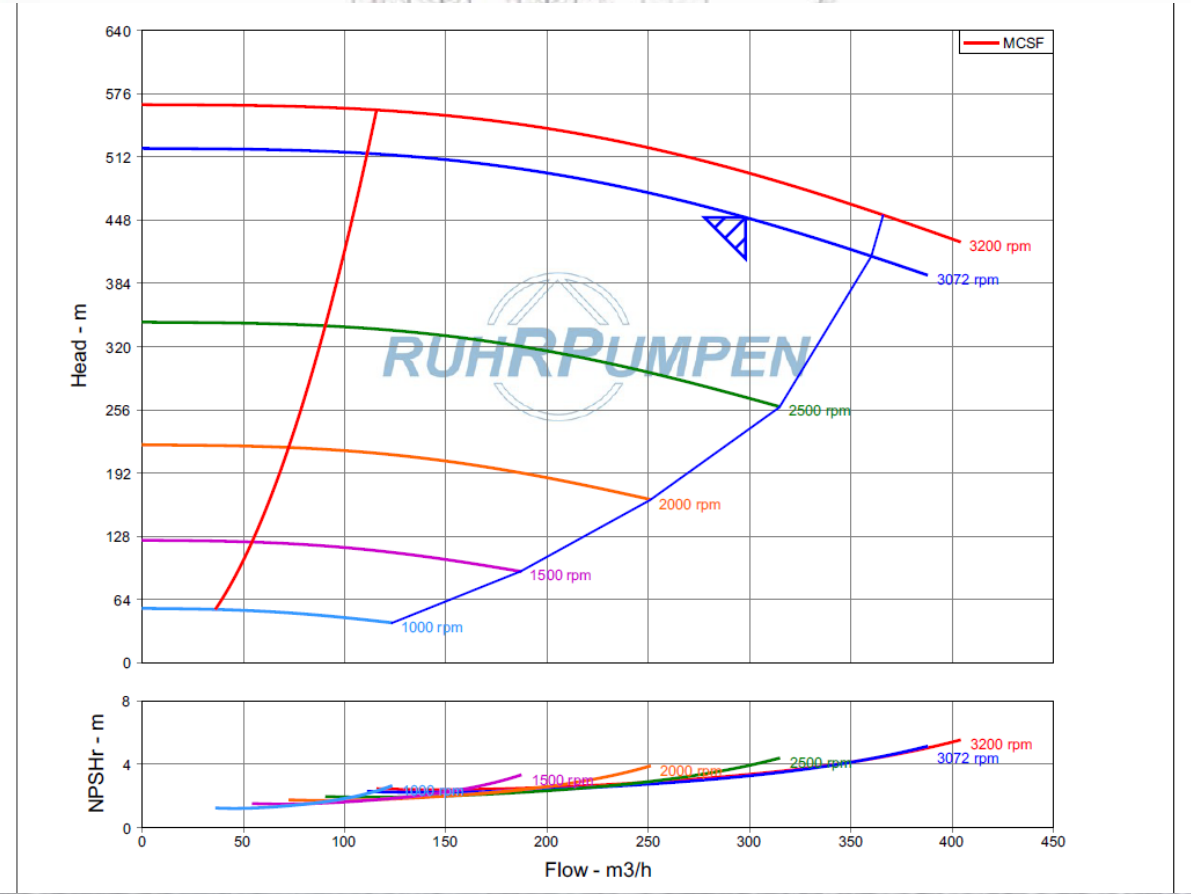
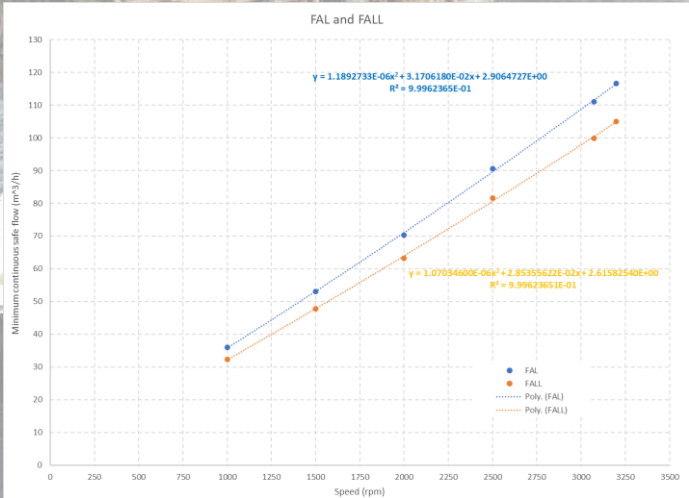
**COE pump only have a FAL
(Low flow alarm)**



Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

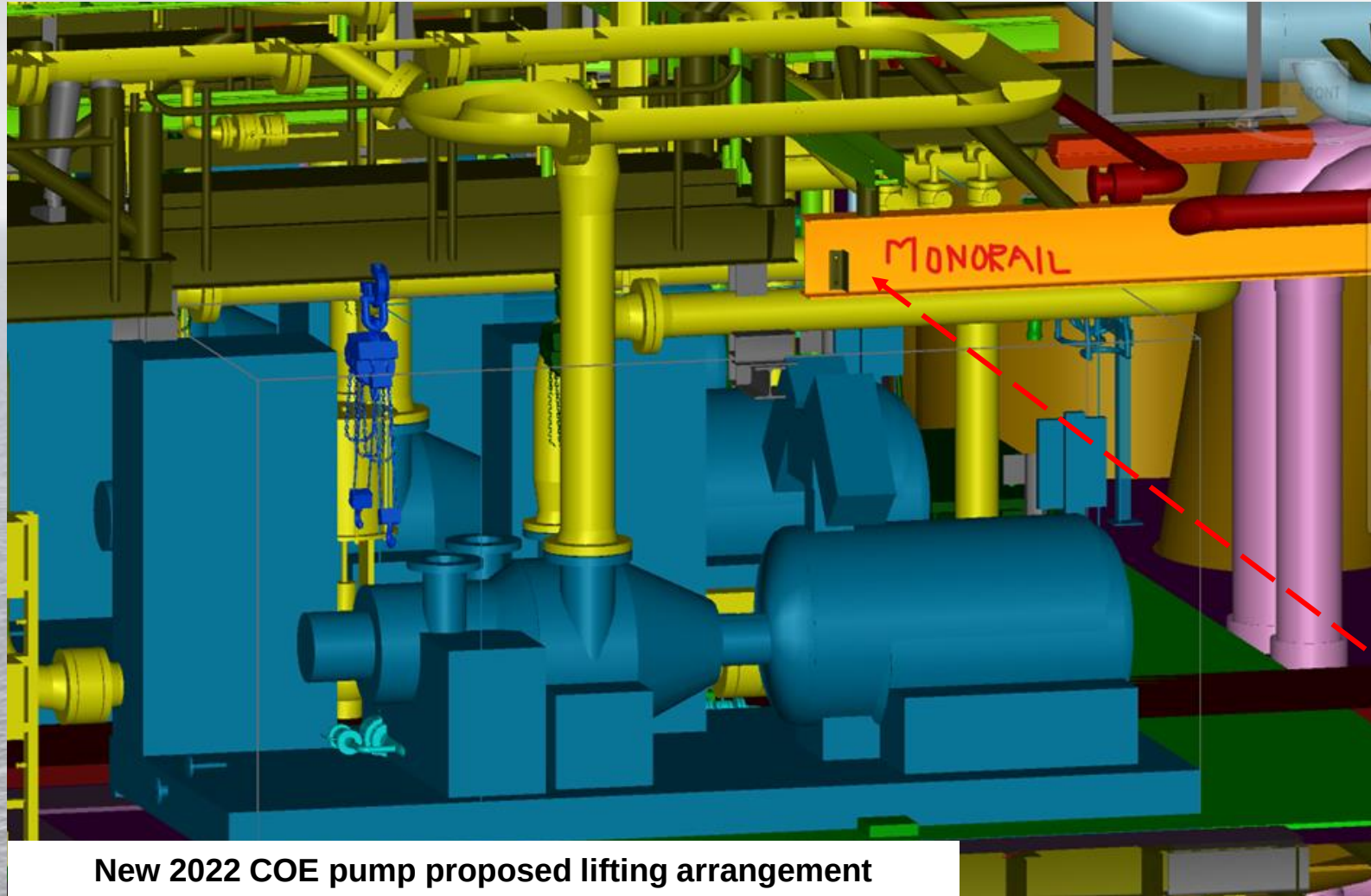
- The normal Oil & Gas industry practice is to have a low flow trip FALL to protect the COE pump to run below the pump continuous flow and overheat and seize;
- The pump OEM clearly recommended that we should have a trip at low flow at around 90% of MCSF (minimum continuous stable flow) of each pump speed. For the rated speed of 3072 rpm this FALL should be 99 m³/h;
- For each COE pump speed, we have different MCSF values, as per below picture:

	FAL	FALL
Speed (rpm)	Minimum continuous safe flow (m³/h)	0.9 x Minimum continuous safe flow (m³/h)
3200	116.7	105.0
3072	111.0	99.9
2500	90.6	81.6
2000	70.3	63.3
1500	53.1	47.8
1000	35.9	32.3



Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

➤ COE pumps lifting arrangement



New 2022 COE pump proposed lifting arrangement

- All the COE pumps require a **dedicated permanent monorail beams with lifting hoists** for lifting both pump and electrical motor;
- The permanent monorail beams are critical for **COE pumps removal / installation jobs** to be made in a timely and safe way;

Proposed mono-rail only covered the electrical motor, not the pump

Reliability improvements for new offshore pump projects - *Crude Oil Pumps*

- As you can see below the API 610 “Centrifugal pumps for petroleum, petrochemical and natural gas industries September 2010”, **doesn’t mandate any specific lifting requirements;**

9.2 Between-bearings pumps (types BB1, BB2, BB3 and BB5)

9.2.1 Pressure casings

9.2.1.1 Axially split casings may have a composition sheet gasket or a metal-to-metal joint; the vendor's bid shall state which is being offered.

9.2.1.2 Pumps for service temperatures below 150 °C (300 °F) may be foot-mounted.

9.2.1.3 For pumps with axially split casings, **lifting** lugs or tapped holes for eyebolts shall be provided for lifting only the top half of the casing and shall be so tagged. Methods for lifting the assembled machine shall be specified by the vendor [see 10.2.2.1 a) and Annex L].

- 9.2.1.4 If specified, proposed connection designs shall be submitted to the purchaser for approval before fabrication. The drawing shall show weld designs, size, materials, and pre-weld and post-weld heat treatments.

- 9.2.1.5 For pumps with machined and studded suction and discharge no minimum acceptable length for break-out spool pieces to facilitate maintenance provided by the purchaser.

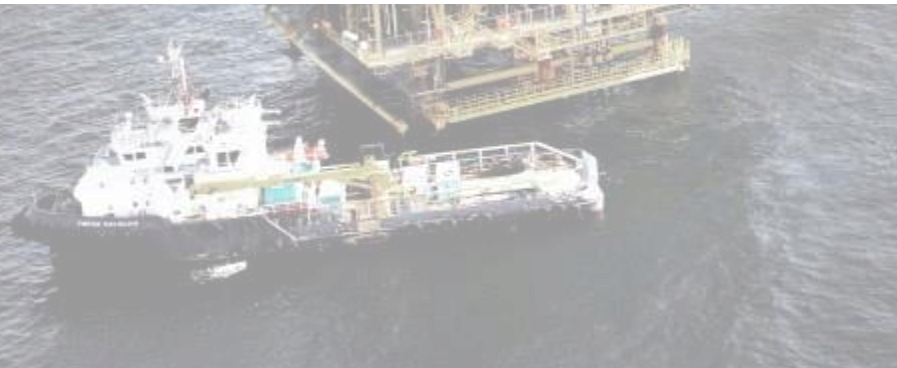
Accessed by account: North Oil | Date: Tue Jan 28 01:46:17 2020 | IP address: 78.100.159.43

10.2.2 Drawings

10.2.2.1 The drawings indicated on the Vendor drawing and data requirements (VDDR) form (see example in Annex L) shall be included in the proposal. As a minimum, the following data shall be furnished:

- general arrangement or outline drawing for each major skid or system, showing direction of rotation, size and location of major purchaser connections; overall dimensions; maintenance clearance dimensions; overall masses; erection masses; maximum maintenance masses (indicated for each piece), **lifting points and methods of lifting the assembled machine and**, if applicable, the standard baseplate number (see Annex D);
- cross-sectional drawings showing the details of the proposed equipment;
- schematics of all auxiliary systems, including the seal flush, lubricating oil, control and electrical systems. Bills of material shall be included.

10.2.2.2 If typical drawings, schematics and bills of material are used, they shall be marked up to show the correct mass and dimension data and to reflect the actual equipment and scope proposed.



Reliability improvements for new offshore pump projects - *Conclusions*

- In order to improve the reliability for new offshore pump projects, several recommendations and guidelines were presented for:
 - Pump materials and coating;
 - Pump field instrumentation;
 - Pump on-line monitoring and protection system;
 - Pump mechanical seal type and design;
 - Pump lifting arrangements;
 - Etc;to increase the equipment's overall reliability and maintainability;
- The Maintenance and Reliability departments experience and know-how must be share and implemented on the new projects, in order not to repeat old mistakes or miss up-grades;
- Just because a new equipment was installed under an EPC company project specification and design and/or by the equipment OEM specification and design , it doesn't make bullet proof or **Gods word**. Always question the new project designs because *“The devil is on the details”*;

Reliability improvements for new offshore pump projects – *Questions and Answers*



Reliability improvements for new offshore pump projects – *Bibliography*

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