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Mitigation of perennial seizure of boiler feed water pumps during commissioning of refinery unit

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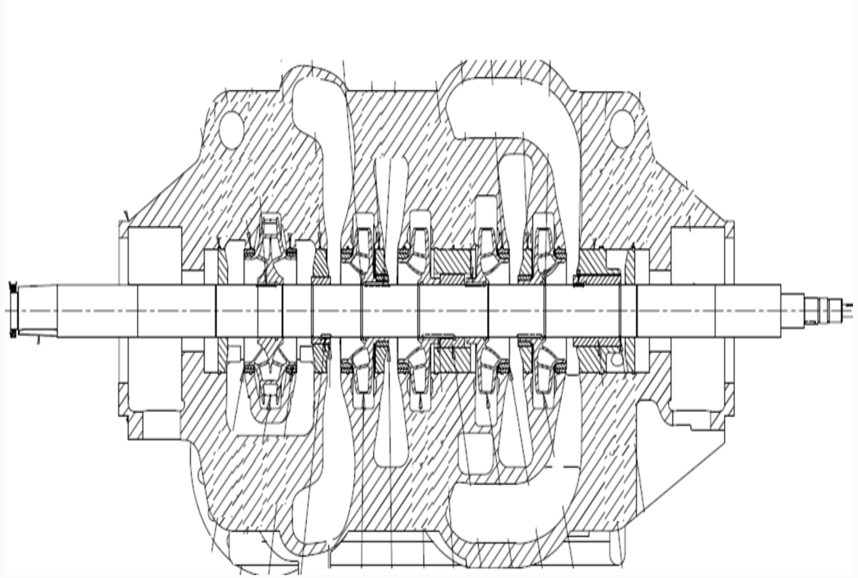
Problem statement –

Two mission critical electric motor driven BFW (Boiler Feed Water) pumps installed in remote site, faced continuous failures of rotor-stator seizures during commissioning and start up of Sulfur recovery units - Pumps had to be refurbished many times at service center by shifting from site and complete dismantling .
One of the Electric Motor faced several months of outage , bent rotor due to start up attempts .
These issues posed critical concern over project completion schedule .

Pump Details-

Pump flow in M3/h –Normal 498 Rated ,546
Pump head in m -642 , NPSH A, -10.6m NPSH R at EOC - 8.4m
Pump shaft speed 2980 RPM, Pump Hydraulic Power, kW – 1233
Material of construction C-6 based on API 610 Annex H
Case /Impeller Wear Rings A 439 D3 / A 743 CA40(400-450HB)
Shaft -ASTM A479 Type XM19 , Throttle Bush A276 Gr. 420 ,
Throat Bush : A276 Gr. 420



Pump cross section view

Teething stage failures –

The first seizures were assumed to be caused by fine sand loading in close clearance areas in spite of properly sized strainers installed in respective pump suction lines .

In an attempt to mitigate the issue , 60 mesh strainers were installed .

Suction strainer

Mesh vs. Micron Comparison Chart

Mesh	Microns	Object
3	6730	
4	4760	Gravel starts at 4.75 mm
5	4000	
6	3360	
7	2830	
8	2380	
10	2000	
12	1680	
14	1410	
16	1190	Eye of a Needle = 1,230 microns
18	1000	
20	841	
25	707	
28	700	
30	595	
35	500	
40	420	
45	354	
50	297	
60	250	Fine Sand
70	210	
80	177	
100	149	
120	125	
140	105	
	100	Beach Sand (100 - 2,000 microns)
170	88	

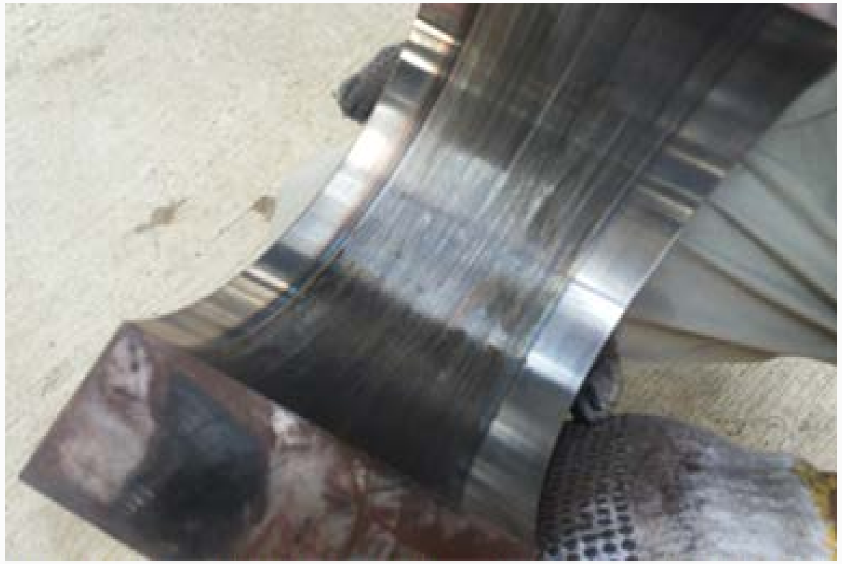
Start up and commissioning stage failure -2nd occurrence –

After refurbishment of pump , within 2 days after service, a possible seizure was reported . (Could not be rotated by hand before start up)

Two actions were proposed and executed after discussing with pump OEM–

- Reducing the alarm and trip values
- Increase clearance of throttle bush and throat bushes to optimal limit

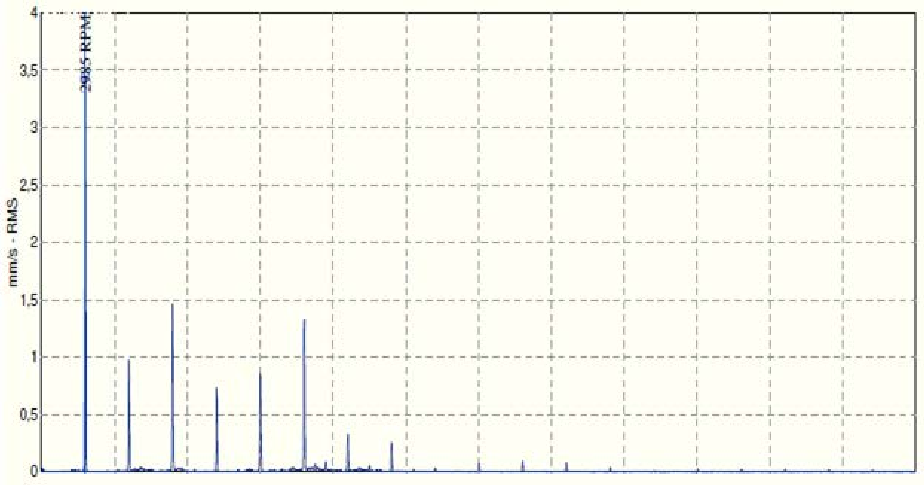
The changes made above could not prevent pumps rotors from seizing .Failures after increasing clearance concluded that sand loading is not the actual reason of rotor stator rub in pumps.

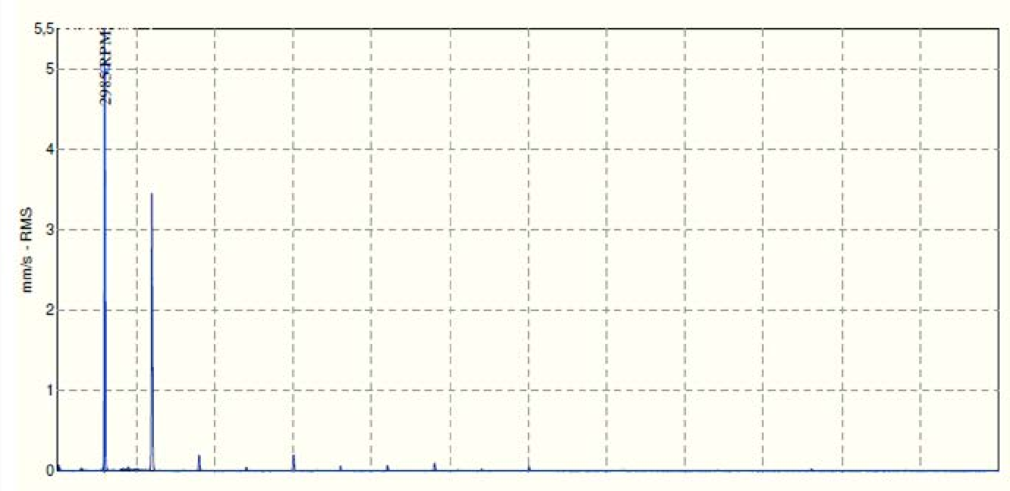


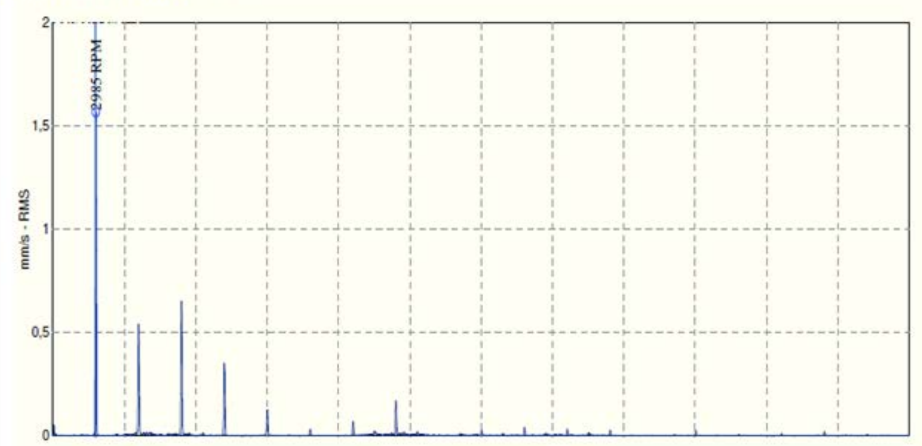
Stator area rub

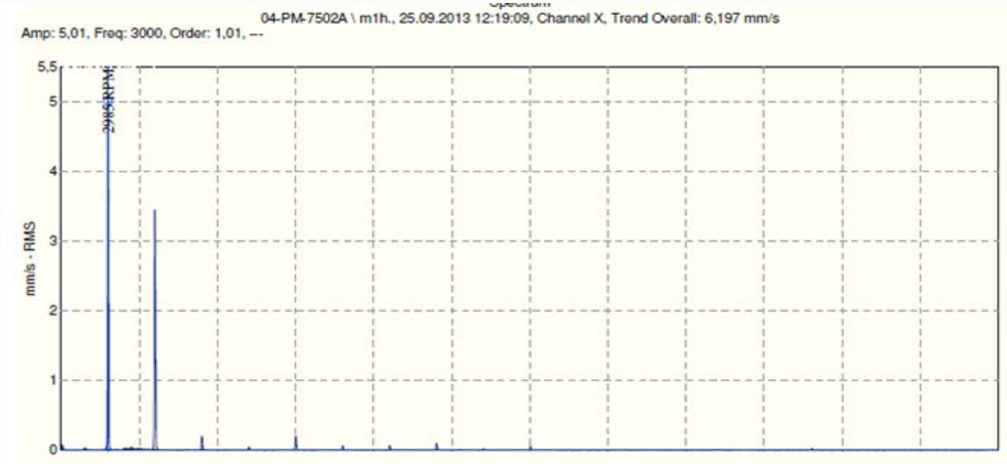
Throttle bush rub

Driver Motor solo run test at site after pump seizure – DE and NDE vibrations









Shell type design
with sleeve bearing

Multiple spectral lines showing possible looseness , High 1x shows a possibility of high unbalance

Driver Motor failure

Findings

Damaged bearings and shaft as well as imbalance in the rotor found.

Repair attempt: refurbishment of shaft and modification of bearing shells,

Rebalancing of the rotor (residual unbalance 5.10 g / 8.38 g) much higher than ISO 1940 limit

No-load test run resulting in repeated bearing damage and imbalance .

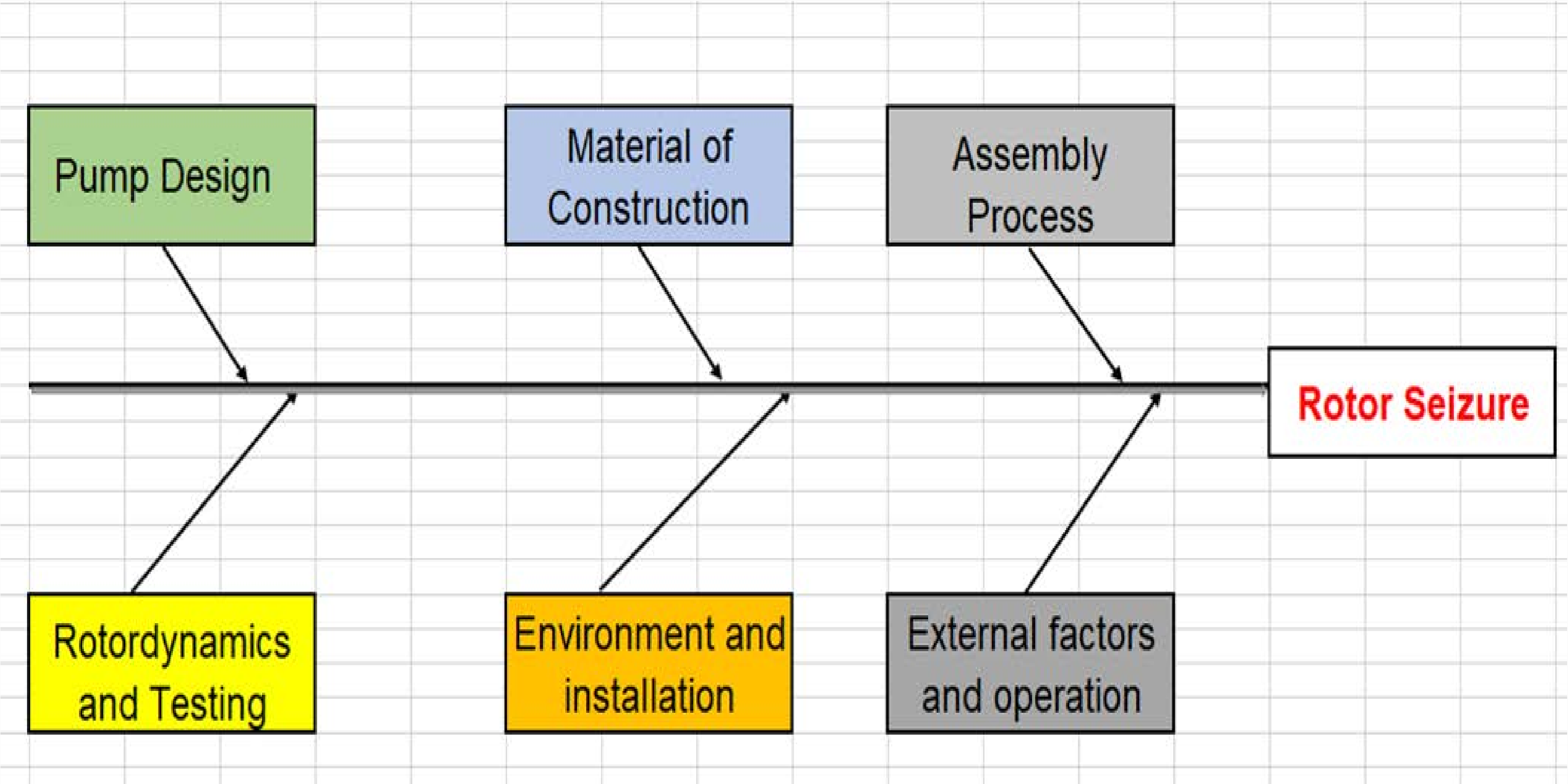
The bow in motor rotor was found to be permanent .

Cause identified –

Several start-up attempts made against a partially jammed pump unit, led to extensive overheating of the rotor, caused mechanical stress in the rotor . This caused lamination damage that resulted in a significant unbalance with the bearing damage.

It was found that balance of the rotor was in tolerance and accepted during the original manufacturing and testing of the motor

Root cause Analysis – Fishbone (Ishikawa) diagram



Root cause Analysis – Possible causes and eliminations

1.**Pump Design** – Proven design and configuration as similar pumps (with low suction type 1st stage impeller) were in operation in same region , ensured during pump requisition phase .
No signs of any damage on the impeller case and hub wear rings after dismantling the pumps .

2 **Pump Material of construction** -Proven and ensured during pump requisition phase. It was compared with same units operating and confirmed that no warm up line is required.

3. **Assembly** - Rotor TIR (Total indicated Run-out) was checked and found to be within limit as mandated by API from manufacturing data records .Electro-mechanical run-out was found within API requirement .

4. **Balancing** of assembled rotors to the grade of 1 of ISO 1940 which itself a very fine level of balancing grade . This is in accordance to Clause 9.2.4.2.2 of API 610.

5.**Pump Rotor-dynamics** analysis showed that no wet critical speed lines are crossed during run-up or rundown. The report even suggested that all modes of critical speeds of interest are well damped even at 2x Normal Clearance.

Root cause Analysis – Possible causes and eliminations

This was concluded after detailed analysis that Pump & Motor does not have any design flaws

6. **Environment and installation** – Pumps were of proven design for operation in particular geographical region , installation procedure followed OEM manual and API RP 686 guidelines for alignment (operating case) , piping installation and layout , soft-foot check and grouting etc. Vibration values never shot up to alarm limit .

7. **External factors and operation** –

7A.Foreign object caused damage- Even after complete cleaning of system loop and increasing clearances as much possible within API 610 limit, the seizures could not be prevented. Failures after increasing clearance concluded that sand loading is not actual reason of rotor stator rub .

7B.Pump rotor encroachment of clearance areas due to possible heat rise at reduced flow.

A heat rise calculation for reduced flow with existing clearance for hot feed water suggested that temperature rise shall not encroach the rotor stator gap leading to pump seizure. This was established as Minimum continuous flow for thermal stability .

Root cause Analysis – Possible causes and eliminations

7C. Pump rotor bow due to thermal distortion – Vibration values should had shot up which did not occur at any point of time . All probes were checked for correct installation . There was no prominent 1x component in FFT spectra .All probes were checked for correct installation

7D. Motor magnetic center caused axial pull / push to rotor during start up – It was ensured that rotor was placed in casing in its center and DBSE has been fixed based on magnetic center of motor in similar procedure to other pump . Motor Vendor confirmed that axial excursion of 2 pole Electric Motor Magnetic Center has no effect which could lead such type of failure in pump. The pump was designed with balance drum not by balance disk, hence axial thrust is well compensated.

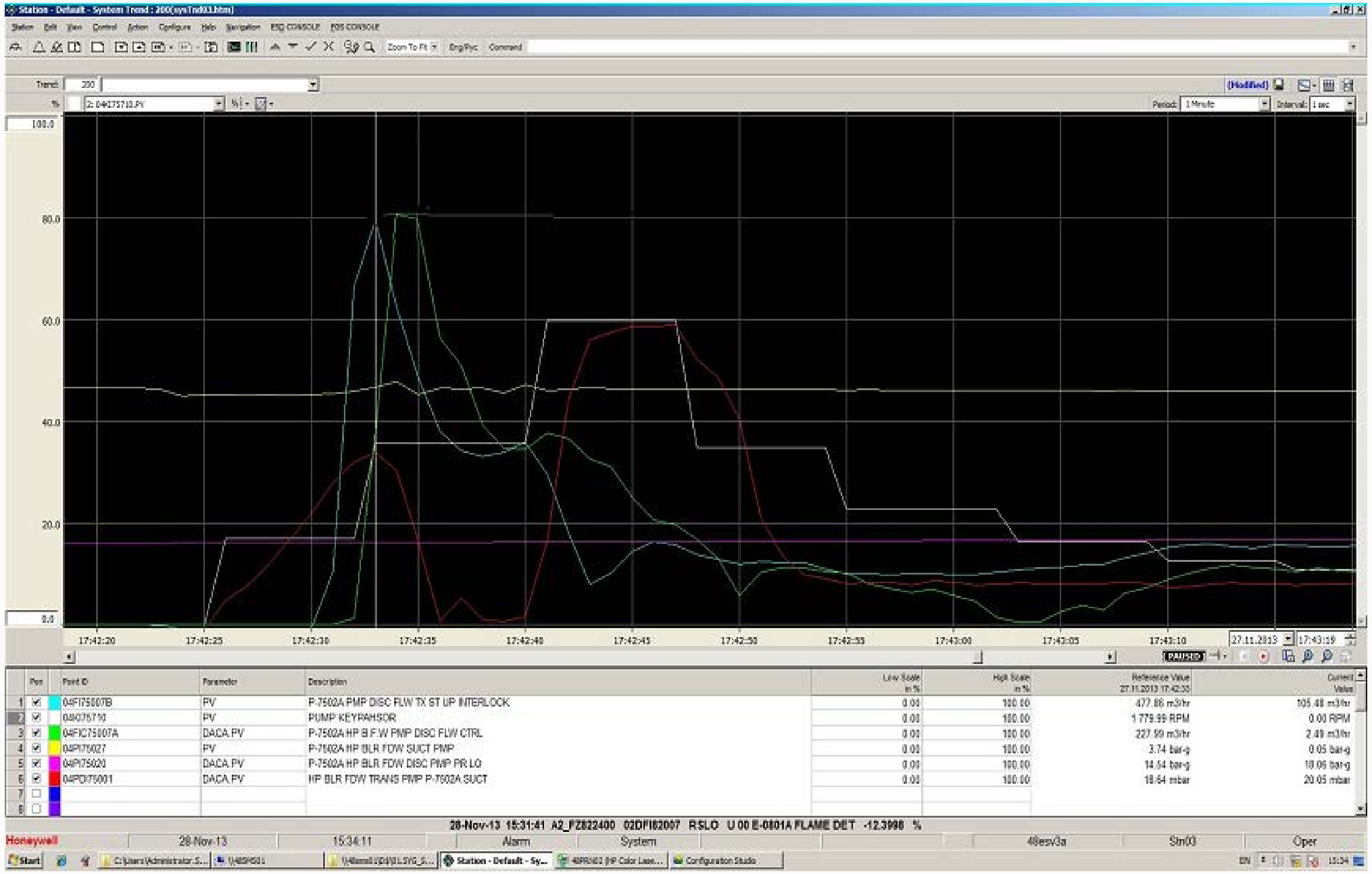
7E. NPSH has not fallen below 3.1 barg , which is much higher than the trip value of 2.0barg of NPSH- as confirmed trend from DCS.

7F. The Recirculation valves were checked for potential valve plugging during plant startup due accumulation of construction debris . Valves found to be good condition.

Root cause Analysis – Possible causes and eliminations

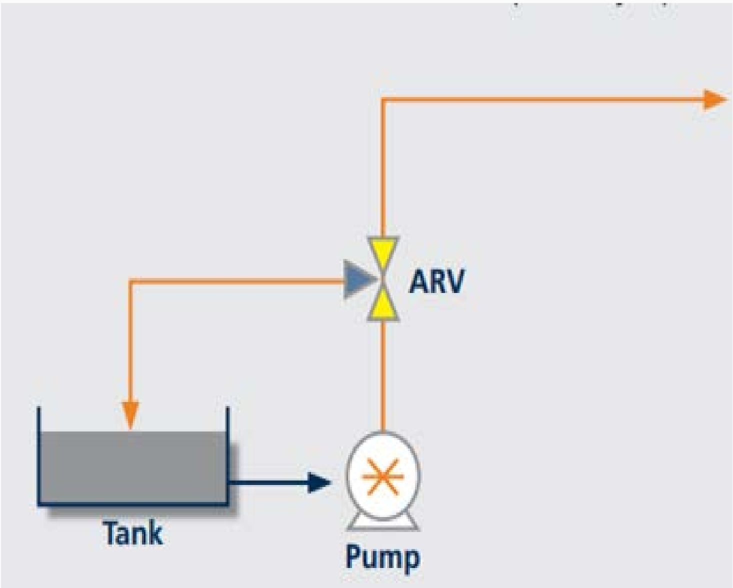
7G.Lack of lubrication at close clearance parts leading to encroachment of clearance parts during start up – It was observed by careful analyzing the trend plots that before pump started to pick up full speed , flow fell down and downfall of flow was continuous and never recovered causing a situation of no flow.

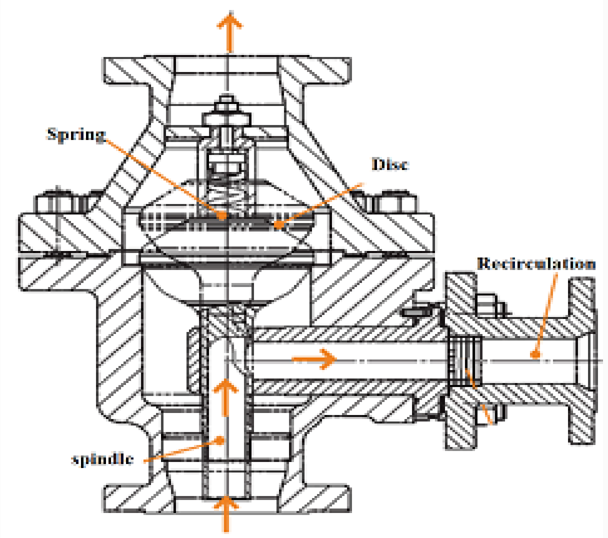
DCS trend of parameters

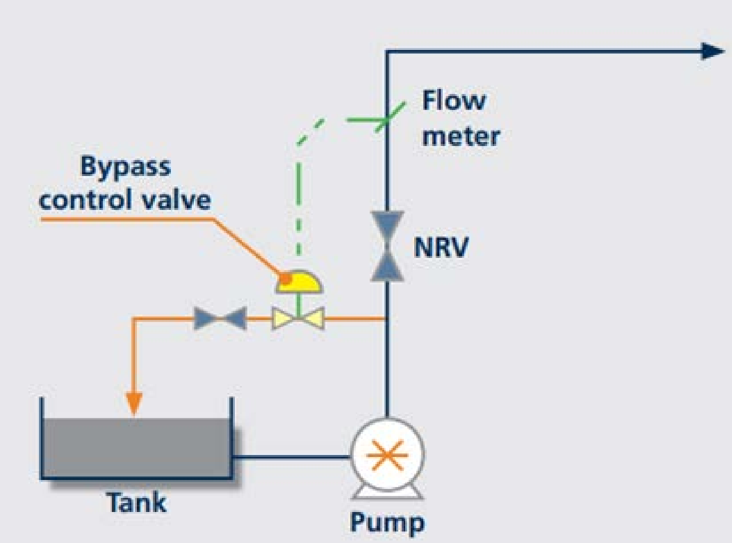


Root cause Analysis – Deliberation on point 7G.

ARV (automatic recirculation valve – Mechanical type) –(shown below left)   is the common application is to protect pumps which handle hot water for boiler feeding where partial evaporation of the water content might cause the pump to run dry. The modification of the on-off recirculation system (ARV) is the modulating system (bypass type flow control valve) which was installed in system right from beginning . NRV is the check valve. The bypass control valve was modulating based on flow meter feedback.



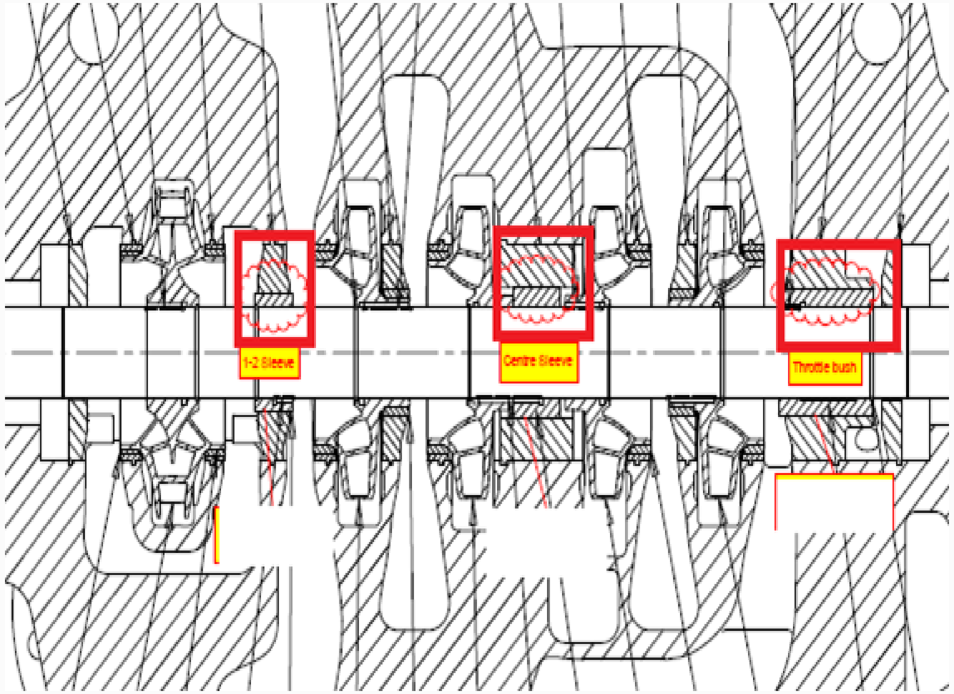




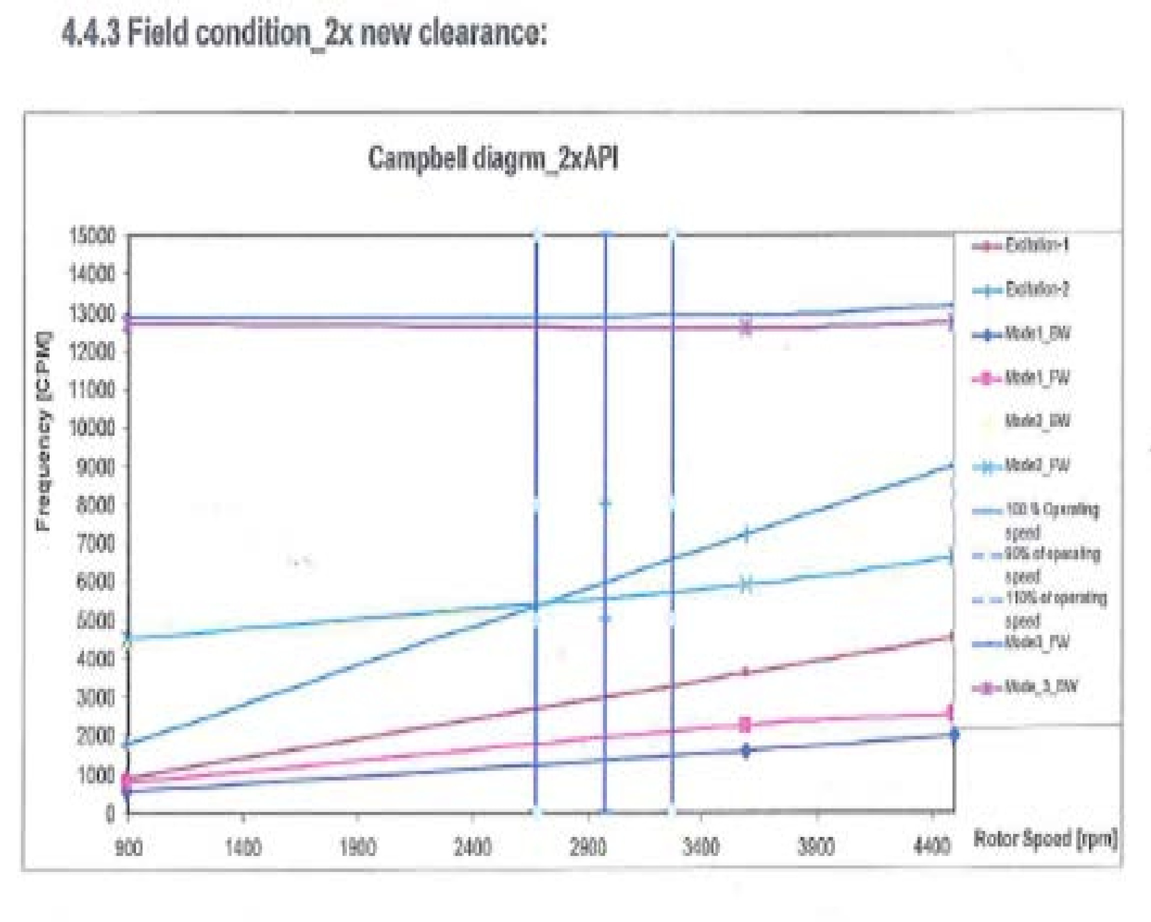
Generic Pump loop with ARV , internals of recirculation valve and bypass type flow control valve

Corrective actions-

1.**Increased inter-stage clearance** – Throttle bush, center bush and stage bush to avoid rubs . Action based on Lateral analysis report of pump – Campbell diagram – extract below –Right



Inter-stage location where clearances were increased



Corrective actions – contd.

2. **Use of rub tolerant (non galling)**inter-stage materials –(to tackle lack of lubrication identified as 7G)
Use of Ni resist material for inter stage bushes and sleeves in place of existing 12 % chrome material . Ni-Resist Specification BS3468 1986 F3 – Flaked Graphite was selected as plausible option. The hard particles of Chromium present (2.5-3.5%) in Ni resist, imparts erosion resistance for occasional sand ingression in pump.
As further modification in rotor bearing system, pump OEM offered a circulatory grooved throttle bush ensure a constant lubrication by working fluid and confirmed there shall be no considerable change in stiffness and damping values.

Type	Grade	Tensile Strength (min) N/mm2	0.2% Proof Stress (info only)	Elongation %	Brinell Hardness BHN	Typical Properties/Uses
	F3	190	-	1 – 3	120 – 215	Erosion resistance in wet steam and salt slurry. Good thermal shock resistance up to 800c along with good high temperature corrosion resistance. Uses include Exhaust gas manifolds, turbocharger housings, filters, pumps and valves.

circulatory grooved throttle bush

End results , conclusions , lesson learnt

Estimated time for procurement of Mechanical ARV and possibly required piping modification – 2-4 months
Time taken to put pumps back to service – 8-10 days.

End Result –
The above suggestions were implemented on both pumps. A very close monitoring of pump and associated parameters had been carried out relentlessly during start- up of pump B till full stabilization of stream.
The pump performed to level of end user satisfaction for six months then switched over to operation of unit A with replaced Motor as a change-over plan. However , it was suggested to OEM to explore installing Mechanical ARV in next annual outage of plant .

Conclusions and lessons learnt -
The existing safety of BFW pumps heavily relied on Flow circulation valves which are instrumented, any small malfunction can lead to droop and subsequent damage of pump. The new proposed solutions are not widely known for BFW application but can be easily implemented at start of design detailing of pump particularly when Mechanical ARV is not opted (a modulating valve is opted) by Pump OEM or End user.
Mechanical type ARV is standard solution ; other solutions should be well deliberated .
It is very important to feed clean fluid to BFW pumps to avoid any seizures .

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