51ST TURBOMACHINERY & 38TH PUMP SYMPOSIA
SEPTEMBER 13-15, 2022 | HOUSTON, TX | GEORGE R. BROWN CONVENTION CENTER

INTERACTION BETWEEN ROTODYNAMIC PUMP BEHAVIOUR AND WEAR SURFACE COATING TECHNOLOGY: A MULTISTAGE PUMP CASE ANALYSIS

Giorgia Valeria Viviani
Giancarlo Cicatelli

FLOWSERVE

Authors' biography

Giorgia Valeria Viviani is currently working in Flowserve Pump Division as Product Engineer for BB5 multistage pumps. She obtained the Master's degree in Energy Engineering from University of Pisa (Italy) and the Research Master degree in Fluid Dynamics from the von Karman Institute of Fluid Dynamics (Belgium).
Before joining Flowserve, she worked in the field of Automotive and Nuclear power plants.

Giancarlo Cicatelli is currently holding the position of Product Engineering Manager for Flowserve in the Engineered Pump Division. He has started his industrial career serving as product design specialist, R&D team leader and manager of the Customer Service for the O&G business. He has his office in Italy.
Previously he was Research assistant at the von Karman Institute in Belgium and at the University of Cambridge (UK), focusing his interests in the field of Fluid Dynamics of Turbomachinery, in the area of gas turbine research.
He holds a PhD in Applied Sciences from the University of Brussels and has a master in Nuclear Plant Construction management from Polytechnic of Milan. He obtained his BS degree in aeronautical engineering from the University of Naples, Italy.
He is author of several scientific publications in the field of Fluid Dynamics applied to turbines and pumps.
He is member of the Advisory committee for the Middle East Turbomachinery Symposium and member of the Europump Technical committee.

Case study

Problem:

- Seizure of two multistage pumps during performance test caused by coating detachment from the wear surfaces.

Objective:

- Determine root cause of unexpected failure
- Propose solution
- Learn lessons

Pump service and specs

- API 610 BB5 pumps
- Application: Produced water injection

	Pump 1	Pump 2
Stages number	7	8
Speed	3583 rpm	3583 rpm
Rated capacity	29.5 m^3/h (129.7 USgpm)	30 m^3/h (132.5 USgpm)
Rated head	1156 m (3792 ft)	1411 m (4629 ft)

For the sake of brevity, discussion focuses on pump 2 (8 stages). Similar considerations apply to pump 1.

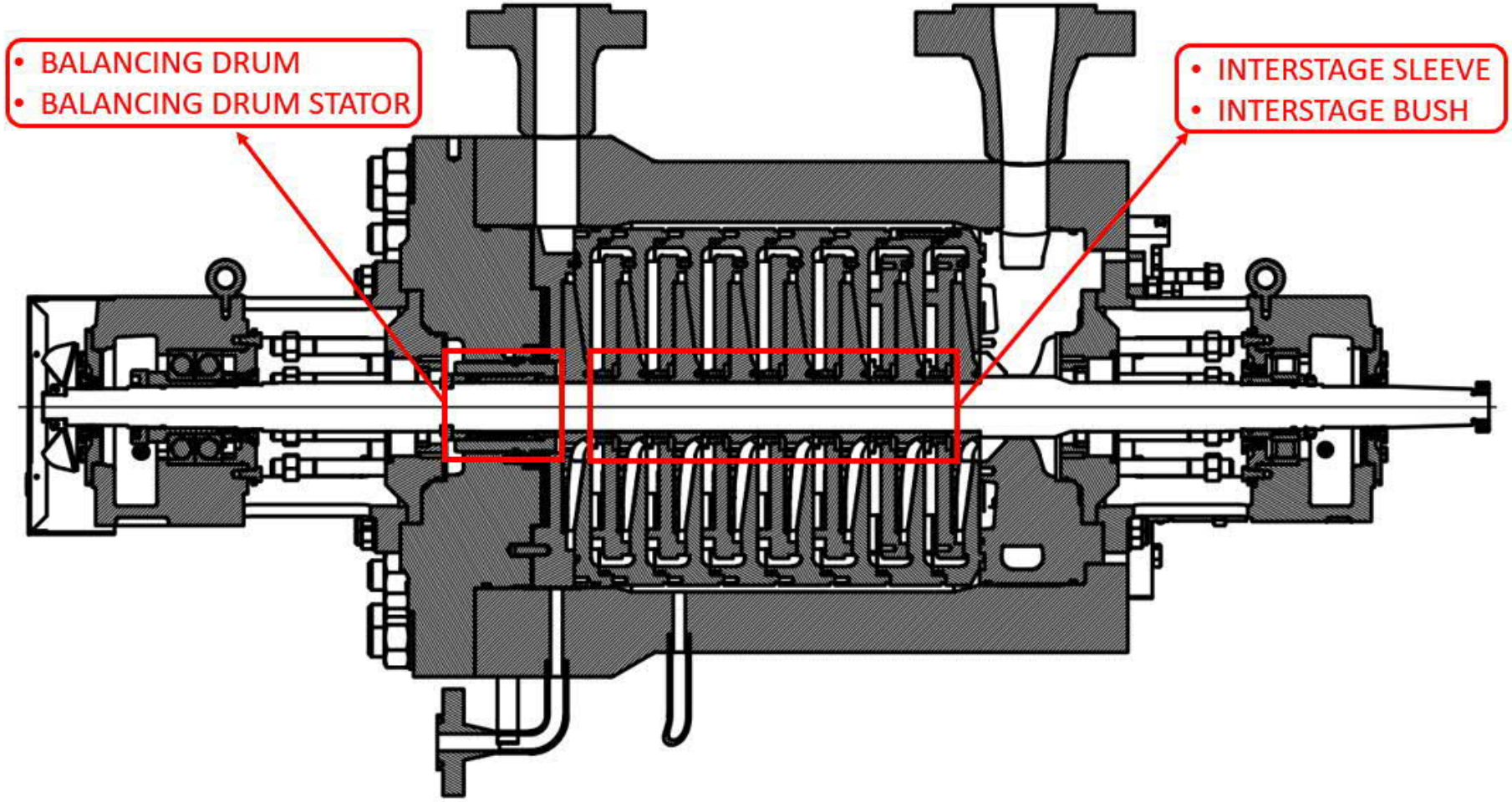
Pump 2 design

- Unshrouded impellers – no front wear rings, vaned diffuser
- D_2 impeller / D_{shaft} = 4.9
- Wear components clearance:
  - Interstage sleeve: API
  - Balancing drum: 75% API

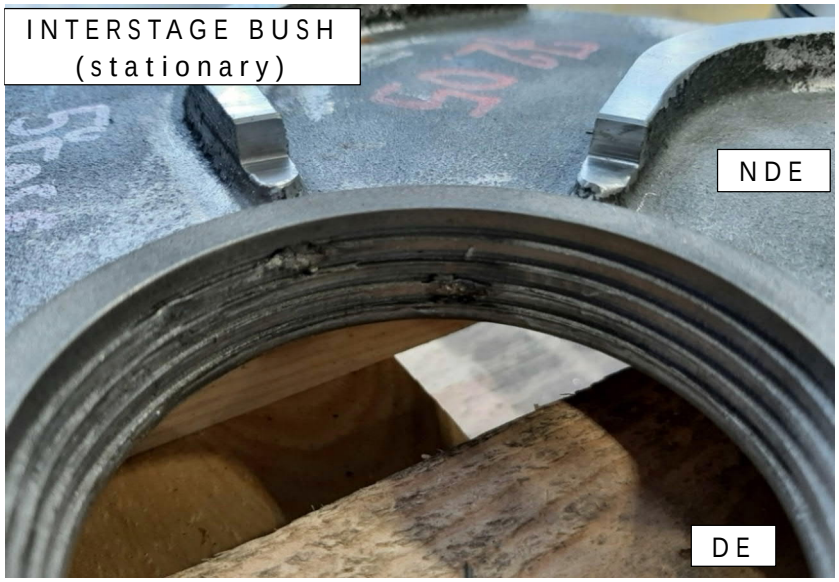
Coating:

- Process: High Velocity Oxy-Fuel (HVOF)
- Material: Colmonoy 6 – Hardness: ~60 HRC
- Coated components:
  - Interstage sleeve (rotating) and interstage bush (stationary)
  - Balancing drum (rotating) and balancing drum stator (stationary)

Components damaged



Signs of adherence and coating detachment



Root Cause Analysis (RCA)

- All potential failure causes → identified
- All possible contributors to the failure → investigated

Ranking:

- DISCARDED: no influence on the failure
- EVALUATED: possible cause of failure, analyzed more in details with model calculations or test.

RCA

Category	Event	Ranking
Hydraulic design	Erroneous hydraulic design	DISCARDED
	Turbulence issues	DISCARDED
Mechanical design	Erroneous clearances	DISCARDED
	Erroneous rotodynamic analysis	DISCARDED
Metallurgy	Erroneous base material selection (Incolloy 825)	DISCARDED
	Erroneous overlay material selection (Colmonoy 6)	EVALUATED
Manufacturing of components	Erroneous manufacturing of base components	DISCARDED
Overlay process	Erroneous process selection (thermal spray Vs welding)	EVALUATED
	Defective coating execution	EVALUATED
	Defective interpretation of drawing	EVALUATED
Assembly	Erroneous rotor balancing	DISCARDED
	Erroneous pump assembly	DISCARDED
	Erroneous final rotor centering	DISCARDED
	Accidental foreign material contamination	DISCARDED
Testing	Erroneous parameter setting	DISCARDED
	Sump water contamination	DISCARDED

Investigation – Coating process

After running: signs of abrasion and adhesive delamination are present on the coated components

<u>Possible causes:</u>

- shear stress concentration → grooved design on interstage bushes
- presence of microdefects in the coating structure
- Lower substrate bond strength of HVOF coating

Reference: R. Ahmed, Contact fatigue failure modes of HVOF coatings. Wear 253 (2002), 473-487

Investigation – Coating process

Thermal spray - High Velocity Oxy-Fuel (HVOF)

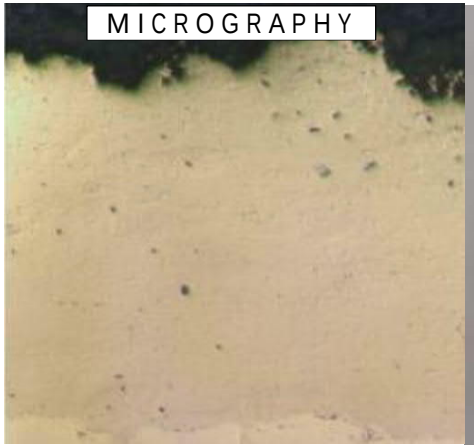
Coating material: Colmonoy 6

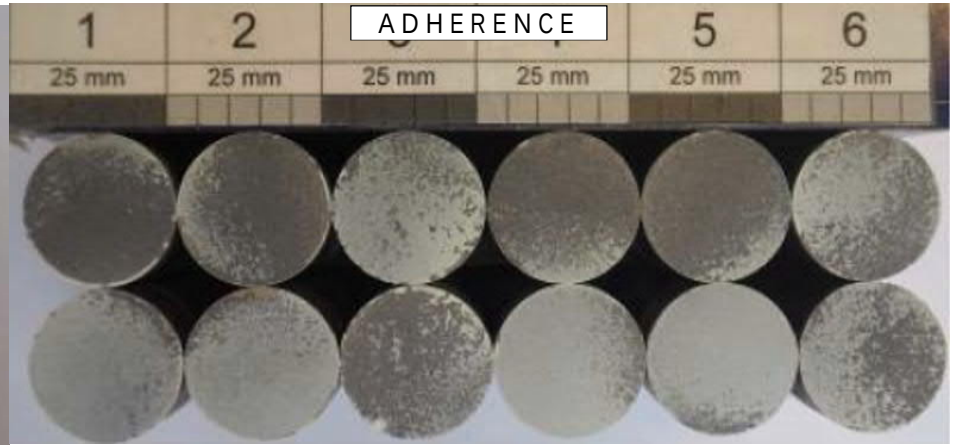
Performed stationary test on samples:

- Micrographic examination
- Bend test
- Adherence test

} Satisfactory results

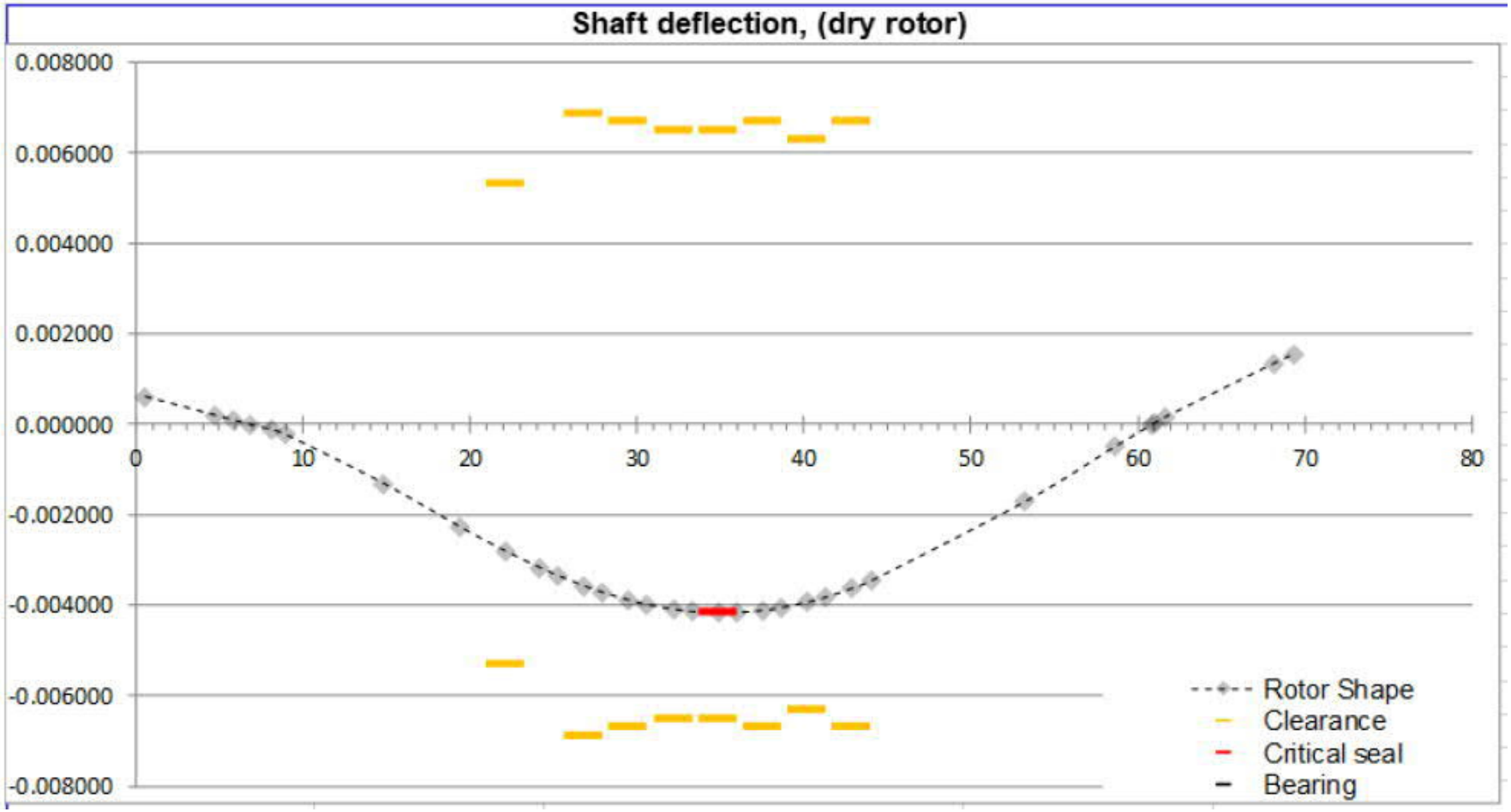
→ Coating process performed correctly





Investigation – Shaft deflection

Rotor static study indicates no touch due to shaft deflection

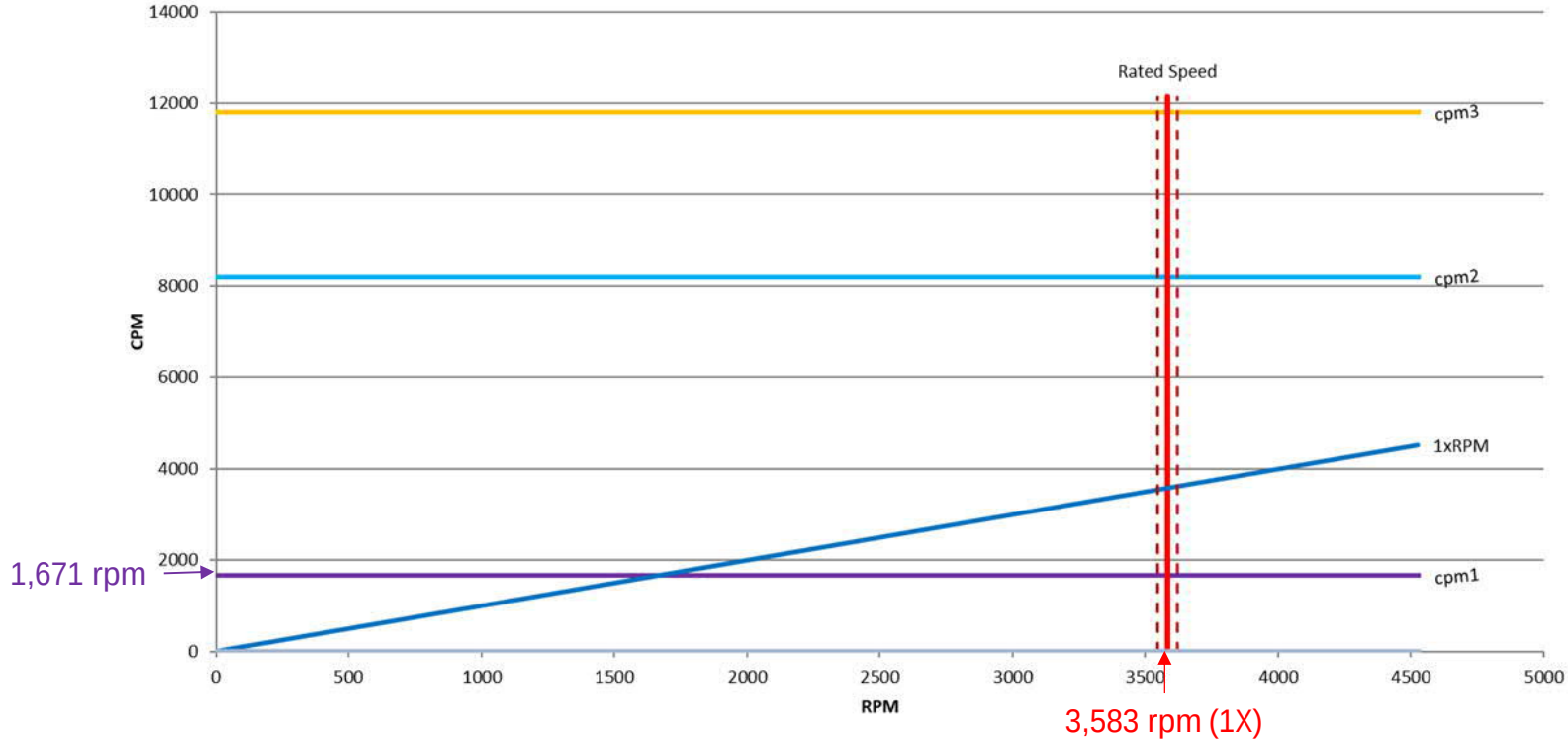


Investigation – Rotordynamics

Undamped (dry) lateral analysis: first dry bending mode (1,671 rpm) lower than 1.2 x pump running speed (3,583 rpm)

→ Rotor not classically stiff

Campbell diagram – Dry Pump modes



Investigation – Shop test

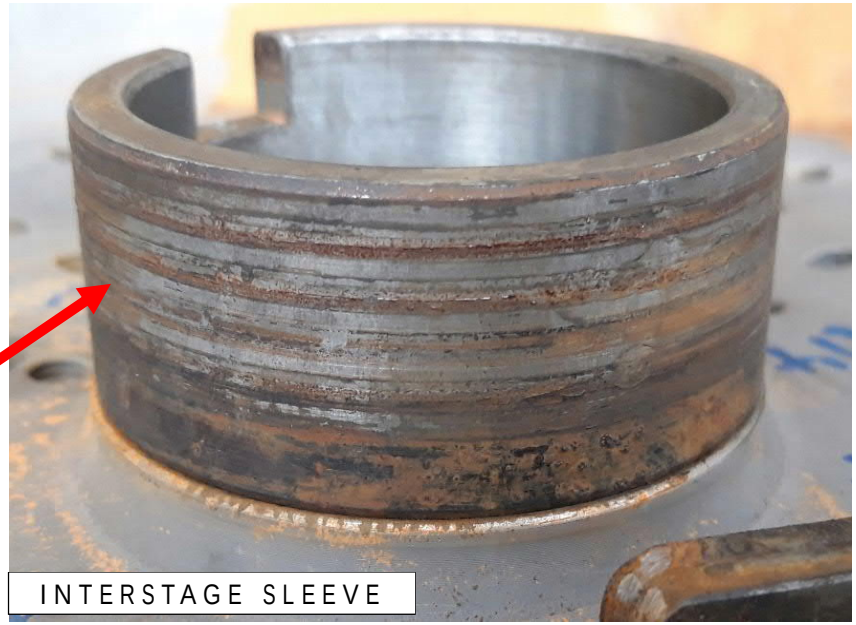
Scope: investigate the presence of contact between wear components and their likely influence on the pump seizure

Temporary wear components:

- non-galling material - bronze/steel (without coating)
- actual geometry with grooves (interstage bush and balancing drum)

Results:

- No seizure
- Signs of contact on the wear surfaces



INTERSTAGE SLEEVE

RCA conclusions

Failure caused by a combination of two main factors:

- Shear stress concentration on interstage sleeves due to grooving design of paired surfaces
- Insufficient metal bonding of the coating on wear surface

Enhanced by the negative effects of

- Pump high rotational speed
- Non-stiff or flexible rotor
- Increased rotor displacement during first seconds of start-up due to the absence of Lomakin effect (dry pump)
- Transient effects due to flow regulation

Proposed solution

- Reduce shear stress concentration
  → interstage bush design changed from grooved to flat in all stages
- Optimize coating to increase its substrate bond strength and wear resistance
  → change coating process from thermal spray (HVOF) to welding
- Different hardness for the mating surfaces (stator and rotor components)
  – Old material: Colmonoy 6 (rot. and stat.) - hardness ~60 HRC
  – New material:
    - Stellite 12 (rotating) – hardness 59-60 HRC
    - Stellite 6 (stationary) – hardness 43-54 HRC

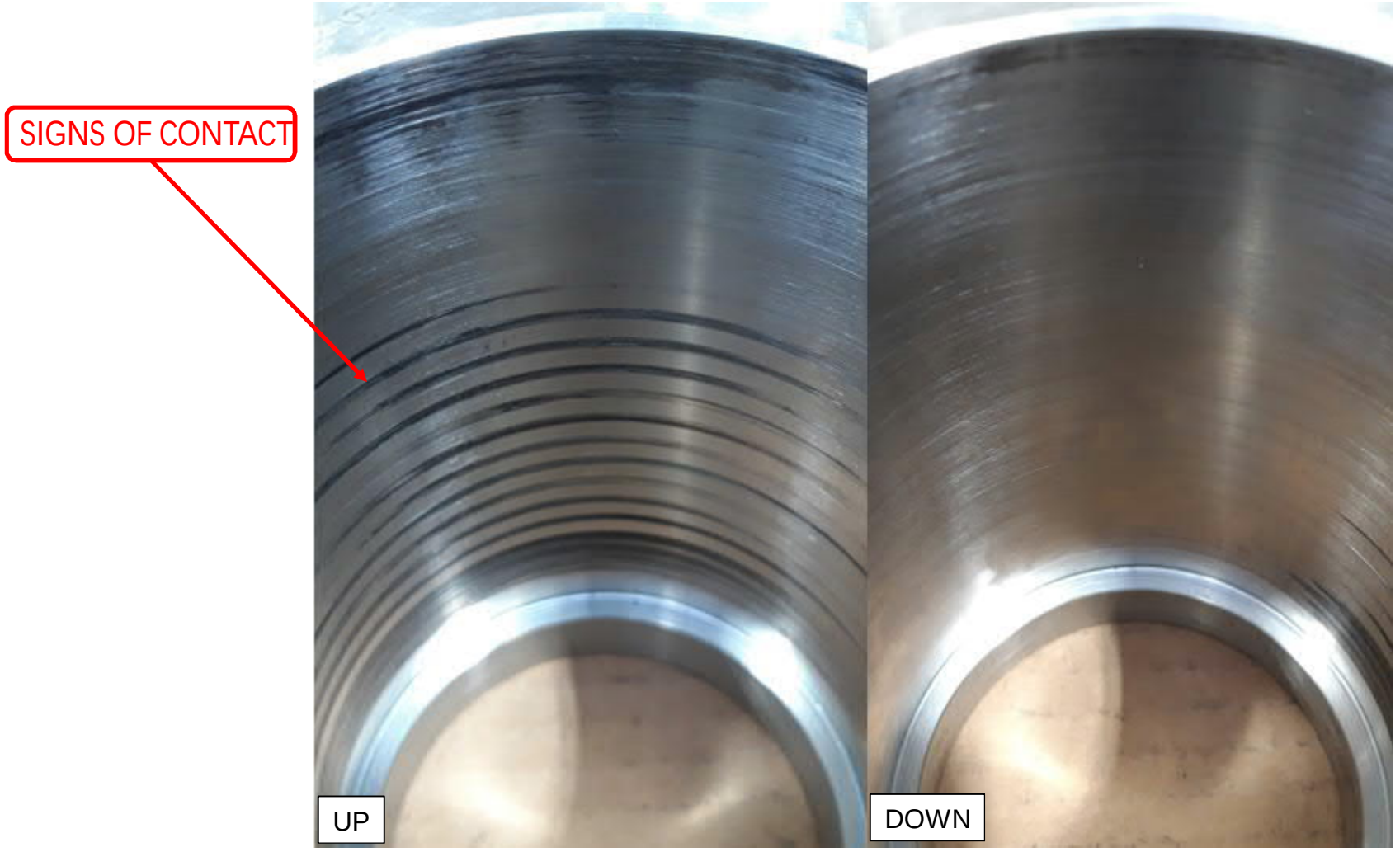
Design change investigation

Validation test performed with final components to demonstrate the suitability of proposed solution and to validate the pump rotodynamic behavior with the uniform surface interstage bushings.

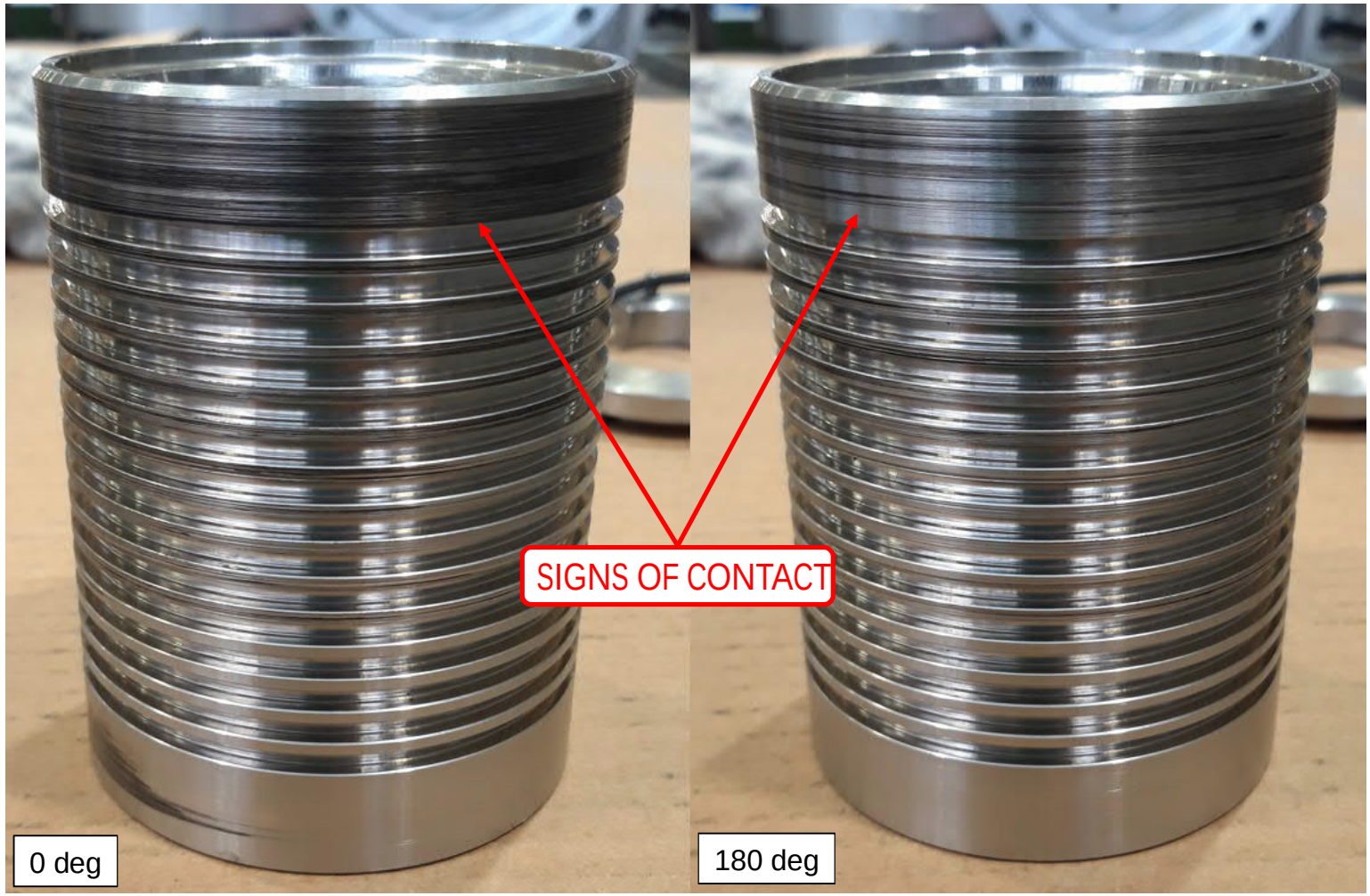
Results:

- Pump runs without mechanical issues
- Performance results: satisfactory
- Visual inspection after test: persisting minor signs of contact in rotating wear surfaces

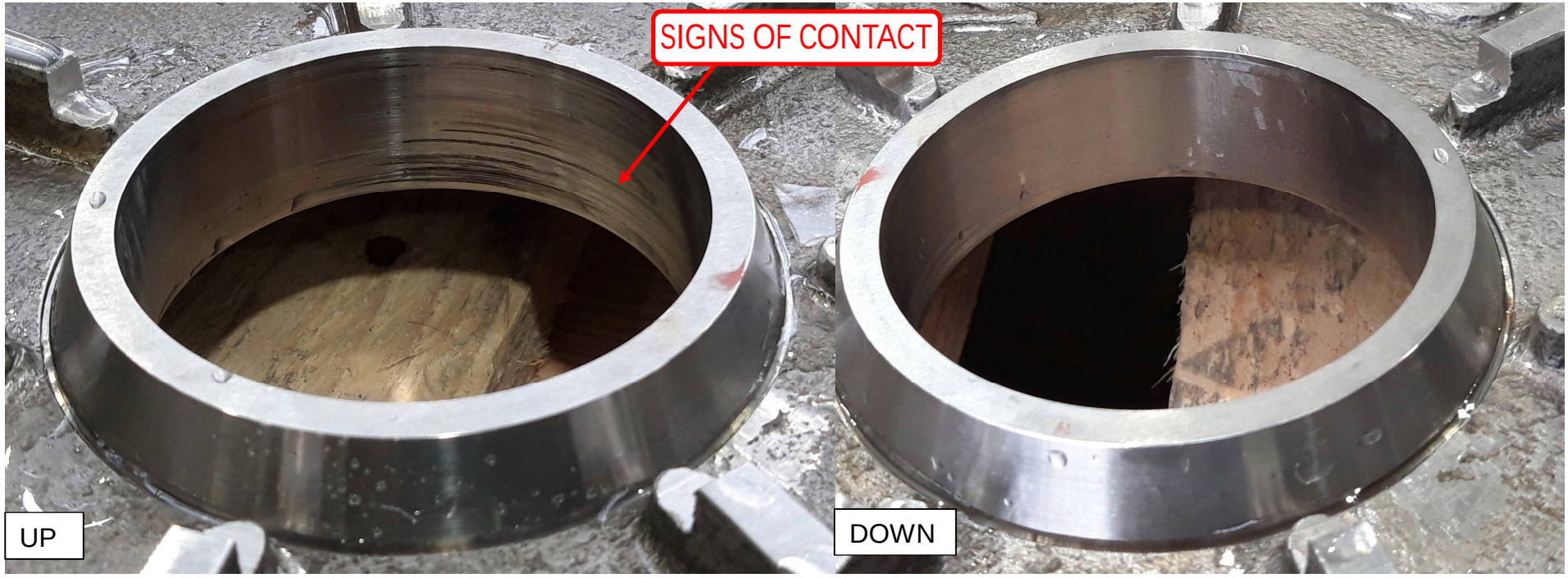
Visual inspection: Balance drum stat.



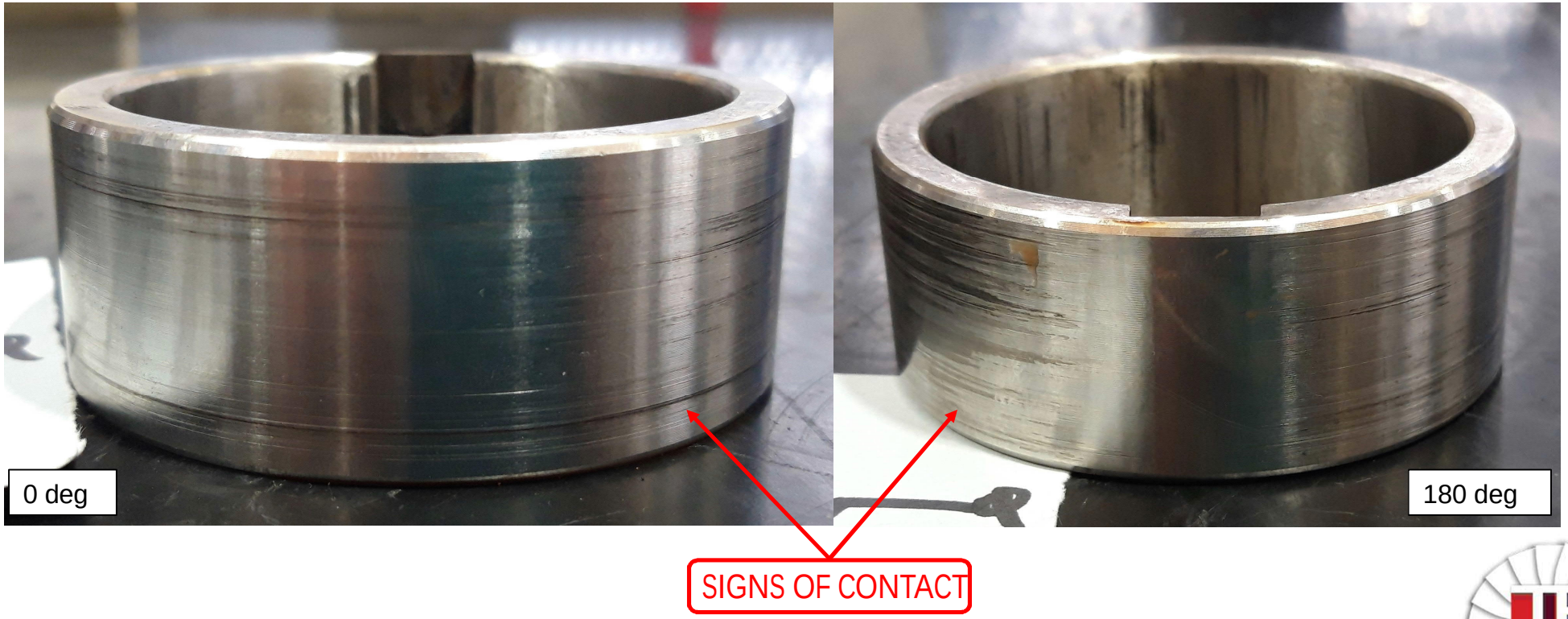
Visual inspection: Balancing drum



Visual inspection: Interstage bush



Visual inspection: Interstage sleeve



Conclusions

- Failure caused by the interplay between the rotordynamic behavior of the rotor and the original grooved design of the interstage bushings.
- Solution involves a change of the overlay process and design modification of the wear components.
- Welded coating is a consolidated process, largely used in the past in similar pumps.
- Solution validated with test with final components:
  - Modified design: flat surfaces
  - Coating: PTA Stellite 6/12

Lesson learned

- Thermal spray (HVOF) coating has a limited substrate bond strength when subjected to shear stress concentration.
- Grooved surfaces cause a shear stress concentration on the components undergoing wear.
- The surfaces' coating process should be carefully selected considering the pump characteristics (speed, wear surfaces geometry)
- In multistage pumps with flexible shaft, minor contact is expected during transient operations

THANK YOU FOR YOUR ATTENTION!

ANY QUESTION?