Omega Dot

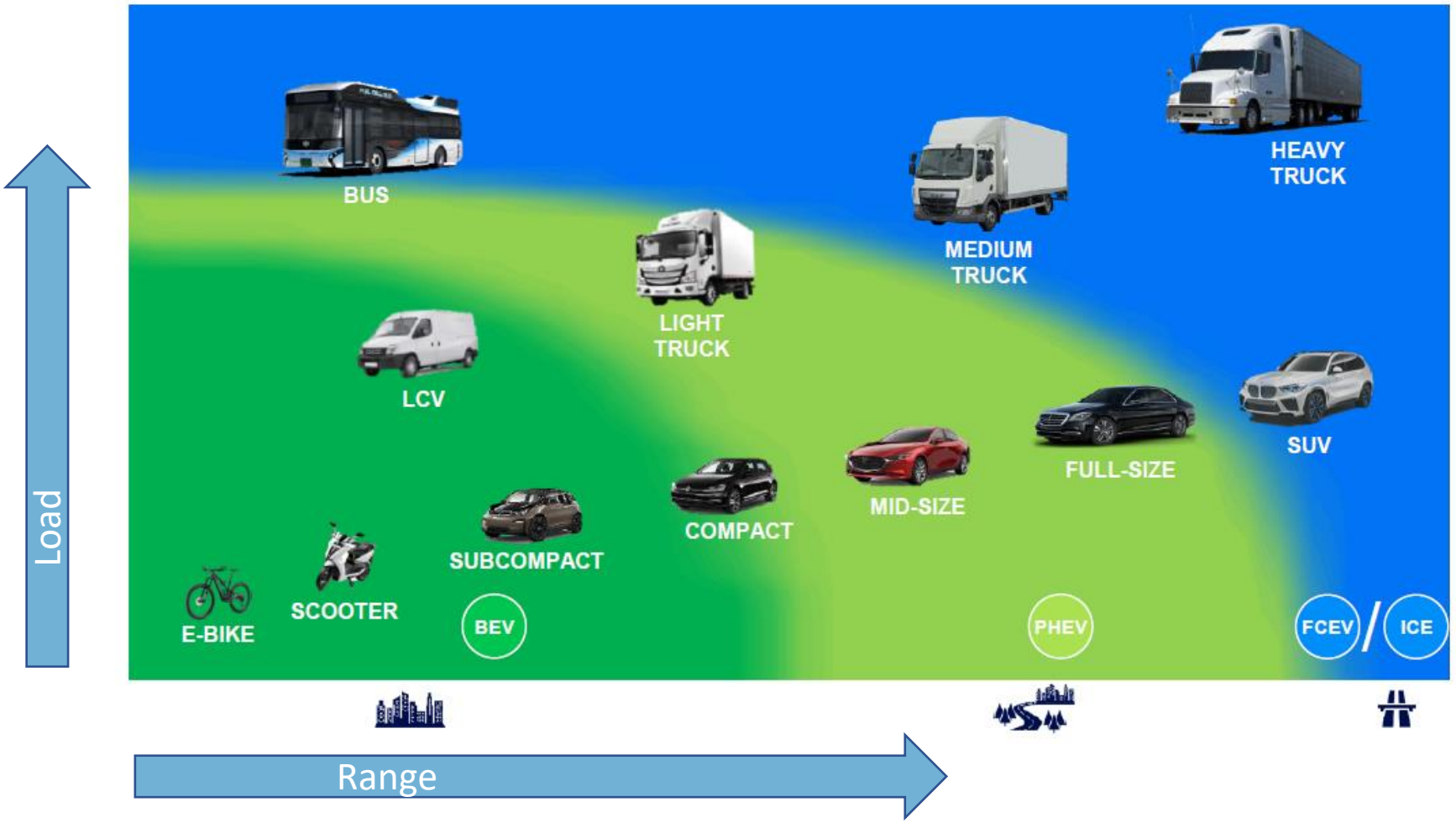
Research and Engineering Solutions

Coating Wear Testing of Air Foil Bearings to Validate Fuel Cell System Applications

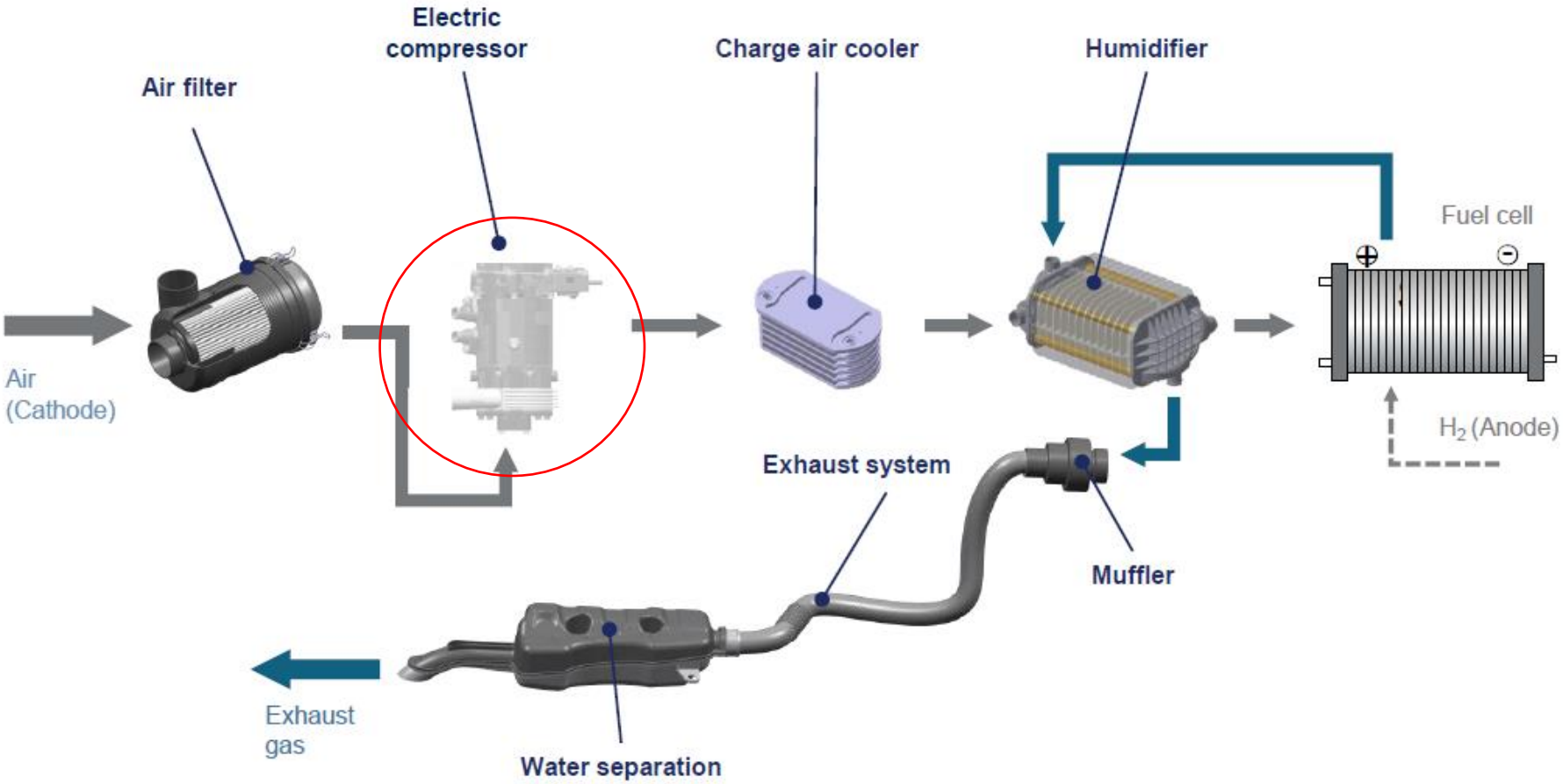
Dr Duc Ha and Alishah Ahmed

March 2023, Issue A

Role of Fuel Cells in Future of Transports

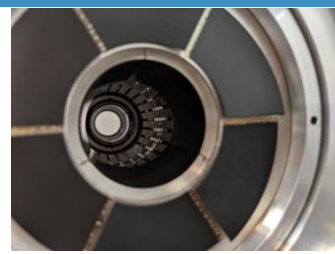


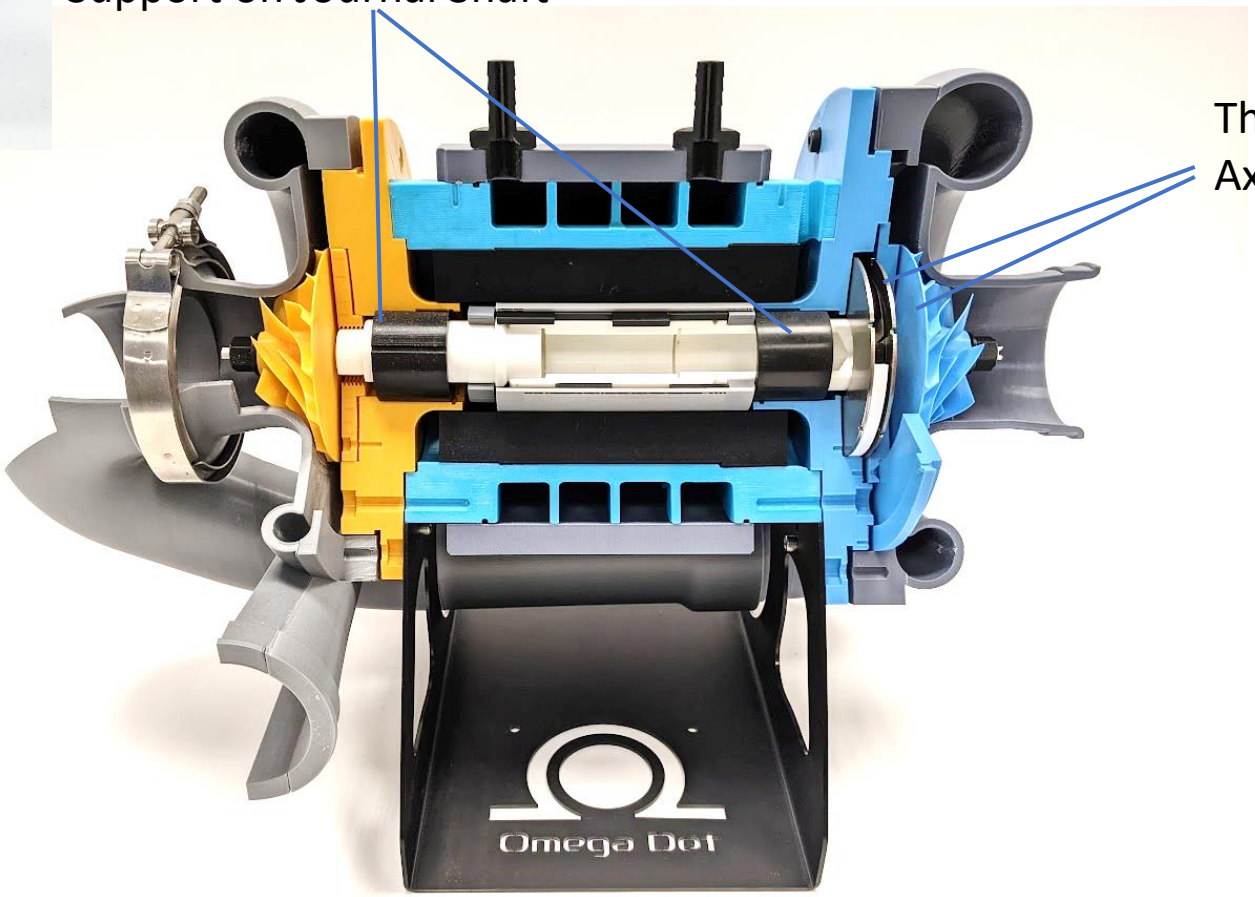
Air Management System for Fuel Cells



Air Compressor

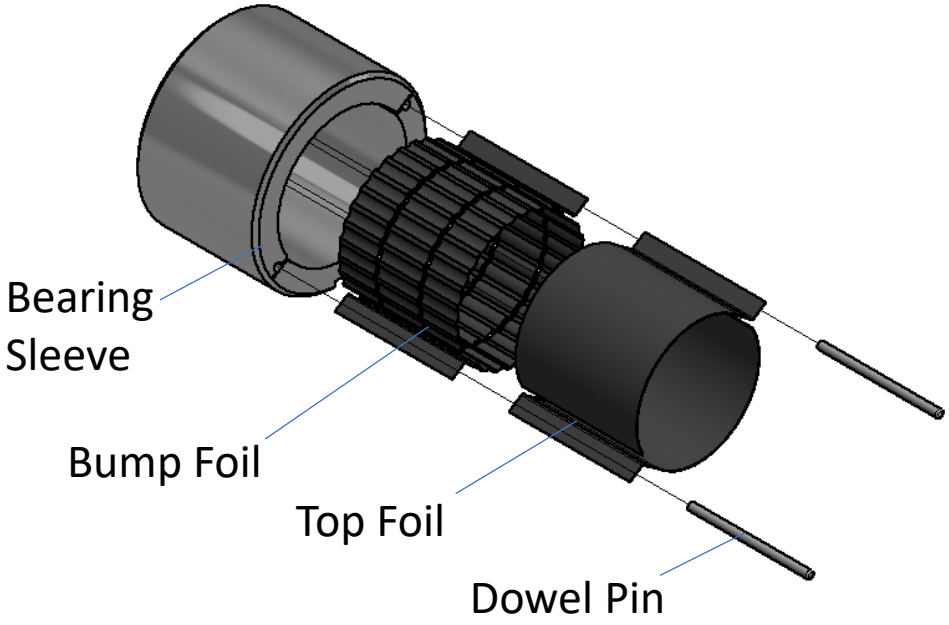
Radial Bearings – Radial Support on Journal Shaft

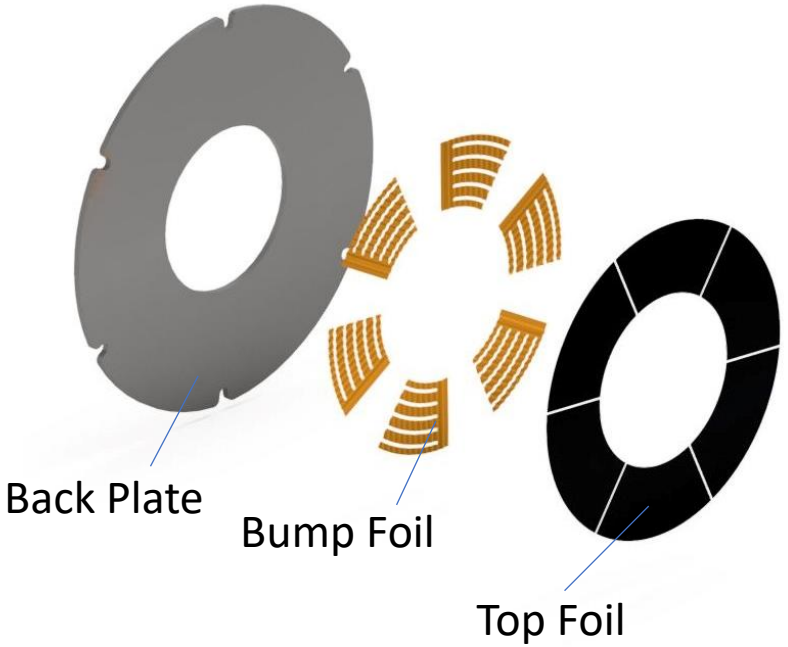




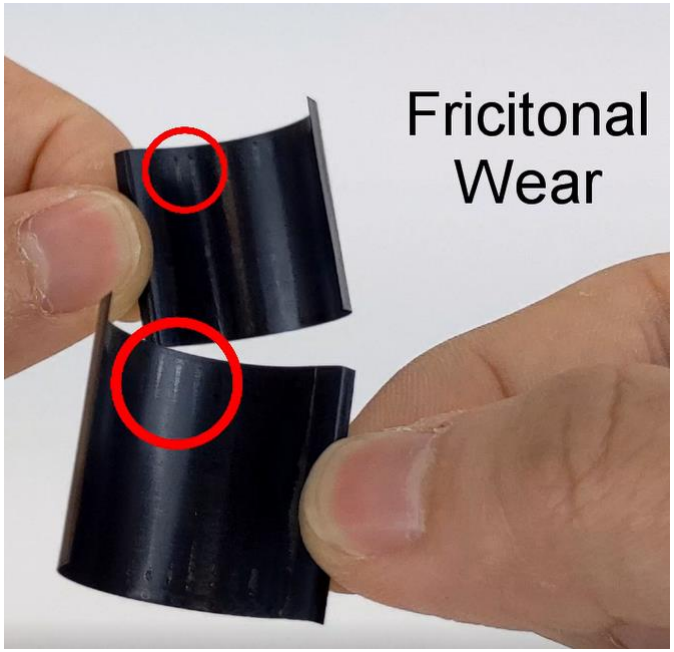
Thrust Bearings – Axial Support

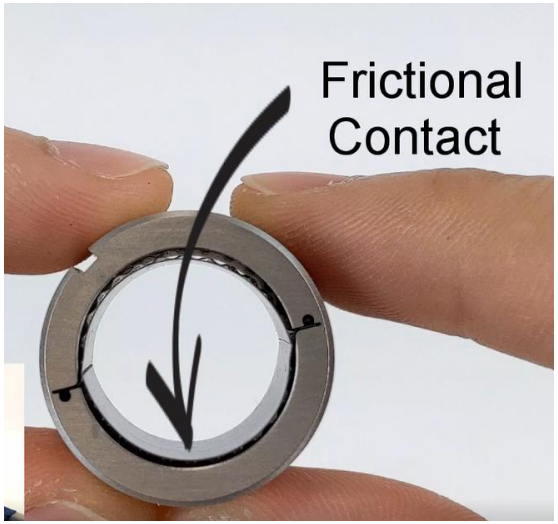
Air Foil Bearings



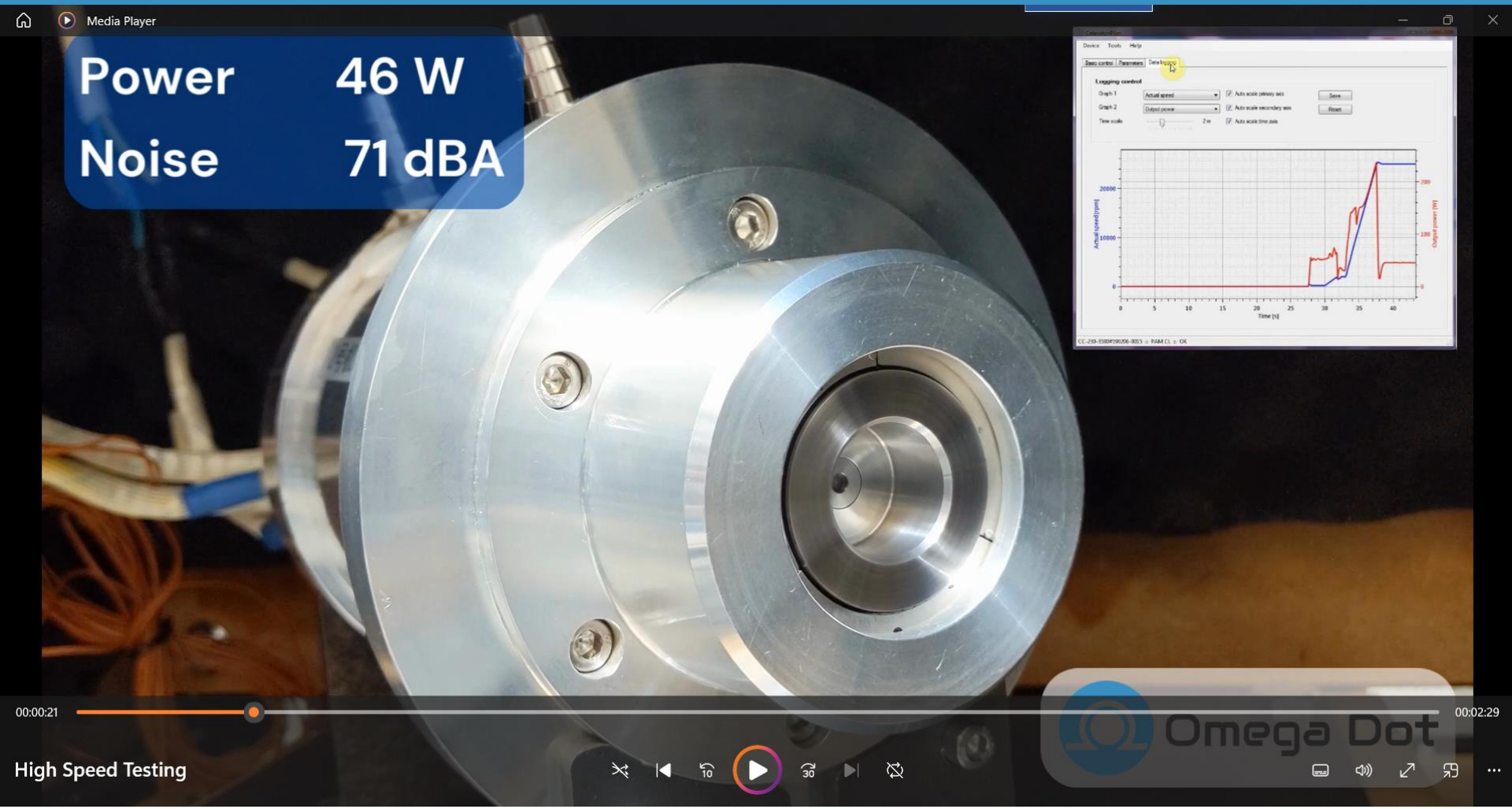


Challenge for Air Foil Bearings
Friction and Wear

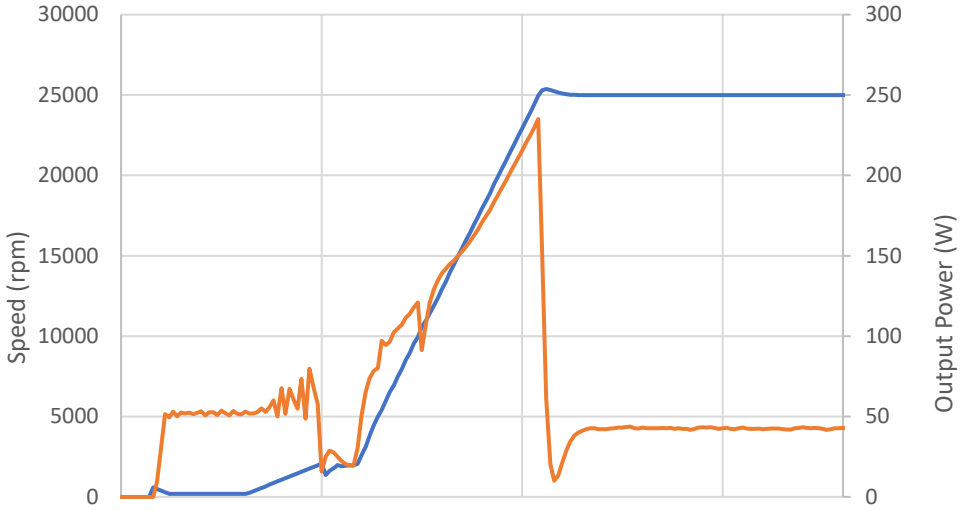


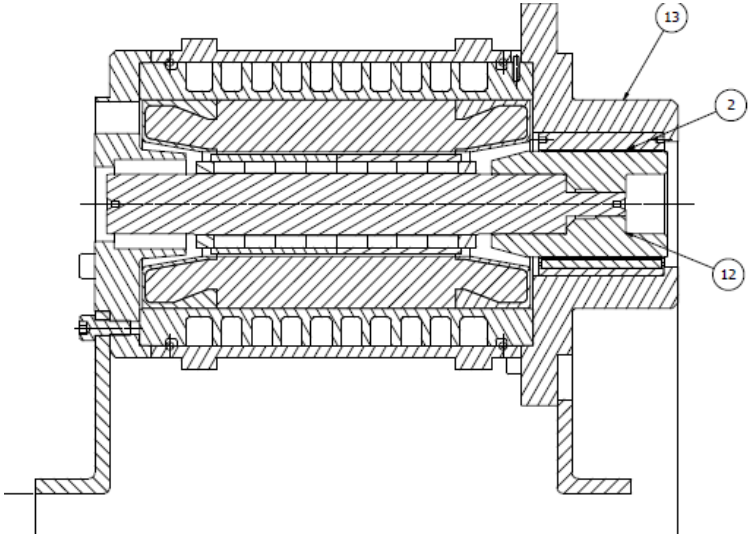


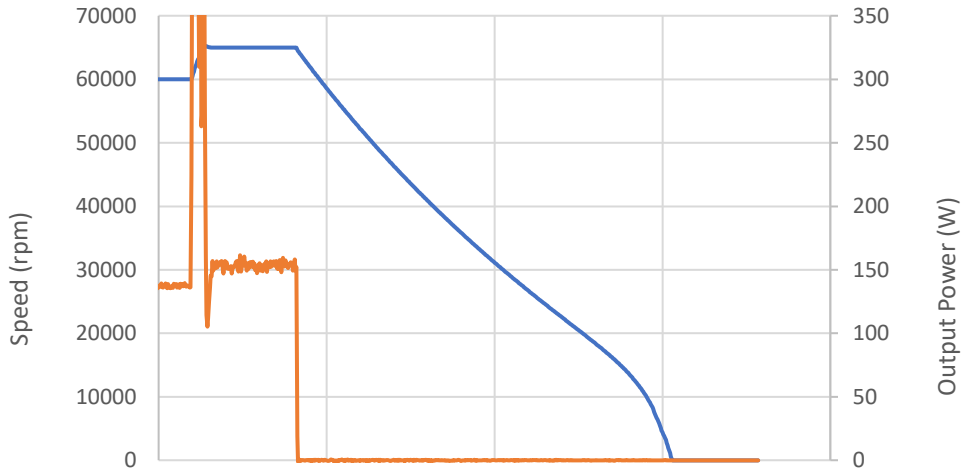
Video - Air foil bearing testing on High-Speed Spindle



Air foil bearing testing on High-Speed Spindle







Bearing life requirements from OEM Manufacturers

Compressor Size (kW)	Required Start-stop cycles	Application	Sector
15 kW	75,000	Air Compressor	Aerospace
14 kW	200,000	Air Compressor	Automotive
250 kW	4,000	Micro Gas Turbine	Power Generation
10 kW	250,000	Air compressor	Automotive
N/D	5,000	Compressor	Aerospace
N/D	20	Engine	Aerospace

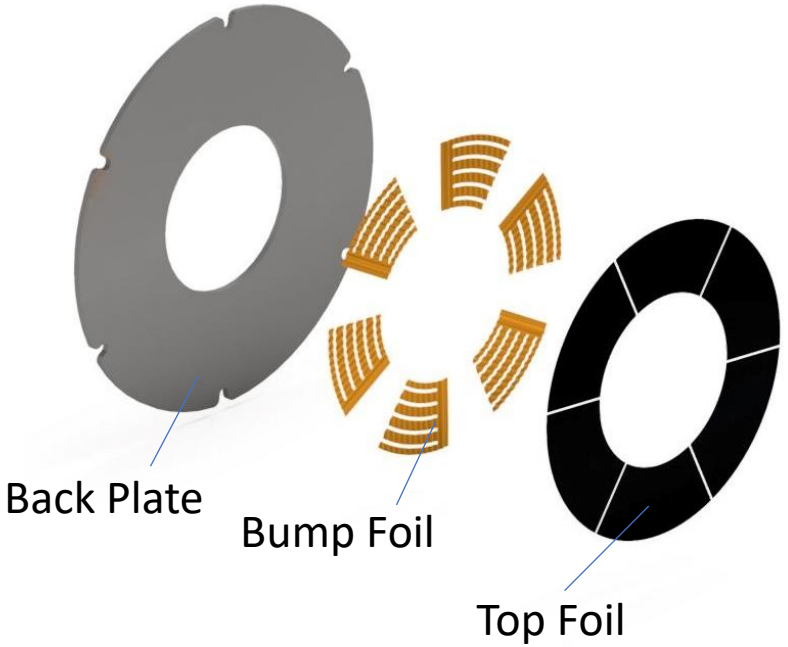
Difficulties of Air Foil Bearings from OEM

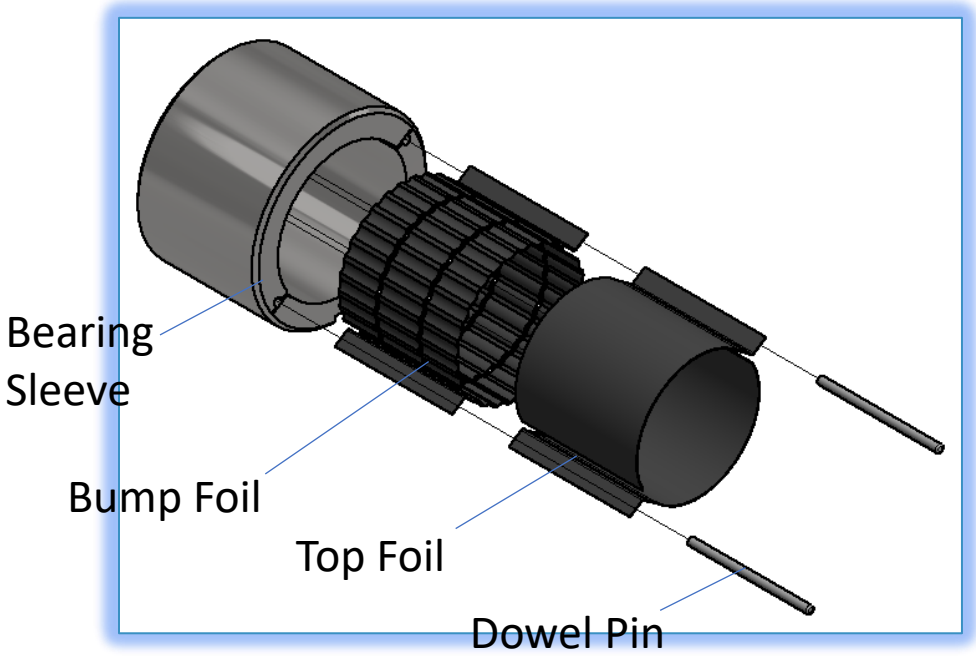
"… hereby we provide you the picture of our old air bearings that worked 450 start-stop cycles…. most of them cannot be used after 700 cycles."

"… indeed it's an old one which probably suffered… We were also surprised by this virtual absence of bumps and also the clearance seemed to us really tight…."

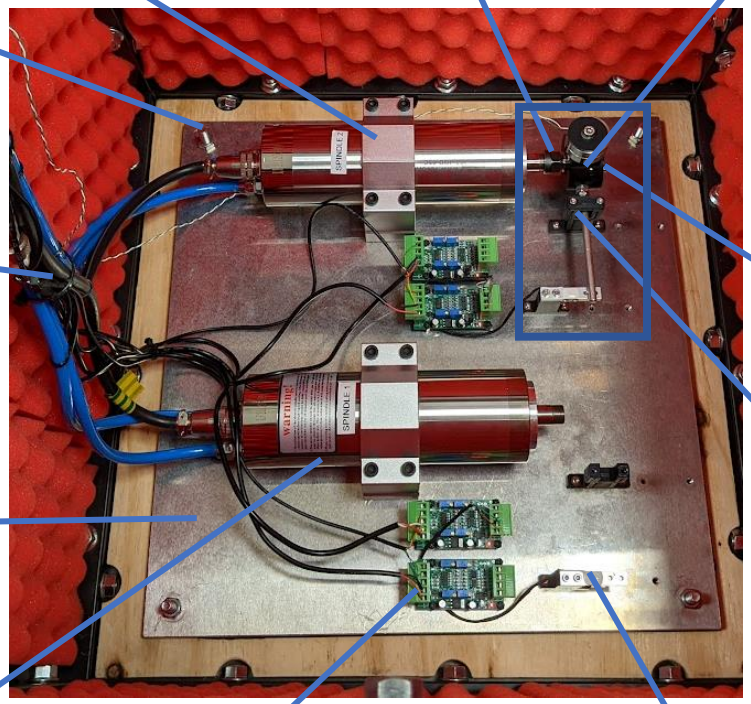
Radial Air Foil Bearing Testing Objective

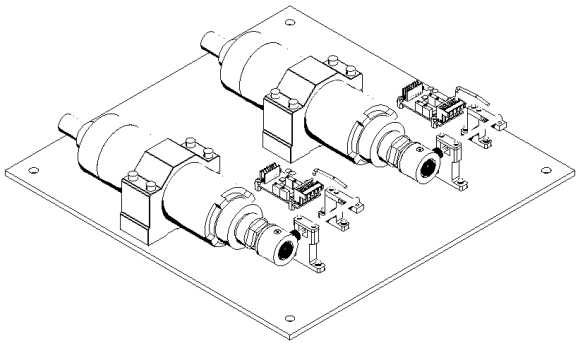
- Cyclic testing of radial bearing
- Work package lead by Omega Dot



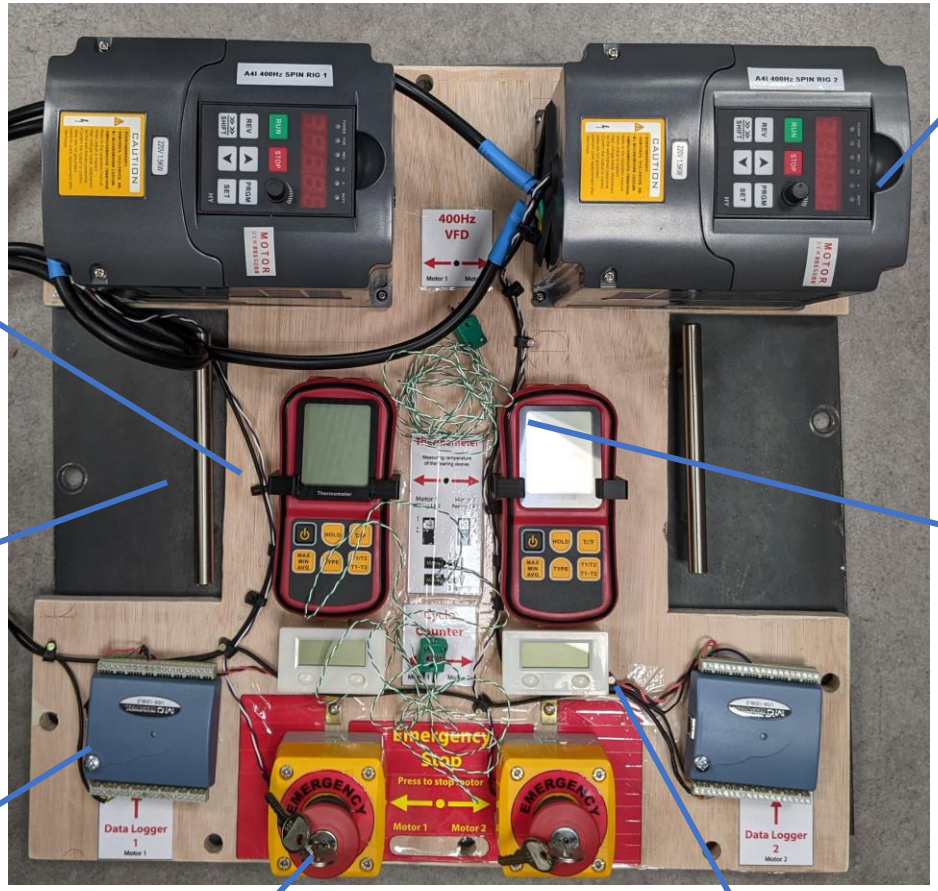


Radial Bearing
Omega Dot Cyclic Test Rig Design





Radial Bearing
Omega Dot Data Set Up



Inverted Drive
VFD Top

Electrical
Assembly Board

Mounting Crate
Lid with Handles

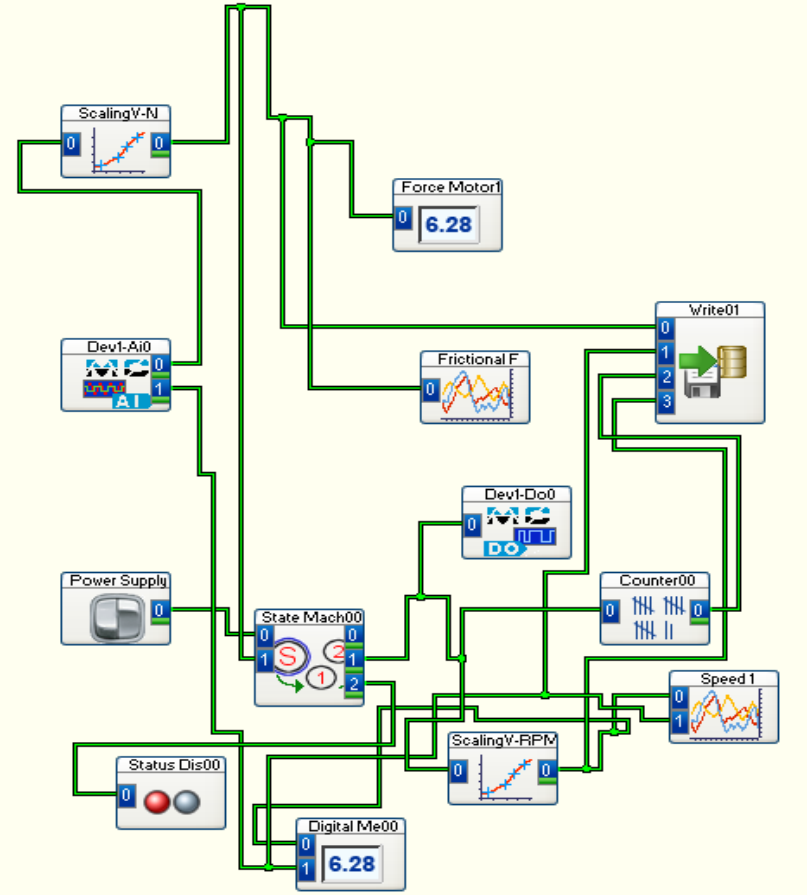
Thermocouples
Attached to
Temperature Displays

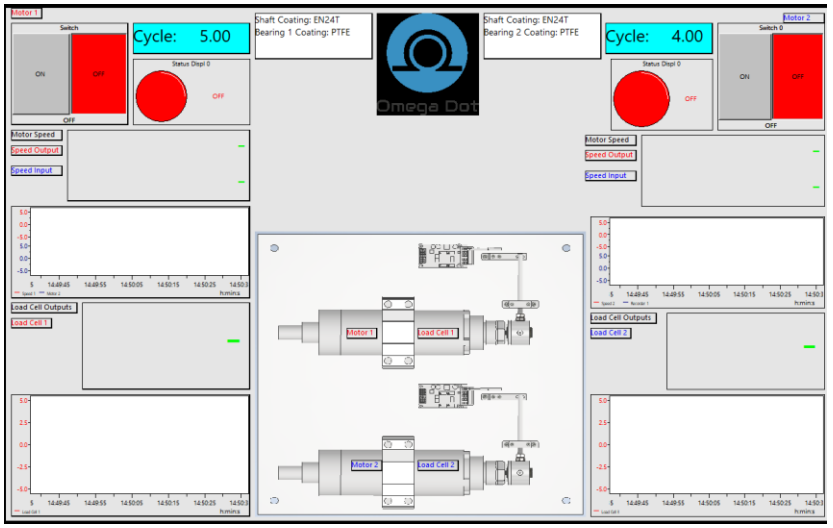
USB-1208 FS 12-Bit
50KS/s,
Multifunctional
USB Data
Acquisition Device

Emergency Stop Button

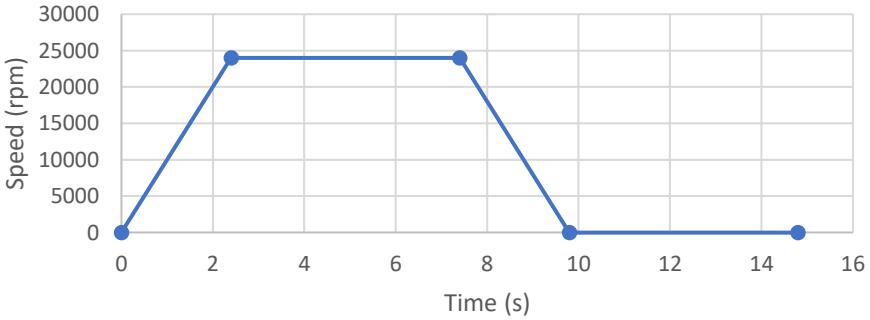
Cycle Counter

Radial Bearing
Automated Cyclic Testing

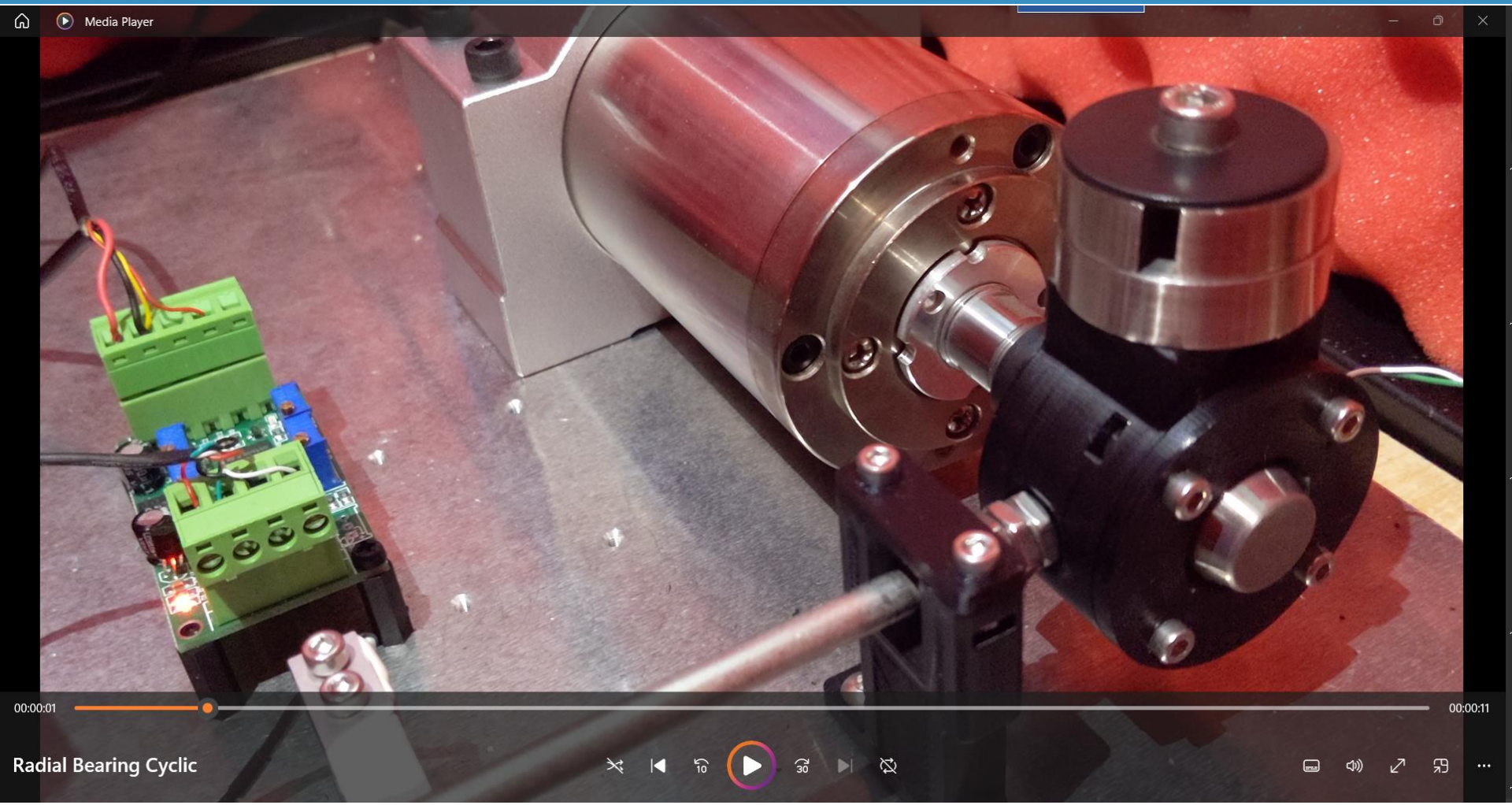




Elements of one complete cycle on the start-stop rig

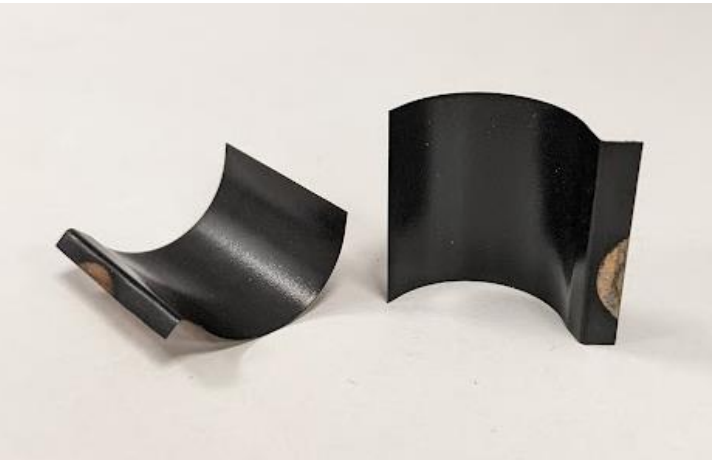


Video
Radial Bearing Cyclic Testing



Radial Bearing
Coating Combinations Selection

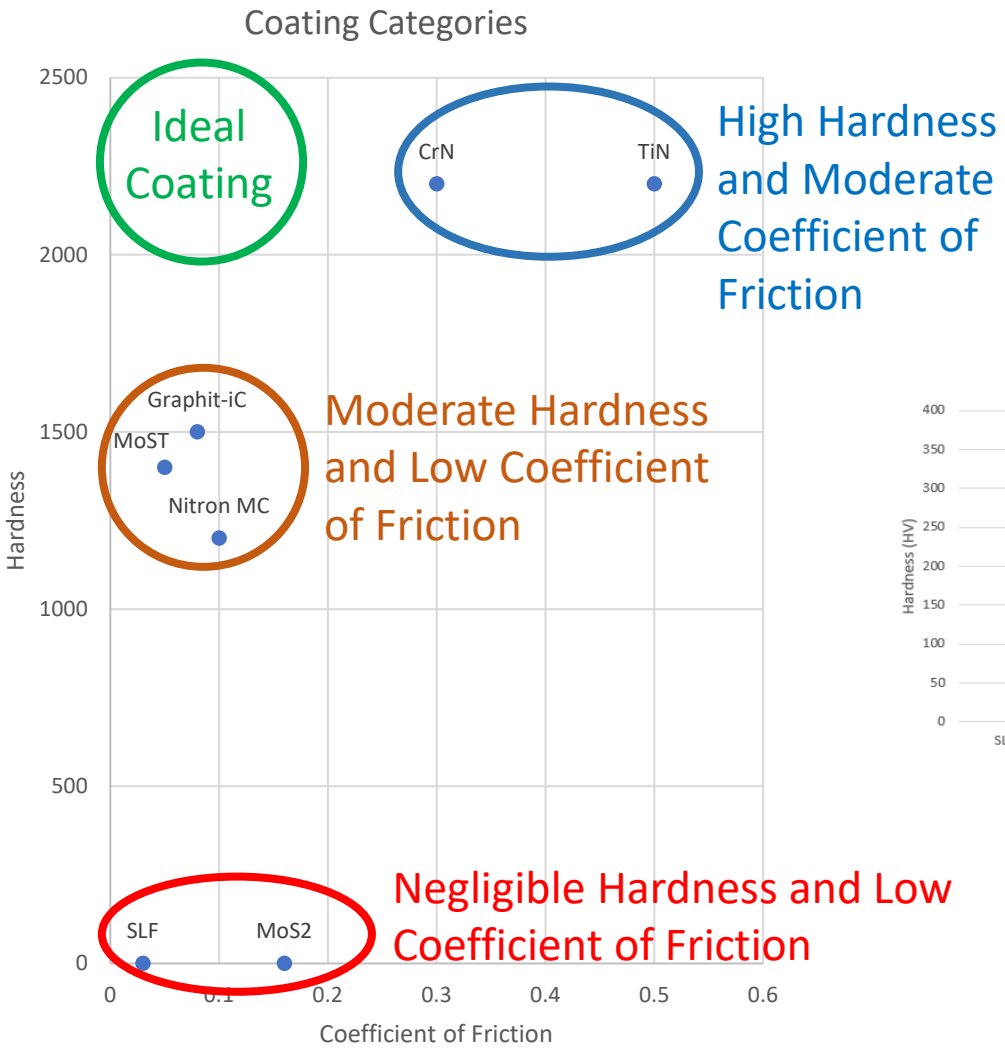
- EN24T Shaft – to be coated
- Teflon (PTFE) on Foils

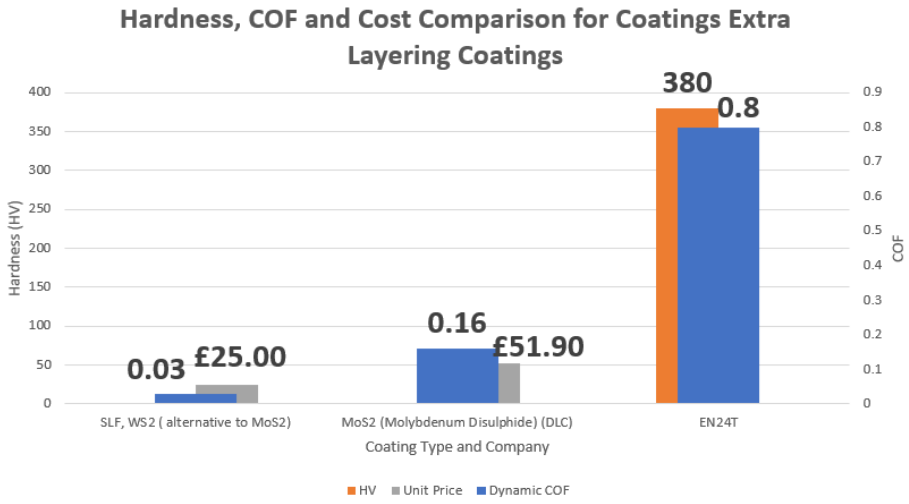


Coating Options on the Shaft

Company	Coating	Thickness (microns)	Dynamic COF	Hardness (HV)	Unit Price
Wallwork	Titanium Nitride	1-4	0.3	2300	£19
	SLF, WS2 (alternative to MoS2)	0.5	0.03	0	£25
	CrN (Chromium Nitride)	1-4	0.45	2300	£19
	Nitron MC	1-4	<0.1	1200	£24
Jackson Plating	Titanium Nitride				
	Hard Chrome				
Teer Coatings	Titanium Nitride	2-4	0.5	2200	£111
	MoST	1-2	0.05	1400	£111
	CrN (Chromium Nitride)	2-4	0.3	2200	£20
	Graphit-iC (DLC)	2-4	0.08	1500	£111
Carter Bearing	Titanium Nitride	1-4	0.3	2300	£52
	MoS2 (Molybdenum Disulphide) (DLC)	< 0.1	0.16	0	£52
Techniplant	Hard Chrome			1245	
	Crionising Chrome			2300	
	Eas-i-dure				

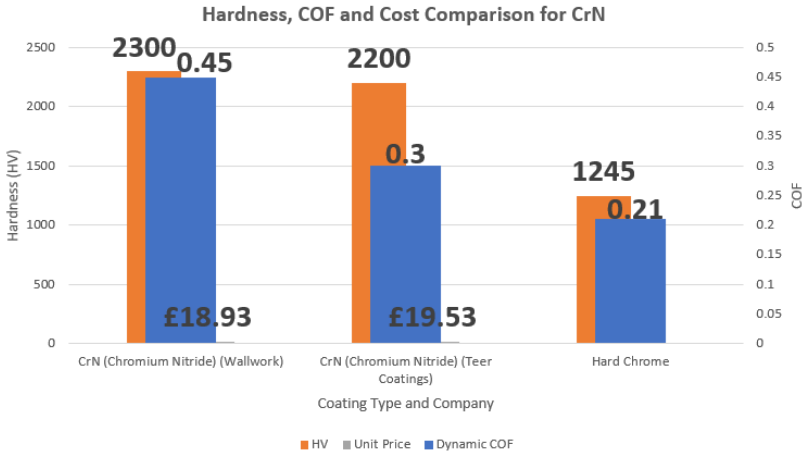
Coating Options

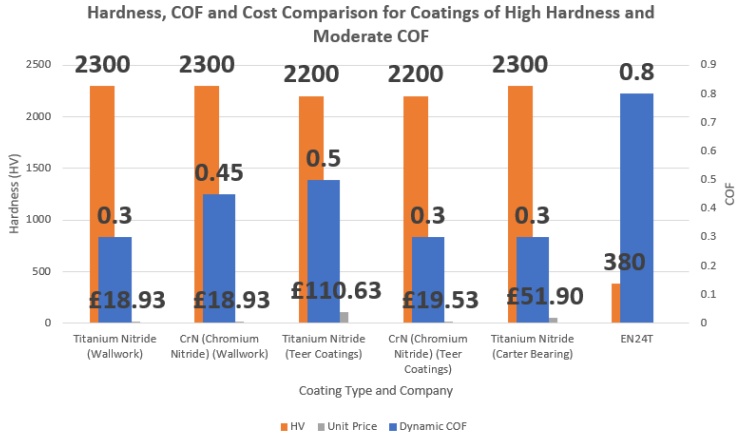




CrN

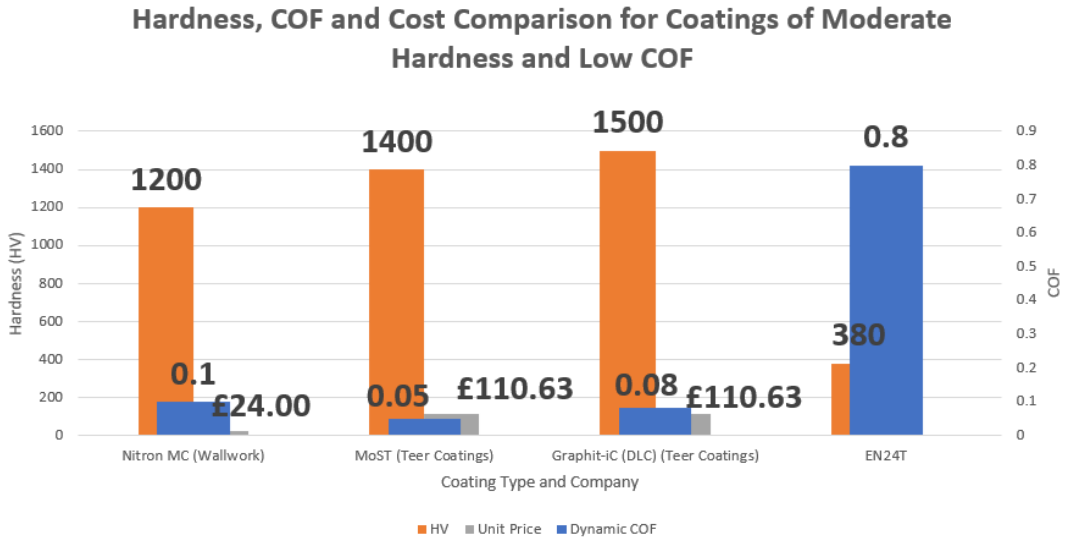
- High wear, high abrasion and high oxidation resistance
- 2-4 microns thick
- 2200 (HV 0.05)
- 0.3 coefficient of friction





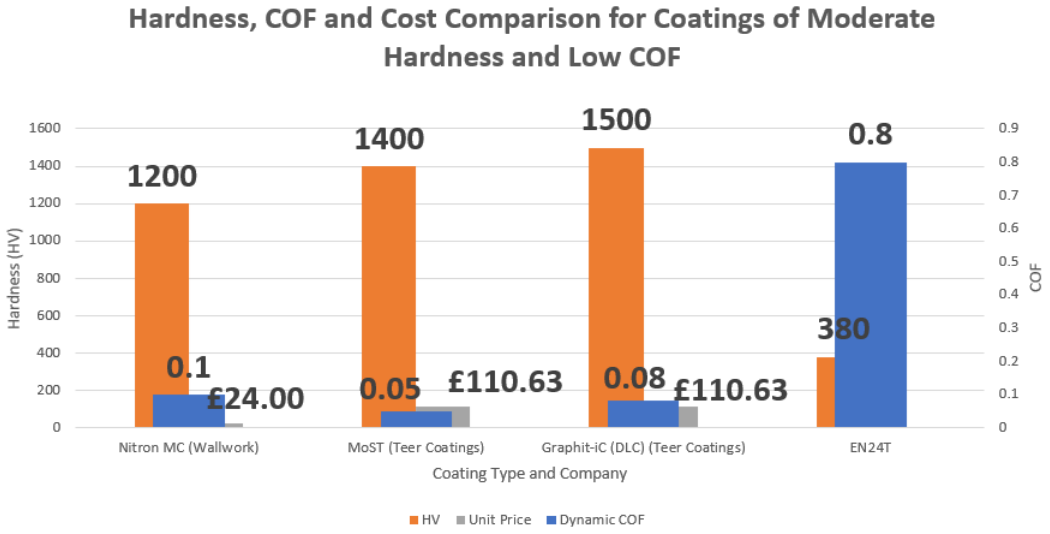
MoST

- Patented MoS2, metal solid lubricant coating
- 1-2 microns thick
- 1400 (HV 0.05)
- 0.05 coefficient of friction

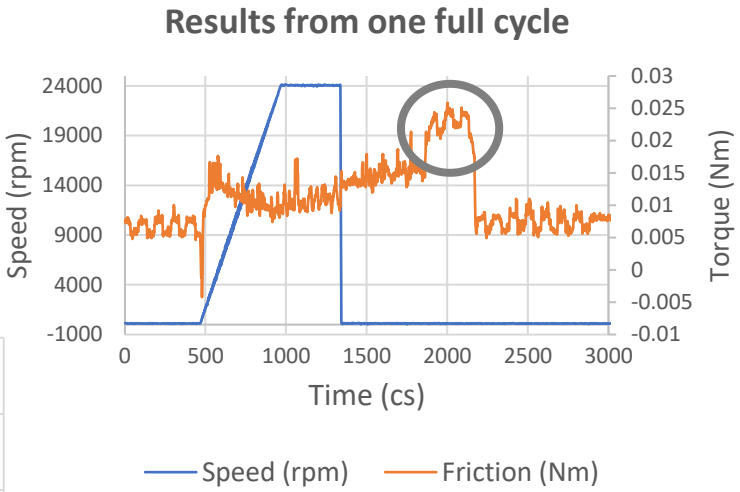


Nitron MC

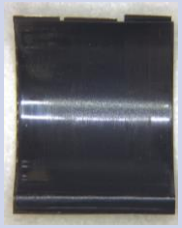
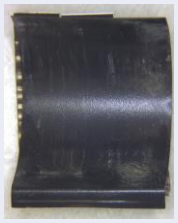
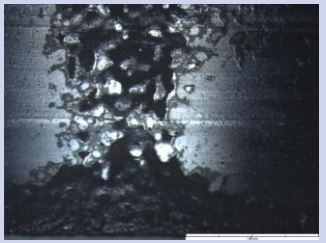
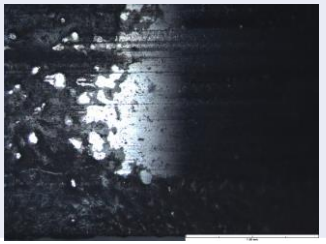
- Hard tungsten carbide particles in a soft amorphous carbon matrix
- 1-4 microns thick
- 1200 VPN
- <0.1 coefficient of friction



PTFE VS Uncoated EN24T Running-in Period

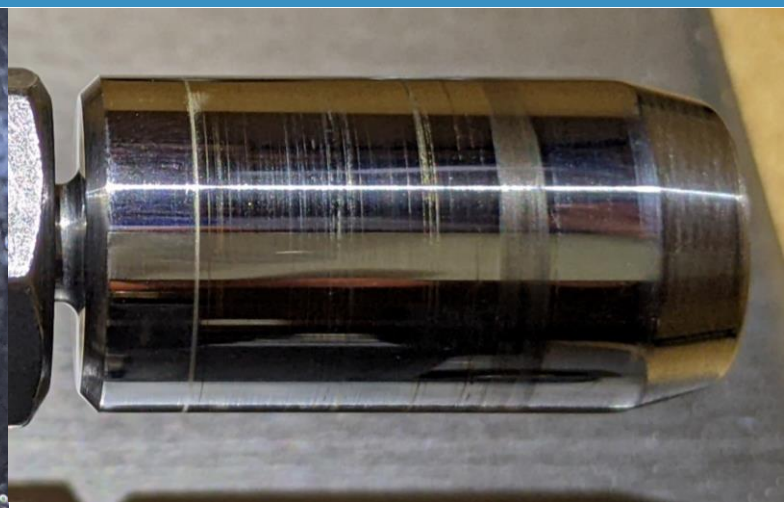


Stage 1 – Cyclic Testing to 10k cycles Comparison

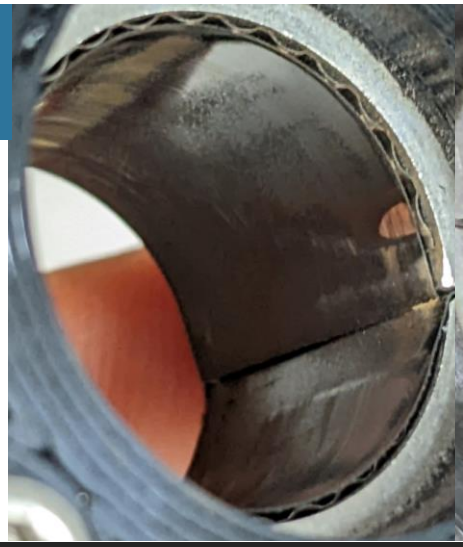
Shaft Coating	Shaft	Foil	Microscopic
Uncoated EN24 T			
CrN			
MoST			
Nitron-MC			

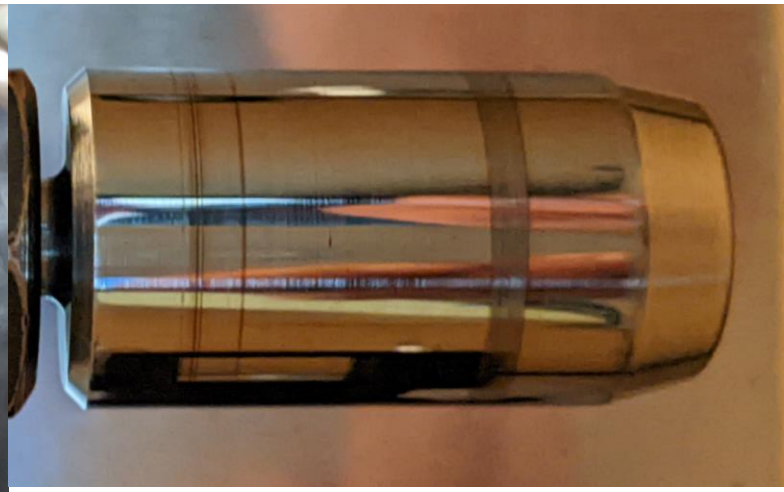
Stage 2 – Testing to 250k cycles
Uncoated EN24T vs Teflon

10k
(41 hrs)



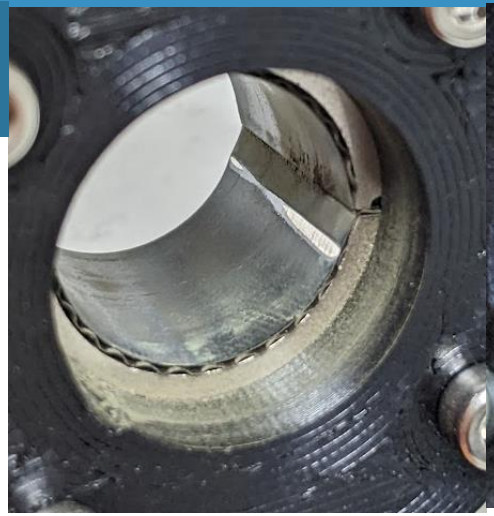
250k cycles
(43 days)



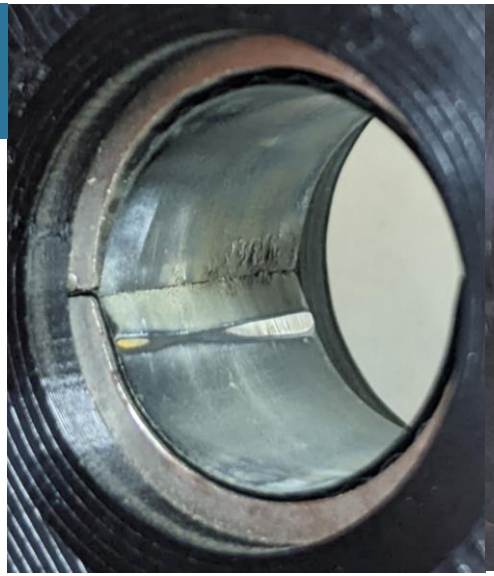


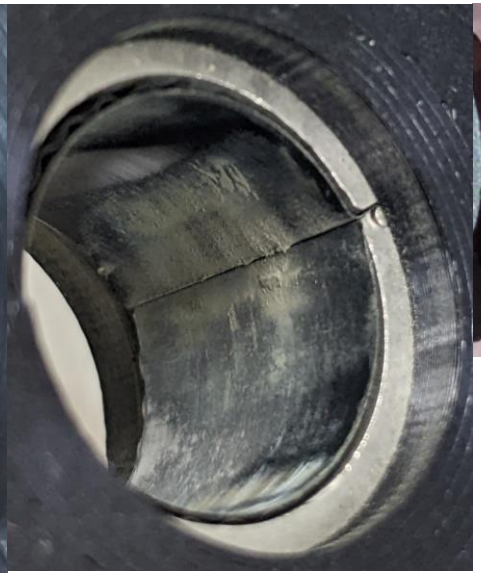
Stage 2 – Testing to 250k cycles
CrN Coating vs Teflon

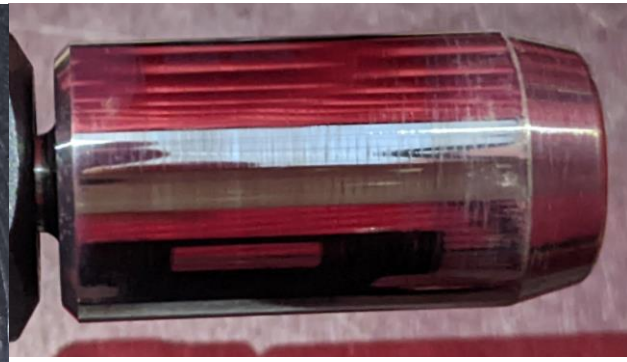
10k
(41 hrs)



250k cycles
(43 days)

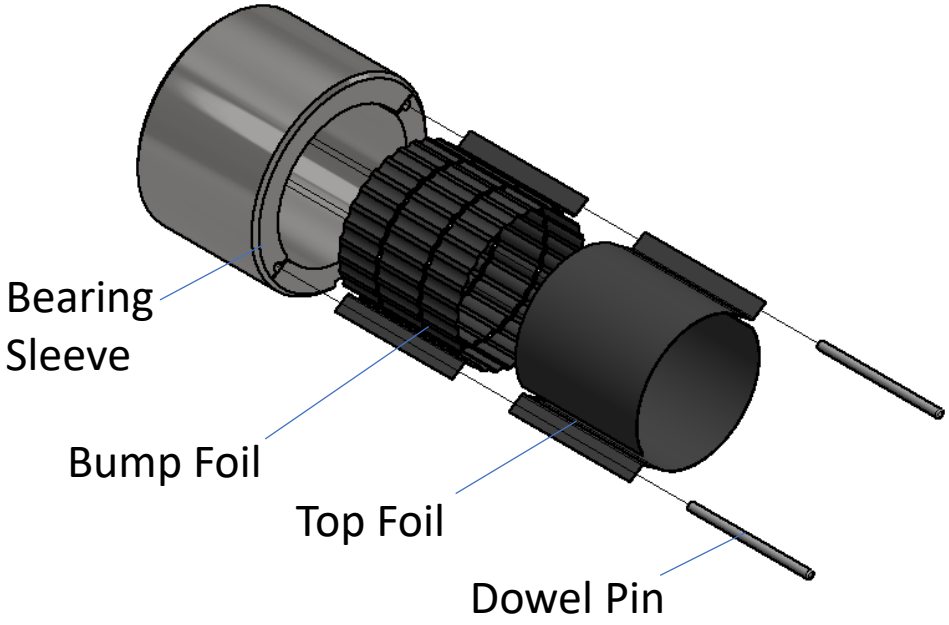


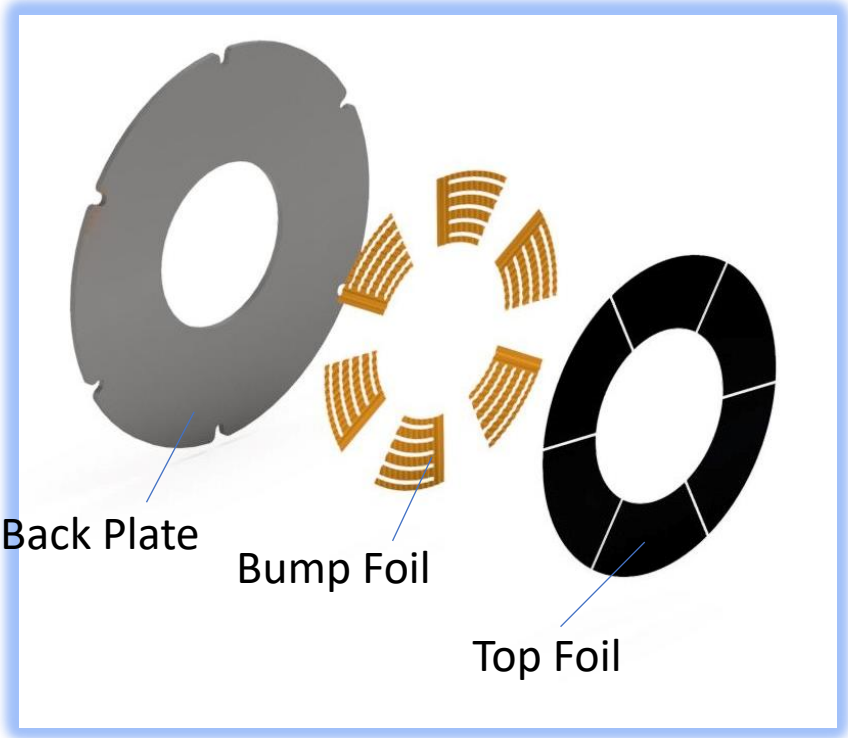




Thrust Air Foil Bearing Testing

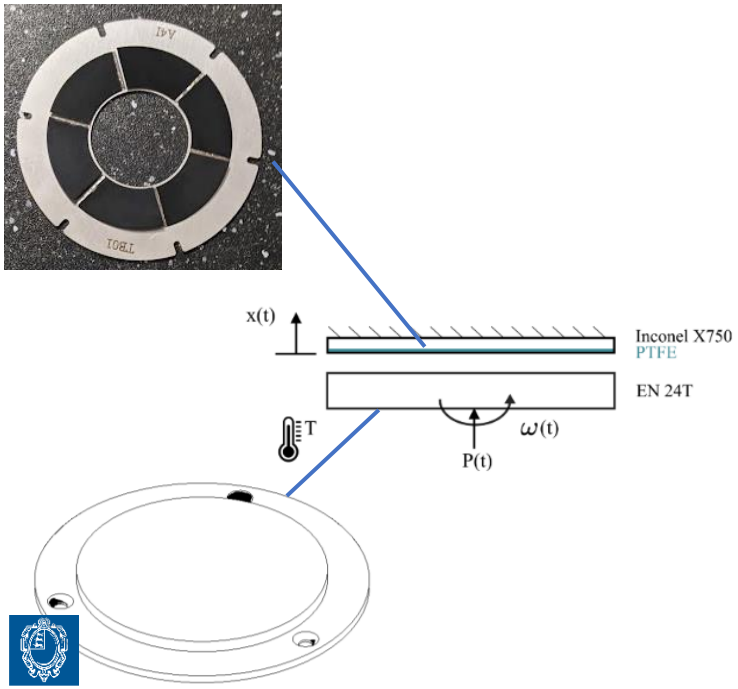
- Friction and wear testing on thrust bearing configuration.
- Work package lead by NPL.

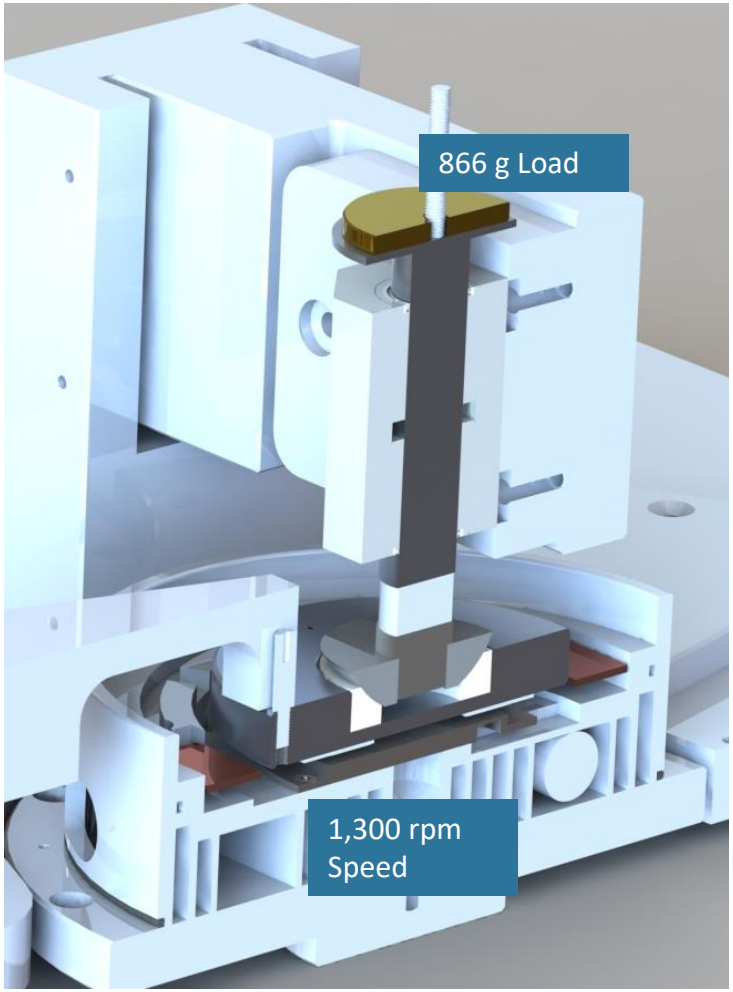




Thrust Bearing Testing Continuous Run

- Continuous contact testing on thrust bearing for 9 days (250k cycles)
- Measuring friction, temperature and displacement

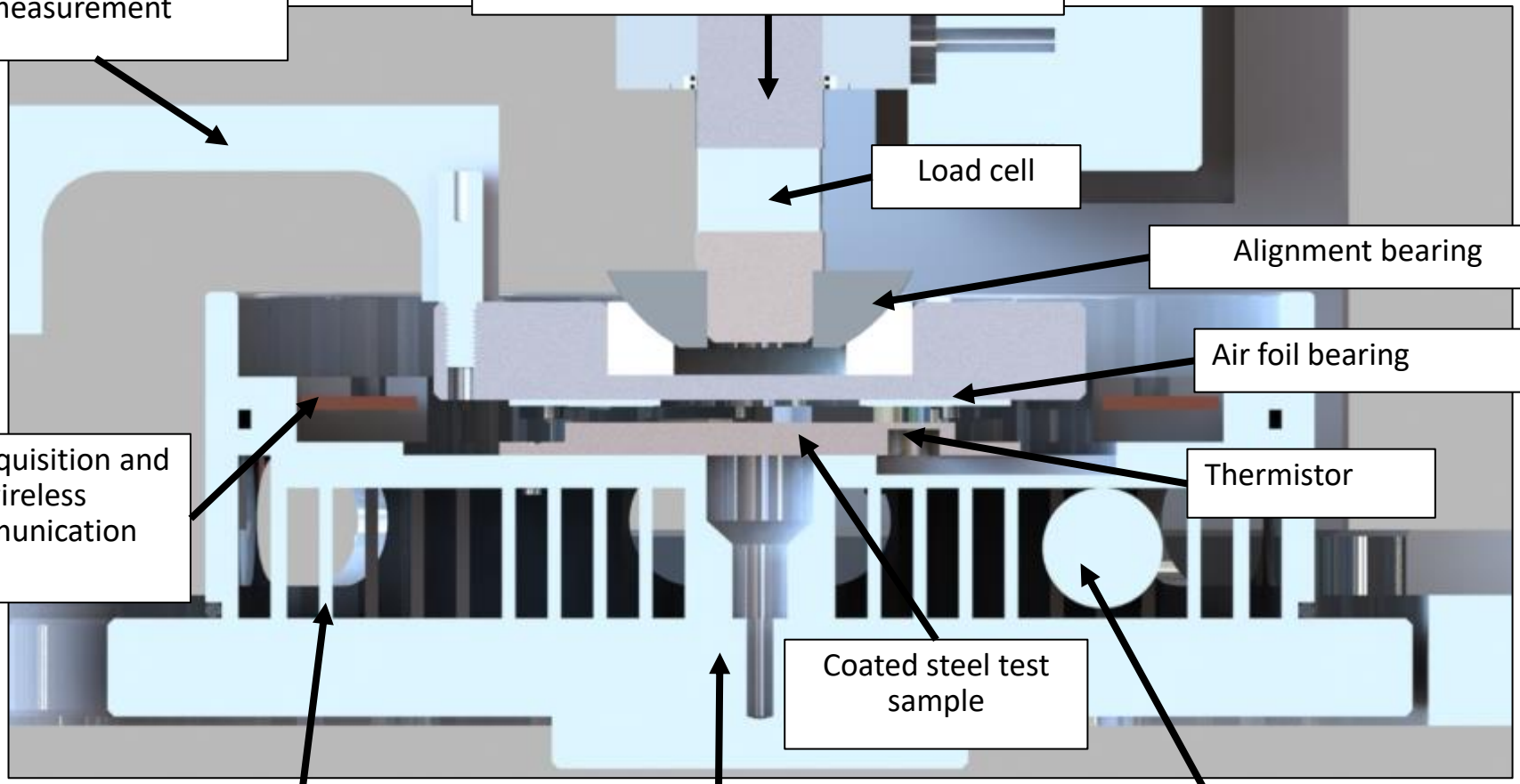




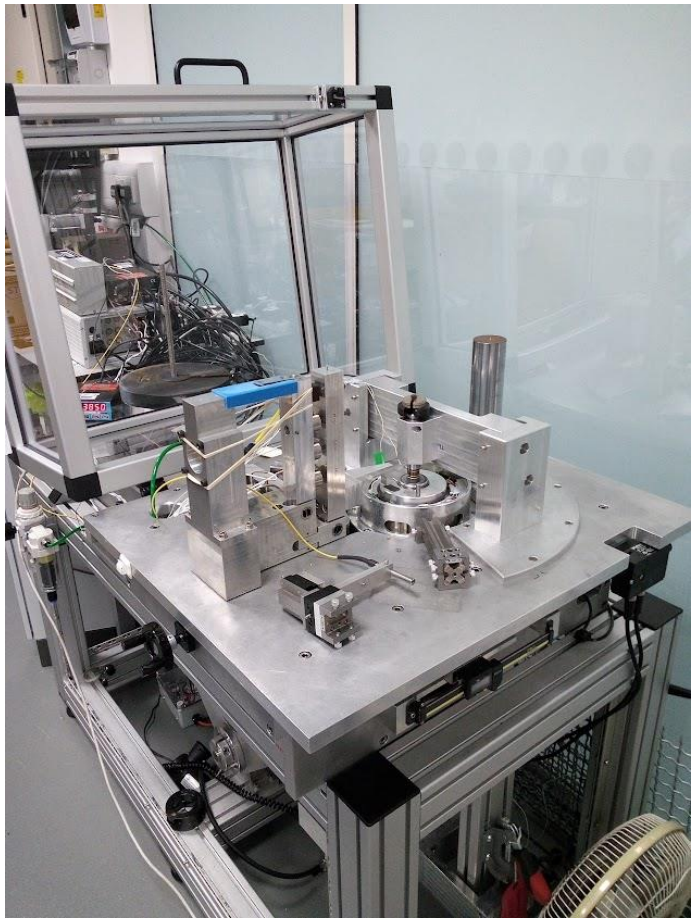
Images from NPL, Continuous Testing Rig Set Up

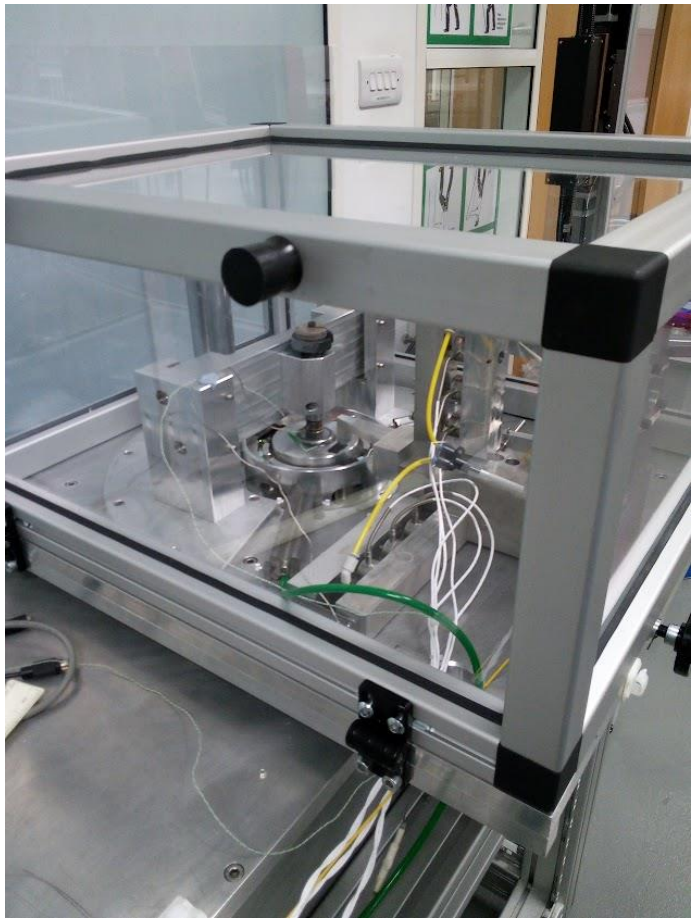
NPL National Physical Laboratory

Thrust Bearing
NPL Continuous Contact Testing



Thrust Bearing
NPL Disc-on-Disc Test Rig





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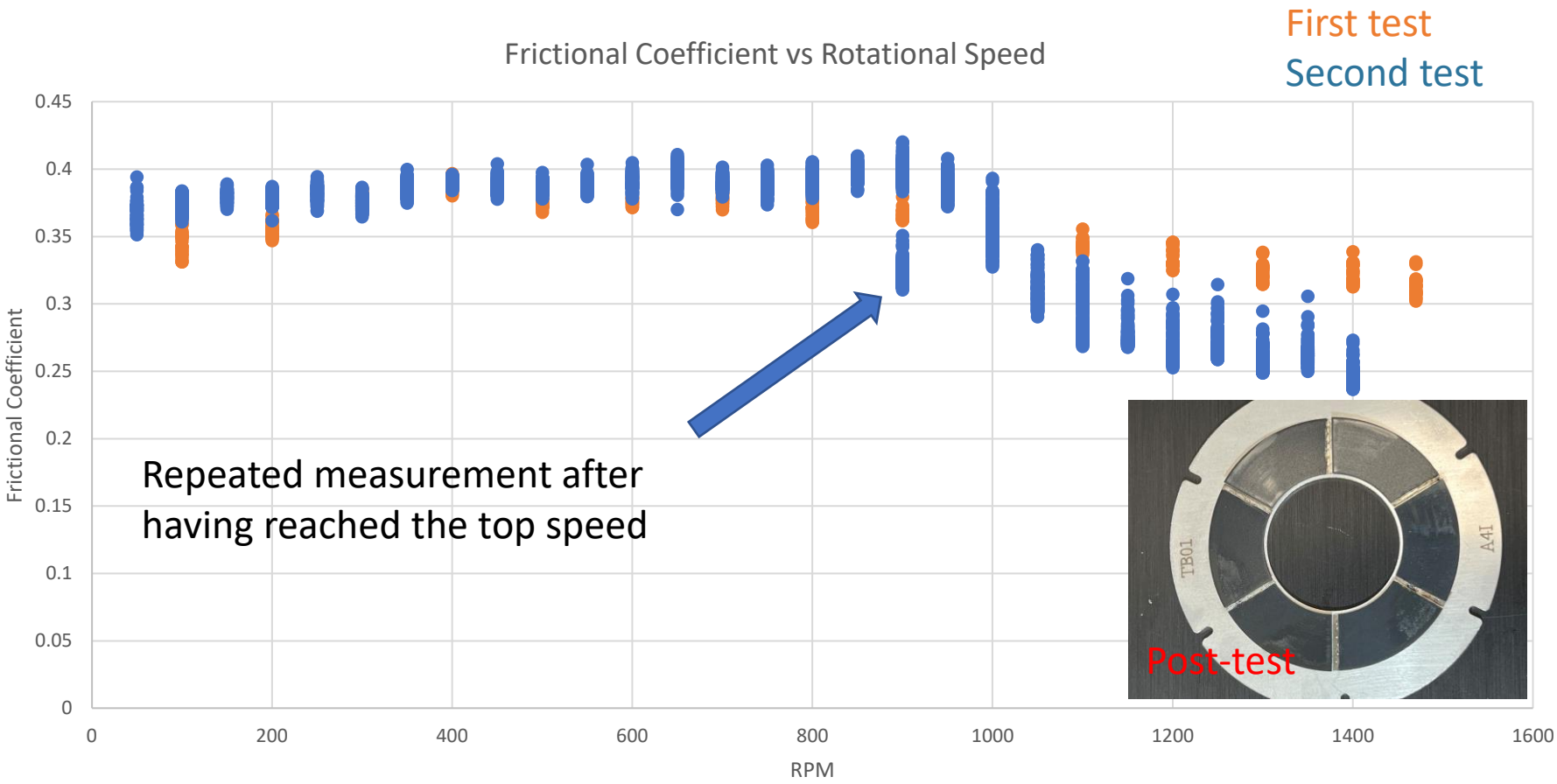
Video
NPL Disc-on-Disc Test Rig

Friction vs Speed Test
No Aerodynamic lift confirmation



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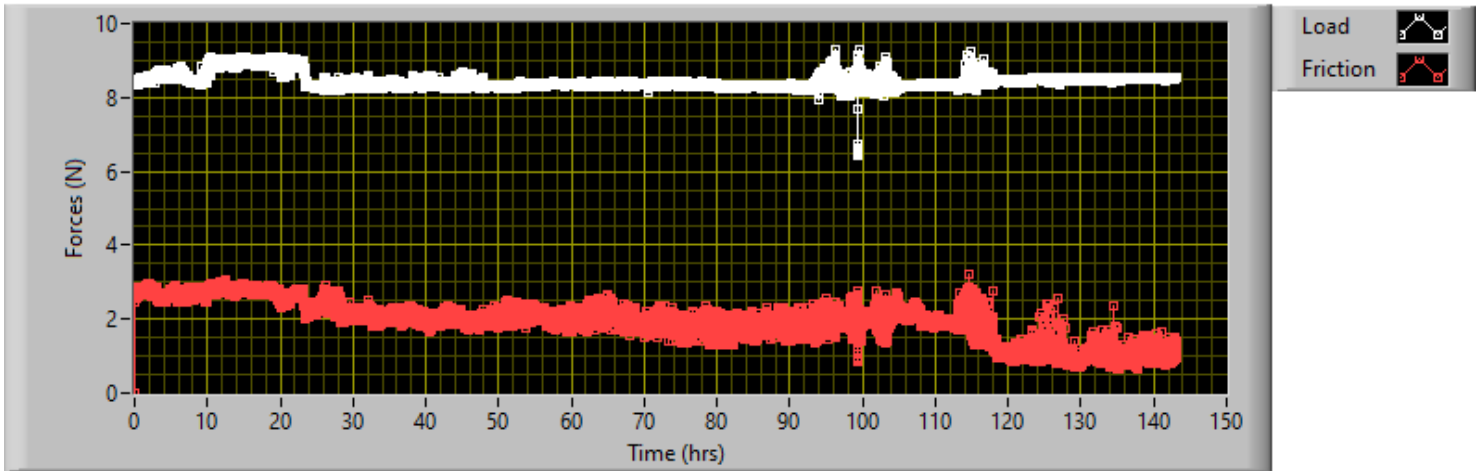
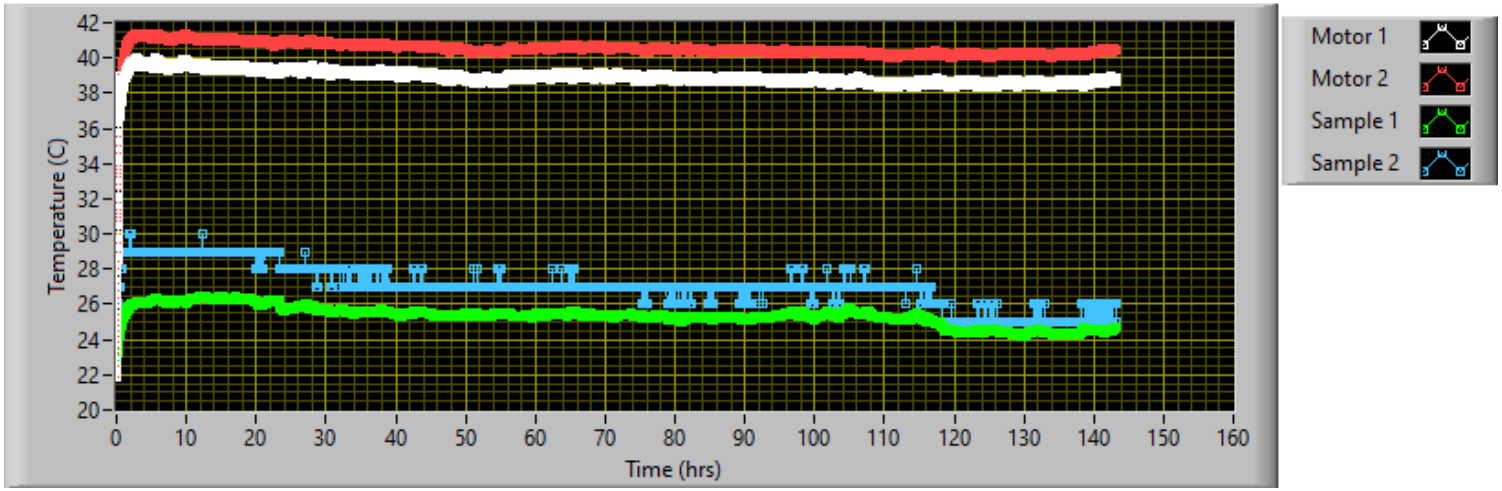
Thrust Bearing Test at 1,300 rpm
Uncoated EN24 T vs Teflon

Load and Frictional Force



Temperatures



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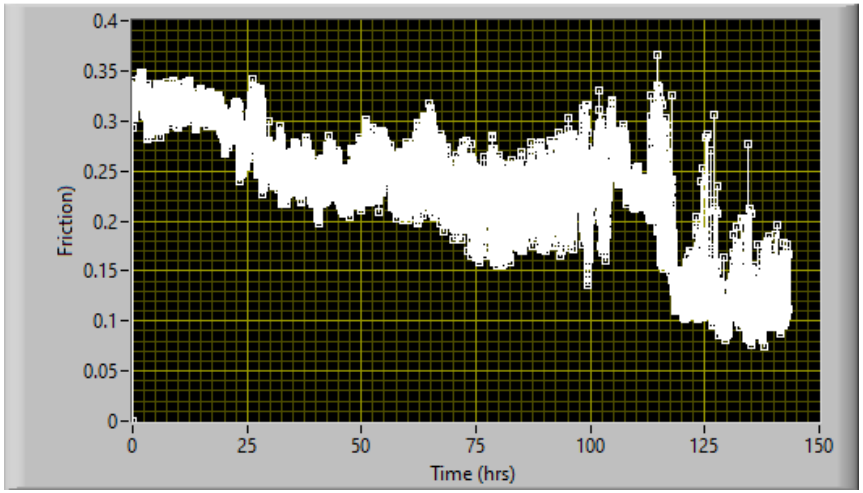
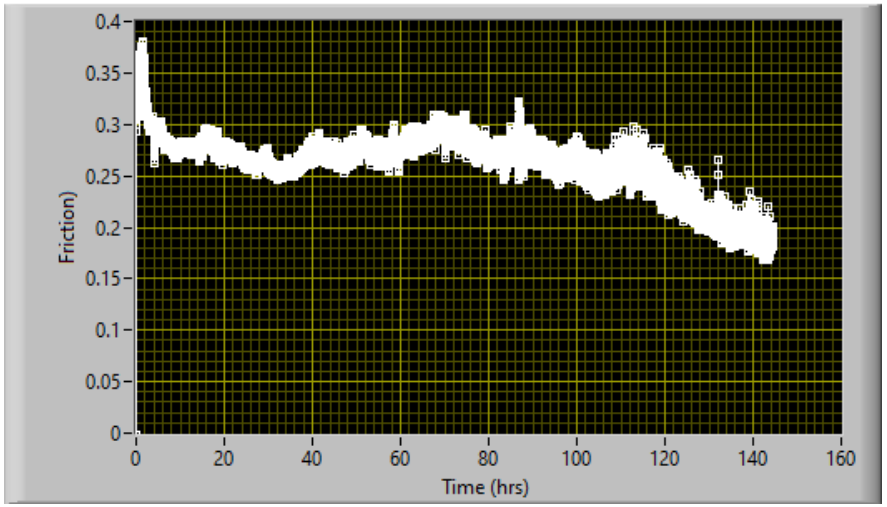
Thrust Bearing Friction Results @ 1,300 rpm Coating Comparison over 6 days

- Friction drops after running

Friction vs Time: TB02 vs Uncoated Steel



Friction vs Time: TB03 vs CrN



- The friction against CrN is generally higher and less variable

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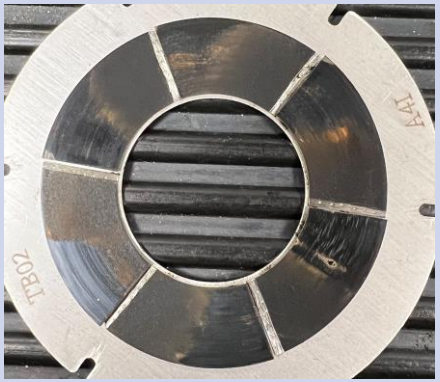
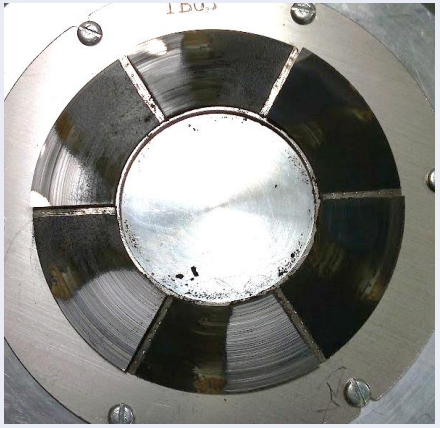
Thrust Bearing Outcome
Coating Comparison over 6 days

Shaft Coating	Disc	Foil
Uncoated EN24 T vs Teflon		
CrN vs Teflon		

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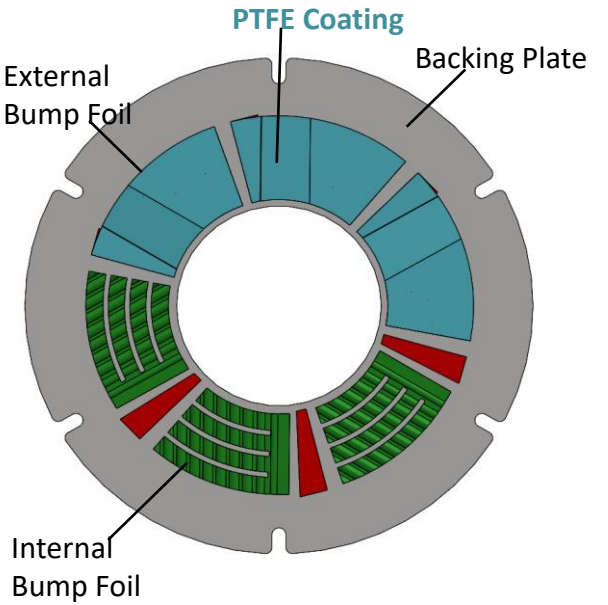
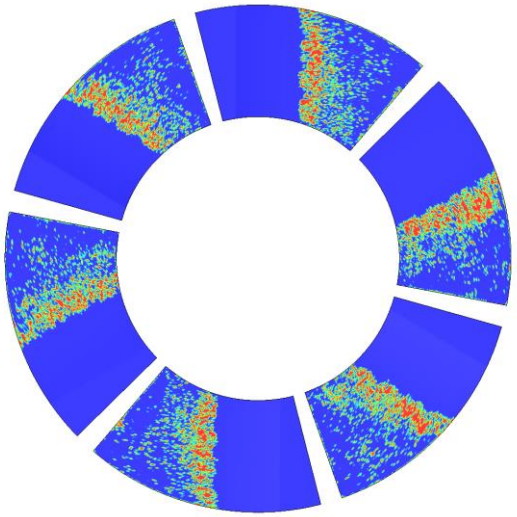
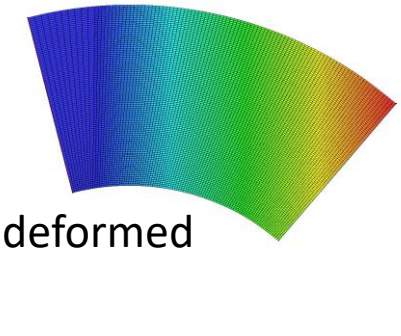
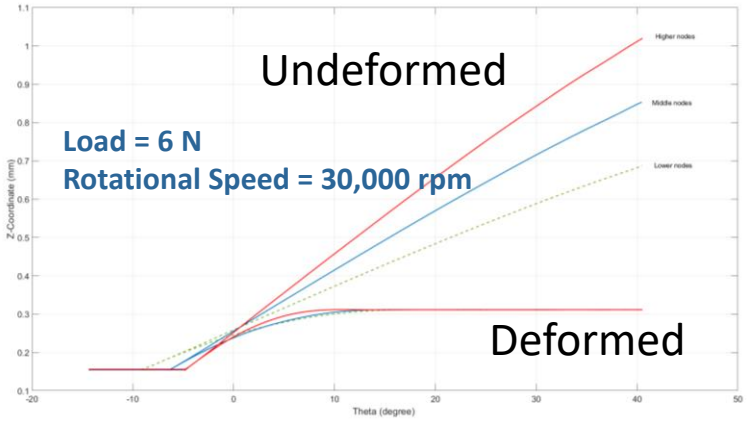
Modelling of Thrust Bearing

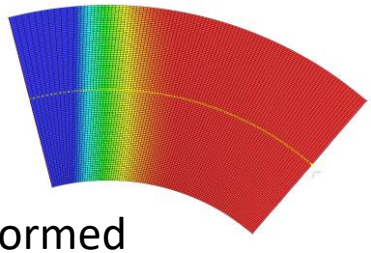






Undeformed

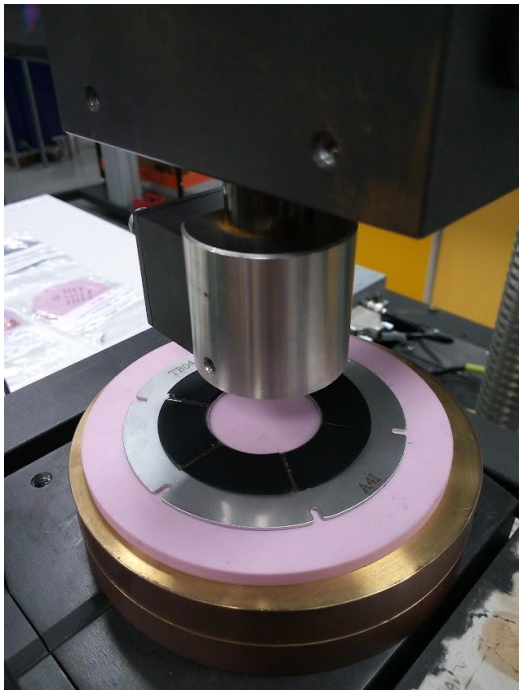


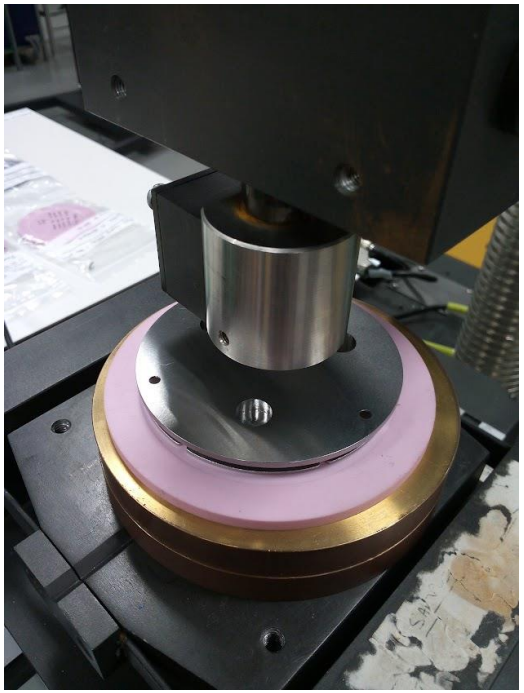


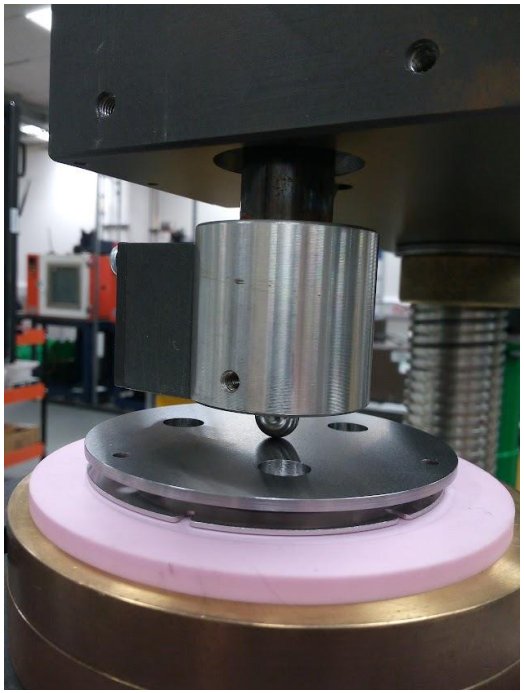
Deformed

Thrust Bearing Stiffness Measurement

- Modified instrumented scratch tester to determine displacement vs load







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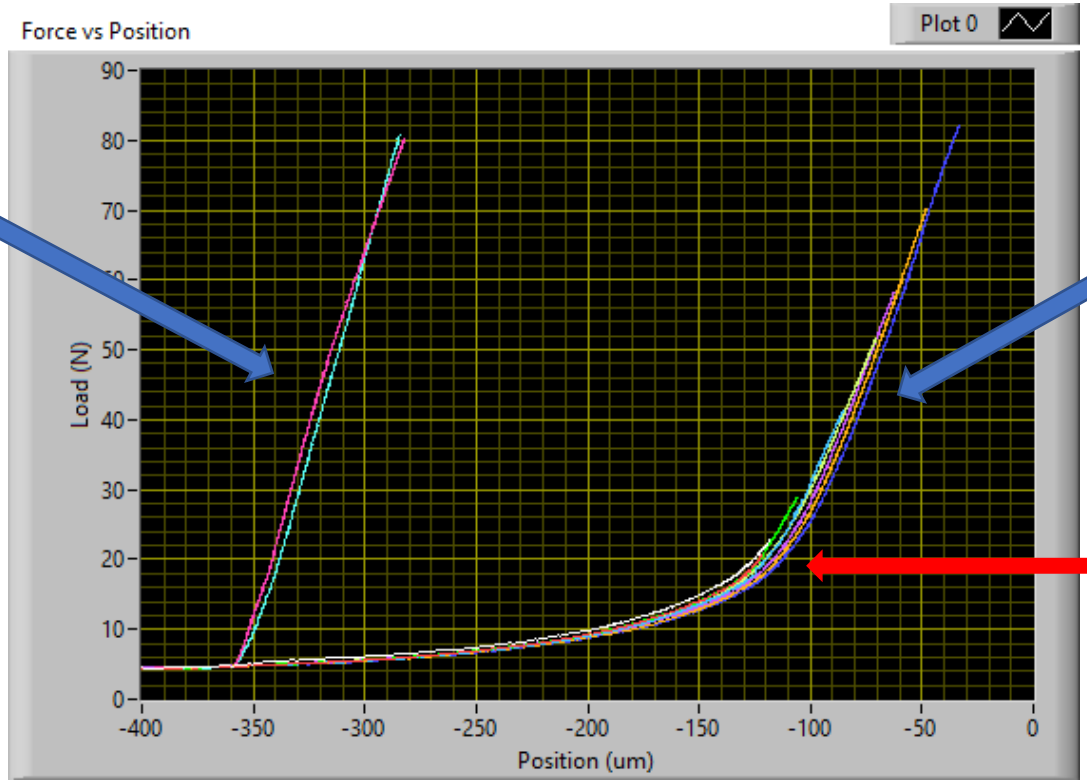
Thrust Bearing Stiffness Measurement

Machine Stiffness



Bearing Compliance

There is a gradual stiffening. something happens around 20N,

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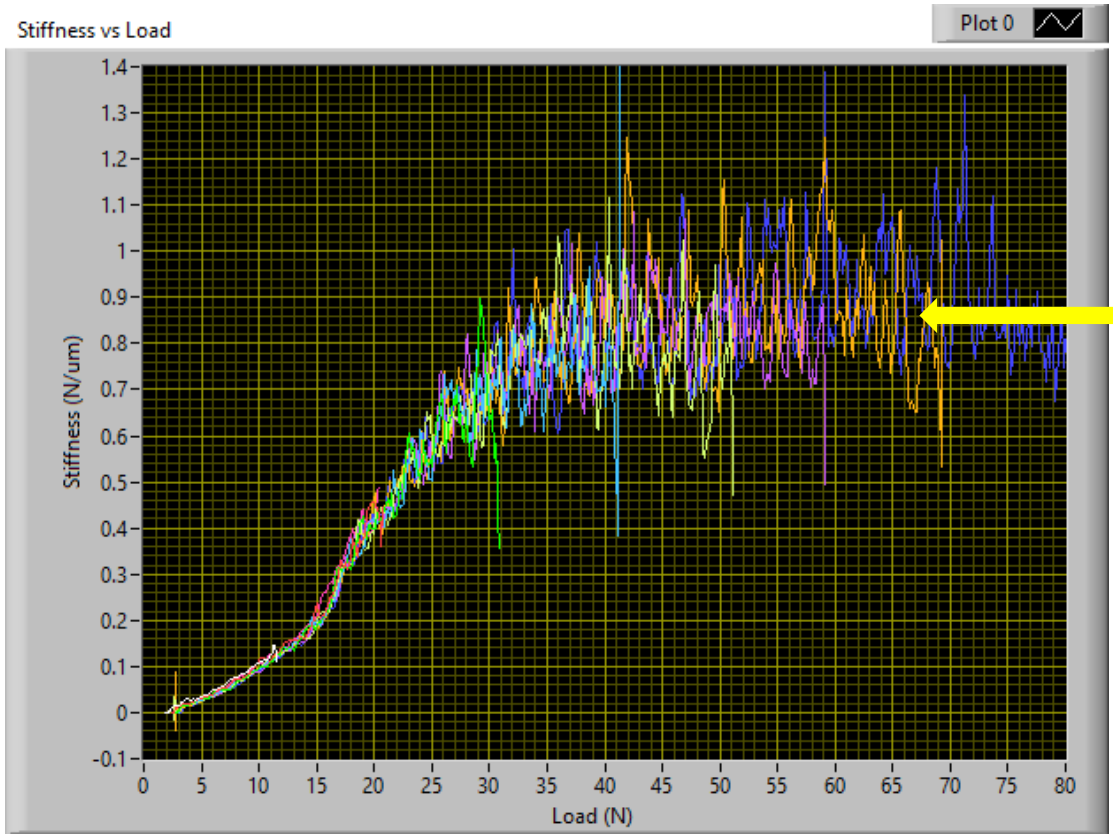
Thrust Bearing
Stiffness Measurement



Max Slope
~0.85 N/µm

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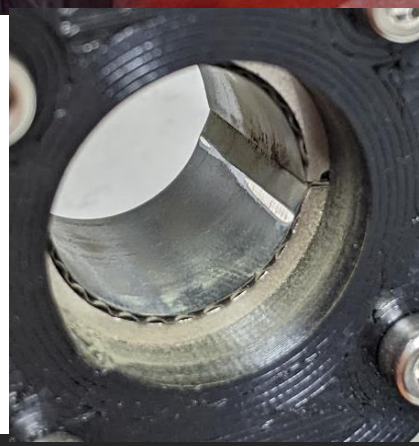
Conclusion

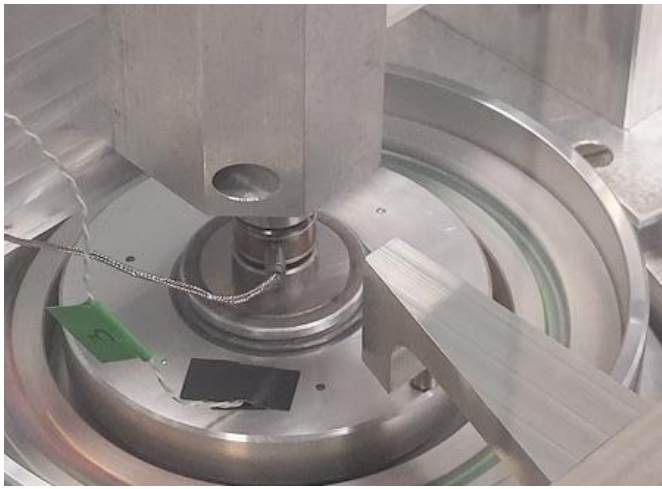
- Most air foil bearings has Teflon (PTFE) coatings on the top foils to improve the friction and wear resistance during start-stop cycles. Mainly because its soft, compliant and low cost.
- Bearing counter face, either shaft or disc runner is generally hard material and can be enhanced with coating.

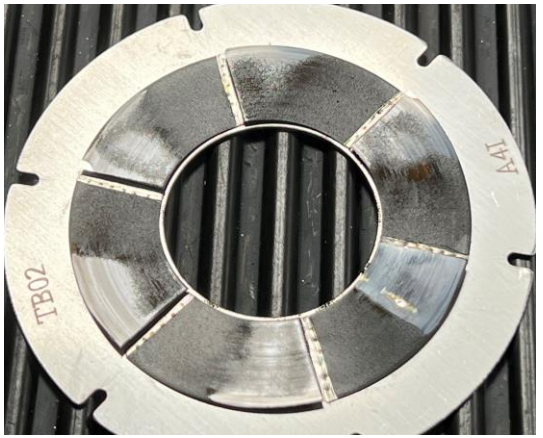
- Our tests shows our radial air foil bearings can exceed 250,000 start-stop cycles.
- Cyclic test results showed the great majority of the bearing wear activity occurred within the first 5,000 cycles, and localised at the trailing edge of the bearing
- Our results showed CrN to be a good coating choice on the counter-face material



Conclusion

- NPL conducted continuous contact testing of our thrust bearing to simulate rubbing of up to 250,000 cycles.
- Their results also suggests running-in within the first 100 hours, where the coefficient of friction drops from 0.3 to ~0.15.
- Wear on the top foils also shown to be localised at the trailing edge.
- Their results showed our thrust bearing can exceed continuous rubbing of 6 days, simulating 167k cycles.





Acknowledgements

Omega Dot

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UKRI Innovate UK KTN

A4I Analysis for Innovators