

Overview on services and heritage



# Tribo-Testing for Space

Services to validate your materials and  
components for Space Mechanisms

AAC (C. Jogl, R. Holzbauer, A. Merstallinger)

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Key areas of consulting, testing, research and development activities:



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# History of AAC in Space

## Space Materials Testhouse under ESTEC-contract

### Objectives:

Assistance to ESTEC by characterisation and qualification of materials and processes of industrial suppliers



### History:

Frame contracts since 1989 as department of AIT (Austrian Inst. of Technology)

### Spin-Off to AAC as SME:

Operational since 2010 as privately owned SME  
Keep synergy Materials AND Space





# Roles of AAC in Space

## Space Materials Testhouse (contracts to ESTEC > 30 years)

- AAC is an independent SME (no producer),
- Contract to ESTEC covers testing for ESA and Industry
- Proposals from industry - selection by ESA



## Subcontractor to Industry

- ... in ITTs and ESA projects (testing, development, consultancy)
- Direct, bilateral and confidential contracts



## Prime-Contractor to ESA

- AAC as Prime contractor (role: testing & consultancy)



## Research coordinator (to other programs)

- AAC runs and coordinates R&D-programs on national (FFG) and international (EU) funding schemes

## Tribology

- Vacuum tribometer
- Cold welding testing
- Testing of bearings, gears, sliprings, ...
- Temperatures from -269°C to +300°C
- From air to vacuum to Mars

## Microstructure

- Metallographic analysis
- SEM / EDX / EBSD / FIB
- 3D profilometry
- (Micro)Hardness

## Bake-Out / TVAC-testing

- From materials, to EMs and flight hardware (clean room)
- From small to medium TVAC chambers (30x30cm to 130x180cm)
- from -180°C to +200°C (some +500°C)

## One-Stop-Shop to Space



## Outgassing

- Outgassing acc. to ECSS-Q-ST-70-02
- Kinetic outgassing acc. to ECSS-Q-TM-70-52A
- Vacuum-TGA up to 400 °C
- CME (Coeff. of Moisture Expansion)

## Consulting

- Requirements for space
- Verification plans
- Reviews on materials and processes

## Mechanical testing

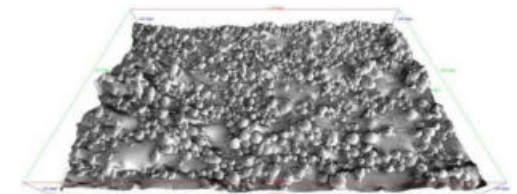
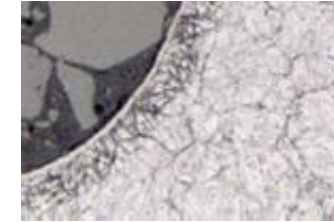
- Vacuum Pressure: <10<sup>-6</sup> mbar
- Different gases under changing pressure
- Temperatures: from -269°C to 2500 °C
- Mechanical Loads: up to 200kN / 70Hz

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# AAC's Involvement in Technology Developments for Space (TDA)

(Examples where AAC assists industry to get their products to/de orbit)

- Development of solid lubrication for Harmonic drives
- Development of solid lubricant cages for Ball bearings
- Heat treatments for SCC-resistance of “space steels”, optimisation of nitriding process for PH-steels
- Lubrications concepts for low temperatures (exploration)
- Additive Manufacturing (ALM): qualification of materials, processes
- Multi Layer Insulation (MLI) - Nano-Hybrid transparent polymers
- “Demisability of materials”



# Tribo-Material & Component Testing - Space Tribology: Test Rigs

Test rig	Samples /Components	Output	Environment
<b>Vacuum Tribometer</b>	Pin/Ball-Disc Slip-Rings	friction, linear wear el. contact resistance	vacuum, air, CO2 -100 ... +300°C
<b>Cold Welding Tribometer</b>	Pin-Disc	friction, adhesion	vacuum, air, CO2
<b>Cold weld – Vacuum shaker</b>	3-Pin-on-Disc Cubesats	Adhesion, HDRM-validation	vacuum, air, CO2 -/+50°C
<b>Cryo-Tribometer</b>	3-Pin-on-Disc	friction, lifetime	vac, gHe, -269°C to RT
<b>Journal Bearing Test Rig</b>	Bush-Shaft	torque	vacuum, air, CO2 -100 ... +300°C
<b>SALOTTE 1 HADES</b>	Gears, brakes, Ball/Plain bearings	torque & life time	vacuum, air, CO2 -170 ... +250°C
<b>SALOTTE 2 ECM</b>	Pin-Disc/Brush/Wire	friction, el. contact-resistance	vacuum, air, CO2 -100 ... +300°C
<b>Ball bearing test rig BBT (Vac-HT-Tribometer)</b>	Ball bearings Ring-Ring 3Pin/on-Ring	torque, lifetime, friction	vacuum, air, CO2 RT ... +200°C (Vac ... +700°C)
<b>Ball bearing test rig BBT<sup>2</sup></b>	Ball bearings (swiveling)	torque, lifetime, friction	vacuum, air, CO2 -80... +80°C

# Tribo-Component Testing - Modular Test Device - HaDES

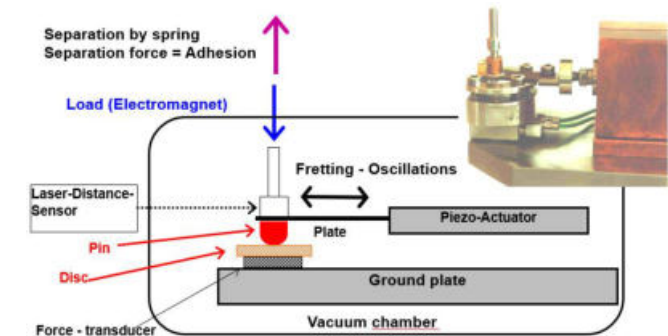
Test item	Top shaft is used as	Bottom shaft is used as	Properties measured (selected ...)
<b>Harmonic Drive ® Gear</b>	Actuate (<500rpm, 0,7Nm)	Brake (<50Nm)	Efficiency, stiffness, NLRT, TA, ..
<b>Ball bearing (axial loads)</b>	Actuate (<500rpm, 0,7Nm)	Pre-load changing	Bearing torque (>2mNm) Axial loads
<b>Ball bearing (Bi-axial loads)</b>	Actuate (<500rpm, 0,7Nm)		Bearing torque (>2mNm)
<b>Planetary gear</b>	Brake (<500rpm, 0,7Nm)	(None) use TVAC-motor + torque	Efficiency, axial load
<b>Magnetic brake</b>		None	Detent torque
<b>Actuator (&lt; 0,7Nm)</b>	Brake (<500rpm, 0,7Nm)	None (test item as acuator)	Output torque, ratio to motor current
<b>Actuator (&lt; 50Nm)</b>	None (test item as acuator)	Brake (<10rpm, 50Nm)	Output torque, ratio to motor current
<b>Journal bearings (radial load)</b>	None	Actuate, torque, angle	Bearing torque, radial load force



# Cold welding – 1/2 - Testing of material pairs

## Determination for in-orbit life or for launch (HDRMs, ...)

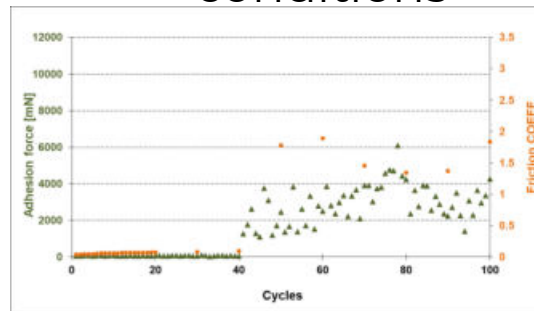
- Fretting- Pin-On-Disc system
- High vacuum / ambient / gases (Martian)
- Motion representative for HDRMs, end stops, wires, harness, antennas
- Data base for referencing <https://coldweld.aac-research.at/>



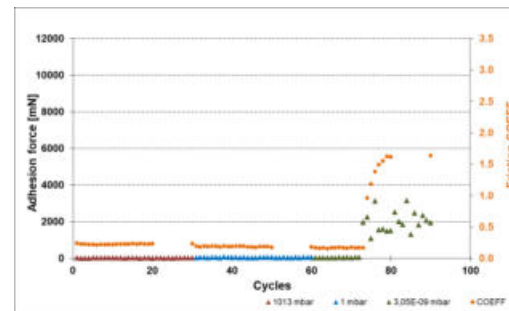
Fretting (Pin-on-Disc)

## Output

- Separation forces for materials and coatings
- Life time of coatings in launch conditions



Coldwelding in vacuum



Coldwelding in launch conditions

# Cold Welding

Cold Welding

acc. to: ARCS-standard issue:

2

1

Testing

Specimen								Contact parameter	
Designation	Composition	Supplier / Manufacturer	Condition	HV (air/Hertz)	Y (N/mm²)	Poisson (ν)	σ (N/mm²)	Static Load (Hertz)	Load (N)
Pin	SS17-7 Pin	TPC-76-5A	AMS	441	1697	0.29	210	1.13	1.13
Coating	Brass							1.13	1.13
Disc	SS17-7 Pin	TPC-76-5A	AMS	441	1697	0.29	210	1.13	1.13
Coating	Nitriding	Microplate (R) plasma-nitriding (0.1µm)	AMS					1.13	1.13
Coating	Brass							1.13	1.13
Comments (operator, supplier, preparation):								1.13	1.13
Steel: 1040Cr10MnNiV and QuenchN2 & 954Cr10MnNiVvacuum & QuenchN2 & RT5h & -74°C & 2 times/SS170Cr15								1.13	1.13
Nitriding: Microplate (R) plasma-nitriding (0.1µm), hardness 1310 HV1, done by RUG								1.13	1.13
Wrong side of disc was nitrided, this test was performed on nitrided side (back side)								1.13	1.13

Results									
Comments to Test performance / Print specification									
Filler number of cycles performed in all tests				8195	Adhesion (maximum)		Bond strength (maximum)		Comments
Adhesion: remarkably lower than for uncoated SS17-7Pin				µN/mm²	1000	1000	1000	1000	1000
BEMEXID: testing marks on disc, typical for uncoated stainless steel				1 Cycle	291	0.041	0.5	0.03	1000
Profile: wear scar on disc (40 µm) rat through nitriding layer (~100 µm)				1 Cycle	322	0.17	0.6	0.03	1000
				1 Cycle	322	0.17	0.6	0.03	1000
				1 Cycle	322	0.17	0.6	0.03	1000
				1 Cycle	322	0.17	0.6	0.03	1000
				1 Cycle	322	0.17	0.6	0.03	1000
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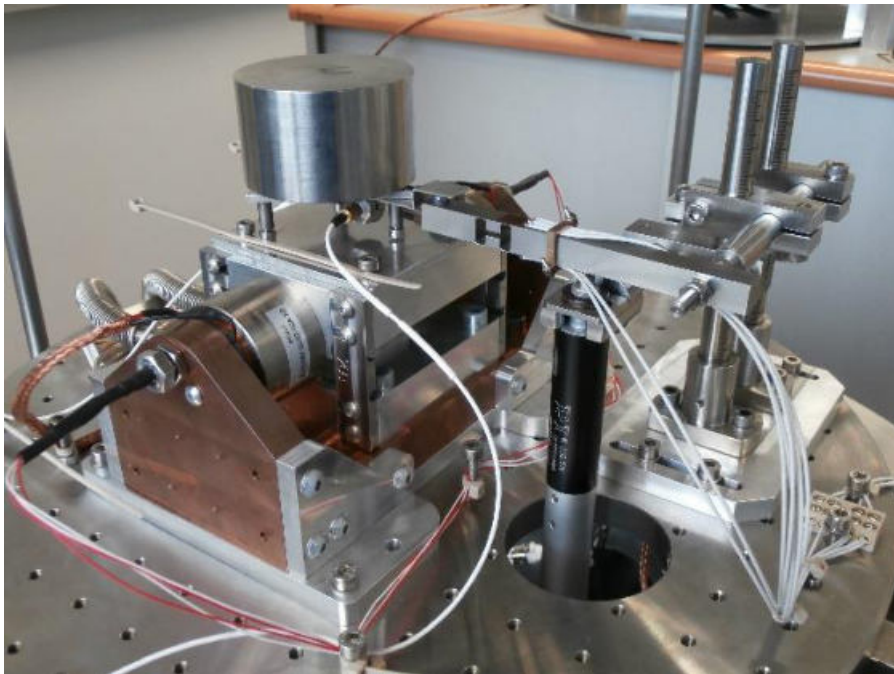
Data sheet from Cold Weld Data base

# Cold welding – 2/2 - Testing of material pairs and Cubesat

## Determination of cold welding for launch mechanisms (HDRMs, ...)

- Fretting- Pin-On-Disc system
- High vacuum / ambient / gases (Martian)
- Motion by acceleration representative for HDRMs, end stops, wires, harness, antennas
- FRESSCO vacuum shaker for components (cubesats)

**Vacuum shaker for  
HDRMs of cube sats**



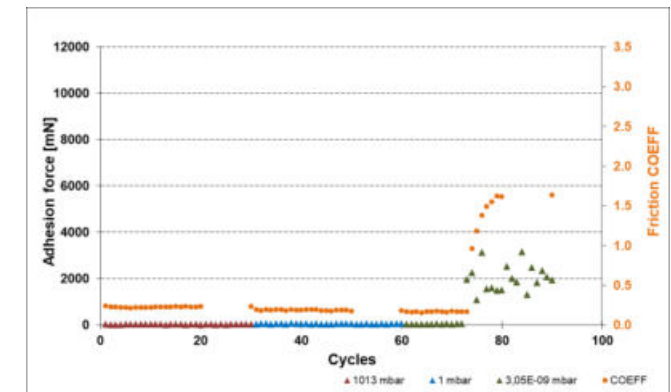
FRESSCO (Vacuum Shaker)

## Specimens

- Pins and Discs
- HDRMs (up to 1kg)

## Output

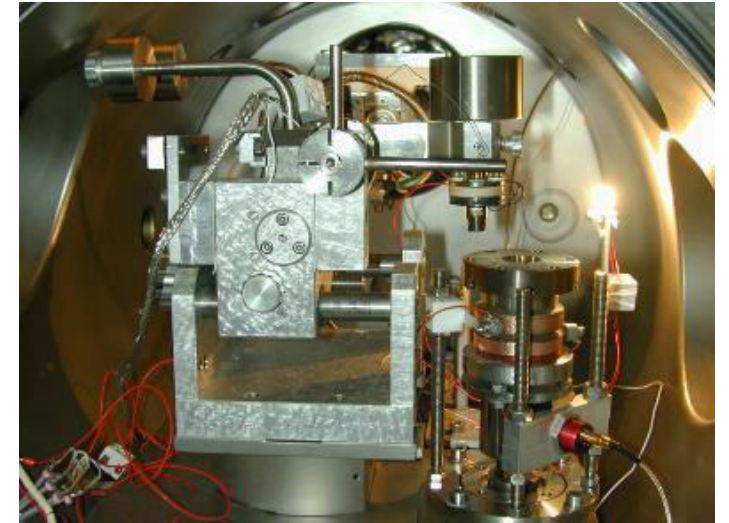
- Separation forces for materials and coatings
- Life time of coatings in launch conditions
- Validate deployment after vibration in vacuum



# Tribo-Testing of materials 1/2

PoD to screen new materials, processes, coatings ...

- Pin-On-Disc system
- High vacuum / ambient / gases (Martian)
- Temperatures form -100 to +300°C
- Motion: oscillating (customer profiles) up to unidirectional
- Residual Gas Analysis (optional)



## Specimens

- Pins, balls, cylinders (lying)
- Discs plates, rings

## Output

- Friction as function of revs
- Linear wear (on-line)

Vacuum Tribometer (Pin-on-Disc)



# Tribo-Testing – from Cryogenic to High Temperature 2/2



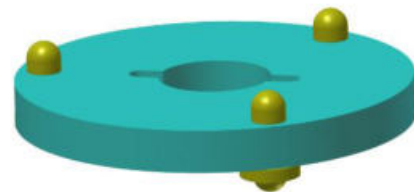
Vacuum Tribometer for cryogenic temperature testing

## Determination of friction at extreme temperatures:

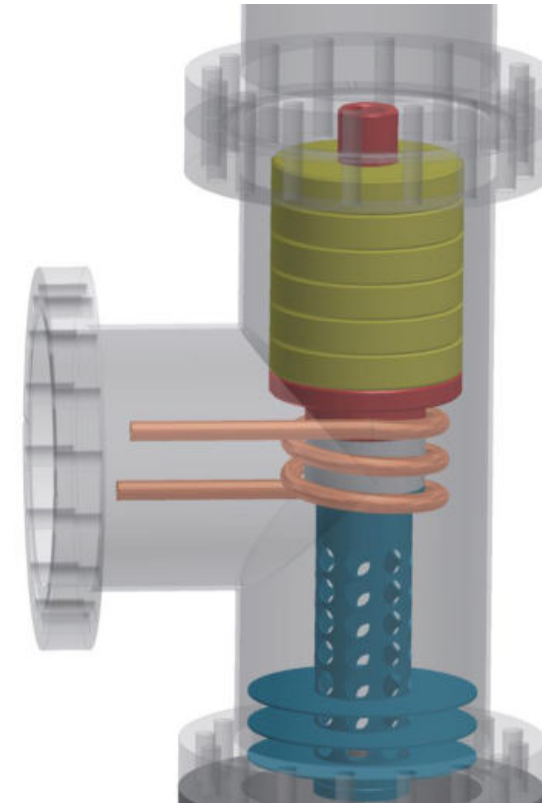
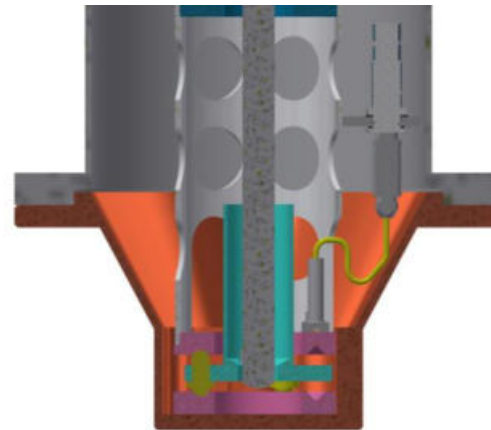
- 3-Pin-On-Disc system
- High vacuum or gases (e.g. Martian)
- Oscillating and unidirectional motion

## Friction and lifetime in

- CryoT: down to 4K
- HighT: up to +700°C



3-Pin-specimen and Detail of cold cell



Vacuum Tribometer for high temperature testing

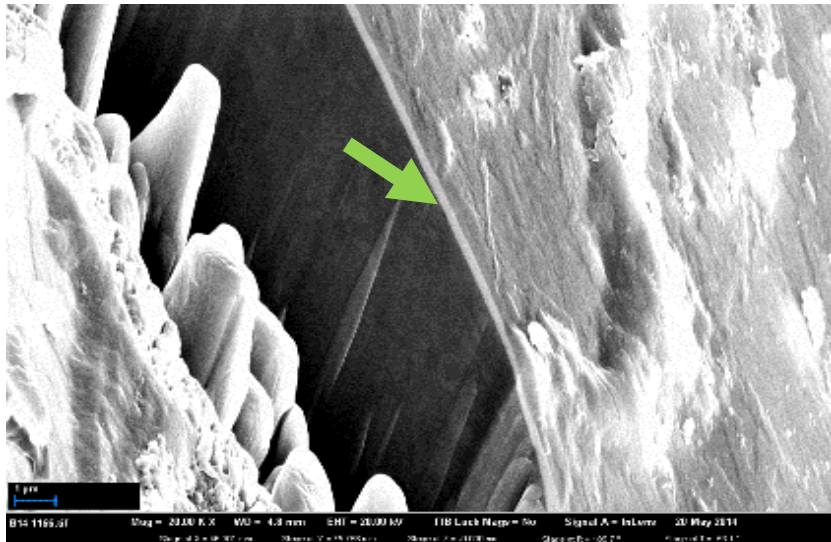


# Tribo-Testing – Post analysis

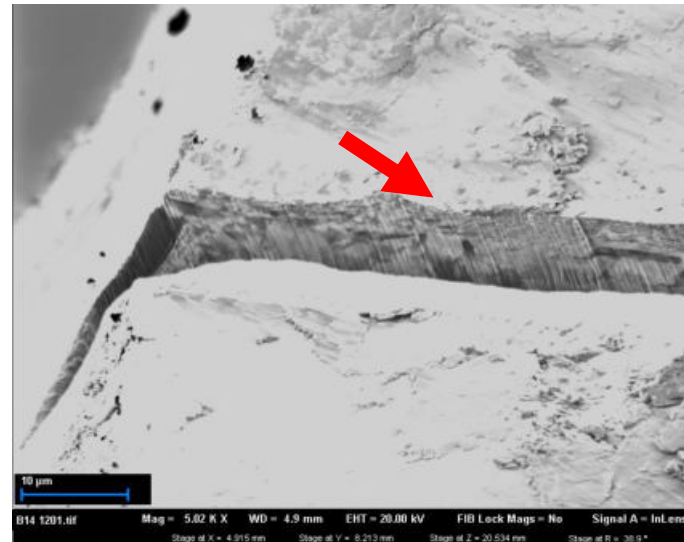
## Wear and wear mechanisms:

- Determination of volumetric wear (topography)
- Investigation of wear mechanism (SEM)
- Verification of coatings (after testing, FIB)
- Change of Sub-surface microstructure (e.g. FIB)
- Failure analysis of customer components

**Failure analysis of  
tested hardware  
(indication of cold  
welding)**



Solid lubricant coating: thin layer present



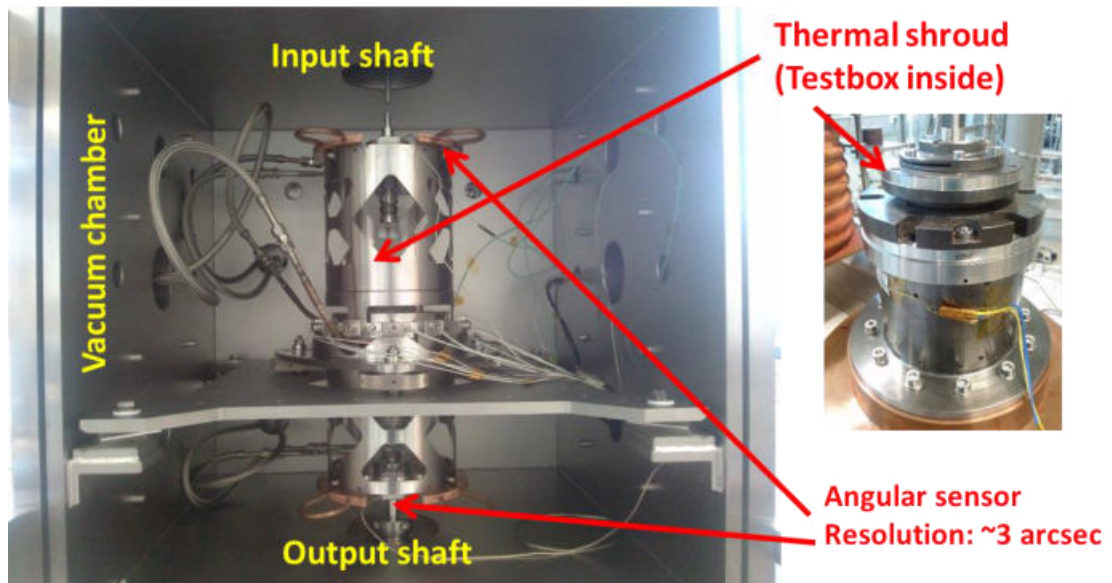
Coating worn off and severe subsurface damages

# Tribo-Component Testing - Modular Test Device - HaDES

Testing of gears Harmonic Drive ® gears for use in space :

- High Vacuum / planetary (Martian) / ambient
- Input/Output: motors, torque and angle
- Output- torque loads selectable up to 50Nm
- Post test investigation SEM/FIB (e.g. wear, debris)
- Characterisation: Efficiency, stiffness, NLRT, ... >>> life testing

**Gear stiffness in-situ  
at all temperatures**



Thermal Vacuum Setup



Testbox for gears (size 14 / 20)



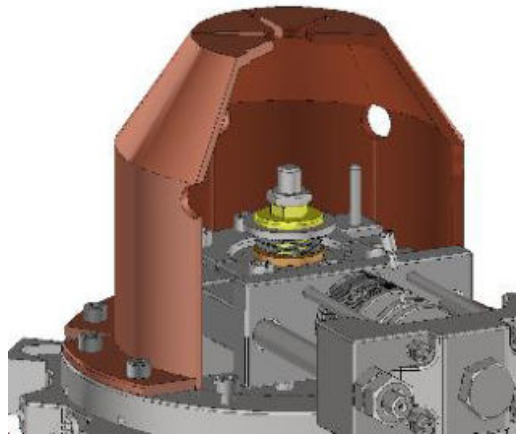
Vacuum chamber „HADES“

# Tribo-Component Testing - Modular Test Device - HaDES

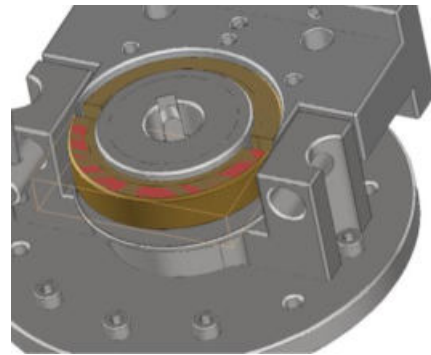
## Testing of plain bearings for use in space :

- High Vacuum / planetary (Martian) / ambient
- Input motors: up to 50Nm, customer motion profiles
- Torque and high resolution angle resolvers
- Radial load measured during tensioning
- TVAC from -100°C up to +100°C
- Life tests of commercial bushes in TVAC feasible

**Commercial bushes  
can be tested up to  
50Nm in TVAC**



Thermal Vacuum Setup with



Insert: to fix commercial bushes up to OD55mm



Vacuum chamber „HADES“

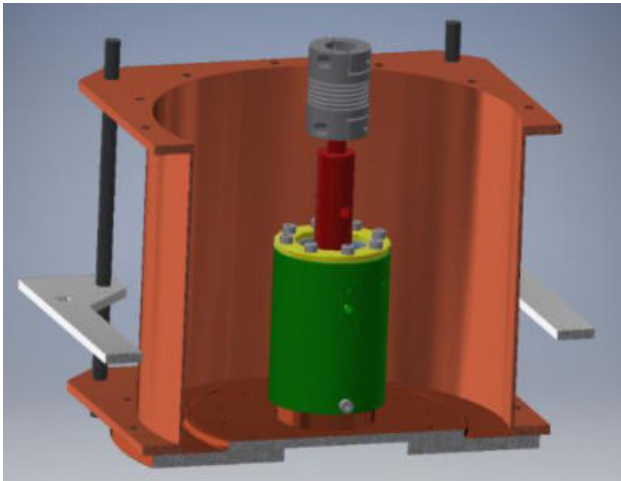


# Tribo-Component Testing – Bi-Axial-Testing of Ball bearings

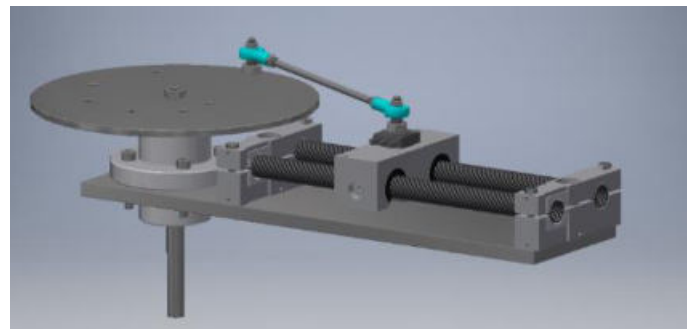
## Testing of bearings for use in space :

- High Vacuum / planetary (Martian) / ambient
- From -170°C up to +240°C
- Input motors, torque and angle
- Preloads: axial, radial and combined
- Post test investigation SEM/FIB (e.g. wear, debris)
- Long term Life testing with torque measurement
- Short term test (for deployment mechanisms)

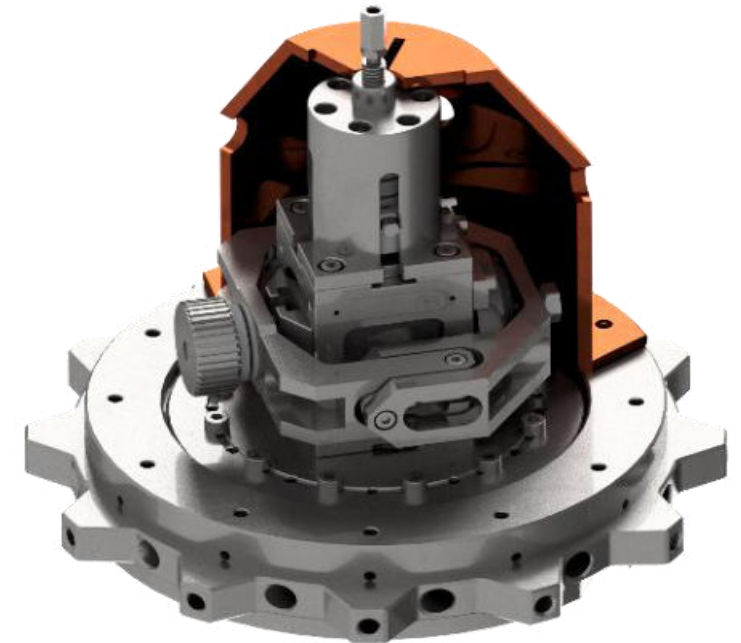
**NEW: Bi-Axial load  
and Dynamic-Load  
for Ball bearings**



Thermal Vacuum Setup for ball bearings



Setup for testing of linear bearing



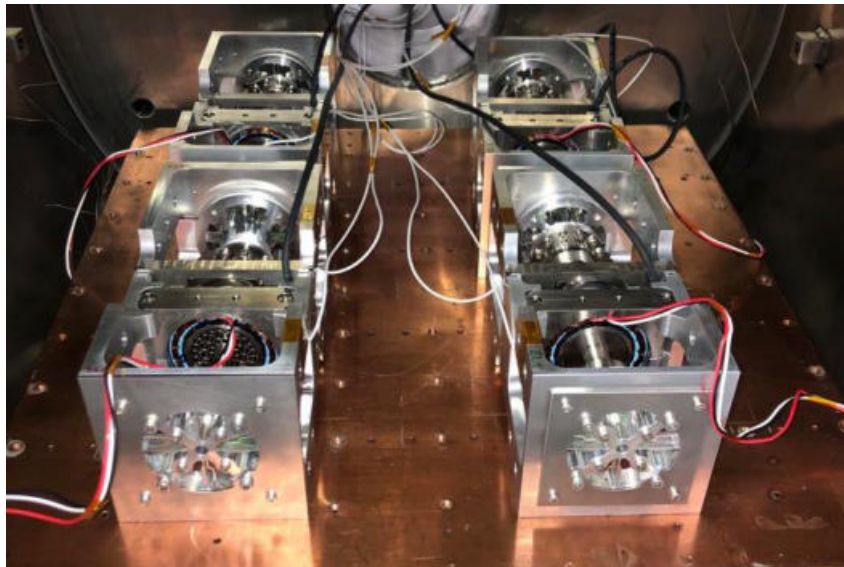


# Development of Test methods – Swivelling of ball bearings

## BBT<sup>2</sup> - New setup for life tests of bearings under small motions ...

- Environment: Vacuum ( $10^{-5}$  mbar), Air, N<sub>2</sub>, Mars (CO<sub>2</sub>, 15mbar)
- Temperature from -80 to +80°C
- Pre-Loads: TBD (e.g solid lubricated 850MPa, for Type 7004)
- Motion: oscillating from +/-2deg up to unidirectional
- Speed: up to 60Hz (small angles), up to 1000 rpm (unidirectional)
- Measurement of torque: +/- 1mNm, up to 10kHz (for uni at 2 rpm)

**High frequency  
swivel motion  
based on  
bearingless motor**



### Specimens

- Ball bearings (single or paired)

### Output

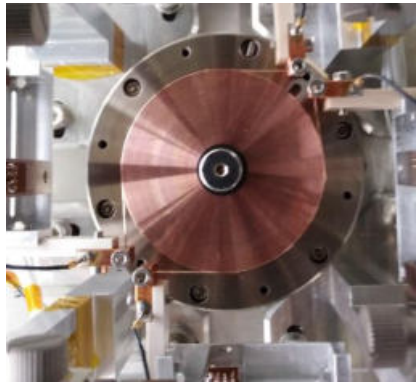
- Torque as function of revs
- Separately for each bearing (or pair)
- Up to 4 setups controlled independently

BBT<sup>2</sup> new setup (4x) for life tests under small motions

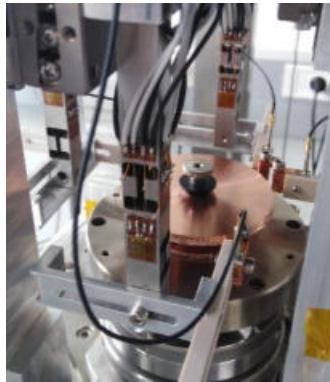
# Tribo-Component Testing - Electro tribology

## Testing for slip-rings for use in space on component level:

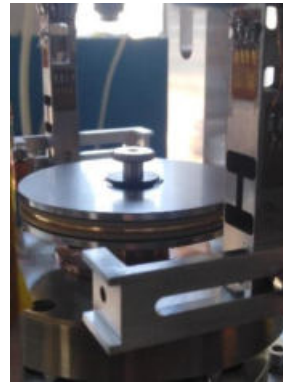
- Max 4 brushes (friction and load forces measured)
- Heatable ring uptake
- High precision resistance measurement
- Post test investigation SEM/FIB (e.g. wear, debris)
- Validation of materials / coatings / lubricants
- Life tests on component level



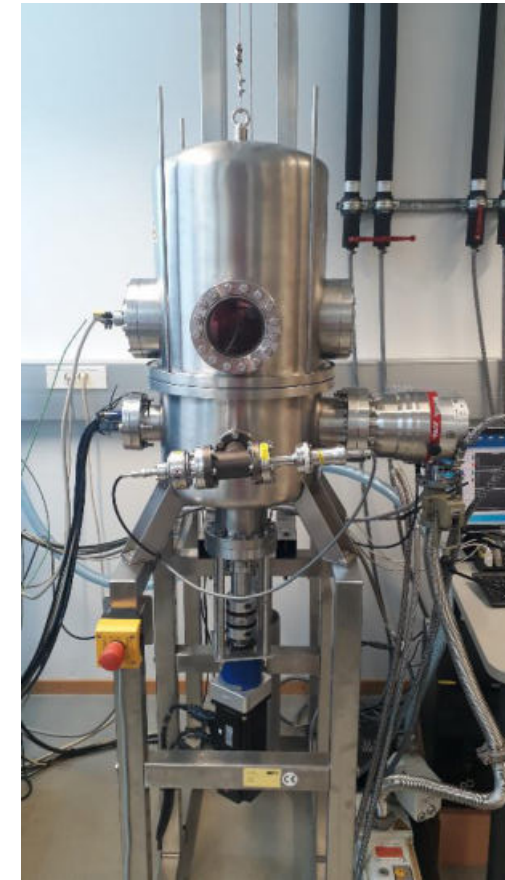
Slipring with wirebrushes



Force measurement



Current / voltage

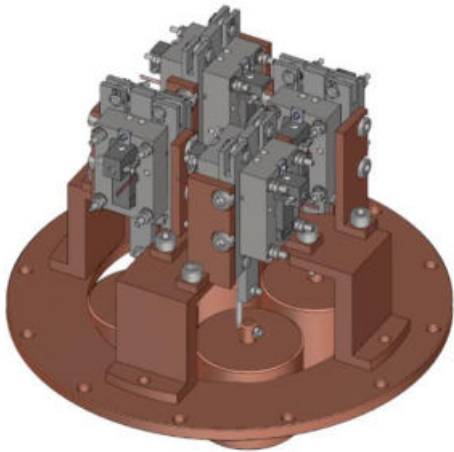


in thermal vacuum environment

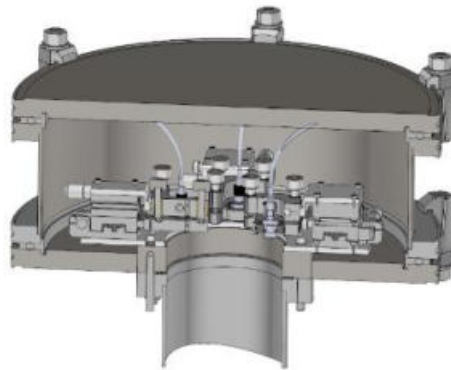
# Tribo-Component Testing – Piezo Linear Actuator

## Testing of friction pairs for linear actuators (piezo) in thermal vacuum:

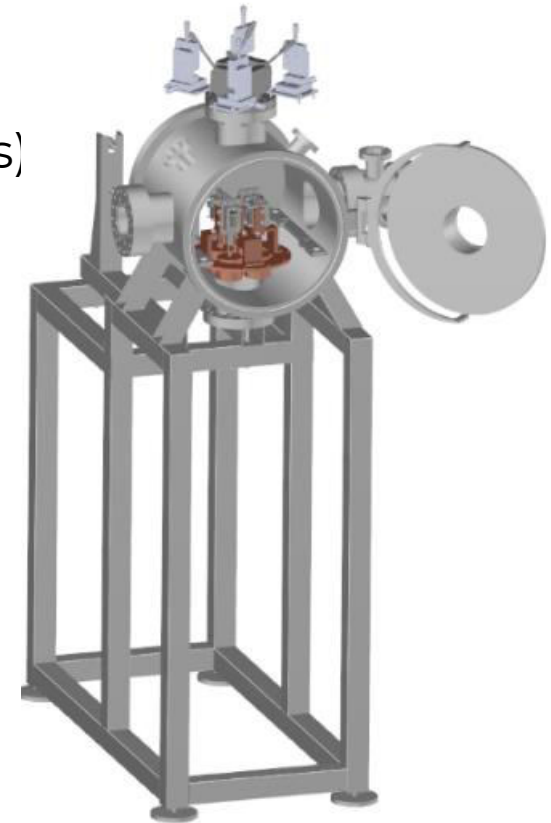
- High Vacuum / planetary (Martian) / ambient
- Loading: dead mass load force in motion line
- Temperatures form -100 to +150°C
- Output: lifetime, high resolution motions profiles (laser sensors)
- Post test investigation SEM/FIB (e.g. wear, debris)
- Characterisation: Lifetime, available torque, ... >>> life testing



Thermal Vacuum Setup



Head for laser position monitoring

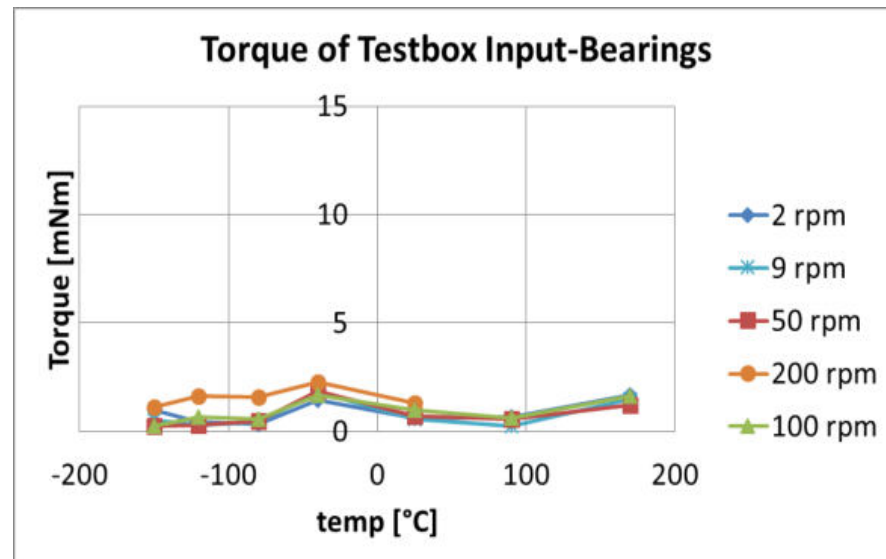


Vacuum chamber „SALOTTE“

# Development of Lubrication concepts – Solid Lubricated Bearings

## Extend the temperature range of a gear box by solid lubrication

- Low torque few mNm
  - Torque almost independent of temperature !
  - Minor dependence on speed (increase with speed)
- Enables testing of Solid Lubricated Harmonic Drive ® gears over wide temperatures including in-situ characterisation



### Specimens

- Ball bearings Steel
- Cages made of PTFE-compound (prototype to TS 8591)

Torque of support bearings in TVAC



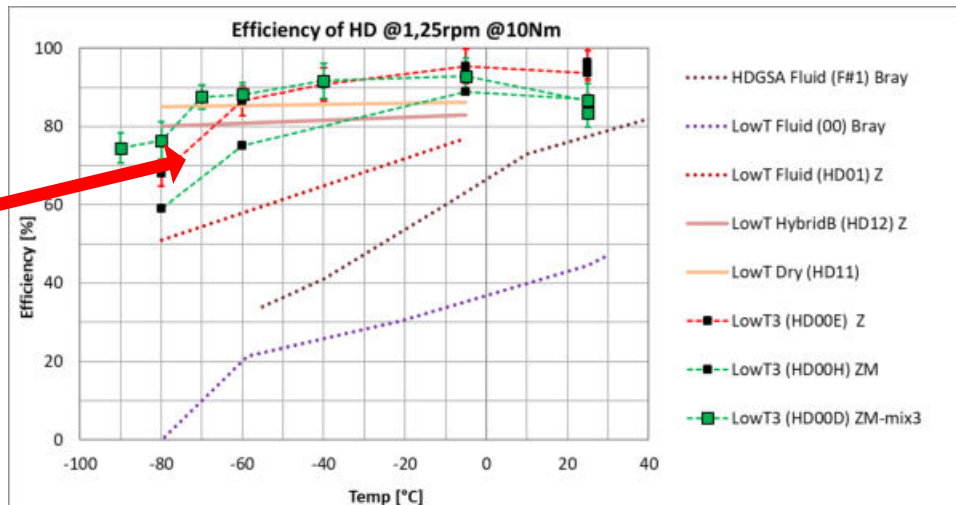
Test Box for HD-20-1xx  
(developed by HDAG)



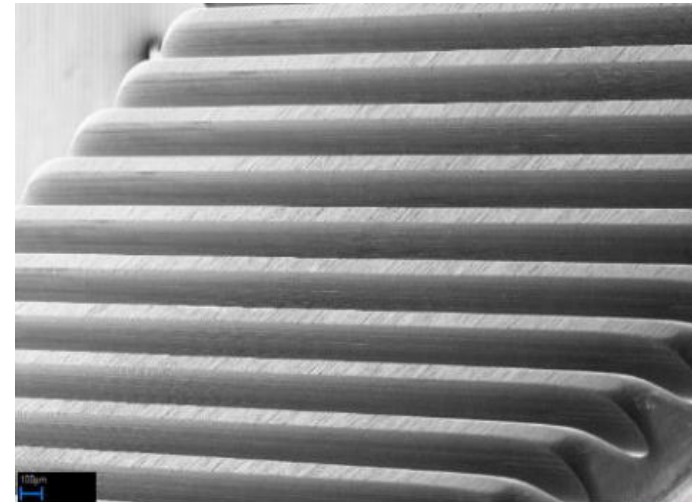
# Development of Lubrication concepts for Low Temperatures

## Extending the life of a HD gear by combined lubrication ...

- Appropriate surface treatment of tothing of the gear
  - Fluid lubrication in gear tothing, with fluid lubricant optimized to low temperatures
  - Solid lubrication in bearings by new PTFE-based polymer (like TS 8591)
- Enables high efficiency down to  $-80^{\circ}\text{C}$  combined with significant increase of life



Efficiency (T) close to fully solid lubrication , but more than 5fold life



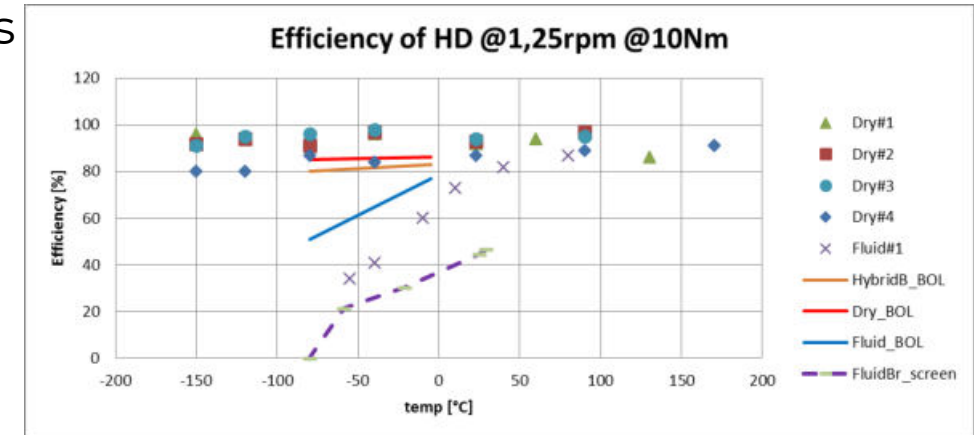
No wear on tothing after 48.000 OPR

# Development of surface processes for Long Life of HD-gears

## Extending the life of a HD gear by surface treatments of PH-steels ...

- Solid lubricated HD offers high efficiency over wide temperatures, but limited life !
- Nitriding process was optimized towards PH-steels avoiding brittle WEL (white etching layers)
- Gear parts were first nitrided, then Solid lubricant coated (reinforced MoS<sub>2</sub>)

- Nitriding improves support to MoS<sub>2</sub> coating
- .. and increases the life of the gear in TVAC



Nitrided tootinging

### Dry lubricated Harmonic Drive® Gear.

#### Overview achieved endurance [OPR] (under vacuum)

Gear 1 (V1.2)	<800	not nitrided
Gear 2 (V1.2)	<3,700	
Gear 3 (V2.2)	(nitrided version)	14,600

Increase of life of a fully solid lubricated HD-Gear



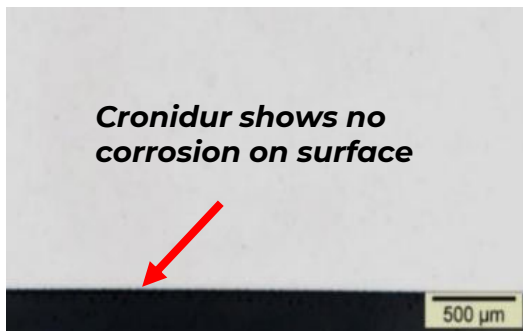
# Heat treatment on bearing steels for SCC-resistance

New HT can be offered for higher SCC resistance on bearing steel:

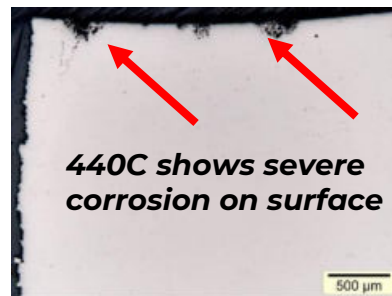
- Intense work on several steels to derive a heat treatment
- AISI440C threshold only 20% if yield strength, severe corrosion
- Cronidur X30 ~50% of yield strength, no corrosion

**Heat treatment for X30  
allows use in tensile  
loaded parts**

- SCC resistance of X30 could be improved to Class 2 (acc. NASA)
- Successful life test of a HD-gear with WG-bearing made of new X30: No signs of degradation in the bearing races
- Further applications like gears now feasible (tensile loaded parts!)



Cross section of specimens after SCC-test showing severe corrosion pits for 440C and nothing for Cronidur X30



Wave Generator Bearing (WGB)



AAC test device "HADES"  
with test box for Harmonic  
Drive ® Gears

# References

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Industrial partners:







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