TRIBOLOGY IN EXTREME ENVIRONMENT:
STATE OF THE ART AN SOME SOLUTIONS FOR SOLID LUBRICATION IN UHV

M. Belin, J. Fontaine, Th Lemogne

Laboratoire LTDS, UMR CNRS 5513, Ecole Centrale de Lyon
36 rue Gay de Collongue, 69134 Ecully, France
michel.belin@ec-lyon.fr
Tribology in extreme environment: 
state of the art and some solutions 
for solid lubrication in UHV

Michel BELIN, Julien FONTAINE and Thierry Le MOGNE
michel.belin@ec-lyon.fr

LTDS - Laboratoire de Tribologie et Dynamique des Systèmes
Ecole Centrale de Lyon - UMR 5513
Outline

1. Introduction
2. Background on tribology
3. Vacuum tribology
4. Experimental simulation
5. C-based coatings
6. Conclusions & perspectives
1. Introduction

- In SR: complex systems in extreme envir.
  - vacuum
  - thermal gradients

- Moving parts
  - positioning
  - dynamic motion

- High precision
  - mechanical components
  - electronics, magnets, high loads

**Objective of this presentation:**
- Reduce the gap between space technol. and SR word
- Present a group/a facility, show some results
2. Background on tribology

- Interaction between solids
  - sliding: accommodation of speed difference
  - load carrying
  - friction, wear, interface, lubrication...

- Friction
  - level of friction \((f = F_t / F_n)\)
  - energy loss

<table>
<thead>
<tr>
<th>friction value (f)</th>
<th>(10^{-3})</th>
<th>(10^{-2})</th>
<th>(10^{-1})</th>
<th>1</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHD lubrication</td>
<td>0.02</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HD lubrication</td>
<td>0.003</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry lubrication</td>
<td>0.05</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vacuum friction</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>
- friction stability
  noise (stick-slip)

- $f(N)$, evolution with cumulated sliding distance

sputtered MoS$_2$ in vacuum storage duration effect in moist env.

■ Wear

- weight loss
- lifetime ➔ malfunction
- coupling to friction
- wear possible emission ➔ debris, vapors
  ➔ major breakdown of mechanism
  ➔ environment pollution

The tribological behaviour is not intrinsic to a material, or to a material pair
- Dependence vs environment


- strong dependence vs environment
- no clear link with structure & chemical composition
3. Vacuum tribology

- Space tribology
  - reliability
  - life time
  - precision
  - performance stability
  - debris, O g conditions, pollution of instruments

- SR instrumentation
## Comparing space/SR requirements

<table>
<thead>
<tr>
<th></th>
<th>space</th>
<th>SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>vacuum (hPa)</td>
<td>$10^+3 \rightarrow 10^{-8}$</td>
<td>$10^{-9} \rightarrow 10^{-11}$</td>
</tr>
<tr>
<td>lifetime</td>
<td>critical (15 years)</td>
<td>high</td>
</tr>
<tr>
<td>radiation, particles</td>
<td>AO, $h\nu(\lambda)$, $e^-$, protons</td>
<td>$h\nu(\lambda)$, $e^-$</td>
</tr>
<tr>
<td>thermal</td>
<td>150 - 400 °K</td>
<td>? 1 - 400 °K</td>
</tr>
<tr>
<td>vibration</td>
<td>few g (launching)</td>
<td>&lt; 1 g</td>
</tr>
<tr>
<td>microgravity</td>
<td>x</td>
<td>/</td>
</tr>
</tbody>
</table>
Specific solutions for space applications

1. Liquid lubricants

- Vapor pressure, Pa
  - $10^{-4}$: Ordinary mineral oils, 10 Minutes
  - $10^{-6}$: Fluorosilicones, 1 Day
  - $10^{-8}$: Super-reified mineral oils, KG-80, Apiezon C, Silicones, Polyalphaolefin, NYE 179, Demnum (S 200), PFPE oils, 100 Days
  - $10^{-10}$: Fomblin (Z 25) PFPE oils, 10 Years
  - $10^{-12}$: Krytox (16256) PFPE oils, 1000 Years

- Minimizing evaporation in vacuum
2. Solid lubricants for space

- Soft metals
  - Au, Ag, In, Sn

- Chalcogenides
  - MoS$_2$, WS$_2$, Sb$_2$Se$_3$

- Polymers
  - PTFE, polyimide

- Technological issues
  - sputtering thin coatings (0.05 to 1 micron)
  - ion plating
  - painting / binders

### 3. Some benefits and limitations

<table>
<thead>
<tr>
<th>Lubricant</th>
<th>+</th>
<th>--</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Liquid</strong></td>
<td>- long lifetime</td>
<td>- dep. with temperature</td>
</tr>
<tr>
<td></td>
<td>- low friction</td>
<td>- migration</td>
</tr>
<tr>
<td></td>
<td>- heat evacuation</td>
<td></td>
</tr>
<tr>
<td><strong>Solid</strong></td>
<td>- low dependance with temp</td>
<td>- reduced lifetime</td>
</tr>
<tr>
<td></td>
<td>- possible acc. testing</td>
<td>- dep. of environment on friction &amp; lifetime</td>
</tr>
<tr>
<td></td>
<td>- no dynamic effect</td>
<td>- possible solid debris</td>
</tr>
<tr>
<td></td>
<td>- protection from corrosion</td>
<td>- possible instabilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- no heat evacuation</td>
</tr>
</tbody>
</table>
4. An example: the typical behaviour of MoS2 coating

diff environments
life time
cycle to failure CtF
4. Experimental simulation

- **Surface analysis facility**
  - Auger, XPS
  - SEM
  - ion etching

- **in-situ tribometer**
  - sphere / plane
  - reciprocating motion
  - contact pressure: 0.3 to 2 GPa  (W: 0.5 to 5.0 N)

- **Specific tools**
  - preparation: annealing, metal evap., magnetron sputtering
  - gas introduction
  - temp. control: 100K up to 800K
Some fundamental studies

- MoS$_2$
  supra friction
  anisotropy in f
  MARTIN J.M et al. (1993)

- Carbon-based films

Applied projects

- Electrical contacts
  adhesion & seizure concerns
- Coatings for hi precision accelerometers
  lo wear, no debris
an example: the behavior of SiC/SiC

the oxygen effect of 50 Pa $O_2$

MARTIN J.M. et al. (1990)

▶ evidence for the effect of environment
▶ friction level $\div 8$
b. $O_2$ gas, 50 Pa  
  $f= 0.1$

a. UHV  
  $f= 0.8$

- strong difference between wear scars
- UHV: hi friction / lo wear
- 50 Pa $O_2$: lo friction / hi wear + debris
AUGER analysis of the wear tracks

a. UHV, outside
b. UHV, inside
c. $O_2$, outside
d. $O_2$, inside

- Auger surface analysis of wear scars
- with $O_2$ gas: evidence for $SiO_x$ formation
- "tribochemistry"
5. Carbon-based coatings

- **A wide family of materials**
  - from polymers to diamond
  - C sp\(^2\) and C sp\(^3\)
  - various H % content

- **Deposition techniques**
  - PVD, PACVD
  - ..
- **Hi performance**
  - good adherence
  - hi mechanical properties
  - relation composition / structure

- **Recent study for space application**
  - CNES  *Centre National des Etudes Spatiales* (Fr)
  - HEF Group coatings supplyer
  - LTDS CNRS research lab. (Fr)

- **Different model coatings**
  - H:DLC (hydrogenated diamondlike coatings)
  - variable H content, by changing the process parameters
  - typical thickness: 2 microns (underlayer+coating)
  - tribological characterization in air, gas (*N₂*, *O₂*, *Ar*), UHV
**hardness**  

viscoplastic exponent

<table>
<thead>
<tr>
<th>Sample</th>
<th>AC8</th>
<th>AC5</th>
<th>CY5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Precursor</strong></td>
<td>$C_2H_2$</td>
<td>$C_2H_2$</td>
<td>$C_6H_{12}$</td>
</tr>
<tr>
<td><strong>Bias / Pressure</strong></td>
<td>-800 V / 100 mTorr</td>
<td>-500 V / 200 mTorr</td>
<td>-500 V / 200 mTorr</td>
</tr>
<tr>
<td>$C,sp^2 : C,sp^3$ (%)</td>
<td>70 : 30</td>
<td>65 : 35</td>
<td>56 : 44</td>
</tr>
<tr>
<td>Hydrogen content</td>
<td>34 %</td>
<td>40 %</td>
<td>42 %</td>
</tr>
<tr>
<td>Bonded H% (FTIR)</td>
<td>57 %</td>
<td>73 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Bonded H% (RMN)</td>
<td>93 %</td>
<td>98 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>

**Friction coefficient**

**Wear track**
Optimization of H:DLC coatings
- influence of the polarization bias
- deposition at 2A, bias ranging from -35 to -260 V

Fontaine J. (2000)

-major influence of H% content on friction in UHV
Evidence for a threshold in H content
- Millirange f values can be reached
- Stable value
- Good stability, long lifetime
- Near zero debris

On the way...
- Optimization by metal doping of coatings
- Effect of radiations, particles
  - Atomic oxygen (low earth orbit flight simulation)
  - UV
  - e−
6. Conclusions & perspective

1. Vacuum tribology is highly specific
   - high friction, adhesion, dramatic seizure

2. Comparison of SR instrumentation and space applications

3. Development of “experimental modelling” of tribosystems in vacuum
   - dedicated facility & expertise
   - fundamental studies & testing real world solutions

4. Solid lubricants are good candidates in vacuum SR instrumentation.
   - the solutions developed for space applications are not necessary directly applicable.
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