Friction Control and Nanotribology

Takahisa Kato

DSML (Data Storage Mechanics Laboratory)

AIST (National Inst. of Advanced Industrial Science and Technology)

National Institute of Advanced Industrial Science and Technology

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1

Purpose of Tribology:

Friction control and Reliability

2

Friction control in Egypt

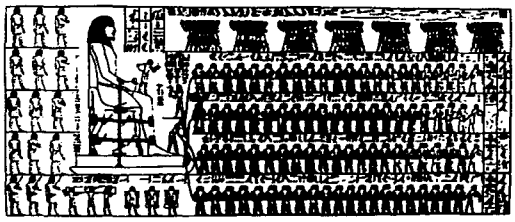


Fig. 4.15
Transporting an Egyptian colossus—from the tomb of Tehuti-Hotep, El-Bersheh (c. 1880 B.C.).

W=60ton, 172mm, 800N/mm

μ = 800 x 172 / (60x1 000 x 9. 8) = 0.23

D. Dowson, History of Tribology, Longmans Gr, 1979

3

Friction control in Assyria

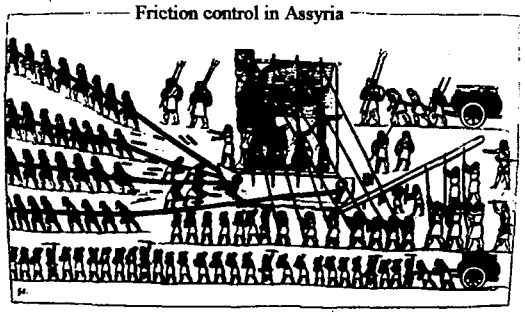
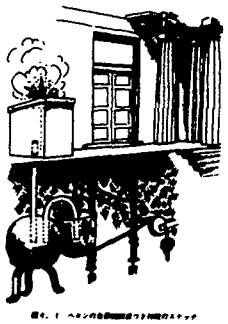


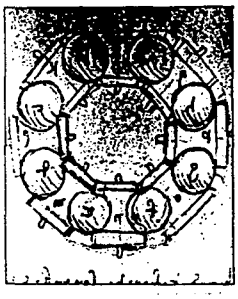
Fig. 4.14
Assyrians positioning a human-headed bull—partly restored from a bas-relief at Khorsabad (c. 700 B.C.).

4



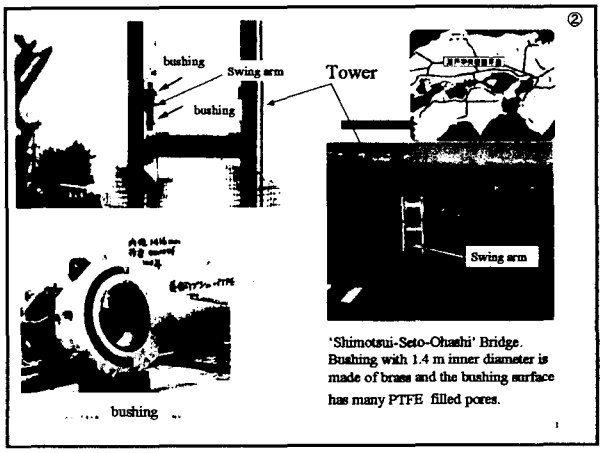
Magic door in Greece! Pivot bearing was used.

5

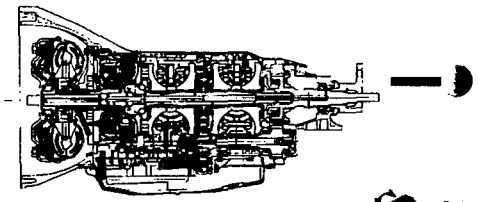


Thrust bearing of Leonard da Vinci

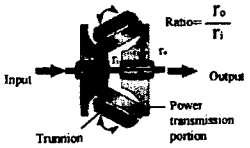
6



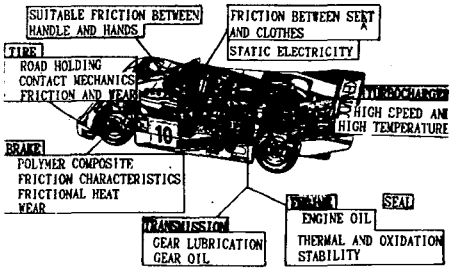
'Shimotsui-Seto-Ohashi' Bridge. Bushing with 1.4 m inner diameter is made of brass and the bushing surface has many PTFE filled pores.

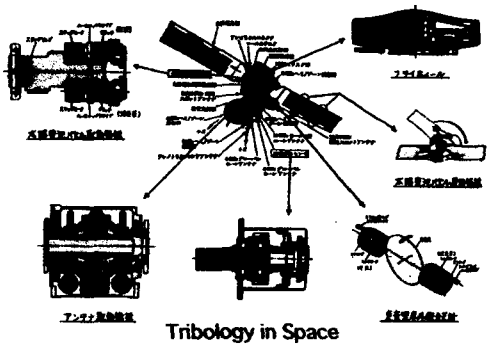


Troidal CVT developed by cooperation of automobile, bearing and lubricant companies.



Tribology issues of automobiles





Tribology in Space

技術はどこまでせまれるか？

1 m

$\frac{1}{100}$ m

$\frac{1}{100} \times \frac{1}{100}$ m

$\frac{1}{100} \times \frac{1}{100} \times \frac{1}{100}$ m (1μm)

$\frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100}$ m

$\frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100}$ m (1Å)

Tribology: beyond the scale

How to achieve the friction control?

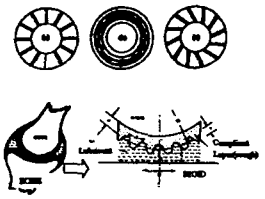
(1) **Geometry modification**

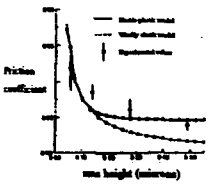
(2) **Structure modification**

(3) **Active control**

Examples of geometry modification

Clutch and brake plates with grooves



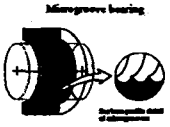


modeling of human joint

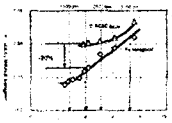
Friction v.s. roughness

Examples of geometry modification

Microgroove bearing



Texture on hard disk

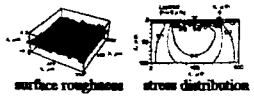


Roughed surface at piston skirt

Friction control by roughed surface

Examples of structure modification

Hard coating covers surface of concentrated contact



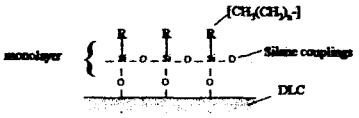
surface roughness stress distribution

Brake Pad

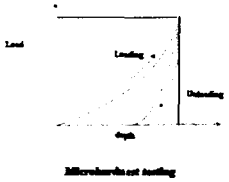
Constituents of brakes: fibers, resin, graphite, Alumina, Copper, MoS_2, Cashewdust, ...

Examples of structure modification

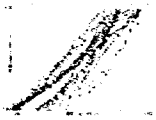
Surface energy control by self assembled monolayer (SAM)



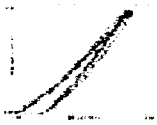
Stable testing of microhardness testing with SAM



Microhardness testing

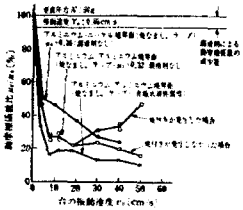


without SAM



with SAM

Possibility of active friction control



Friction reduction by vibration

But

Wear amount (surface deformation) increases with vibration.

What is the role of tribology in early 21st ?

Keywords:

Environmetal Technology

Information Technology

Nanotechnology

Biotechnology

1

Nanotribology : the key of nanotechnology

(1) Scale of sliding is 1/1,000 ～ 1/1,000,000 of machine elements.
(2) Machine elements are downsizing.

Examples
EHL film thickness: 10 –100 nm
Journal bearing in mobile phone: shaft diameter (0.7 mm)
HDI flying height: 10 nm
HDI lubricant thickness: 1-2 nm
Positioning for LSI production: less than 10 nm
Positioning for SPM: 1 nm for atom handling

2

HDI, the treasury of nanotribology research!

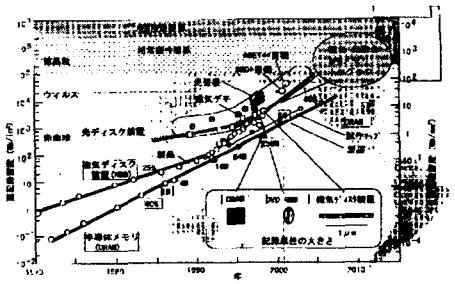


図３ 磁気・光ディスク装置、半導体メモリの面記録密度推移

Ultra high memory density towards 1Tb/in²

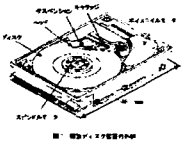
25.4mm×25.4mm

3

Tribological issues of HDI

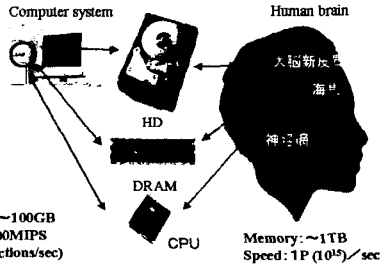
Design tool of HDI for stable flying of magnetic head at lower than 10 nm is expected.

1. Understanding the tribology phenomenon of HDI
2. Development of protective hard coating of 2 – 3 nm and characterization, (DLC or else.....)
3. Development of lubricant film of 1-2 nm and characterization, (PFPE or else.....)
4. Modeling the surface roughness and intermittent contact
5. Contamination
6. Start/stop mechanism with high durability



4

Comparison of computer system and human brain



Memory: ～100GB
Speed: 1000MIPS
(10^9instructions/sec)

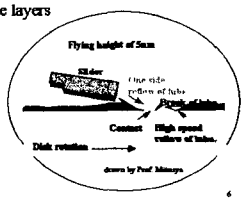
Memory: ～1TB
Speed: 1P (10^{15})／sec

5

Development of lubricant nanofilm and characterization

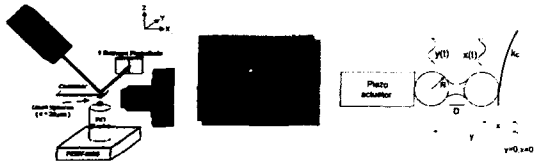
(Research topics at DSML: Data Storage Mechanics laboratory)

1. Dynamic characteristics of nano meniscus bridge
2. Replenishment of lubricant nanofilm
3. MC and MD simulations of lubricant nanofilm
4. Characteristics of mobile and immobile layers
5. SAM on DLC
6. Further problems
   - ·inherent roughness
   - ·dewetting



6

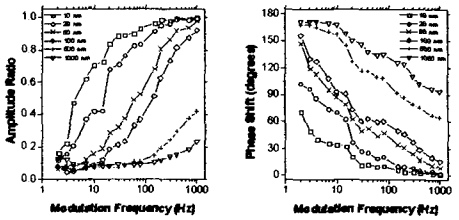
Dynamic characteristics of nano meniscus bridge



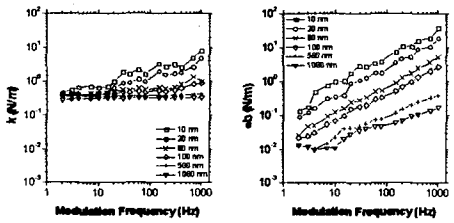
Force Modulation

- modulation frequency : 2 ~ 1000 Hz
- modulation amplitude : 1.5 nm
- surface separation(D) : 10 ~ 1000 nm (10 ~ 1000 Rg)

Amplitude Ratio & Phase Shift



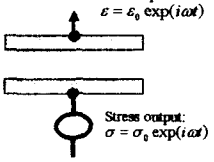
Elastic and Viscous Force Constant



- The system is dominated by the elastic force at low frequency and by the viscous force at high frequency.
- The elastic force is predominant at large separation.
- The viscous force increases remarkably as the separation decreases and the frequency increases.

Rheological characterization

Strain input:
$\varepsilon = \varepsilon_0 \exp(i\omega t)$



Stress output:
$\sigma = \sigma_0 \exp(i\omega t)$

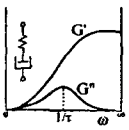
$\sigma_0 / \varepsilon_0 = G' + iG''$

where G': storage modulus

G": loss modulus

Example: PFPE in a bulk

$G' \approx \omega^2$, $G'' \approx \omega$ when $\omega \to 0$



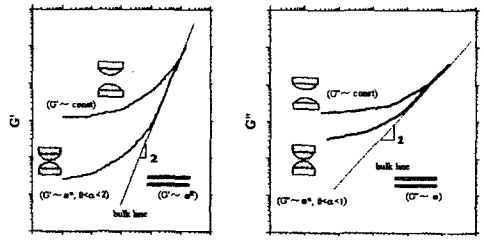
Storage modulus and loss modulus

	long bridge (l > 50nm)	short bridge (l < 50nm)	bulk
			
G' (~k)	const	ω^{α} $0<\alpha<2$	$\sim \omega^2$
G" (~ωb)	const	ω^{α} $0<\alpha<1$	$\sim \omega$

Force Modulation

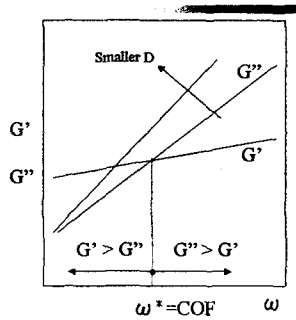
- modulation frequency : 2 ~ 1000 Hz
- modulation amplitude : 1.5 nm
- surface separation(D) : 10 ~ 1000 nm (10 ~ 1000 Rg)

Frequency dependency of storage modulus and loss modulus



J. Chen and T. Kato, "Nano-rheological properties of Perfluoropolyether lubricant bridge in the range 10 to 1000 nm," ASME J Tribology, will be published.

Retardation time $\tau_R = 1/\omega^*$

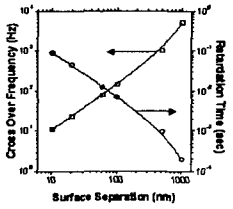


$\tau_R = 1/\omega^*$

Smaller D
→ Smaller COF
→ Larger τ_R

1

Retardation time of nanomeniscus bridge



Summary

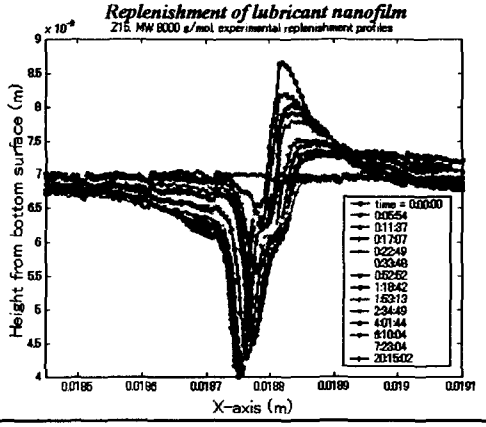
The longer the bridge, the more elastic.

Inside the bridge:
Viscous element dominates.

Interface:
Elastic element dominates.

2

Replenishment of lubricant nanofilm



3

Replenishment of lubricant nanofilm

Diffusion equation

$$\frac{\partial h}{\partial t} = \nabla \cdot (D(h)\nabla h)$$

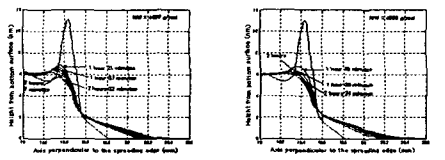
h: film thickness

t: time

D(h): diffusion coefficient

4

Calculation of diffusion coefficient (Mw=4000)

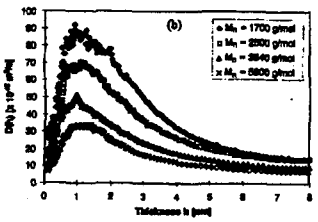


experiment → Diffusion coefficient → Calculation

(Ellipsometer) D(h) (Diffusion equation)

5

Example of diffusion coefficient of lubricant nanafilm



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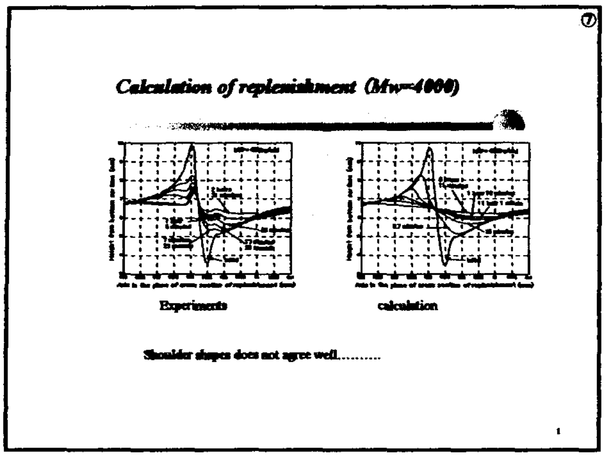
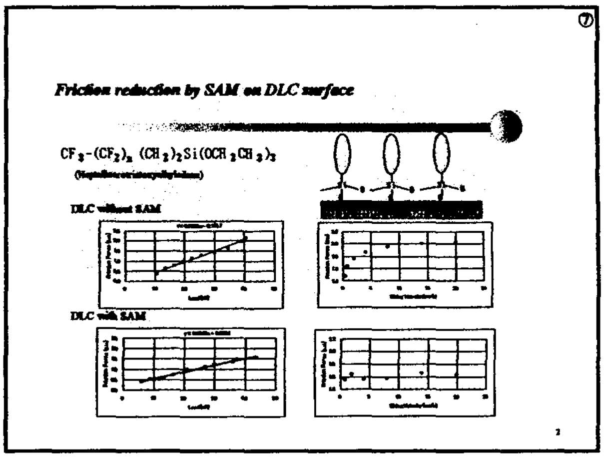
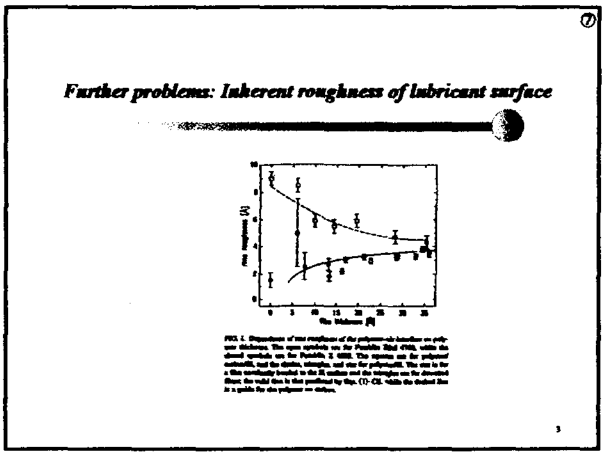
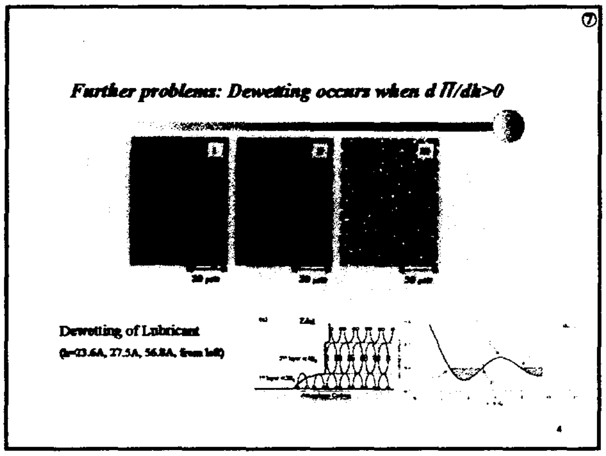
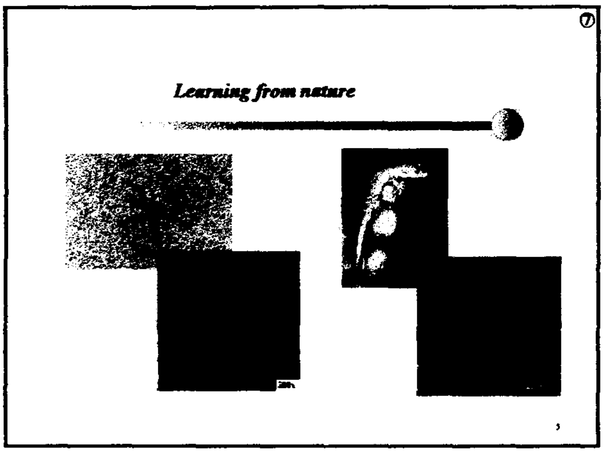
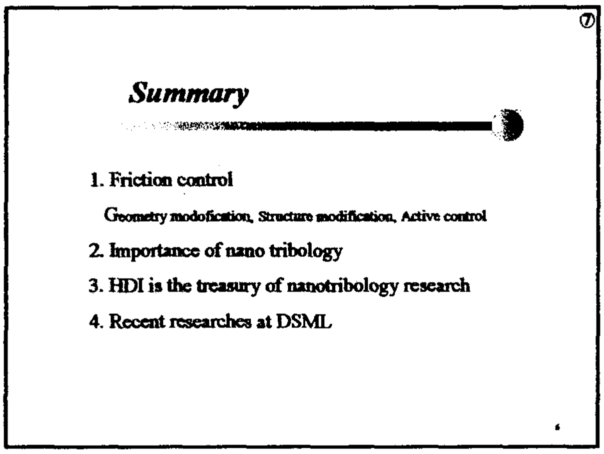

Calculation of replenishment (Mw=4000)
Experiments
calculation
Shoulder shapes does not agree well.........
1


Friction reduction by SAM on DLC surface
CF3-(CF2)n (CH2)2Si(OCH2CH3)3
DLC without SAM
DLC with SAM
2


Further problems: Inherent roughness of lubricant surface
3


Further problems: Dewetting occurs when d Π/dh>0
20 μm
20 μm
20 μm
Dewetting of Lubricant
4


Learning from nature
5


Summary
1. Friction control
Geometry modofication, Structure modification, Active control
2. Importance of nano tribology
3. HDI is the treasury of nanotribology research
4. Recent researches at DSML
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