Research on Mechanical Moving Components for Space Use

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Shingo OBARA
Electronic, Mechanical Components and Material Group
Institute of Aerospace Technology
JAXA
Activities in mechanical components sub-group

- Outline
- Development of mechanical moving components
- Project support
Activities in Mechanical Components Subgroup (1/2)

Electronic, Mechanical Components and Material Group

Electronic components sub-group

Material sub-group

Mechanical components sub-group
- Development of selected moving mechanical components (MMCs)
- Research on generic technology for space mechanisms
- Standardization activity for space mechanisms
- Project support

High Vacuum Mechanical Component Test Facilities
Activities in Mechanical Components Sub-group (2/2)

Technical trends of space mechanisms and satellite

Year | 2005 | 2010
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1st phase | 2nd phase

- High accuracy positioning and sensing
- Long life
- High agility

Requirements

- Harmonic drive gear
- Resolver
- Slip-ring
- Low shock hold-down & release mechanism

Applicable to all advanced space mechanisms

- Development of high-priority MMCs
- Research on Generic technology: **Space tribology**
- Documentation & Standardization
  - Fluid (oil & grease) lubrication
  - Solid lubrication
  - Bearings
  - Gears
  - Sliding electrical contacts
  - Design guideline, Handbooks, Standards

For high reliability
Development of selected MMCs

Committee on Space Component Technology, Space Mechanical Components & Materials Subcommittee

Selection of high-priority MMCs
- For solving availability problem
- To obtain higher performance
- For growing the market


1) Resolver
   (Angular sensor)
   - High accuracy
   \(< 0.0015^\circ\)
   - High resolution
   \(21\) bit

2) Harmonic drive gear
   - Light weight & compact
   - Long life
   \(> 10^6\) rev.
Project Support

Performance verification test
Life evaluation test of ball bearings for GOSAT satellite

Failure analysis
SEM observation of fracture surfaces of H-II LE-7 engine
Failed FTP inducer
Starting point of fatigue fracture
Research on space tribology

- Fluid lubrication
- Solid lubrication
Fluid (oil & grease) lubrication

**Fluid lubricants**
- M AC (+additives)
- M AC based grease
- PFPE

**Tribological characteristics of existing fluid lubricants**
- Wear and friction coefficients
- Effect of additives

**Feasibility of new lubricants**
- Tribological characteristics

**High-priority MMC related research**
- Lubrication mechanism of harmonic drive gears

**Lubrication mechanism of ball bearings**
- In-situ measurement of film thickness
- Tribological characteristics of oil-impregnated retainer
- Life tests

**Ball bearing dynamics simulation**
- Effect of gravity on bearing performance
- Retainer instability

**To be presented**
- To establish fluid-lubricating method for space applications
- To accumulate technical data of mechanical components

Collaborated with universities, companies and JAXA advanced space technology research group
Solid lubrication

Solid lubricants
- MoS₂
- Gold alloy
- DLC

Effect of environment & operating conditions
- Long term storage in atmosphere (non-operative)
- Vibration & operating mode (small angle rotation, linear reciprocal motion, etc.)

Guidelines of solid lubrication for space applications
- Use in harsh environment (fluid lubrication cannot be used)
- Life limitations (sensitive to operating conditions)

Advanced lubricant and/or lubricating method for future missions
- Long life solid lubrication
- Extremely low friction

High-priority MMC related research
- Feasibility tests of friction materials for slip-rings

Feasibility for space applications
- Existing, high-performance non-space lubricants
- New lubricants

To be presented

Collaborated with universities, companies and JAXA advanced space technology research group
Tribological characteristics of space oils
- Collaboration with Tokyo Institute of Technology (TIT) -

* Friction and wear characteristics of promising oils for space use have been evaluated with a pin-on-disk tribometer.
  - MAC
  - PAO
  - PFPE
  - Mineral oil

* Effectiveness of inclusion of extreme-pressure additives and/or anti-oxidants in hydrocarbon oils is investigated.
  - TCP
  - Hindered phenols
  - Amines

Wear test results for space oils

SUS440C-ball/ SUS440C-disk
- Sliding speed: 11.2mm/s
- Load: 100N
- Duration: 60min

Ball surfaces after the wear tests
Downsized, high-resolution Laser Induced Fluorescence (LIF) system was developed for measuring oil film thickness during ball-bearing operation. The film thickness on the raceway was decreased by repeated ball passings, and finally, a submicron scale thin film was left, contributing to hydrodynamic lubrication of the bearing.
Ball bearing dynamics simulation

Dynamic analysis code of ball bearings has been developed
– for understanding the effect of gravity condition on bearing performance, and
– for rapid evaluation of key bearing design factors.

Effect of gravity condition on retainer motion.
(Mass centre loci of gyroscope bearing retainer at 9000 r/min)

3-D animation of unstable retainer motion.
(Gyroscope bearing at 9000 r/min. The retainer motion is exaggerated.)
Lubrication mechanism of Harmonic Drive Gears

Generally, life of Harmonic Drive Gears (HDGs) in vacuum is remarkably shorter than that in air. Why?

Electric resistance measurement among HDG elements

This is probably because the lubricant between Wave Generator (WG) and Flexspline (FS) is rapidly starved when HDG is operated in vacuum.
Applicability of advanced solid lubricating method called “tribo-coating” to ball bearings is investigated.

Tribo-coating:
- Periodic resupply of a solid lubricant to sliding surface by evaporation.
- Long lifetime over $10^7$ revolutions and low friction coefficient under 0.02 were achieved in pin-on-disk experiments.

Micro Evaporation Source Array produced by MEMS technology

Tribo-coating lubrication system for ball bearing
Summary

Activities for moving mechanical components
- Development of selected moving mechanical components
- Research on space tribology
- Providing handbooks, guidelines and standards for space mechanisms

Space tribology research
- Key technology to develop future space mechanisms with high performance and high reliability.
- Continuing effort to gather technological data and to get perspective of phenomena involved.