Lunar Dust Simulant in Mechanical Component Testing - Paradigm and Practicality

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Abstract. Due to the uniquely harsh lunar surface environment, terrestrial test activities may not adequately represent abrasive wear by lunar dust likely to be experienced in mechanical systems used in lunar exploration. Testing to identify potential moving mechanism problems has recently begun within the NASA Engineering and Safety Center Mechanical Systems Lunar Dust Assessment activity in coordination with the Exploration Technology and Development Program Dust Management Project, and these complimentary efforts will be described. Specific concerns about differences between simulant and lunar dust, and procedures for mechanical component testing with lunar simulant will be considered.

In preparing for long term operations within a dusty lunar environment, the three fundamental approaches to keeping mechanical equipment functioning are dust avoidance, dust removal, and dust tolerance, with some combination of the three likely to be found in most engineering designs. Methods to exclude dust from contact with mechanical components would constitute mitigation by dust avoidance, so testing seals for dust exclusion efficacy as a function of particle size provides useful information for mechanism design. Dust of particle size less than a micron is not well documented for impact on lunar mechanical components. Therefore, creating a standardized lunar dust simulant in the particulate size range of ca. 0.1 to 1.0 micrometer is useful for testing effects on mechanical components such as bearings, gears, seals, bushings, and other moving mechanical assemblies.

Approaching actual wear testing of mechanical components, it is beneficial to first establish relative wear rates caused by dust on commonly used mechanical component materials. The wear mode due to dust within mechanical components, such as abrasion caused by dust in grease(s), needs to be considered, as well as the effects of vacuum, lunar thermal cycle, and electrostatics on wear rate.

MSFC-655-Presentation

Lunar Dust Simulant in Mechanical Components Testing (draft)

Tim Jett
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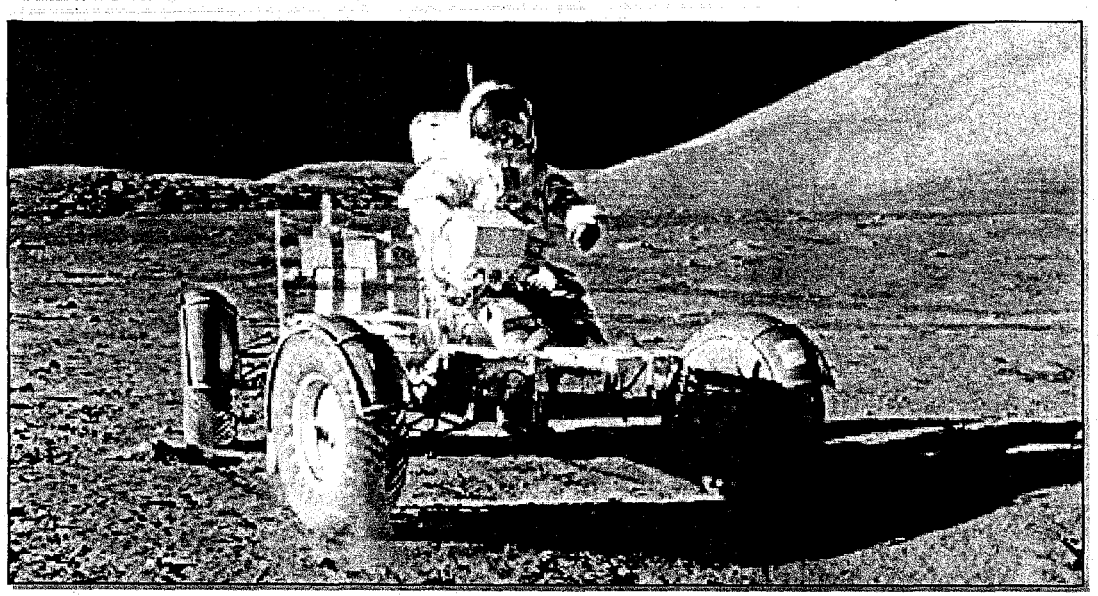
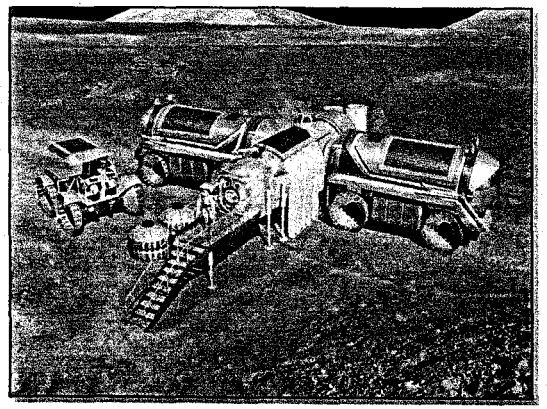
Tribology Concerns about Lunar Dust





Abrasive, glass-like edges of lunar dust must be considered when designing transportation, protective gear, habitats, and any mechanical mechanisms (human or non-human related)

Marshall Space Flight Center Tribology Laboratory Equipment and Capabilities

MSFC Tribology Laboratory

- Provides testing and analysis for lubrication, friction, surface wear, and bearing function and failure analysis of tribology-related issues
- Has special expertise with bearings operated at cryogenic/elevated temperatures, solid-film lubricants, wear-resistant coatings, greases and oils, and vacuum-compatible lubricants
- Performs high-speed cryogenic bearing tests using rolling element bearings and hydrostatic bearings
- Supports design and failure analysis with bearing analysis capabilities, using modeling codes to predict bearing life and perform parametric studies
- Equipped with state-of-the-art ASTM and specialized test equipment for evaluating all types of lubricants under a comprehensive range of conditions

Marshall Space Flight Center Tribology Laboratory Equipment and Capabilities

Test Plan for NESC at MSFC

- Purpose
  - To evaluate the effect of lunar dust on the life of mechanical components such as bearings and gears
- Testing
  1. Block on Ring
     - Used a standard ASTM test to determine the wear and friction of dust contaminated grease using various materials that made be used in lunar applications
  2. Low Speed bearing testing in atmosphere
     - Determine wear and life of bearings when lubricated with dust load grease at room temperature and atmospheric conditions
  3. Bearing testing in vacuum conditions
     - Determine wear and life of bearings dust loaded grease under EHD and boundary conditions in high vacuum

Block on Ring Testing

Objective: determine effects of lunar dust on tribological surfaces

Lubricants: Braycote® 601 EF

Three mixtures of each lubricant:
1 %, 3% 5%, dust stimulant (JSC-1AF)

Materials: 6160 Aluminum and 440 C steel

Tested in both oscillating and rotating motions

150 lb load

72 rpm

60 min and 30 min

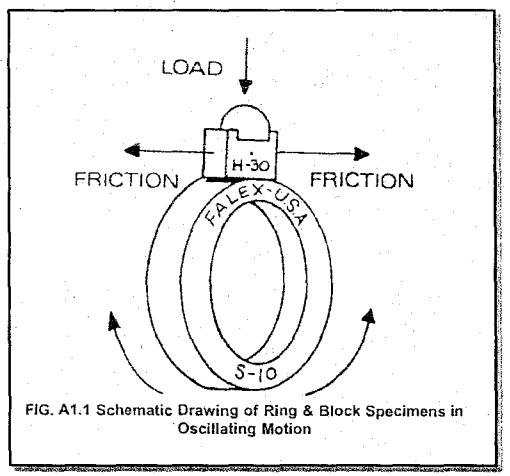
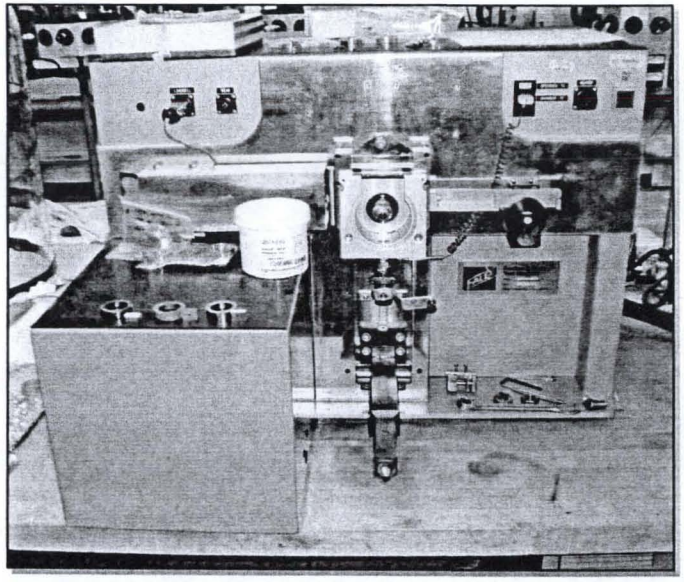


FIG. A1.1 Schematic Drawing of Ring & Block Specimens in Oscillating Motion

Block on ring (oscillating test configuration)

Block on Ring Testing

Block on Ring Tester



This test has been used to evaluate friction and wear for 50 years

This test is quick and simple and can be used for ranking materials, coatings greases etc for resistance to wear when exposed to lunar dust.

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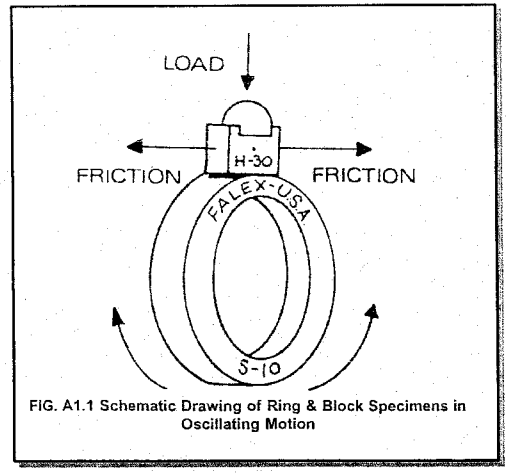

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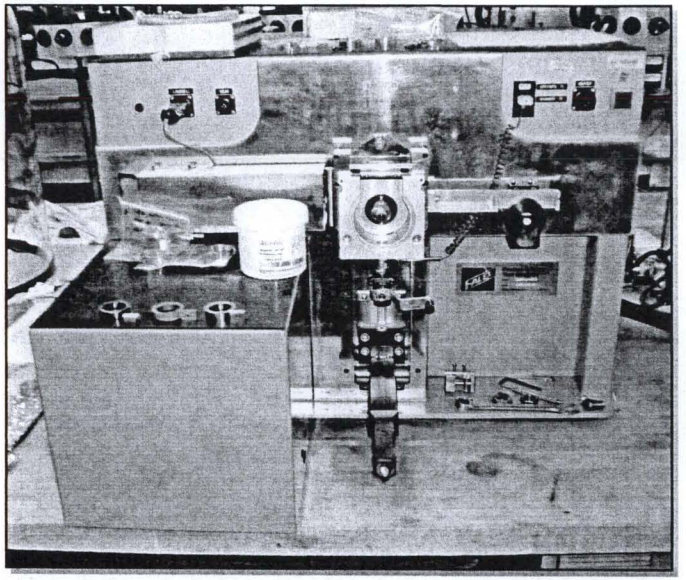

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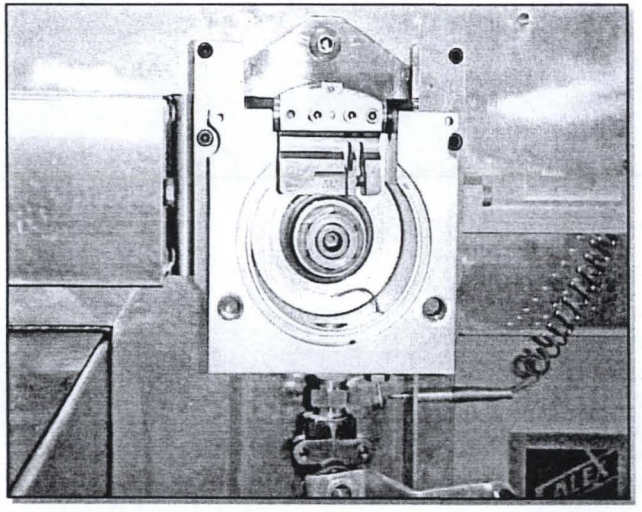


Performs standard American Society for Testing and Materials (ASTM) test for grease, oil, and wear-resistant coatings.

Measures friction force and wear scar dimensions for materials, coatings, and greases; friction force and wear scar dimensions are reported

Tests a block loaded against a rotation ring

Can be loaded up to 1300 lb with oscillating and rotating motion and speeds up to 7,200 rpm

Block on Ring Testing Results

- Initial shows no significance degradation in tribological properties of dust loaded grease (up to % 5 by weight)

Low Speed Bearing Testing in Atmosphere

Objective: Determine the wear and life of bearings when lubricated with dust loaded grease under low speed, boundary conditions

Lubricants: Braycote® 601 EF with load of
0 %, 5%, dust simulant (JSC-1AF, JSC-1A)

Test Specimens: Two 52100 angular contact bearings

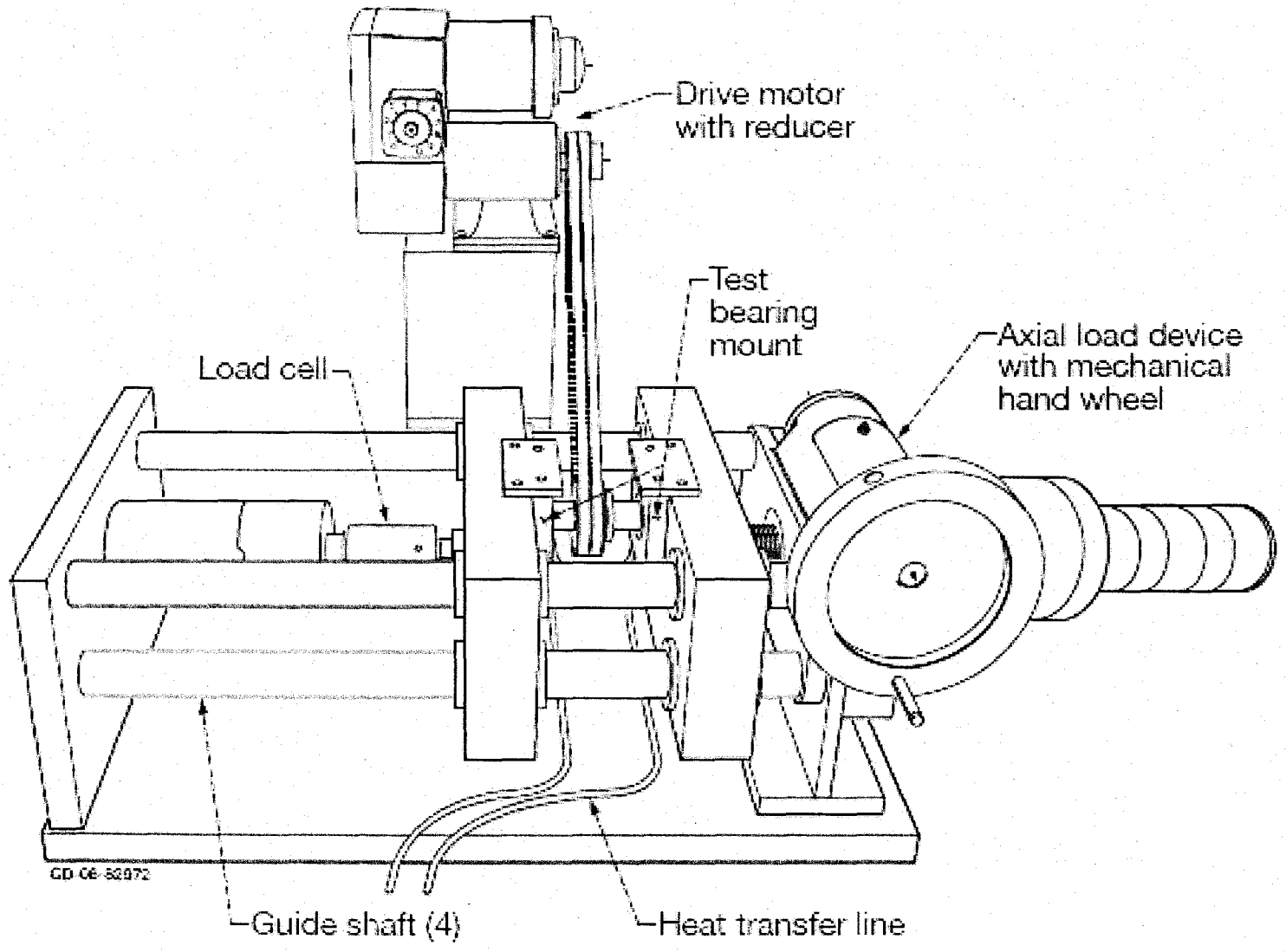
Tested Conditions:

3500 # axial load, 200 # radial load

50 rpm

Run until failure

Low Speed Bearing Testing in Atmosphere



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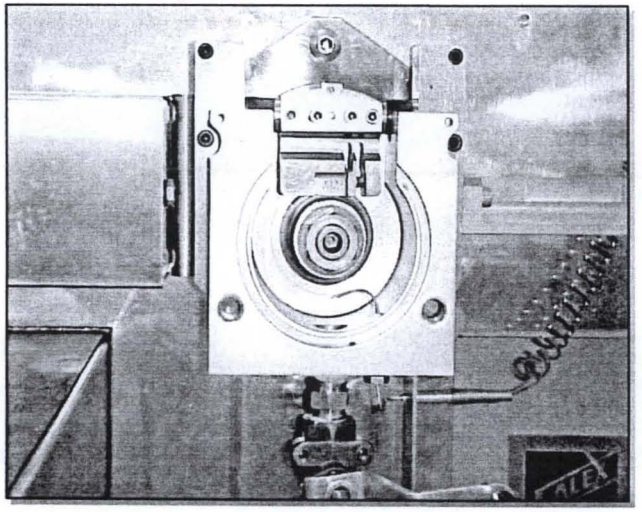

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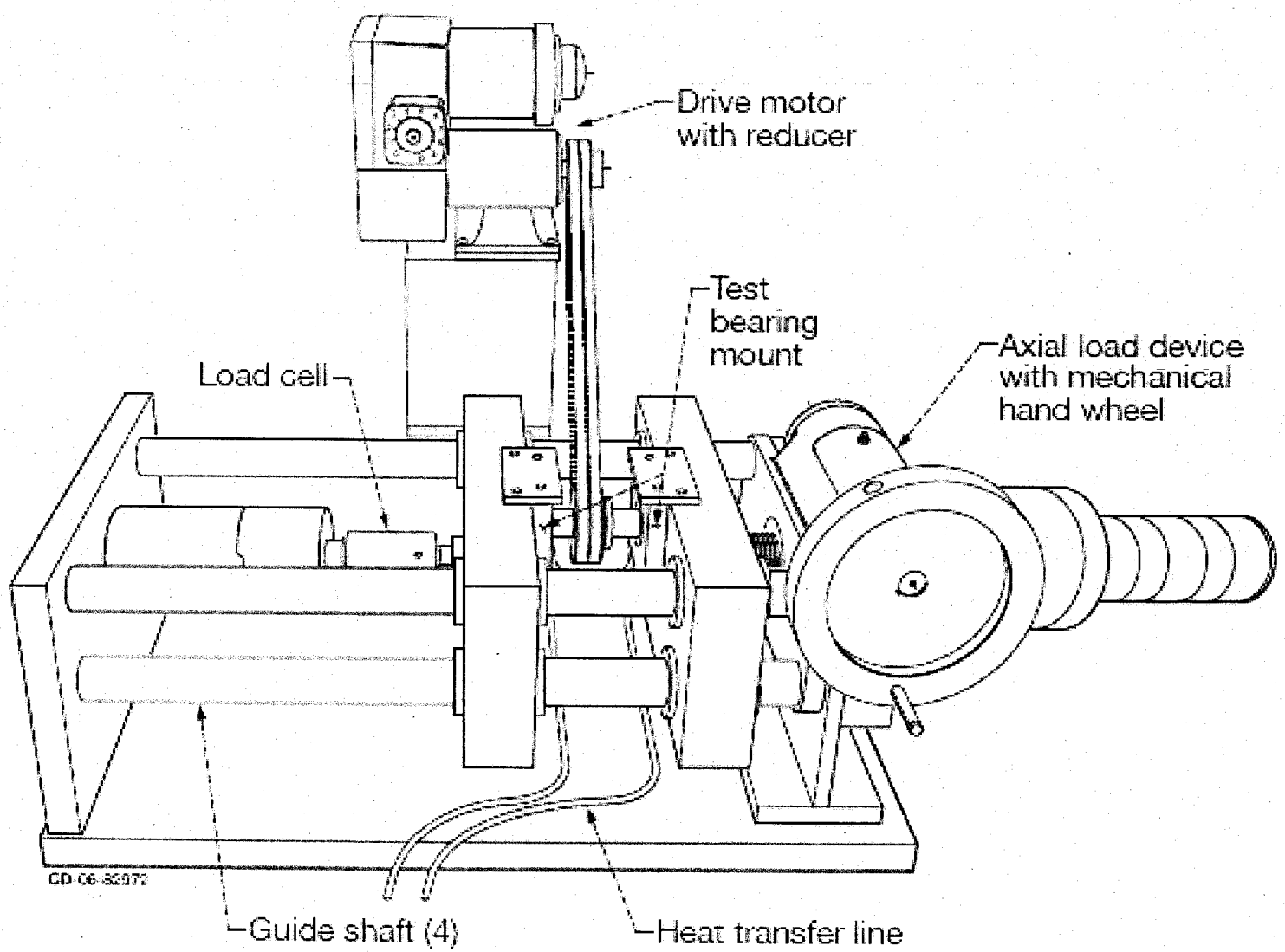

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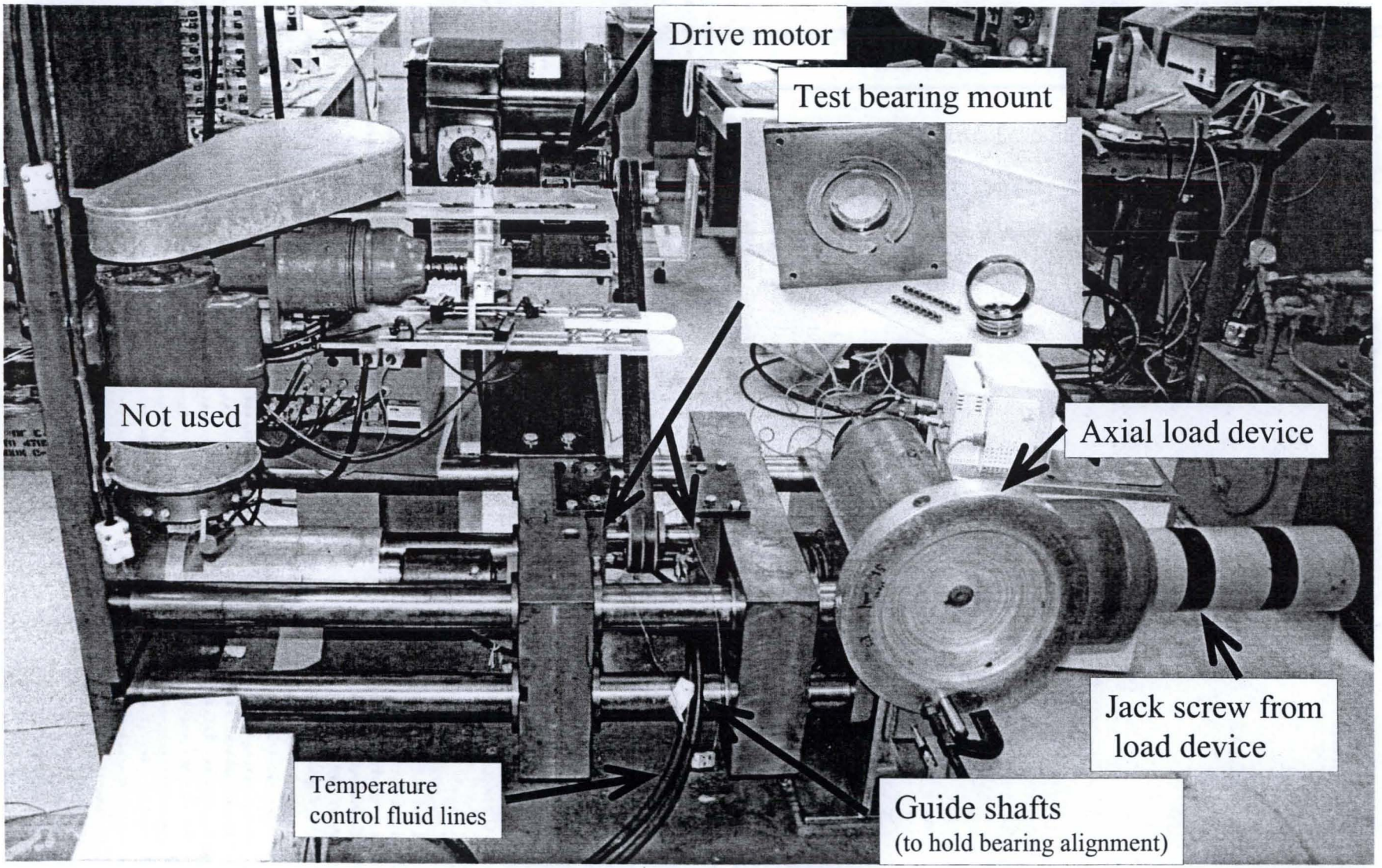
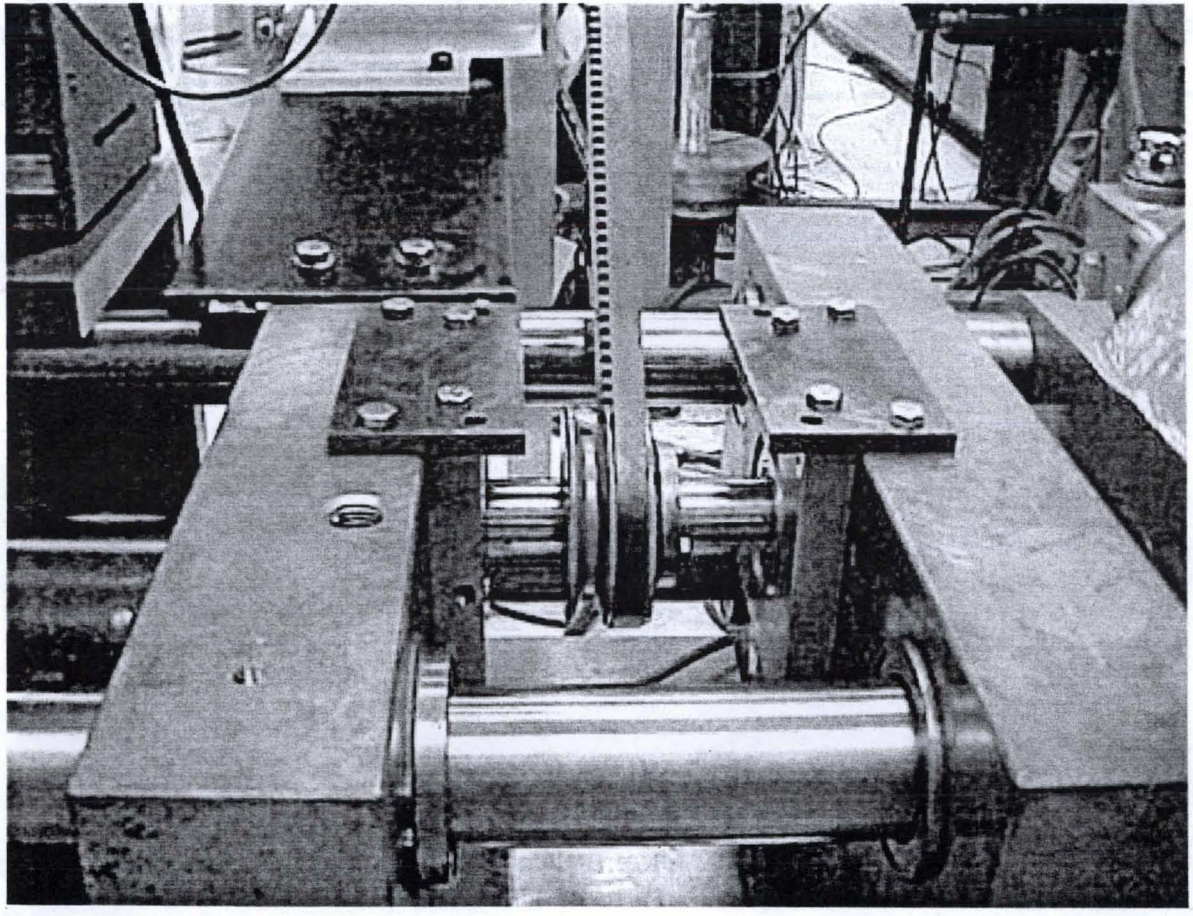


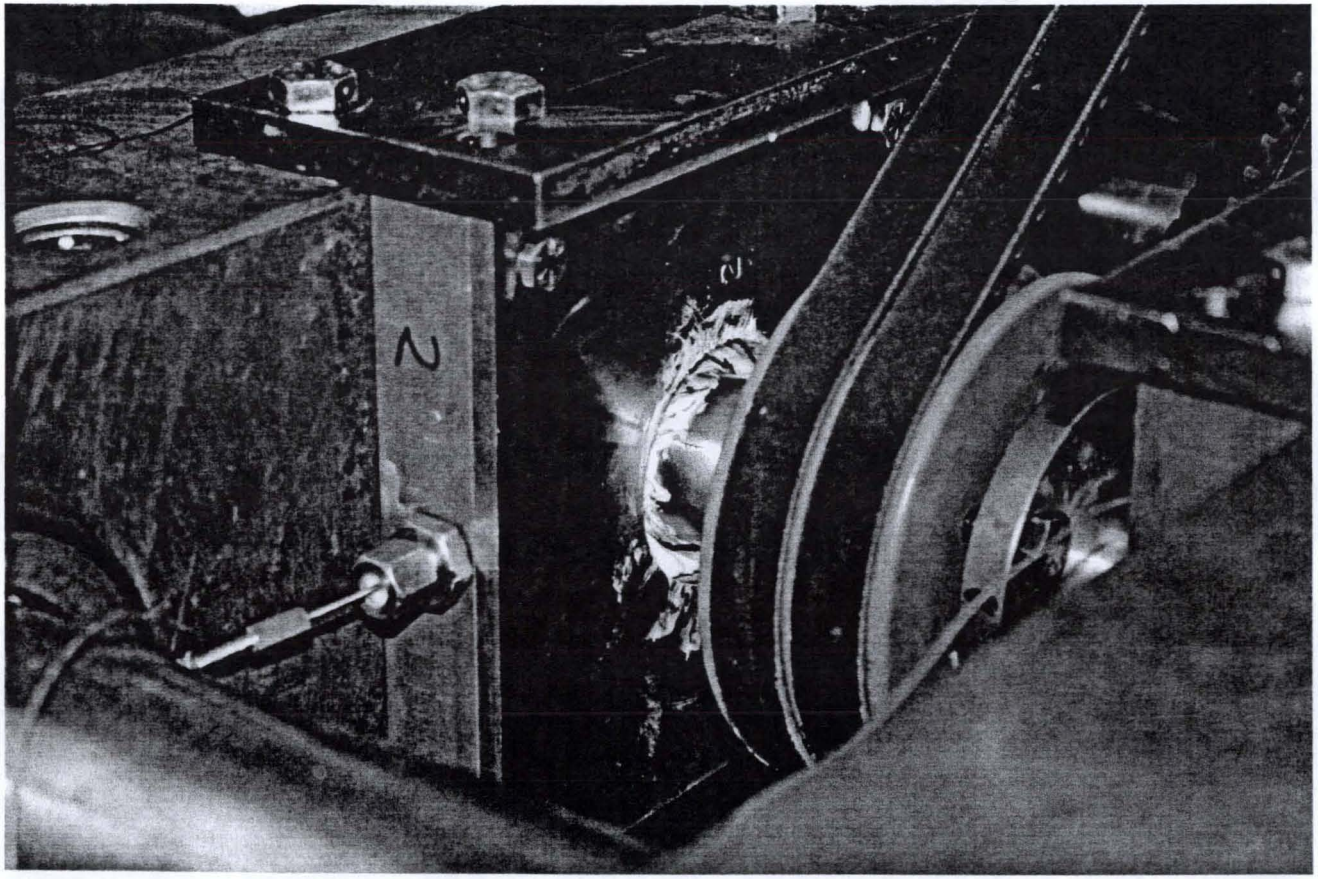
Not used

Low Speed Bearing Testing in Atmosphere



Marshall Space Flight Center Tribology Laboratory Equipment and Capabilities

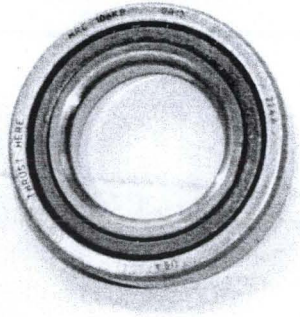
Low Speed Bearing Testing in Atmosphere

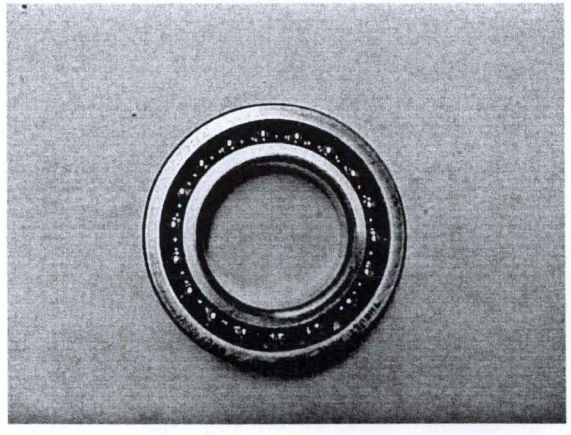


Marshall Space Flight Center Tribology Laboratory Equipment and Capabilities

Bearing Testing in High Vacuum

- **Test Bearing**
  - Modified off the shelf bearing
    - 106 Size (30 mm bore)
      - Same size as BF shaft bearing (P/N 5902051)
      - ABEC 1
      - Full compliment 18 balls





Low Speed Bearing Testing in Atmosphere (Results)

- Testing initiated in Dec 2007
- Two tests have been completed
- Initial results shows no significance degradation in bearing life with dust loaded grease (5 % by weight)

Bearing Testing in Vacuum

Objective: Determine the life of bearings when lubricated with dust loaded grease under boundary conditions and EHD conditions

Lubricants: Braycote® 601 EF loaded with
0 %, 5%, dust simulant (JSC-1AF, JSC-1A)

Test Specimens: 440 C angular contact bearings

Test Environment: High Vacuum

Two Test Setup

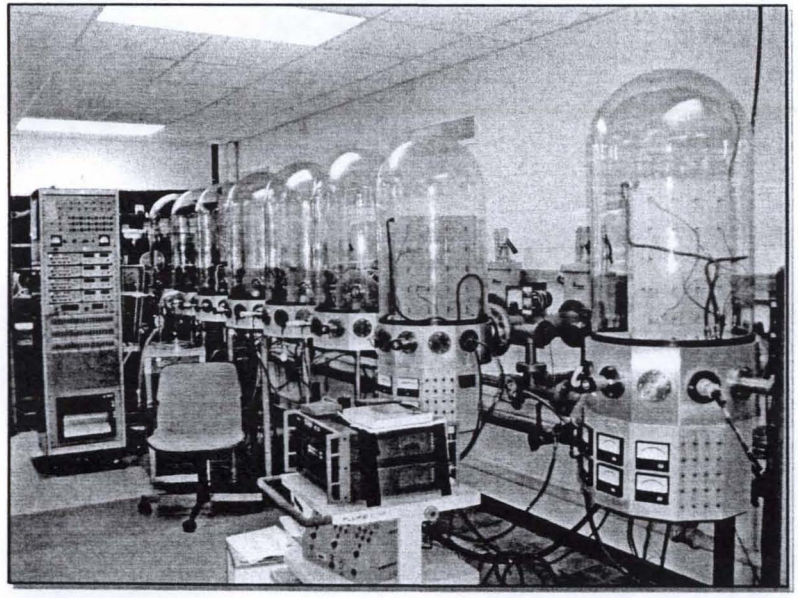
35 rpm(boundary)
3600 rpm (EHD)

Bearing Testing in High Vacuum

- In 1970's, MSFC built a high vacuum test facility to test oils and greases in space environment
- The facility is unique and has allowed MSFC to established a data base of space compatible lubricants that is one of a kind
- This data base has been intensely used as an aid in selection of lubricants for space applications

Bearing Testing in High Vacuum

Long-Term Lubricant Evaluation



Bell jars and motor plates used to evaluate lubricating properties of greases used in space environments at 10^{-6} vacuum levels

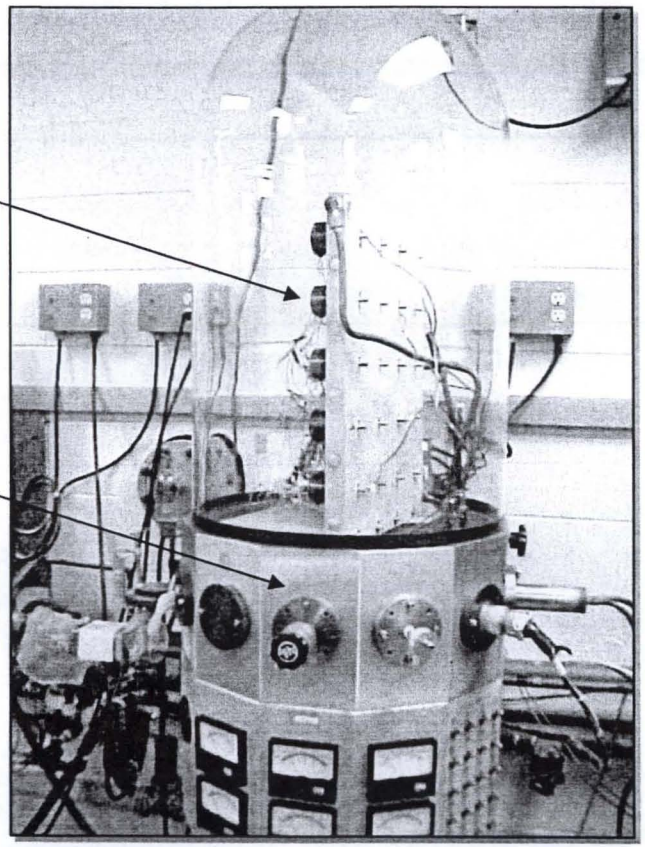
Test duration: 1 month to 5 years; uninterrupted

Bell jars also used for other test environments needing a long-term vacuum.

Bearing Testing in High Vacuum

Motors with grease-filled bearings

Temperature control plate



Determine how mechanism motors behave in vacuum environment for long time periods with exposure to dust

Bearing Testing in High Vacuum

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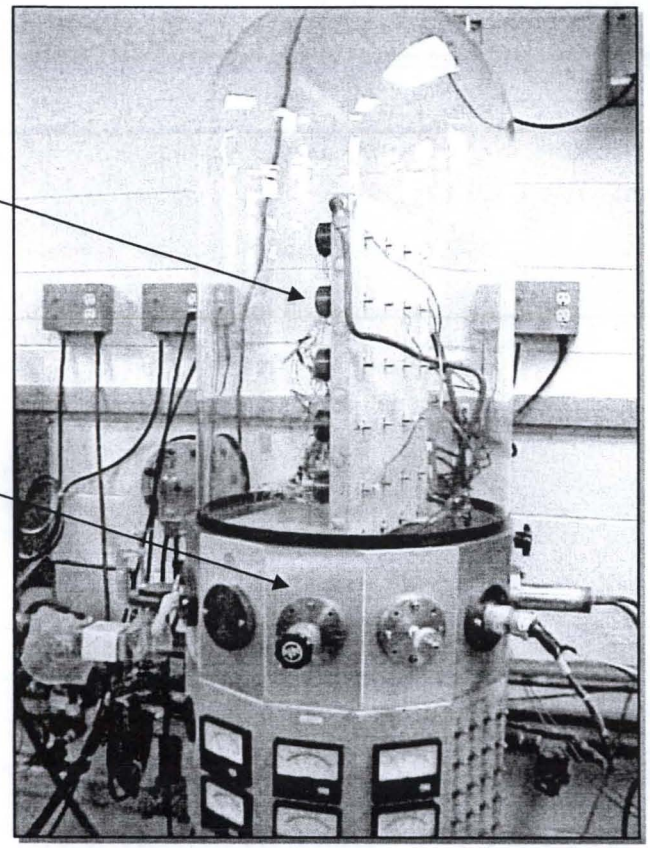


Determine how mechanism motors behave in vacuum environment for long time periods with exposure to dust

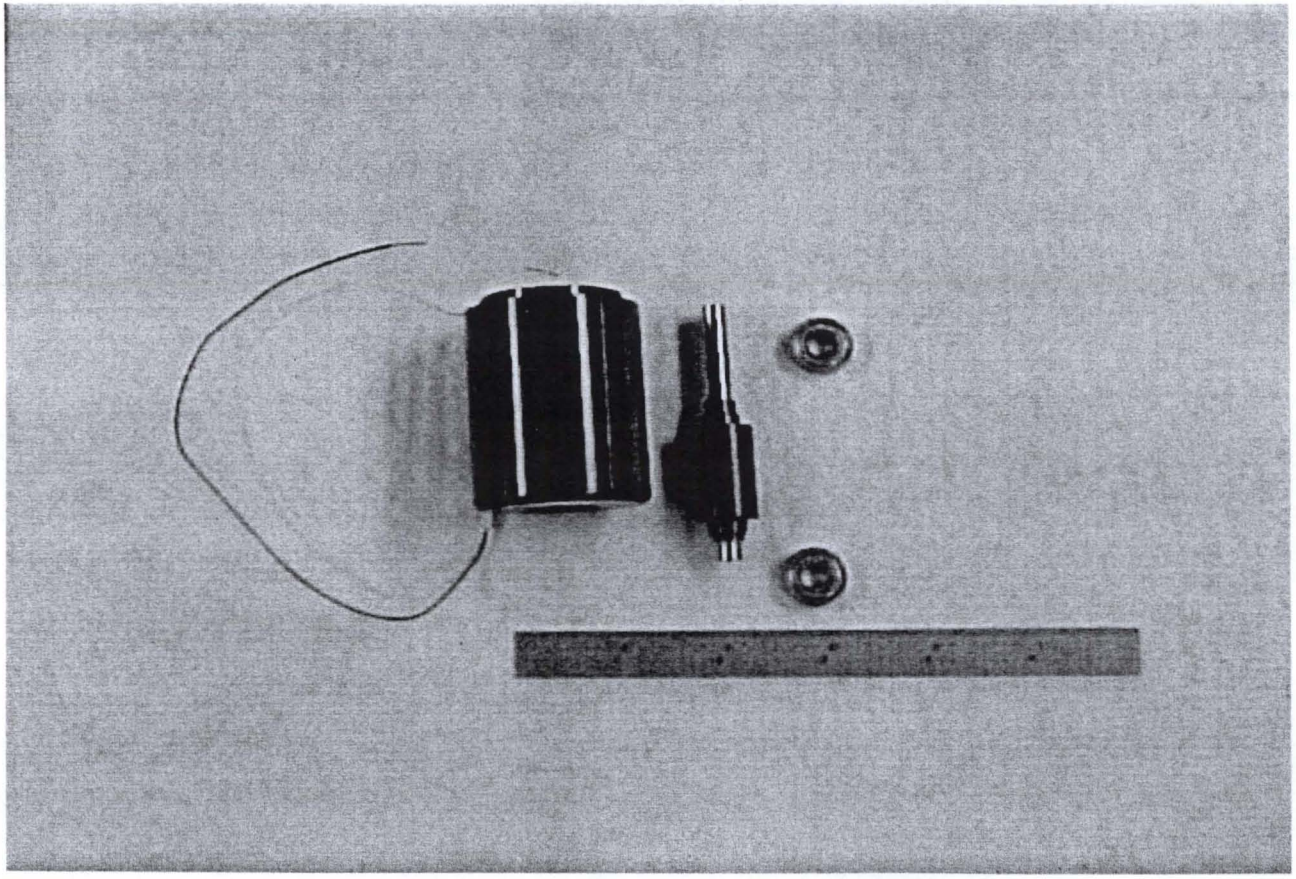
Bearing Testing in High Vacuum

- Testing performed in MSFC High Vacuum Test Facility
  - Twelve station vacuum manifold with bell jars
  - Two 10 inch diameter diffusion pumps
  - E-6 Torr
  - Variable Operating Temperature

Bearing Testing in High Vacuum

- Twenty small motors mounted on aluminum plate per bell jar
- Two R4 440C bearings per motor

Bearing Testing in High Vacuum



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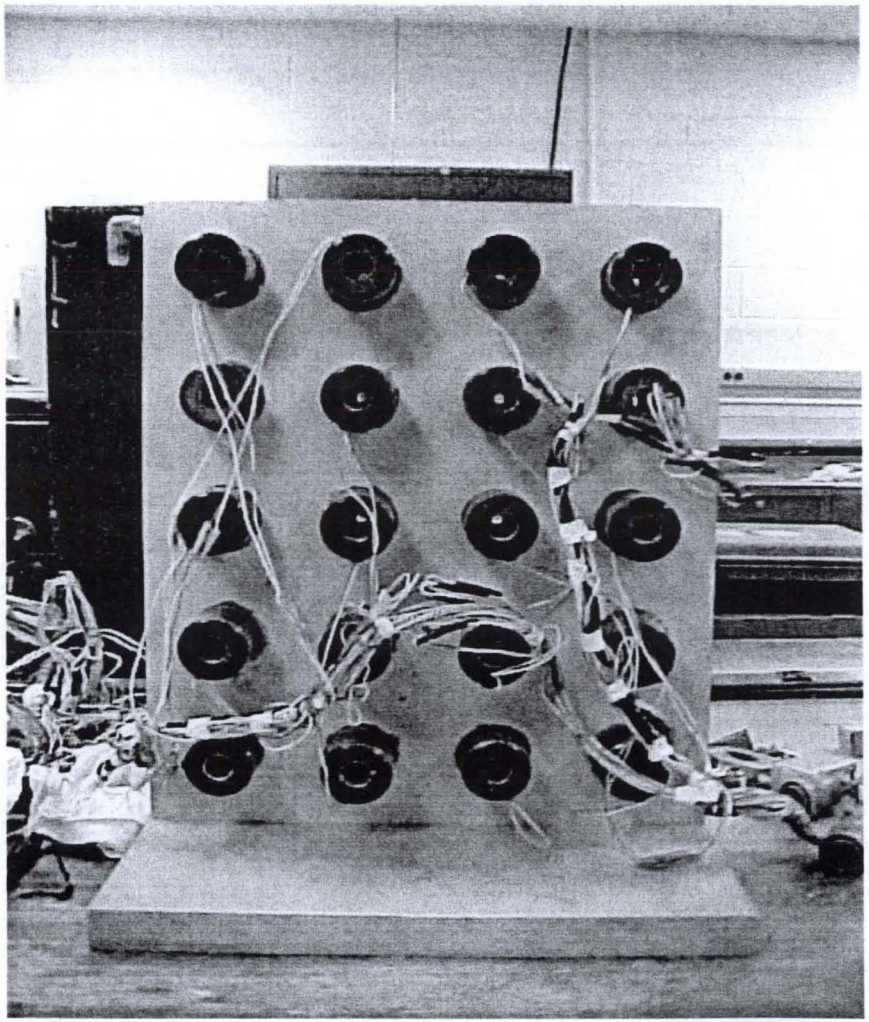

Bearing Testing in High Vacuum

- Test conditions
  - High Vacuum
  - 90 C or 38 C
  - one year duration
  - 3600 rpm
  - 22 N load axial load
  - no radial load
  - 1.70 Gpa(246 ksi) Max hertz stress
  - EHD lubrication

Bearing Testing in High Vacuum (Test Method)

- Bearings are weighed, dried and then lubricated with candidate grease and re-weighed (25-30% fill)
- Bearings are mounted on armatures and installed in motors
- Motors are mounted on an aluminum chill plate inside bell jars
- Motors tested for one year under high vacuum
- After one year bearings are removed and evaluated

Bearing Testing in High Vacuum (Evaluation Techniques)

- Motor failure rate due to lubricant failure
- Mass loss of lubricant
- Visual analysis of tested bearing and lubricant under optical microscope
- Taly-Surf Profilometer used to measure depth of wear track on bearing races

Bearing Testing in High Vacuum (Status)

- EHD Test Setup is underway, testing will be initiated in Feb 2008
- Boundary Test Setup
  - New motors that run at 35 rpm have been order and should delivered in Feb 2008
  - New Chill Plate to accommodate new motors have been fabricated and are ready for use
  - Testing should be initiated in March 2008