EVIDENCE FOR PATCH EFFECT FORCES ON THE GRAVITY PROBE B GYROSCOPES

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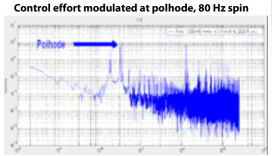
Experimental Observations

Coupling of rotor-fixed frame to the GSS

Modulation at polhode frequency

- Z (telescope axis) bias: 2×10^{-8} N
- Control effort at 1.3Hz spin: 30% of ~2×10^{-7} N
- Position & suspension voltage at 1.3Hz spin :$60nm_{pp}$
- Control effort at 80 Hz spin: 30% of ~10^{-8}N
- Orbit instability at polhode = orbit for drag free Gyro3

Control effort modulated at polhode, 80 Hz spin

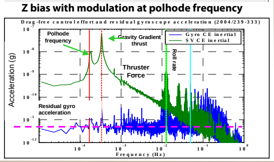


<CE>=6×10^{-8} N

CEPol=6×10^{-9} N

VP~100mV

Z bias with modulation at polhode frequency



$$F = C\cdot 2\cdot V_{DC}\cdot V_P$$

$$@\,\omega_{spin}\, or\, \omega_{polhode}$$

$$V_P \approx 100mV$$

ΔV ~ 50mV-100mV

Possible Rotor-fixed Mechanisms

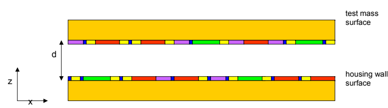
1. Rotor geometry
   a. Mass unbalance: ~10nm (3×10^{-3} of gap)
      ⇨ Small compared to > 10% effects
   b. Surface waviness: ~10nm (3×10^{-3} of gap)
      ⇨ Small compared to > 10% effects

2. Trapped flux interacting with housing
   Three independent calculations
   (Todd Walters, Alex Silbergleit, Paul Worden)
   ⇨ Effect too small by orders of magnitude

3. Non uniform potential of rotor surface
   ⇨ Patch effects consistent with data

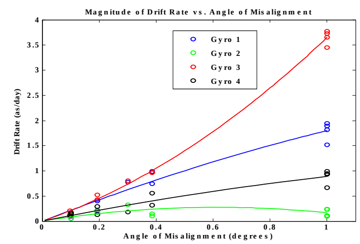
The Patch Effect

- Variation of electric potential over the surface
  - It can arise due to the polycrystalline structure
  - It can be affected by presence of contaminants
- Modeled as dipole layer
- Patch fields present on rotor and housing walls
- Cause forces and torques between surfaces



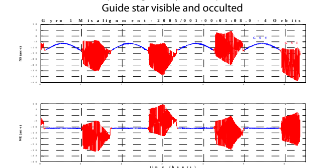
Effects and Solutions

- Misalignment torques
  - Orthogonal to misalignment
  - Fully separable from Relativity
- Polhode damping
  - Period and phase determined to high precision
- Spin-down 1μHz/hr
  - Spin-speed determined to high precision

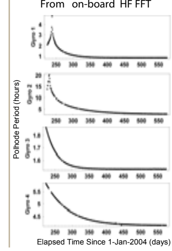


The Patch Effect

Accurate pointing history for torque calibration
Guide star visible and occulted



Polhode period histories for gyros
From on-board HF FFT



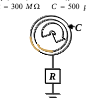
Dissipation in ground-plane resistor

$P_{SD} = I\omega\dot{\omega} = 10^{-11}\, W/(\mu Hz/hr)$

$P_{CP} = \frac{1}{2}\frac{V_P^2}{R}\left(\frac{R^2\omega^2C^2}{1+R^2\omega^2C^2}\right)$

$V_P(mV) = 72\cdot\dot{\omega}(\mu Hz/hr)$

$R = 300\ M\Omega \quad C = 500\ pF \quad \omega = 500\ sec^{-1}$



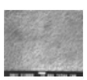
~ 70mV dipole for 1 μHz/hr spin-down

Spin-down rates 0.3-1.5 μHz/hr

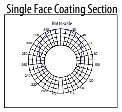
Refinements in Data Analysis Process
Exact knowledge of spin-speed

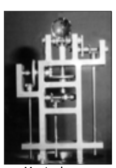
Rotor Fabrication

- Fused Quartz Sphere
  - Lapped and Polished
  - Roundness < 20 nm Peak to Valley
- Coating
  - Polycrystalline Niobium
    - Thickness 1.2 μm
    - < 30 nm Peak to Valley Variation
  - RF Diode Sputtered
    - 15 cm ϕ Target
    - 10 cm Target to Substrate Distance
    - 64 sequentially deposited partial coverage deposits
    - Pattern based on 20 faces + 12 vertices of an icosahedron



Single Face Coating Section





Manipulator

Icosahedron Symmetry

Coating Plasma

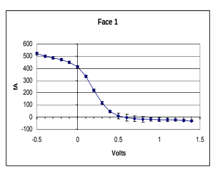
UV Work Function Mapping

- Work function ϕ is the potential difference between the Fermi level within a material and the field free vacuum state just outside the material.
- The energy of the emitted electron is $E_e \leq (hc/\lambda)-e\phi$
- Spatial variations in the work function causes variations in energy of photoelectrons.
- Map bias voltage for zero photoelectron current.

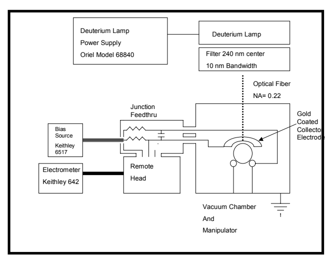
Measuring Apparatus in Vacuum Chamber

UV scan of rotor surface

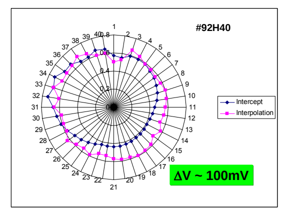
240 nm center, 10 nm width
((5.10eV, 0.20eV)



Block Diagram



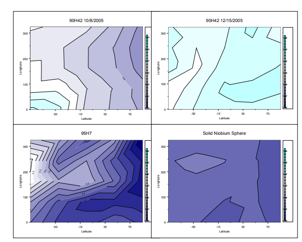
Mapping Plots



Great Circle Trace

Alternative Analytical Methods

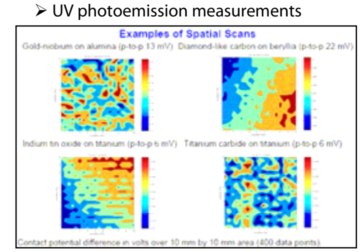
Deposition Pattern Contour Plots of Niobium Surfaces



Contour Interval 0.0425 V

Lessons Learned

- Surface characterization
  - Kelvin Probe measurements
  - UV photoemission measurements



- Large gaps
  - The stiffness is of the form:

$$K\varepsilon_0 \frac{Av^2}{d^3}$$

A is the area,
v is the standard deviation of the potential fluctuations
d is the gap,
K is of order 1

This research supported by NASA on contract NAS8-39225