Design and validation of an articulated solar panel for CubeSats

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Abstract
- CubeSats mission more and more demanding.
- Current design mostly limited to surface mounted solar cells.
- Additional potential by deployable solar panels like in large satellites.
- Further enhancements possible by proposed articulated solar panel.
- Successfully validated prototypes to vibrational loads during launch phase.

Motivation
- Increasing power demands on small satellites.
- Currently increase of solar cell area by deployable solar panels with fixed angle.
- Proposed further improvements by adjusting solar panels for an optimized sun-incident angle.

Subsystems
- Release mechanism:
  - Required for releasing panel from locked configuration during launch.
  - Simple, light, small and reliable mechanism required.
- Articulation mechanism:
  - Proposed to increase efficiency of solar cells.
  - Rotation of deployable solar panel in plane at one degree of freedom.
  - Simple, light and reliable mechanism required.
- Type of solar cells:
  - Comparison of solar cells regarding cost, availability and achievable efficiency.
- Control mechanism:
  - To adjust the attitude of the solar panels to achieve optimal sun-incident angle.
  - Electronic controller embedded in on-board data handling system preferably.

Environmental Challenges
- Launch Environment:
  - Large vibrational load during rocket launch.
  - Risk of physical destruction by moving of mechanical parts (e.g., screw connections).
- Orbital Environment:
  - Cycle changes of temperature during one orbit.
  - Induced stress on mechanical components by difference in thermal expansion.
- Vacuum environment:
  - Outgassing of mechanical components.
  - Particle radiation.
- Degradation of applied materials.

Problem Statement
- Additional available energy: 12 Wh at AM0 by articulated solar panels.
- Output voltage between 10 and 20 volts.
- Embodied torque coil including interface.
- Temperature sensor at back side of panel.
- Possibility to print antenna circuit on or within the array substrate without degradation of array performance.
- Electrical interface for antenna, torque coil, power and temperature sensor.
- More.

Conceptual Design
- Hinge design with stepper motor enhanced by planetary gears for larger available torque and higher precision of sun-incident angle.
- Attachment of solar panel by nut which can be heat winding.
- Ultra, Triple-junction solar cells for highest efficiency.
- Electronic controller for calibration and control signal to stepper motor.
- CAD drawing of proposed mechanisms:
  - Constructed first prototype with mock-up solar panel.
  - First mode found in modal analysis at approximately 240 Hz.
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  - Second step: classical analysis with constant excitation.
  - Resulting deflections:
  - Resulting stress in whole panel.

Estimated Solar Cell Area: 0.05 m²
- Improvements by articulated Solar Panel.
- Fixed mounting, panel can be removed at higher efficiency.
- Additional rotations around z-axis: average of 800 W / m² per year.
- Additional rotations around y-axis: average of 800 W / m² per year.
- Additional rotations around x-axis: average of 800 W / m² per year.

Refined Specification
- First two calculated fundamental modes:
  - 239.5 Hz
  - 1107.4 Hz
  - 1041.9 Hz
  - 648.8 Hz
  - 848.5 Hz

Evaluation and Testing of the proposed Solution
- Classical numerical vibration analysis:
  - First step: sine survey (modal analysis), required to find oscillatory modes of analyzed system.
  - Frequency:
    - Mode number
    - Frequency
    - Mode 1: 240 Hz
    - Mode 2: 496 Hz
    - Mode 3: 50 Hz
    - Mode 4: 60 Hz
    - Mode 5: 80 Hz
    - Mode 6: 100 Hz

Conclusion and Future Work
- Large improvements by adding one degree of articulated degree of freedom.
- Validated feasibility of proposed design.
- Consistent results from numerical and experimental vibrational analysis.
- Further tests for outgoing, particle radiation.

Acknowledgments
- SpaceMaster Consortium for funding the work at Utah State University.
- Utah State University and Space Dynamics Lab for opportunity to design and validate design.
- Dr. Rose Pilliner and team at Space Dynamics Lab for sharing their practical experience and continued support throughout the whole project.
- Dwarf Planet Project for the funding the opportunity to attend the conference.

References