Future Power Solutions for Exploring Hypothesized Surfaces

FS2024 ME 481 Capstone Design Project

Michigan State University Mechanical Engineering

DG7: Cameron Tsivitse, Gerrid Rutledge, Ihsan Murtadho Advisors: Dr. Abraham Engeda (MSU), Dr. Cassie Bowman (ASU)

INTRODUCTION

Psyche is a metal-rich asteroid in the asteroid belt between Mars and Jupiter. NASA has launched a spacecraft, arriving in 2029, that will study the asteroid from orbit. It is believed that Psyche could be remnants of a planetesimal core and could provide insight of the formation of Earth's core. Our project consists of a solar panel power solution that could enhance the study opportunities if NASA decides to explore the surface of Psyche. The design maximizes the panels contact with the sun by rotating towards the sun considering the model's location on the asteroid.

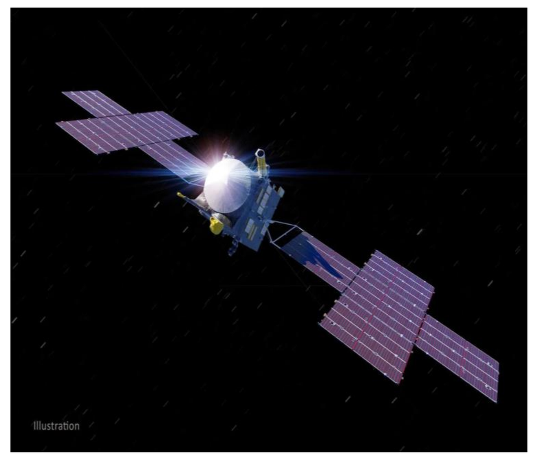

Figure 1. The Psyche Spacecraft

Figure 2. The Psyche Asteroid

PROJECT CHALLENGES

Designing a hypothetical energy system on an asteroid very far away provides many challenges. We designed a solar powered based solution, which will be operated by a mechanical adjustor. This adjustor will be able to locate the Sun at any instant so that the solar panel is most efficient in providing power. We based our hypothetical solar panel based off past NASA Mars rovers that used solar energy. The challenge with Psyche is that it is much farther away than Mars from the Sun. The Asteroid is also much smaller, and the length of day is only around four hours long. This means that when deciding on what solar panel to use, it was very crucial that it was the most efficient one. Choosing the materials that our solar panel adjustor would be made from, as well as the motor that would be used, also provides challenges, when taking the environment of Psyche into account. This includes the gravity, extreme environmental conditions, and temperature fluctuations that can all occur on the asteroid. Finally, when relying on sunlight for power, the solar panel needs to be clean, and so debris can pose a threat to the solar panel's effectiveness.

CODING OUTLINE

- Average LDR sensor values compared to determine necessary directional change and sent to motor controls
- If rotation is needed: both motors move in opposite directions at same speed
- If tilt is needed: motors move in the same direction
- Feedback loop for adjustment until optimal orientation achieved
- End stop switch incorporated to ensure no structural collision

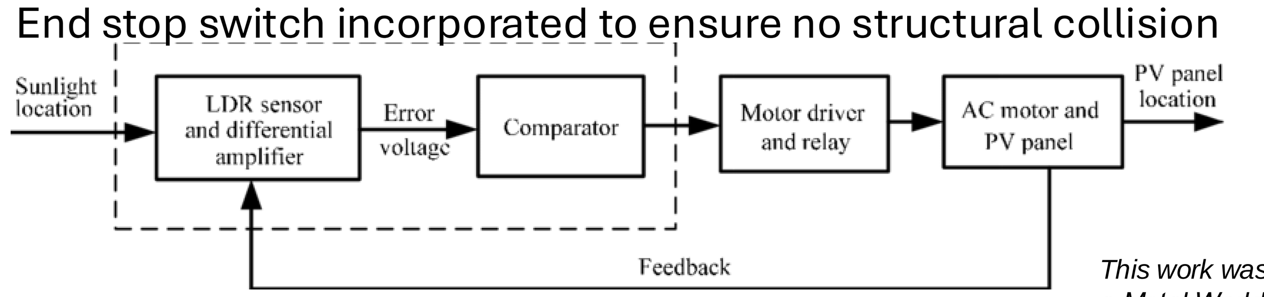

Figure 4. Block Diagram of Solar Tracking System

DESIGN AND RESULTS

Solar Panel Selection/ Specification

- Triple-Junction Solar Cells (Used on Psyche spacecraft)
- Hyper-efficient, lightweight, radiation-resistant
- Designed to work in low light of deep space
- Light Dependent Resistor (LDR) sensors placed at each corner

Material Selection

Gears (Advanced Composite):

- Lightweight:
- Durable in Psyche's Low Gravity
- DLC Coating (Diamond-Like-Carbon) ensure longevity
- Strength-to-Weight Ratio

Material	Density	Strength/ Weight	Durability	Wear resistance	Resource
Aluminum	2.7	Good	Low	low	https://www.aluminum.org/
Titanium (Ti-6Ai-4v)	4.43	Medium	High	medium	https://titanium.org/
Beryllium Copper	8.25	High	High	High	https://www.becotools.com/
Advanced Composite	1.5-2.5	Medium	Medium (Coated)	Medium (Reinforced)	https://www.compositesworld.com/

Table 1. Brief Decision Matrix for Gears

Motor Selection

Moog DB-14520 Frameless Brushless Motor:

- Up to 750 Nm Continuous torque, directly satisfying high-torque requirements.
- Frameless allow seamless integration to design.
- Utilized in past NASA application.
- Operates at 90% Efficiency.

Motor		Continuous Torque	Dimensions (Diameter/Length)	Application	Source
EC-4pole	Maxon	180 nm	40 mm/140mm	Robotics	https://www.maxongroup.com/en
DB14540	Moog	758nm	370mm/12-63.5mm	Aerospace mechanisms	https://www.moog.com/
KBM118	KM	300 nm	≈292,50/50mm	Direct Drive Robotics	https://www.kollmorgen.com/en-us
HpDm-250	H3X	250 nm	220mm/180mm	Aerospace vehicles	https://www.h3x.tech/

Table 2. Motor Selection Decision Table

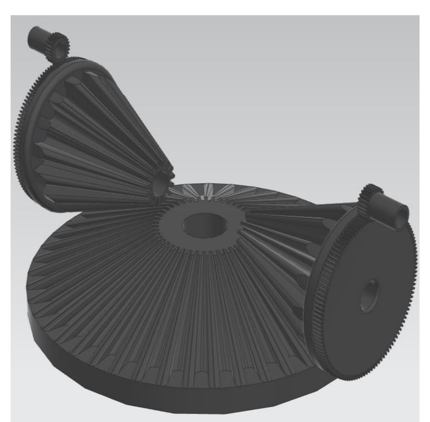

Figure 5. Gear Layout (Without Axle/Casing)

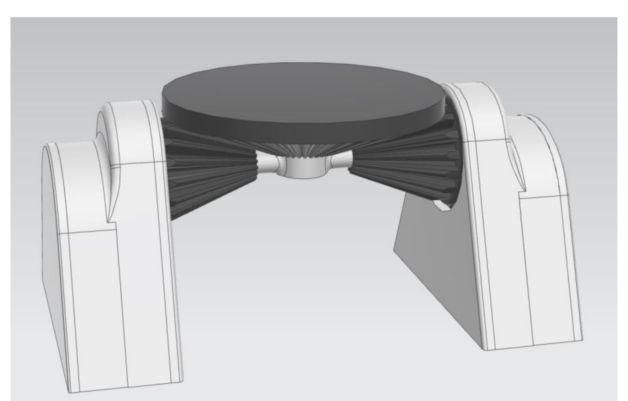

Figure 6.Front View of Adjuster Assembly

Gear Design

- Head Bevel Gear : 45 Teeth
- Side Bevel Gear: 15 Teeth (Bevel Side), 120 teeth (Motor Side)
- Motor Gear: 24 Teeth

Stand/Housing and Axle Decision:

Stand/ Housing (Aluminum Alloy (6061-T6)

- Lightweight
- Corrosion Resistance
- Structural Strength

Axle (Titanium Alloy (Ti-6Al-4V)

- High Strength/Weight Ratio
- Durability
- Corrosion Resistance

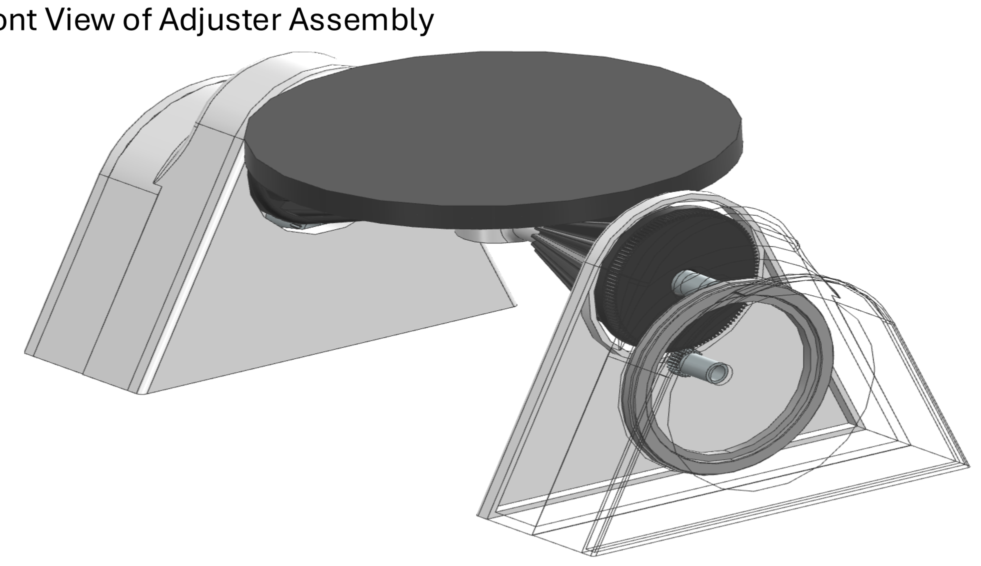

Figure 7. Isometric View of CAD Design

DECISIONS & POWER CALCULATIONS

Solar Panel Calculations (Area, Volume, Intensity, Irradiation, Power Produced)

$$Area_{Solar\ Panel} = \frac{600W}{152\ W/m^2} = 3.95m^2$$

$$\text{Solar Intensity} = \frac{1{,}367\ W/m^2}{(Distance\ from\ Sun\ in\ AU = 3)^2} = 152\ \text{W/m\^{}2}$$

$$\text{Solar Irradiation (S)} = S_0 \frac{1}{d^2} * \max(0, N \bullet \hat{S}),\ S_0 = 1365\ W/m^2$$

$$Volume_{Solar\ Panel} = 3.95m^2 \times 5\ mm = 19{,}750{,}000\ mm^3$$

$$Rover_{Power\ Required} = \frac{150\ watts}{0.25\ (solar\ panel\ efficiency)} = 600W$$

Mass Calculation of Gear System

$$Mass_{Side\ Gear} = 6{,}349{,}292.27\ mm^3 \times 2.0 * 10^{-3}\ g/cm^3 = 12{,}698.58\ g = 12.7\ kg$$

$$Mass_{Total\ Side\ Gear} = 12.7\ kg \times 2 = 25.40\ kg$$

$$Mass_{Head\ Gear} = 31.852.201{,}73\ mm^3 \times 2.0 * 10^{-3}\ g/cm^3 = 63{,}704.4 = 63.7\ kg$$

$$Mass_{Solar\ Panel} = 19{,}750{,}000\ mm^3 \times 2.5\ g/cm^3 = 49{,}375\ g = 49.38\ kg$$

Torque Calculation

Earth Gravity (9.81 m/s^2):

$$Torque_{Head\ Gear} = 63.70\ kg \times 9.81\ m/s^2 \times 0.35\ m = 218.96\ Nm$$

$$Torque_{Total\ Side\ Gear} = 25.40\ kg \times 9.81\ m/s^2 \times 0.1483\ m = 36.89\ Nm$$

$$Torque_{Solar\ Panel} = 49.38\ kg \times 9.81\ m/s^2 \times 0.5\ m = 242.36\ Nm$$

$$Total\ Torque_{Earth} = 218.96 + 36.89 + 242.36 = 498.21\ Nm$$

$$Torque\ Per\ Motor:\ Total\ Torque/2 = 498.21/2 = 249.11\ Nm$$

Psyche Gravity (0.114 m/s^2):

$$Torque_{Head\ Gear} = 2.55\ Nm$$

$$Torque_{Total\ Side\ Gear} = 0.43\ Nm$$

$$Torque_{Solar\ Panel} = 2.81\ Nm$$

$$Total\ Torque_{Psyche} = 5.79\ Nm$$

Earth's gravity will be used as product will require testing before Deployment

Power Calculation

$$Gear\ Ratio_1 = \frac{Teeth\ on\ Side\ Bevel\ Gear}{Teeth\ on\ Motor\ Gear} = \frac{120}{24} = 5$$

$$Gear\ Ratio_2 = \frac{Teeth\ on\ Head\ Bevel\ Gear}{Teeth\ on\ Side\ Bevel\ Gear} = \frac{45}{15} = 3$$

$$Gear\ Ratio_{Total} = Gear\ Ratio\ 1 \times Gear\ Ratio\ 2 = 15$$

$$\omega_{Psyche} = \frac{2\Pi}{4\ hours\ 12\ min} = 0.000413\ rad/s$$

$$\omega_{motor} = \omega_{Psyche} \times 15 = 0.000413\ rad/s \times 15 = 0.00624\ rad/s$$

$$P_{mechanical} = 250\ Nm \times 0.00624\ rad/s = 1.56\ W$$

$$P_{electrical} = \frac{P_{mechanical}}{efficiency} = \frac{1.56}{0.90} = 1.73\ W$$

Considering the low gravity of the Psyche asteroid, the torque and power required to move the system are significantly reduced, enhancing the system's overall efficiency during operations on Psyche

CONCLUSION & RECOMENDATIONS

We believe our solar panel with mechanical adjustor design would be able to satisfy the requirements needed for a hypothesized future mission on the surface of the Psyche asteroid. By using a solar panel power source, surface missions would be able to run for the entire length of day on Psyche and would be able to maximize the sunlight energy captured using a solar tracking system. The tracking system would work using sensors in conjunction with the motors integrated in the solar panel adjustor device. Through careful design analysis and engineering iteration, using an advanced composite based material for the adjustor would make the most sense. This material is lightweight and suitable for Psyche's environment and low gravity. Our team was also careful with implementing the proper solar panel. Through researching past NASA rover missions, the use of triple-junction solar cells was decided to be the best option. The team also ran numerous calculations for the solar panel size and efficiency, motor torque and power and power needed to run a hypothetical rover. The solar panel energy system on Psyche is intended to be used for a wide range of missions on the surface. A rover is just one-use case scenario. For future improvements, we believe using larger and multiple solar panels would make the system more efficient and store more energy. This means the use of multiple adjustors would also be required. Additional future recommendations include the use of multiple energy sources, so that solar energy is not the only energy source relied on to conduct future missions.

*This work was created in partial fulfillment of {{**Michigan State University**}} Capstone Course "{{**ME481**}". The work is a result of the Psyche Student Collaborations component of NASA's Psyche Mission (https://psyche.asu.edu). "Psyche: A Journey to a Metal World" [Contract number NNM16AA09C] is part of the NASA Discovery Program mission to solar system targets. Trade names and trademarks of ASU and NASA are used in this work for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by Arizona State University or National Aeronautics and Space Administration. The content is solely the responsibility of the authors and does not necessarily represent the official views of ASU or NASA.*