Vibrissae Inspired Mechanical Obstacle Avoidance Sensor for the Venus Exploration Rover AREE

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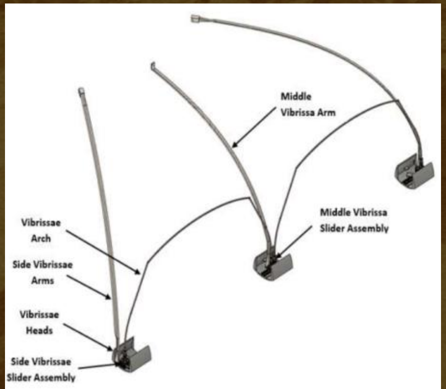
Background

- NASA's Venus Rover Challenge was an invitation for the global community to develop a robust mechanical obstacle avoidance sensor capable of functioning on the surface of Venus, a planet with surface pressures 92 times greater than that of Earth and temperatures exceeding 450°C.[1]
- The sensor was to be incorporated into a wind-powered Automated Rover for Extreme Environments (AREE).
- It was required that the sensor be able to detect a wide array of environmental obstacles.

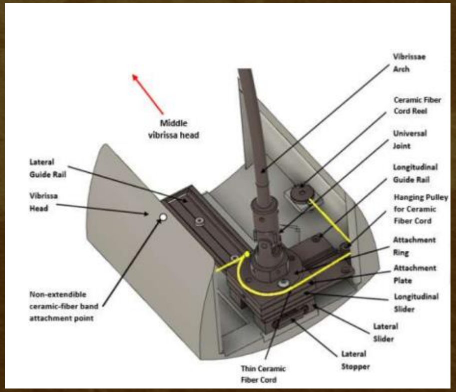
Vibrissae Mechanism



Vibrissae Mechanism

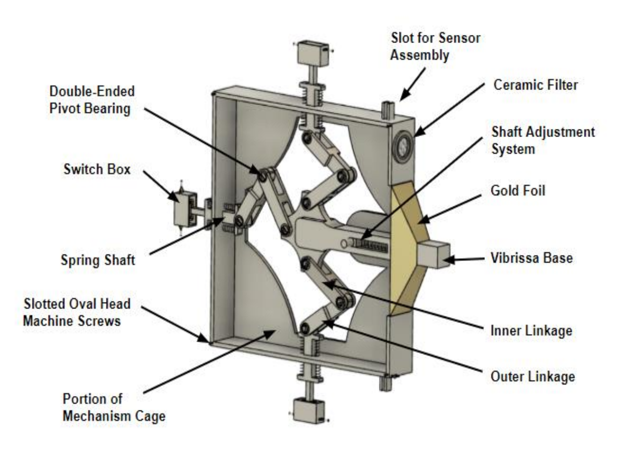
- The first component of this relay is the vibrissae mechanism, an assembly of three mechanical vibrissa that extend from the front of the rover to the Venusian surface to detect obstacles.
- The vibrissae are connected by rigid arches made of a carbon-carbon composite that allow motion hindering obstacles between the vibrissae heads to be detected, while allowing shorter obstacles to pass undetected.
- Rotary motion of these arches is possible through universal joints that connect the arches to the vibrissa heads, both made of Ti-6Al-4V.

- To enable the outer vibrissa heads to be continuously stationed directly in front of the rover wheels, the arches are fixed to slider assemblies on the vibrissa heads, and non-extendible ceramic fiber loop bands are used to connect the outer vibrissa heads to eyebolts.
- During vertical extension of the vibrissa head, all sliders translate from their initial position towards the opposing ends of the vibrissa head.
- The sliders are associated with self-retracting cord reels, which provide a spring force that allows all sliders to return to their initial position when backing away from obstacles upon detection.



Slider assembly for outer vibrissa head

Trigeminal Mechanism



Trigeminal mechanism components with a section of the mechanism cage removed for interior visualization

- The second set of components are characterized as trigeminal mechanisms, which function via flexural-based mechanics to convert vibrissa displacement into an electrical signal.
- The trigeminal mechanism, of which there are three included within the OAS, translates the two-dimensional movement of each vibrissae, into compressions or extensions of three sets of linkages and accompanying spring shafts. Much of the trigeminal mechanism is composed of Ti-6Al-4V, apart from the springs, foil, and screws.
- The linkages are constantly held in a resting state that resists displacement of the vibrissa head from level surface, where rover inclination acts as the reference but are displaced by the slightest movements of the vibrissa.

- The system of nine differentiated double-ended pivot bearings and three spring shafts provide precise rotation with low hysteresis.
- The trigeminal mechanism to resist inappreciable vibrissae movement, sustain a resting state, and allow angular displacement to specified degrees that define the pin actuating configurations.[3]
- When specific configurations of the trigeminal mechanism are meet, gold contacts are closed, which leads to pin actuation. The springs, foil, and screws mentioned above will be made of Ti-6Al-4V, gold, and steel A-286, respectively.

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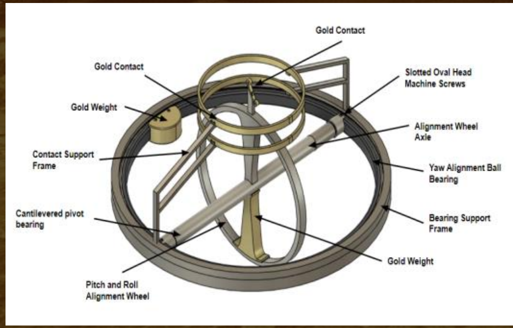
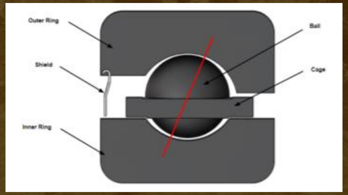
Inclination Sensor



OAS Inclination Sensor

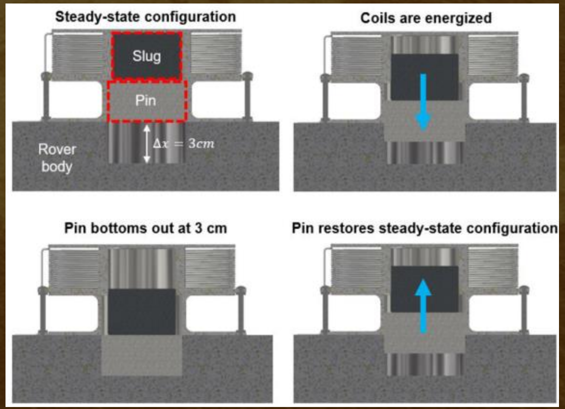
- When inclination increases or decreases gradually, such as a slope on a hill or mountain, the previous systems will not detect this change since they are limited to sensing obstacles in reference to the plane tangent to the bottom of the rover wheels (i.e. rover inclination).
- To mitigate the risk that gradual inclines pose, a mechanical-based inclination sensor was designed for use in the OAS to detect gradual declines and inclines in any directions by referencing the orientation of gravity.



Cross-section of the unloaded ball bearing raceway

Electromagnetic Actuation System

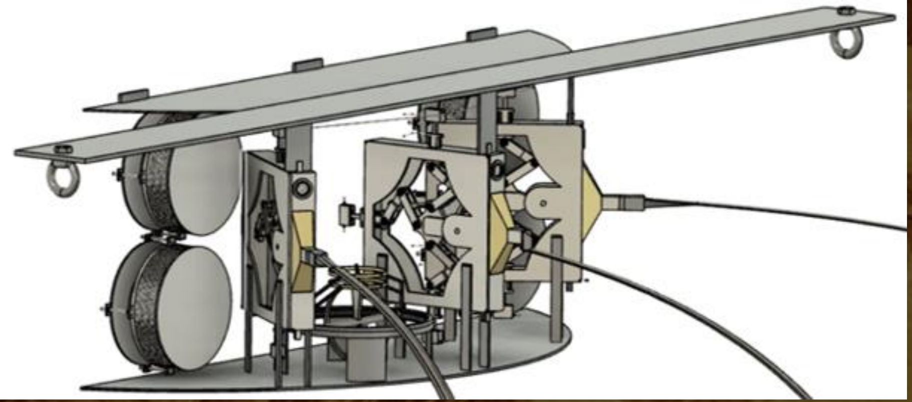
- An electromagnetic actuation system is employed to notify the rover via pin actuation that an obstacle has been encountered.
- The magnetic field generated by an energized solenoid exerts an axial force on the pin, pushing it into the rover body and relaying the obstacle detection to AREE.
- The electrical circuit used to energize the pin-actuating solenoids is designed with 10 switching mechanisms and four solenoids.
- Using up to 4.5 W of power provided by the rover wind turbine, this system allows the detection of a multitude of obstacles but can differentiate them into four distinct signals, which include holes and negative 30-degree inclines, positive 30-degree inclines, 90-degree or near 90-degree inclines, and gradual inclination that accumulate to 30-degree in any direction.



Pin actuation diagram

Conclusion

- The function of the various mechanisms, along with an extensive material trade study to determine the appropriate composition of OAS components, and failure modes with mitigation strategies, ensure that all problematical obstacles outlined by NASA are detected.
- This OAS ensures that the AREE can operate in the extreme surface conditions of Venus for an extended period and was officially recognized by NASA as one of the top design solutions.[5]



OAS with side hull removed for visualization of internal components

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