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DUST CONTROL FOR ENABLER

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Abstract

The dust control group designed a system to restrict dust that is disturbed by the Enabler during its operation from interfering with astronaut or camera visibility. This design also considers the many different wheel positions made possible through the use of artinuation joints that provide the steering and wheel pitching for the Enabler. The system uses a combination of brushes and fenders to restrict the dust when the vehicle is moving in either direction and in a turn. This design also allows for ease of maintenance as well as accessibility of the remainder of the vehicle.

Introduction

The purpose of the Enabler project was to design a lunar work vehicle. The Dust Control group was responsible for the design of a device to restrict dust from interfering with astronaut and camera visibility.

In a previous Apollo mission, the astronauts noticed that lunar dust had a tendency to "rooster-tail" from the wheels of the lunar rover. The dust was electrostatically charged and thus stuck to almost everything, including the astronaut, the lunar rover, and the lenses of cameras. This presented a problem, especially for astronaut and camera visibility.

This report presents a possible solution to this problem.

Problem Statement

The objective of the Dust Control group was to devise a system to keep dust down, so it would not interfere with visibility of the astronaut and the cameras. The device needs to satisfy the following criteria:

1. The device should not weigh more than 200 kg.

2. In the event of damage to the system, the astronaut must be able to repair or replace all damaged parts easily.

3. All main parts of the device should last 10 years. Replaceable parts should last a minimum of 2 months of continuous use.

4. The astronaut should have easy access to the sides of the vehicle at all times. Any dust control device should allow for this access.

5. The device should keep at least 80% of the dust down.

6. The device should be independent of vehicle power systems.

7. Parts of the device that may come in contact with rocks should be extremely durable. Attachments should be high-strength.

8. The device should be manufacturable on the moon at a later date.

Materials Selection

Materials for the dust control device are a quintessential component for the design of the device. The materials must be able to withstand the harsh environment of the moon.

High doses of radiation cause most man-made polymers to degrade, and they would therefore not be the optimum choice. Radiation tends to cleave the carbon-carbon, carbon-nitrogen, and carbon-oxygen bonds. Radiation also has ill effects on some metals such as steel, causing embrittlement and loss of characteristics necessary for the metals' intended purposes.

The vacuum pressure also has detrimental effects on some materials. Some metals such as cadmium, zinc or magnesium at greater than 125^{o} C sublimate, and some polymers degrade under vacuum.

Strength is a very important characteristic, because the dust control parts must withstand the impact of the lunar soil and small rocks. However, a low coefficient of thermal expansion for the fender, a smaller Young's Modulus for the brushes and sheet and weight are factors to be considered in addition to strength. Since bolts hold the fender in place, the thermal coefficient should be as low as possible, and the material should also have the highest strength and lowest weight possible. Young's Modulus should be low enough for the material to flex but large enough to remain horizontal and strong enough to withstand the forces of the lunar soil coming off of the wheel.

Aluminum 356 was chosen for the support structure of the brushes, the hinges, and the attachment bracket because it is one of the lighter weight aluminums (2.68 g/cm^3). It also has a respectable coefficient of thermal expansion of 21.5 x 10^{-6}/°C which is not the least (19.0 x 10^{-6}/°C for A132) nor the most (25.0 x 10^{-6} for A1220) toward the lower end of coefficients of aluminum alloys. It is 82.7% Al, 0.3% Mg, and 7.0% Si and has a tensile strength of 230 MPa, a yield strength of 165 MPa and the ductility of 4% EL in 5.08 cm. Radiation and vacuum pressure have little effect upon this aluminum.

S glass is the material of the brushes and knit inner sheet because it is stiff enough to remain horizontal when five fibers are braided together. High performance glass fibers could be used but they would be too stiff and would break more easily than the S glass, which will bend under the same stress. The glass bristles are to be Teflon coated. This will increase the abrasion resistance of the bristles. The Teflon coating will also allow the bristles to last longer, because it will reduce the abrasion and therefore reduce flaws created by the lunar soil. Flaws in the glass are the places where failure is most likely to occur. The S glass contains 65 (wt. %) of SiO_2, 25 (wt. %) of AlO_3 and 10 (wt. %) of MgO and has the tensile strength of 4,500 MPa, Young's Modulus of 85,000 MPa, density of 2.48 g/cm^3, and a coefficient of thermal expansion of 3.0 x 10^{-6}/°C. The lower Young's Modulus is necessary because the bending allows the force to be dissipated over a greater distance. Since the distance is greater, the stress is less than a stiffer fiber that does not bend as much. Radiation and vacuum pressure have little effect on S glass.

A molded woven graphite-fiber-reinforced borosilicate matrix is the material of choice for the fender. It has a density of approximately 2.25 g/cm^3 with an elastic coefficient (E) of 380 GPa, an ultimate tensile strength of 2.2 GPa and a coefficient of thermal expansion of $-.6 \times 10^{-6}/°C$. The carbon fibers prevent micro cracks in the structure from propagating, and when the graphite is exposed it acts more like a lubricant. Complex shapes can be made by injection or compression molding into shaped dies at high temperatures. The low coefficient of thermal expansion, high strength, and fairly low density make this material the optimum one for the fender. Radiation and vacuum pressure have little effect on this material.

Detailed Description of Parts

Hinge

The purpose of the hinge in the dust control device is to attach and remove the brushes with great ease. It also will make it easy to access the vehicle by raising the brushes up out of the way. Here the hinge will be made from steel, but on the moon it will be made from Aluminum 356.

There are four different parts to this hinge:

1. The brush bar will be attached to the upper part of the hinge by bolts and will use the three bolt holes at the bottom in the triangular shape. There is also a circular rod to attach the hinge to the chassis (Figure 8).

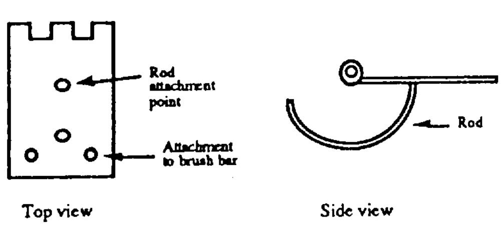

Fig. 8 Brush bar attachment

2. The lower part of the hinge will fit into the slotted part on the chassis. It has a hole in the center so that the rod from the upper half of the hinge can penetrate the lower half and keep the entire hinge in place (Figure 9).

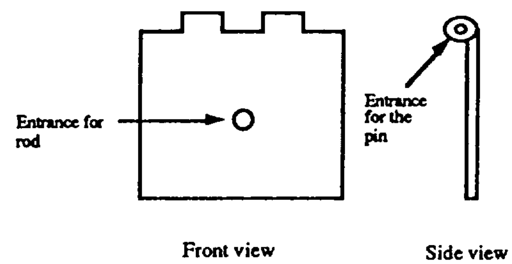

Fig. 9 Hinge and rod placement

3. The spring will wrap around the pin of the hinge in a effort to keep the hinge in the closed position (Figure 10).

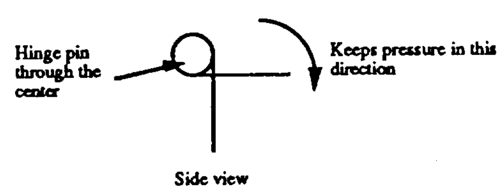

Fig. 10 Spring

4. The last part of the hinge is the pin that holds the two halves of the hinge together (Figure 11).

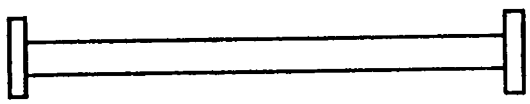

Fig. 11 Hinge pin

Center Brush Assembly

The center brush assembly is the mechanism to control dust between the front and center wheels and center and rear wheels. Because of the large range of motion in these areas, the interference of the assembly is very critical. The center brush assembly consists of two major parts and some minor attachment parts.

Brushes

The brushes are the key to the mechanism. They are able to accommodate a dual task. First, they are able to deflect the dust downward and away from the chassis. More importantly, the brushes do not interfere much in a full near side turn and allow the vehicle to perform unhindered movement.

The brushes are angled so that they are parallel to the opposite side brushes when in a full 30^{o} near side turn. They are at an angle of 14^{o} to the chassis. This allows the brushes to move back and forth with the least amount of angle between them when the maximum amount of interaction of the brushes occurs. The maximum forces between the brushes will be lessened by this setup.

The brushes are connected to a brush bar to form something like a comb. The brush bar slides into the groove from the edge of the solid piece framework. The straight brush bar slides in at the outer edge of the vehicle, while the angled brush bar slides in at the inside. The brush bars are held in place by a pre-threaded wing nut. The angled brush bar is harder to replace, but should not have to be replaced very often because it has shorter brushes and is not the recipient of a large amount of dust.

Solid Piece

The solid piece is much sturdier than the brushes. The solid piece is positioned so that it does not interfere with the solid piece on the opposite side, and it interferes with the brushes on the other side only in a limited capacity. The solid piece conforms very closely to the fender to minimize the dust that escapes between them and also serves as an attachment point for the brushes. The thin sheet allows the assembly to stay light while still providing complete dust protection.

The entire assembly is bolted to and supported by a hinge. The hinge provides several useful functions. The hinge allows the assembly to be lifted so that access to the vehicle's chassis is not impaired. Also, the hinge will allow the assembly to move if it is hit underneath by a large rock that the vehicle might be trying to climb. The hinge also can make it easier to attach the brush bars, especially the angled bar.

Attachment Brackets

Purpose

The purpose of the attachment bracket is to provide hard attachment points for the fender and brush arm assembly, while allowing easy removal of the brush arm assemblies. It also must avoid the bolts that attach the main wheel bearings to the chassis, while providing for easy removal of the wheel bearing bolts. This must be accomplished inside a distance of no greater than five (5) inches axially on the lateral portion of the chassis (Figure 12).

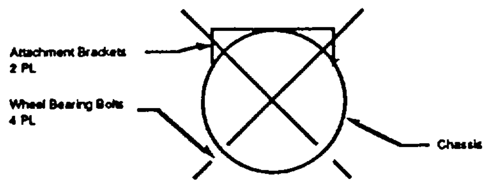

Fig. 12 Attachment bracket

Design Elements

The attachment clamp consists of two steel "boxes" measuring approximately 300 x 120 x 80 mm (Figure 13). These boxes are welded to the chassis at approximately the location shown in Figures 12 and 13. In this position, they allow the brush arm assemblies to be mounted above the center of the chassis and to avoid the wheel bearing mounting bolts.

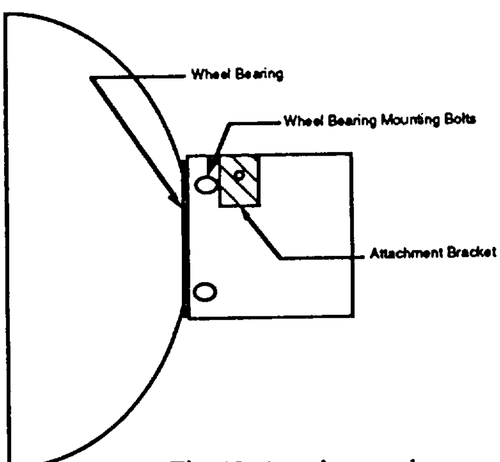

Fig. 13 Attachment clamp

Materials

To facilitate mounting the attachment brackets, the material chosen is steel. This choice was dictated by the fact that steel has already been chosen for the chassis material. By choosing the same material, it is now possible to install the brackets by welding them directly to the chassis. This gives a very strong, solid attachment point for the brush arm assemblies. A firm attachment point was necessary because the brush arms will be undergoing violent displacements and should be able to return to the exact point of rest that was intended by the designer.

Fender

The fender's purpose is to prevent the dust from covering the vehicle when it leaves the wheel from 0^{o} to 90^{o} relative to the horizontal plane. The dust goes around the fender and then back down to the ground. The fender has 12.7 cm of clearance to keep the wheel from touching it when it is deformed from various obstacles. The fender leaves the chassis at a 60^{o} angle to keep space between it and the conical wheel. The fender comes 5.08 cm below the outside of the wheel, which is also at a 60^{o} angle to prevent dust from escaping and covering the vehicle with a thin dust layer. Polyethylene is the material used on the Earth vehicle, but we recommend using a molded woven graphite-fiber-reinforced borosilicate matrix for the lunar vehicle. The fender is 0.4 cm thick because it would be thick enough to withstand the stresses of impact of the lunar soil and small rocks. Each fender would weight 24.5 pounds, and all six fenders would weight 147 pounds.

Front and Rear Dust Brush Assembly

To aid in keeping dust below the chassis in front of and behind the vehicle, a special dust brush assembly is required. The front and rear dust brush assembly differ from the center brush assembly used between the wheels for the following reasons:

1. The center brush assembly is too low to be used in front of and behind the vehicle. If the center brush assembly is used in front of and behind the vehicle, it would be subjected to impact from large rocks being climbed by the vehicle.

2. If used in the front of the vehicle, the center brush assembly would interfere with the seat.

The dust brush assembly consists of four main parts:

1. <u>The Base Support</u>. This aids in supporting the dust brushes. It is welded at the base to the hinge. On the other end, it is welded to the

arm support. The base support is hollow and the walls have a thickness of 4 mm along the entire length of the piece. The base support is made of steel in the Earth model, but aluminum is recommended for use on the moon.

2. The Arm Support. This also aids in supporting the dust brushes. This piece is angled at 30° to the horizontal, and is welded on both ends. At the lower end, it is welded to the base support. At the upper end, it is welded to the brush holder. This piece is also made of steel and is hollow with a wall thickness of 4 mm along the entire length.

3. Brush Holder. This holds the removable brushes. The brush holder is 60 mm x 60 mm x 410 mm. The housing is made of the same type rectangular steel tubing as used for the support arm, but one "long" face is cut open for brush attachment.

4. Brushes. These easily replaceable brushes are each composed of 6000 staggered bristles, held together by a steel "clamp," which can easily be slid into the brush housing. Staggered bristles are used to reduce the total number of bristles needed to function properly. These nylon bristles are 1 mm in diameter and 808 mm long. Teflon-coated fiberglass bristles are recommended for use on the moon.

The total weight of four assemblies needed for the vehicle, using the materials chosen for the moon, is 115 lbs. All materials chosen and reasons for their specification are discussed in the materials section of this report.

Conclusions

The objective of this project was to design a 6-wheeled lunar work vehicle. The Dust Control group was to design a device to restrict lunar dust from interfering with astronaut and camera visibility. Astronauts noticed in previous missions that lunar dust kicked up by the wheels of the lunar rover would hover for long periods of time, thus interfering with visibility. Also, the electrostatically-charged dust stuck to almost everything, including the camera lenses, which hindered filming.

In order to maintain astronaut and camera visibility, a device was designed to reduce the amount of dust thrown up by the vehicle's wheels. The total weight of the dust control system does not exceed 200 kg, while still providing the strength necessary to stand up to impact from rocks when the vehicle is traveling at speed. The design allows for occasional replacement of parts that will see a great deal of wear and tear. This replacement can be easily accomplished by astronauts wearing pressure suits. In the event that access to the vehicle is required, the brush assemblies rotate upward, allowing the astronauts to reach the interior of the vehicle with a minimum of effort. The dust control system will keep approximately 80% of the dust below the chassis while not interfering with the line of sight of the astronaut and the cameras. It does not require power from the vehicle drive motors and is extremely durable. All parts of the design will be manufacturable on the moon.

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