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Design, Simulation and Manufacture of Wheel for Human Exploration Rover

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Abstract

A human exploration rover is usually designed to travel and explore in outer space conditions like a moon-buggy or a mars rover but it should be human powered as in outer space the atmospheric pressure is different than the earth so the wheel of the human exploration rover is an important concern and it need to be designed to survive perfectly in extreme outer space conditions. This paper presents designing process for human exploration rover wheel and manufacturing of this wheel with local accessories that are used in south Asia and without the help of advanced engineering equipment like 3d printer. This paper also represents static load and drop test analysis of rover wheel which is manufactured using locally available material. In this wheel the type of material used is alloy steel. The rulebook of "NASA human exploration rover challenge 2019"is strictly followed and the wheel is designed, simulated and manufactured according to the rules and given conditions of the competition track. The dynamic load analysis was done by multiplying the static load factor with three.

Keywords: Human Exploration Rover, Static Load, Drop Test, Wheel.

1. Introduction

Wheel refers to the rover components that provide contact with the surface. Those components might consist of wheels, belts, tracks, treads, skids, rails, rollers, etc. Through these components, force is exerted on the surfaces being navigated to provide propulsion (thrust) and steering. The surfaces of planetary bodies other than Earth are covered in regolith and sometimes have very low temperature. Wheeled vehicles enable wide-ranging exploration if their wheels and tires are suitable. Wheel/tire technologies, therefore, a critical element of exploration in space and, consequently, an important part of the Rover Challenge. The wheel mounting plate, hub, rims, spokes dish and tire are hereafter referred to as a wheel. To be successful, the wheels of an exploration rover must be designed and fabricated against specific constraints. Rover wheels will encounter hard and regolith-like surfaces. Soft surfaces may include sand and small pebbles. Hard surfaces may include simulated rock outcroppings, fissures or cracks up to 5 inches (~13 cm) wide, and slopes up to 30 degrees. Commercial tires, whether of pneumatic or solid type, are excluded from the competition. Rover wheels should be designed, constructed and tested as new NASA Rover Challenge team creations. The wheels include the outer surface (treads) making contact with the terrain and supporting structure (rims, spokes, etc.). The only commercial items that may be used in the fabrication of the rover wheels are the hubs containing bearings or bushings. Strips or other portions of commercial tires may not be used on rovers competing in the Challenge. Commercially available wheel rims and spokes may not be used on rovers competing in the Challenge [1]. The design should take into account the following criteria such as, safety, adaptability to different surfaces, durability and strength, traction, stability, performance, maneuverability, ground contact Area (wheel footprint), Flotation (less shrinkage) [1]. With proper material this wheel can be very useful. But it will cost very highly again and another problem with this wheel choice is that he has not yet explained their exact specifications, and it is likely that they will not be as durable as off the shelf alternatives. Solid aluminum wheels are another option. These are currently what the Mars Curiosity Rover uses. These wheels are long lasting and greatly exceed the amount of payload they can support when compared to similar designs. The problem with this choice is the added weight, the high cost of material/machining, and the low amount of grip on solid surfaces (no dirt) [2] .The common wheels are standard rubber, inflated wheels. They are good for traversing rough terrain, are easy to transport, and light enough to have spares on board the vehicle. These wheels can traverse large obstacles with the proper propulsion; they have decent traction, and provide some support over soft, hard, and rough surfaces. The cons of these wheels are that they need to be inflated, there are no dust abatement devices, and they can wear down quickly. Solid rubber wheels are the same as the previous design, except that they need no inflation. These wheels have a long useful life, and require minimal maintenance. The main disadvantages of these wheels are that they are heavy and difficult to purchase.

2. Methodology

In modeling the wheels, outer circle of wheel was modeled with circular SS pipe with diameter 1in with thickness 1.5mm and spoke was modeled with circular pipe of diameter .75in with thickness 0.8mm. Some L channel pipe of 0.5*0.5 in with thickness of 0.06in was attached with the outer circle. Afterwards, the whole wheel was covered with SS sheets of 1mm thick. On the top of sheet was coated with the solid rubber of tires of truck wheel. Solid rubber tires are puncture proof and never go flat. However, they are difficult to install onto a rim correctly due to their resistance to deformation. These tires also have a longer life span than standard pneumatic tires due to their resistance to abrasion and lower operating temperatures. The rolling resistance of solid rubber is also much lower than standard tires meaning, less force is needed to propel the tires forward [3]. Traction is not as good for solid rubber tires when compared to pneumatic tires. In a pneumatic tire, the tire conforms to the road or surface providing more traction as the wheel digs into the ground. A solid rubber tire does not conform as much providing less traction. However, the NASA requirements state no air is allowed in the tires, so solid rubber tires are the ideal choice. The very first design of the wheel is given below in Figure 1.

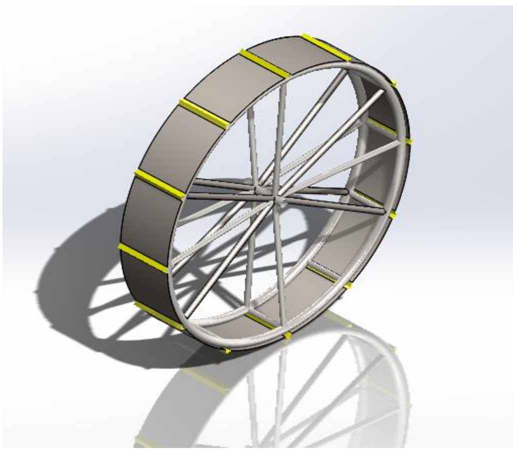

Fig.1. Primary design of wheel.

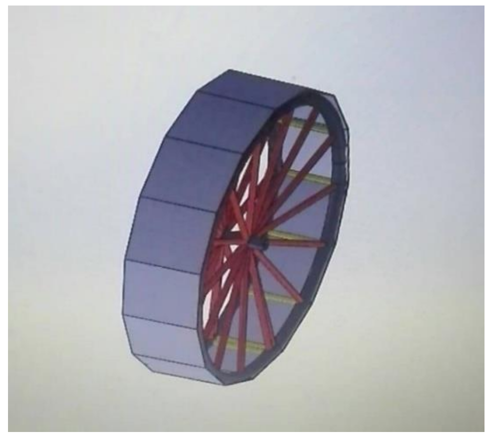

Fig. 2.Modified design of wheel.

After designing this it was realized by R&D that if L channel is covered totally by sheets it will be easier to coat the wheel with sheets. So the model was changed a bit for easily coating the rubber and to make it more reliable in stony road as if the l channel is exposed from the wheel it is likely to stick on road. Again as there is safety concern are related with the design for the drivers the number of spoke was increased to make it more reliable and strong. The modified design is given in Figure 2. Besides, the number of spoke was reduced by static load test and drop test.
As the rule was to keep at least 12in ground clearance and due to suspension the vehicle can shrink to lower width so it was needed to keep the diameter of wheel more than 24in.

3. Material properties

In this context the material grade Alloy Steel (SS) (alloy steel of grade 304) was chosen. The main target for selecting this material is its availability. It is available easily in all welding workshops. Besides, it is cheap and has much more stiffness. The properties of material are given in Table 1.

Table 1. Mechanical Properties of the wheel

Name	Alloy Steel (SS)
Model type:	Circular Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	6.20422e+008 N/m^2
Tensile strength:	7.23826e+008 N/m^2
Elastic modulus:	2.1e+011 N/m^2
Poisson's ratio:	0.28

Mass density:	7700 kg/m^3
Shear modulus:	7.9e+010 N/m^2
Thermal expansion coefficient:	1.3e-005 /Kelvin

The tubes that are finally selected are given below with dimensions.

Table 2. Dimension of tubes

Shapes	Height*width	Thickness
Round tube	.75inch (dia)	0.8mm
L Channel	0.5*0.5in	1.5mm
Round tube	1inch (dia)	1.5mm

4. Analysis of rover wheel

There were several analysis and simulation done on wheel. All of them are listed below.

In case of static load analysis, Beam Mesh and Direct sparse solver were used and the vertical load of 2000N was applied and simulated in Solid works 2018. Load 2000N was derived by using safety factor 2, as the wheel has to take minimum load of 1000N. The simulation result is given in Figure 3.

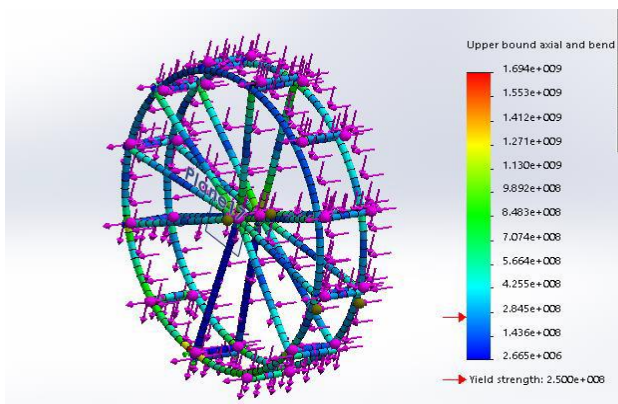

Fig.3. Static load analysis result.

In case of drop test, the rover has to run in a rough terrain, drop test is simulated for 5m height in Solidworks 2018, and here are the results in Figure 4.

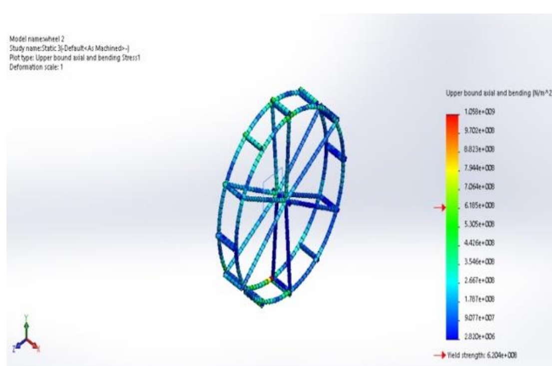

Fig.4. Drop test analysis result.

5. Manufacturing of wheel

While manufacturing we couldn't follow the design properly due to low budget and low funding, so instead of circular bended pipe we used 26" solid steel rim made in a local workshop in a low price. The 26" diameter rims are large enough to support the heavy loads that will occur during the competition and 36 provide the minimum clearance required by NASA. The steel rim has a tensile strength and compressive strength of 370 MPa making it an ideal material for a rim that will traverse harsh terrain as it is resistance to deformation in the longitudinal and lateral directions [4]. Then instead of manufacturing hub, we used commercial hub and spoke as it was allowed to do so. Afterwards, the whole system was coated with sheet metal of 0.5mm width. Finally, the robber from truck wheel was cut as the same dimension as it can cover the whole outer circle of the wheel. Then it was joint around the sheet using rivets. The manufacturing process images are given below in Figure 5, Figure 6 and Figure 7.

Fig. 5. Manufactured wheel.

Fig. 6. Manufactured wheel. (Without rubber coating)

Fig. 7.Human Exploration Rover

6. Cost analysis

Total cost and individual price of materials that we used are given below in Table 1.2 and 1.3.

Table 3. Cost of material.

Shape	Length (quantity)	Price (USD)
Round tube	60 feet	2610 taka (32 USD)
L channel	20 feet	980 taka (12 USD)
Robber	40 feet	2400 taka (29 USD)

Table 4. Cost in manufacture.

Cost type	Unit cost	Total

Machining	300 taka (4 USD)	1200 taka (16 USD)
Welding	250 taka (3 USD)	1000 taka (12 USD)
Wheel hub	300 taka (4 USD)	1200 taka (16 USD)

So, total cost of production of this wheel is 117 USD.

This wheel was designed that for some factors. These are strength, robustness and durability. The wheel is strong and can take load of 4000N to deform. Effective length was used to the optimum range so that it will cause a lot of strength then weight. The links are welded with TIG welding process so it’s kind of strong and the shear transfer from one link to another is balanced. So, in case of bump and uneven surface it will act perfectly. In the drawbacks, this design used stainless steel. That’s heavy and less strong compare to the carbon fiber wheels. And the links are so rigid that it may break under too much load. The traction is not that high, so it’s difficult for the wheel traction to manage the movement on sand and rocky surface. Using rivets can improve the fact. The wheel tends to deform permanently. The solution is still not found. Hopefully the R&D will figure it out.

On the other hand, Hoop Wheels are an innovative type of suspension system where the use of tensioned plastics is used to create the rim of the wheel. The pros of the hoops wheels are that they technically have no components, make the overall design simplistic, and can be maintained. The cons are that they have not been proven to be durable, they are expensive, and cannot be obtained [5]. A hoop wheel example is shown in Figure 8.

Fig. 8. Hoop Wheel Suspension

7. Conclusion

A human exploration rover wheel has been manufactured. Although the design was not perfect in all aspects, but it helps others to make a good Human Rover Wheel in South Asian condition and without the help of advanced engineering tools in a regular workshop. While bending one should bend the tubes under uniform load and perfect shape. Due to welding it tends to deform for head shrinkage. While adding the links the spokes are uneven that causes lots of problem to make a perfect shape. So the process needed a lot of time to be done. Designing a full functioning wheel requires a series of analytical tests and our wheel crossed every analytical test successfully. All the rules associated in NASA Human Exploration Rover Challenge 2019 guidebook, are maintained in design of the wheel. The entire set of wheel was 28 kg in weight and it is much stiffer to carry required loads after manufacture.

8. References

[1] Nasa Human Exploration Rover Challenge 2019 guidebook;

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