Design and Manufacturing of Optimized Loopwheels for Bicycle

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Abstract - *In today's world, Bicycles are the most favourite choice when it comes to causes like health, pollution, and environment. Several researches have been done in order to make the ride comfortable. Different types of cycles have been developed for various applications like Commuter Bikes, Mountain Bike, and Racing bike. This paper presents the Loop wheel which is designed such that the suspension system is integrated within wheel for higher shock-absorbing performance and better comfort. Loop wheels offer you a smoother ride. Loop wheel springs are usually made up of a composite material carefully developed to offer optimum compression and lateral stability as well as strength and durability. The three loops in every wheel work along as a self-correcting system. This spring system between the hub and the rim of the wheel provides suspension that continuously adjusts to uneven terrain cushioning the rider from abnormalities in the road wheel. This will provide an unmatched smooth riding experience on uneven surfaces along with better stability.*

Keywords: Loopwheel, Integrated suspension system, Triangular hub, Self-correcting, Bicycles

1. INTRODUCTION

A wheel which is a circular part is meant to rotate on an axle bearing. Wheels, in conjunction with axles, enable heavy objects to be moved simply facilitating movement or transportation while supporting a load, or performing labour in machines. A wheel greatly reduces friction by facilitating motion by rolling along with the use of axles. For the wheels to rotate, a moment has to be applied to the wheel about its axis, either by means of gravity, or by applying another external force or torsion. The loop-wheel suspension concept represents new approach to off-road mobility taking advantage of modern high strength composites. The loop-wheels excellent ride qualities were overshadowed by their very poor durability and high rolling resistance. New design options are presented which promise further improvement in durability, on road and off-road mobility, noise and vibration suspension, lower part count and lower cost for wide range ofattractive applications ranging from low-speed agricultural trailers to high mobility on/off road motor vehicles. The loop wheels for wheelchairs help people push over uneven streets, rough tracksand gravel paths, with less effort, and the carbon springs give you extra power to get up or down kerbs. They reduce jolting and vibration, by as much as two thirds compared with a spoked wheel.

1.1 Objectives

The objective is to design and analyze a feasible suspension system integrated the rim of the bicycle so as to absorb the shocks more effectively and reduce their transmission to the rider's body.

1.2 Methodology

- Selection of material.
- Determination of loads.
- 3D model generation on CATIA.
- Testing and Analysis.
- Fabrication, Experimental validation and Result Analysis

2. CONSTRUCTION

A Loopwheel integrated suspension system consisting of the following main components:

- Wheel Rim
- Wheel Hub
- Rim Connector
- Tyre
- Spring
- Hub Strut

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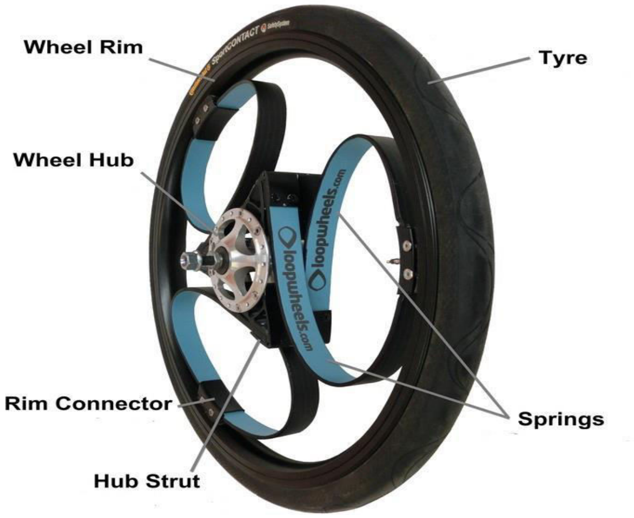

Fig 2.1 Construction of Loopwheels

3. SELECTION OF MATERIAL

Springs are specifically designed to be resilient, even when going through vigorous deflections. A key component to this resiliency is in the spring material. The choice of material is based on numerous factors ranging from fatigue strength, cost and availability, corrosion resistance, magnetic permeability and even electrical conductivity. Based on these requirements, various materials were shortlisted based on their viability like Plain carbon steel, Stainless Steel, Beryllium copper alloy, Spring steel. The hub should be light as well as should have strength hence Aluminum was selected for the hub material. Of these shortlisted materials, Spring steel is the most optimal material. The properties of Spring Steel are given below.

3.1 Chemical Composition:

- Fe: 98.3-98.8%
- C: 0.7-0.8%.
- Mn: 0.5-0.8%.
- P: 0.3% max.
- S: 0.035% max.

3.2 Physical Properties:

- Density: 7.86 kg/m^3
- Melting Point: 1515 ^0C.
- Youngs Modulus: 190-210 GPa.
- Poisson's Ratio: 0.27-0.3
- Bulk Modulus: 78 GPa.
- Fatigue Strength: 290-350 MPa.
- Ultimate Tensile Strength: 740-820 MPa.
- Yield Strength: 450-570 MPa.
- Brinell Hardness: 220-250

4. CALCULATIONS

The basic weight on any bicycle is the weight of the rider, hence the first step is to calculate the weight of an average rider.

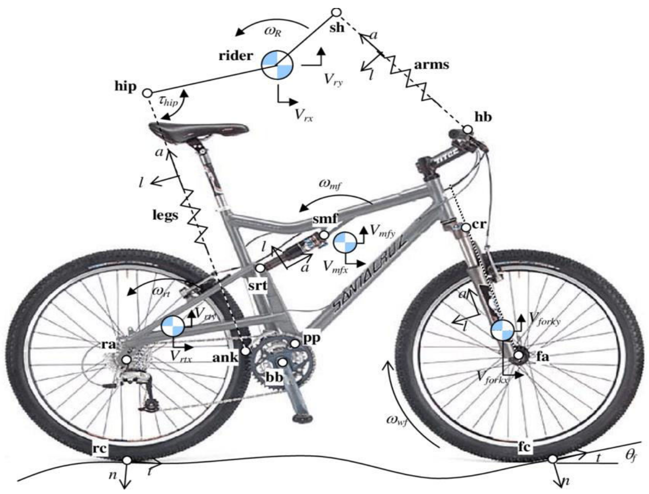

Fig 4.1 Mathematical Model of the Bicycle

4.1 Weight of rider and bicycle:

4.1.1 Distribution of body weight for average weight of 60 kg per person

Head $= \frac{8.26}{100} * 60 = 4.956$ kg

Thorax $= \frac{20.1}{100} * 60 = 12.06$ kg

Abdomen $= \frac{13.06}{100} * 60 = 7.836$ kg

Pelvis $= \frac{13.66}{100} * 60 = 8.196$ kg

Total arm $= \frac{5.7}{100} * 60 = 3.42$ kg

Thigh $= \frac{10.56}{100} * 60 = 6.3$ kg

4.1.2 Total effective weight Distribution in combination

Head & Neck= $\frac{6.81}{100} * 60 = 4.086$ kg

Trunk = $\frac{43.02}{100} * 60 = 25.81$ kg

2* total arm= $\frac{4.715}{100} * 60 = 2.829$*2= 5.658 kg

2* thigh = $\frac{14.47}{100} * 60 = 8.68$*2 = 17.364 kg

Total effective weight = 4.086 + 25.81 + 5.658 + 17.634 = 52.918 Kg

- Taking effective weight of the rider as 60kg.
- Approximate weight of the cycle is taken as 14kg.

Now as the seat is mounted more on the rear side, the weight of the rider is 60% on the rear wheel. Hence the design is based on the rear wheel.

Load on rear wheel is: (0.6*60) + (0.5*14) = 36kg +17kg = 43kg = 421.83N

The coefficient of friction between the tyre and asphalt is: 0.75

The rolling resistance of the wheel is: 0.04

Therefore, calculating the total load: 421.83 + (0.75*421.83) + (0.04*421.83) = 755.057N

4.1.3 Stresses induced in the loop:

Taking Tensile strength = 740 MPa.
Given Data:
Minimum Factor of Safety = 1.2
F = 755.057N.
Major Axis of the loop = 300mm.
Minor Axis of the loop = 200mm.
E = 210 GPa.
Width of spring = 25mm.
Thickness of spring = 5mm.

Maximum Principal stress = $(3FL/2nbt^2)$ = $[(3*755.057*300) / (2*1*25*5^2)]$ = 543.65 MPa
Calculated Factor of safety = (740 / 543.65) = 1.32
As Calculated factor of safety > Minimum Factor of safety, the design is safe

4.2 Selection of Bearing

The bearing is elected based on the Load Life relationship. The relationship between the dynamic load carrying capacity, the equivalent dynamic load, and the bearing life is given by,

$$L_{10} = \left(\frac{C}{P}\right)^p$$

For ball bearings, p=3.

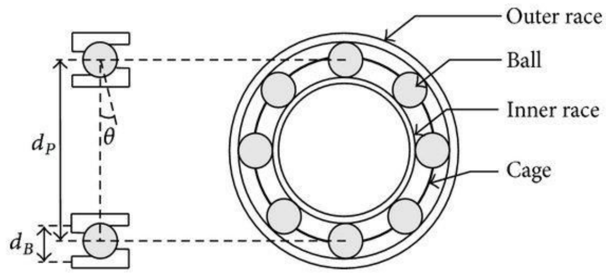

Fig 4.1 Construction of Bearing

Therefore, rearranging the equation,

$$C = P(L_{10})^{1/p}$$

Now rated bearing life (L_{10h}) for wheels used intermittently is between 4000hrs – 8000hrs.

Selecting rated bearing life (L_{10h}) = 8000hrs

$$\text{Now,} L_{10} = \frac{60nL_{10h}}{10^6}$$

For normal cycling speed, n = 150 rpm

Hence, after calculating L_{10} = 72 million revolutions.

From L_{10}, dynamic load capacity of the bearing is calculated as = 6406.87 N.

Now, from the bearing designation table, 6004 bearing is selected with specifications as follows:

Inner Diameter (d) = 20mm.

Outer Diameter (D) = 42mm.

C = 9360 N

C_0= 4500 N

5. GENERATION OF CAD MODEL

Various designing software's are available for creating a CAD model of a particular object, namely CATIA, Solidworks, Autodesk Inventor, CREO etc. The main reason for selecting CATIA was the familiarity with the software, greater number of functions available, flexibility as well as the friendly user interface.

The above calculations procedure led to the determination of the dimensions required to generate the CAD model. The CAD model was generated by observing the basic structure of the Loopwheel being currently being developed and optimizations were made according to our engineering viewpoint.

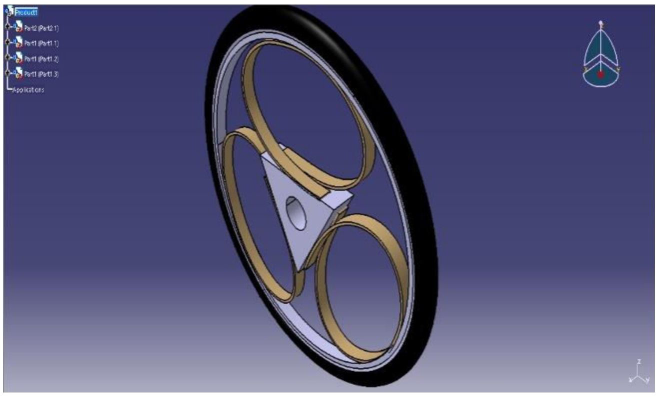

Fig 5.1 Preliminary CAD model in CATIA

6. OPTIMIZATION OF PARTS

6.1 Hub

The main issue we found in the earlier designs of the Loopwheel suspension system was that the loops were being welded to the hub. As we know that welded joints are brittle and not designed for a system that is fluctuating radially continuously. If there were a sudden large fluctuation in the loop, a crack may be generated in the weld which may propagate overtime causing failure at a critical time. If the weld fails it cannot be joined again by welding and the hub as well as the loop will have to be replaced.We found a solution to the problem by introducing slots on the hub to bolt the loop to the hub and a rim connector to bolt the loop at the rim. The main advantage of this is that, even if the bolt fails at any of these joints, due to large fluctuation, then it can be

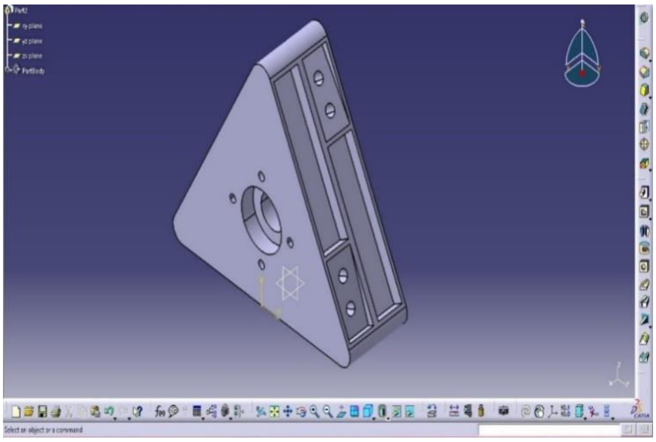

Fig 6.1 Optimized hub model in CATIA

easily replaced without entirely replacing the hub or the loop if they are not damaged. Another advantage of this is that, it will allow larger deflection of the loop as larger area of the loop is free to move which was not the case in welded joint. Although the cost to manufacture gets a little higher but it allows for a lighter and a more user-friendly part.

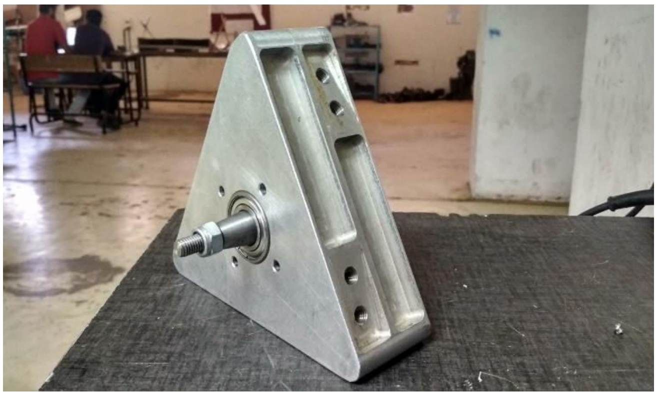

Fig 6.2 Actual assembled Hub

6.2 Loops

The loops are optimized by providing holes for bolting them to the hub. The dimensions are calculated for the changes induced in the original design. The bolt diameter was selected as standard M10 bolts. Holes are also provided on the curved section which meets the rim at a tangent where it is bolted to the connector. The welding technique used to connect the loops to the rim was replaced with using connector to connect them with bolts to the rim. This allows easy removal of the rim and also aids in an easier and less rigid and permanent assembly. If a loop fails there is no need to replace the entire wheel, instead the single failed loop can be swapped for a new one easily making it a more efficient and user-friendly design.

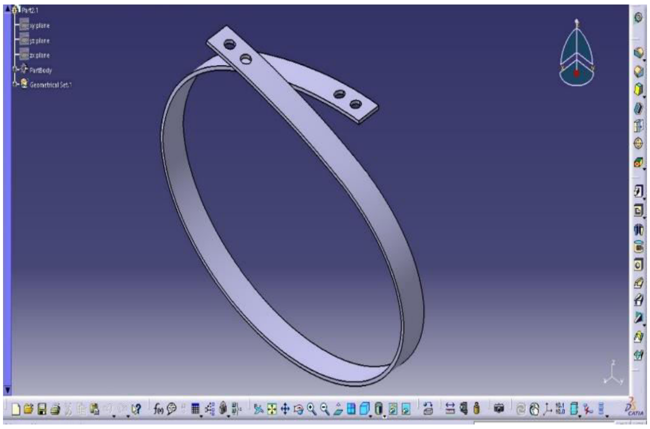

Fig 6.3 Optimized Loop model in CATIA

6.3 Connectors

As the optimization of the wheel lead to the elimination of welding as the method to be used for connecting the loops to the rim and hub, there was a need to design a holder or a connector which can be adjustable if the user according to the terrain.

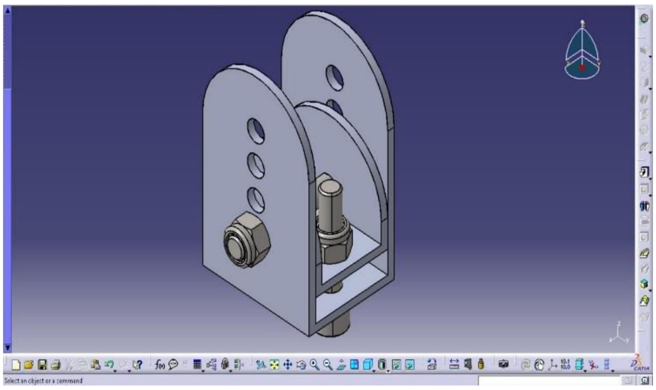

Fig 6.4 Connector Assembly in CATIA

The connector design was basic C section which was formed by welding three plates which were laser printed and welded together with multiple holes provided for bolting and adjustment. The bolts are used to connect the two parts of the connector. The main optimization idea used in this design of the connector was to insert the bolt through the loop so that the loop and the connector can work as one part. This eliminates any movement of the loop in the direction of axis of rotation. The movement of the loop in this direction

causes unstable and fluctuating vibrations in the assembly which can lead to a rough riding experience and may reduce the life of the loop and connector overtime dues to wear and tear of the loop and connector.

Fig 6.5 Actual assembly of Connector

7. ANALYSIS

The designed and optimized parts were assembled together in CATIA to generate the final model for analysis in ANSYS R16.0. The Loopwheel is going to be subjected to static loads as well as vibrational loads of the road surface inequalities. Hence ANSYS R16.0 software was used to simulate these conditions and analyze and verify if the design is safe.

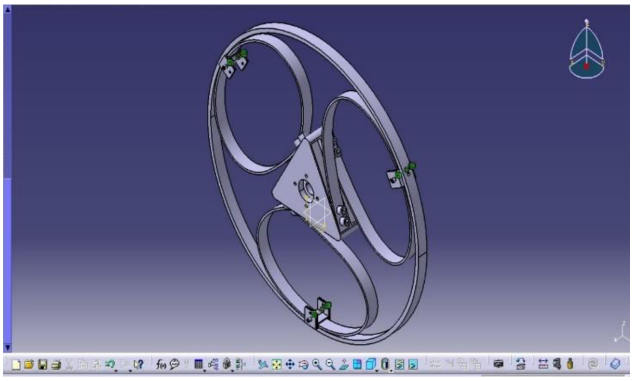

Fig 7.1 Final assembly ready for analysis

7.1 Static Structural analysis

This analysis simulated static loads on the structure and checks for points of for points of failure and high stress concentration areas. Three parameters were checked in this analysis:

- Equivalent Stress.
- Total Deformation.
- Maximum Principal Stress.

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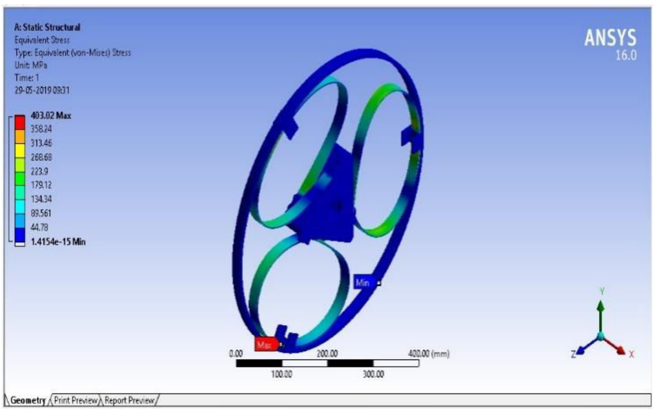

Fig 7.2 Equivalent Stress

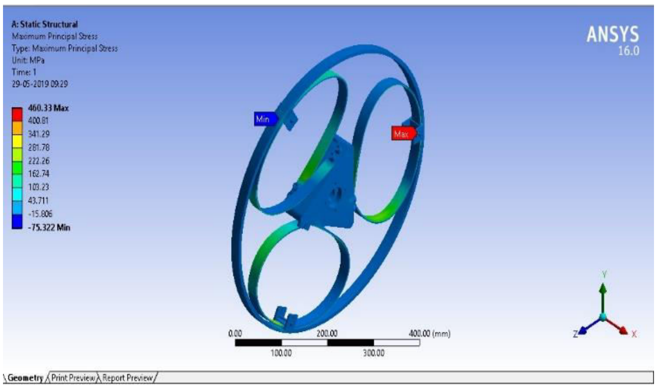

Fig 7.3 Maximum principal stress

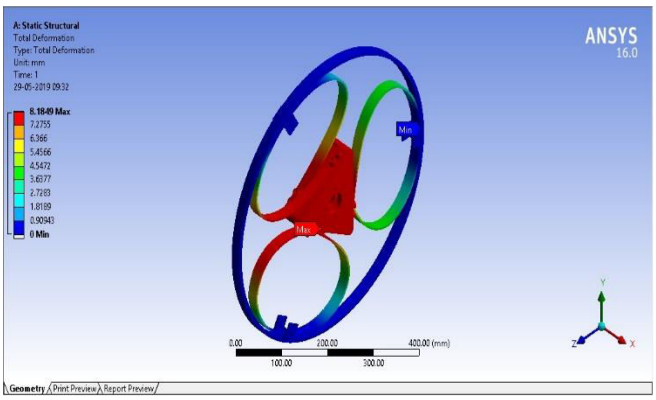

Fig 7.4 Total Deformation

The results obtained from ANSYS were:

- Equivalent Stress = 403.024 MPa.
- Maximum Principal Stress = 460.33 MPa.
- Total Deformation = 8 mm

The results obtained from ANSYS confirm that the stresses induced in the structure are lower than the maximum limit of the material which implies that the design is safe theoretically. Further experimental analysis can be conducted after building a prototype of the model. The experimental analysis will be conducted by one of the methods used by previous researchers and then validating the results with the current outcome.

7.2 Modal Analysis

Modal analysis was done to simulate the vibrational as well as the dynamic effects of these vibration on the Loopwheels. Total of 3 modes were found using modal analysis in ANSYS. This analysis helps in finding the natural frequencies of the structure or assembly and allows us to see the effects on it if they are subjected to these frequencies.

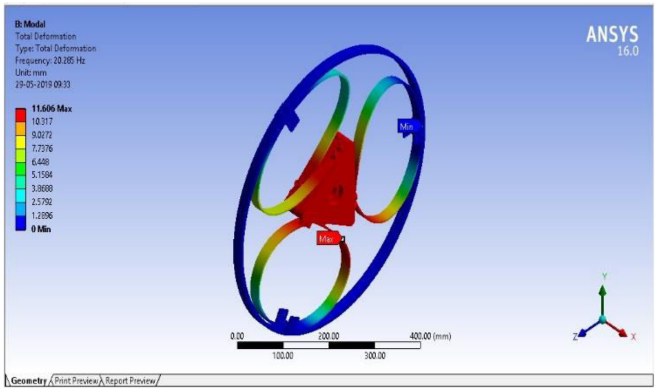

Fig 7.5 Mode 1

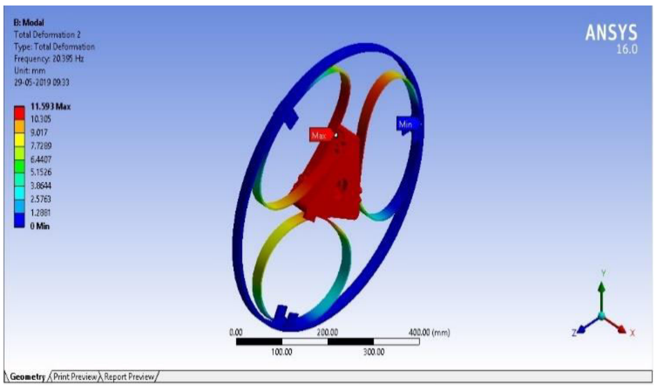

Fig 7.6 Mode 2

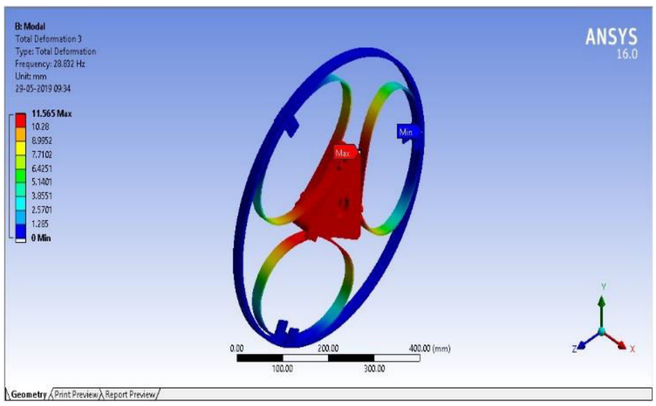

Fig 7.7 Mode 3

Natural frequencies obtained from modal analysis were found out as:

- Mode 1: 20.285 Hz
- Mode 2: 20.395 Hz
- Mode 3: 20.895 Hz

Deformation values induced in the structure were found out as:

- Mode 1: 11.606 mm
- Mode 2: 11.593 mm
- Mode 3: 11.565 mm

7.3 Random vibration Analysis

Random vibration is motion which is non-deterministic, meaning that future behaviors cannot be precisely predicted. The randomness is a characteristic of the excitation or input, not the mode shapes or natural frequencies. A random vibration analysis provides the likely structural response to a spectrum of random excitations. The modal analysis is required since it provides the dynamic characteristics required for the analysis. So, the mode frequencies and shapes are combined in a manner appropriate to the random excitations that you have to give you some form of structural response.

The random vibration analysis was based on Power Spectral Density Displacement Analysis which was linked with the previous modal analysis values. A measurement of the acceleration spectral density (ASD) is the usual way to specify random vibration. The root mean square acceleration (G_{rms}) is the square root of the area under the ASD curve in the frequency domain.

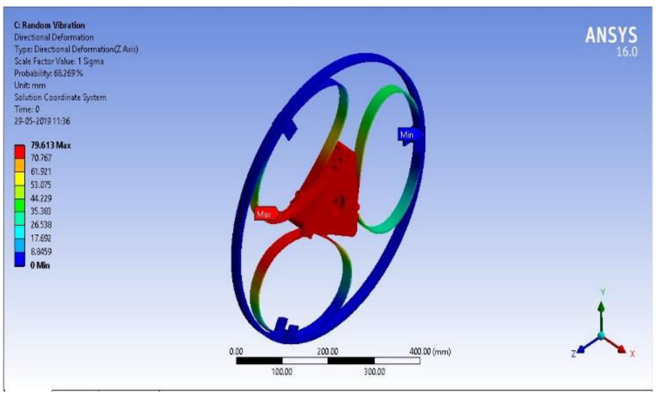

Fig 7.8 Directional deformation

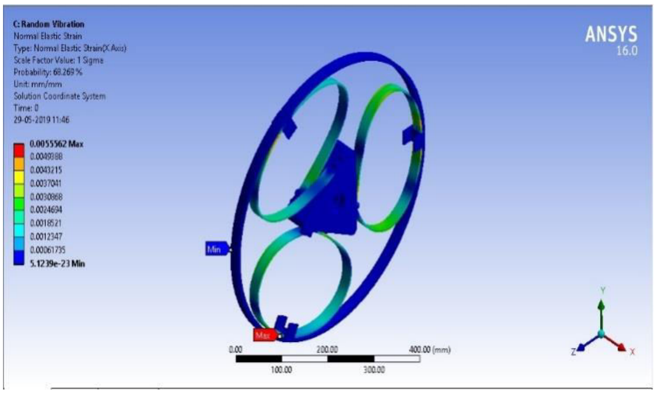

Fig 7.9 Normal elastic strain

Two parameters were used to find the effect of vibrations on the structure:

- Directional Deformation: 79.653 MPa
- Normal Elastic Strain: 0.005

8. CONCLUSION

Upon designing and analysis of the Loopwheels it was found that it provides better vibration and shock damping than spoked wheels and are also more resilient to damage and deformation. These wheels have various other applications as well. They can be used in wheelchairs to provide shock resistance to patients with spinal injuries. By using stronger materials and with a sturdier design Loopwheels can also be used in motorbikes and cars as well eliminating the need for a suspension assembly.

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