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Design and Development of an Innovative Hubless Wheel

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Abstract—*the aim of this project is to design and build an innovative hubless wheel. The hubless wheel will be self driven by a prime mover like a DC motor. The wheel will have three planetary rollers which will be powered by two DC motors. One roller is on the shaft directly coupled to the two motors and the other two rollers are on two separate shafts connected via belt drives. The driving and driven pulleys have same diameters. The belt is a positive timing belt so that there is no loss of power between motor shaft and the two roller shafts. The motor thus drives all the three rollers and the rollers drive the outer main wheel. The speed, torque while running and discharge time of the battery were first calculated theoretically and then compared with those calculated experimentally.*
Keywords—*hubless wheel; centre less wheel; planetary wheels; timing belt drive; electric wheel; Compact wheel*

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I. Nomenclature

P = Power in W
N = Speed in rpm
T = Torque in Nm
σ = Compressive strength in MPa
W = Load in N
L = Length in m
D = diameter in mm
nr = speed of roller
nm = speed of motor
nw = speed of wheel
Tm = Torque of motor
Tr = Torque of roller
Tw = Torque of wheel
Dr = Diameter of roller
Dm = Diameter of motor
Dw = Diameter of wheel
Fa = Axial Force
Fr = Radial Force
C = Static load carrying capacity
L10 = Million revolutions
Lp = Pitch length
Cd = Centre to centre distance

II. Introduction

The hubless wheel is a wheel that does not have a centre rotating hub. This type of wheel is also called the centre less wheel. Advantages of using such a wheel are that rotating inertia of wheel is reduced, since the spokes and hub are removed and more space is created at the centre. This extra space that is available can be utilized to install the prime mover that is the IC engine or in this case a DC brushed/ brushless motor. They can also serve as nice space for active balancing flywheels, continuously variable planetary transmission, and motor with magnetically levitating bearing, battery, and fuel bottle, glass cabinet for luggage and side impact defense.

The model that has been specifically designed in this project uses two electric DC motors. Such a wheel if modified according to a specific vehicular application can replace the IC engine and the gearbox since it is self propelling in its working. This wheel has been designed specifically for application in two wheelers and aims to reduce the emissions caused by use of fossil fuels. It also will help in reducing working cost since electricity is cheaper as compared to petrol and diesel. The specific design fabricated in this project will serve as a compact wheel including all important components like motor, battery and will thus serve to reduce the space taken by them.

III. Literature Review

[1] Following is a US Patent on hubless wheel. Innovative types of hubless wheel that can include a drive assembly, a step lock assembly, a suspension and side wheel assembly. The hubless wheel system can include a drive assembly, a step-lock assembly, a side wheel assembly, and a suspension assembly. The hubless wheel system can be compact, light-weight, and easy to install. From this patent the idea of a compact hubless wheel and he method of procedure for design was referred.
[2] This is a study conducted in making an electric bicycle. Here, simulation study of the operational characteristics of an electric cycle is carried out .This research paper was referred for the circuit diagrams as well as to find components the components that are to be used in an electrically driven vehicle.
[3] The research done in this project deals with study and optimization of the wheels frame material. The simulation study on the hubless wheel designed in this project was referred.
[4] In this research paper describing the project FEM analysis of tire and rim of a motorcycle were carried out. The results of simulation were in agreement with results of static and dynamic analysis. The paper was referred to carry out kinematic simulation in CATIA software.

IV. Construction And Working

The model of the wheel was first designed in CATIA V5R19. The parts were made according to the dimensions and then assembled together. Below is the CAD model of the prototype.

1. Assembly:

Given below is the CAD model s well as the drafted image of the assembly. The assembly is drawn to scale.

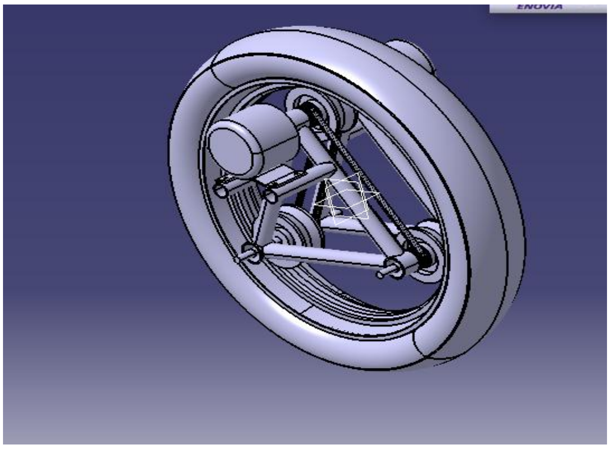

Fig1. Isometric view of assembly

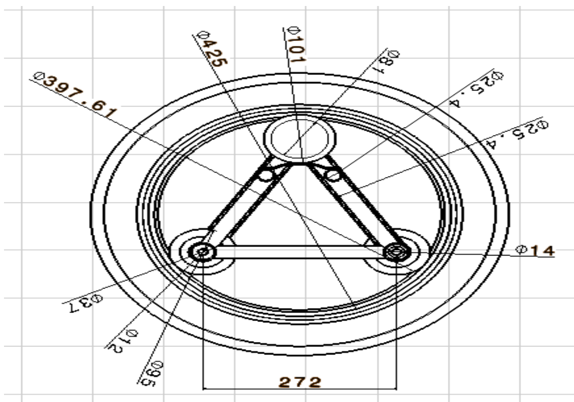

Fig2. Side view of drafted assembly

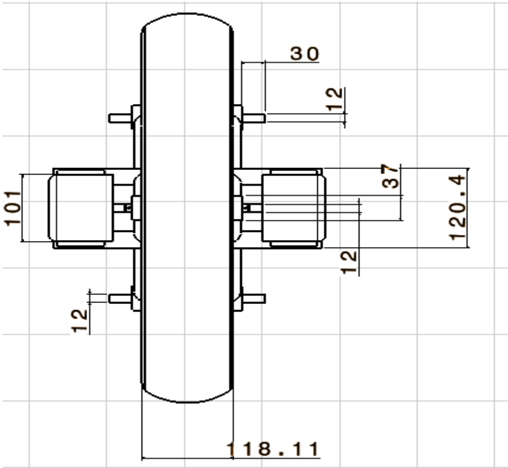

Fig3. Top view of drafted assembly

2. Rollers:

The CAD diagram as well as its drafted figure is given below.

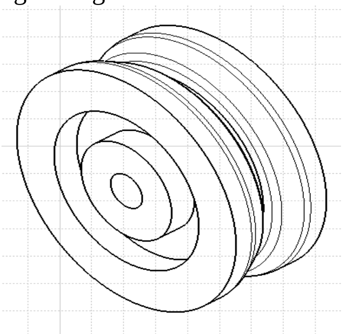

Fig4. Isometric view of roller

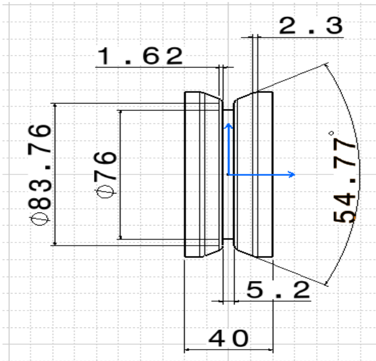

Fig5. Top view of roller

3. Triangular Frame:

The triangular frame is the component that houses the rollers.

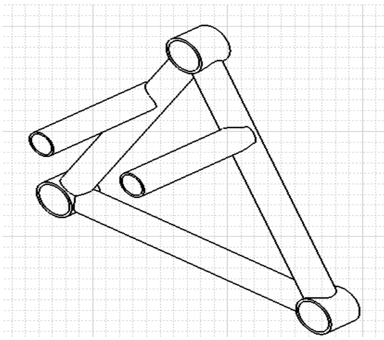

Fig6. Isometric view of draft of frame

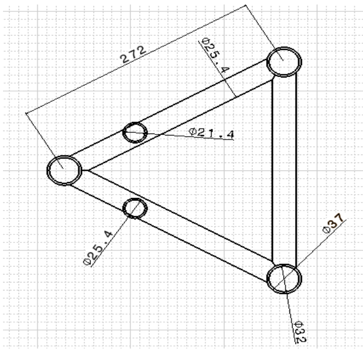

Fig7. Side view of frame

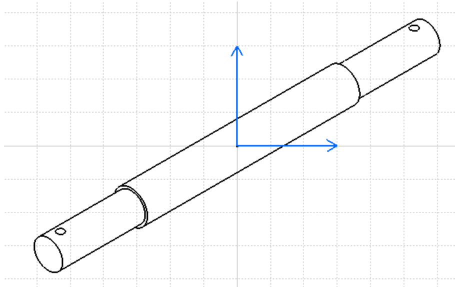

Fig8. Isometric view of shaft

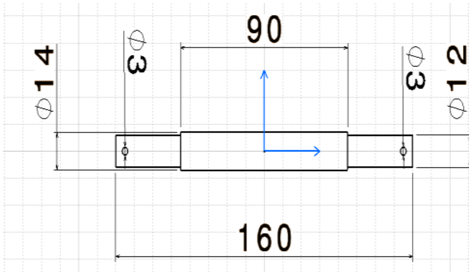

Fig9. Side view of shaft

A. Components

The different components have been listed below. Some of these components were purchased according to standard ones that were available and the rest were manufactured.

1. DC motor: Two DC brushed motors with maximum unloaded speed of 3000rpm and unloaded torque of 5 Nm were used. The maximum power delivered by one motor at 24V is 250W.
2. Battery: two separate 12V 12ah batteries were used. The batteries used are of rechargeable type.
3. Speed Controller: A speed controller conforming to the motor was used. This speed controller varies the current across the motor and hence controls its speed.
4. Twist Throttle: Twist throttle signals the speed controller for amount of current.
5. MS 1018 triangular frame: A frame was manufactured from MS to house three shafts on which the rollers can be mounted.
6. Aluminum 6802 rollers: The three planetary rollers separated by an angle of 1200 were machined from Aluminum and connected to the triangular frame through shaft and bearing arrangement.
7. Outer wheel: The outer wheel was of Bajaj Pulsar 135. The Ally spokes were removed and friction material (neoprene rubber) was applied so that friction was maintained between inner side of rim and rollers.
8. Belt and pulley drive: Two belt drives between upper and lower first and upper and lower second shafts were used. Timing belt of 5mm pitch and length 640mm was used. The Pitch circle diameter of pulley was 31.83mm. The centre to centre distance between two pulleys is 272mm.

B. Working

The two motors at the top are housed on the triangular frame. The shafts of these two motors are coupled to the centre upper shaft by split pins. As the motor shafts spin, the upper shaft also rotates. The roller 1 rotates since it is coupled to this shaft. Also the two pulleys on this shaft rotate which causes the power to be transmitted to the lower two shafts via the two belts. As a result the lower two rollers also rotate. The outer rim which is in contact with the three rollers rotates as a result. The speed of the three rollers is ideally similar to that of the motor because the driving and driven pulleys have same diameters. The motor speed is controlled by throttle and speed controller mechanism.

The circuit diagram of the electronic components involved in the assembly

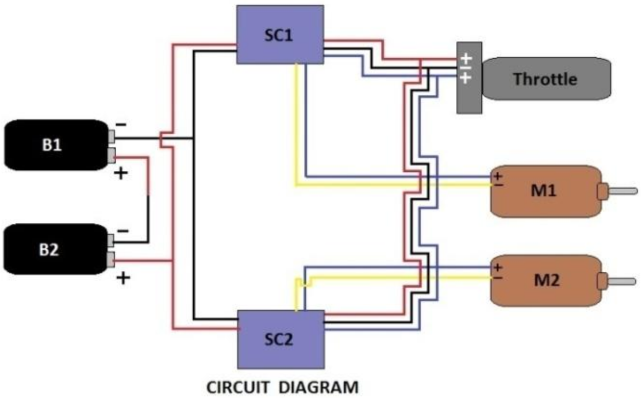

Fig10. Circuit Diagram

The black components B1 and B2 are the batteries. The SC1 and SC2 are speed controllers and M1 and M2 are the two motors.

C. Equations and Formulae

The basic equations used in the project have been illustrated below. The equations were referred from the book 'Design of machine elements' by V.B. Bhandari.

$$P = V \times I \qquad (1)$$

$$P = \frac{2\pi NT}{60} \qquad (2)$$

$$\frac{n_r}{n_w} = \frac{D_w}{D_r} \qquad (3)$$

$$\frac{T_m}{T_r} = \frac{D_m}{D_r} \qquad (4)$$

$$\frac{T_w}{T_r} = \frac{D_w}{D_r} \qquad (5)$$

$$\text{P=X} \times F_r + Y \times F_a \qquad (6)\backslash$$

$$\text{C=}P \times (L_{10})^{\frac{1}{3}} \qquad (7)$$

$$\text{M=}\frac{WL}{4} \qquad (8)$$

$$\sigma\text{=}\frac{16M}{\pi d^3} \qquad (9)$$

$$C = \frac{K + \sqrt{K^2 - 32(D-d)^2}}{16} \qquad (10)$$

$$\mathrm{K} = 4\mathrm{L_p} - 6.28(\mathrm{D} + \mathrm{d}) \qquad (11)$$

D . Calculations

1. Shaft:

   There are three shafts one to hold each roller respectively. The material of shaft was selected as EN 24 hardened mild steel with yield strength as 850N/mm^2. By using equation (8) and equation (9) and taking values of load 'W' on simply supported shaft as 7000 N, the diameter 'd' of shaft comes out to be 13.52mm. Therefore, diameter of shaft selected is 14mm.

2. Bearing:

For the bearing calculations following assumptions were made,

F_a= 1033 N

F_r= 3333 N

Initially, bearing number 6201 was selected with following specifications,

C_o= 2750 N

C_r= 6100N

By using equations (6) and (7) Actual static load carrying capacity comes out to be,

C=5699.9 N

Therefore, Actual Static load carrying capacity < theoretical load carrying static capacity

$C < C_r$

Bearing number 6201 is safe for application.

3. Timing Belt and pulley

Timing belt is a type of inextensible belt that is used to transmit power from one shaft to another. There is positive drive between the belt and the pulley and hence there is no slippage.

The centre to centre distance is fixed at 272mm due to design restrictions as shown in the drafted components above.

Based on this the pulley was assumed to have following specifications,

Pitch= 5mm

Pitch circle diameter (PCD) = 31.83 mm

Teeth=20

By using equations (10) and (11) and,

D= 36mm

d= 24mm

L_p=5mm

C_d= 272mm

The circumference comes out to be 644mm

Circumference =644 mm ~ 645 mm

The belt selected is HTD 5M 645 neoprene rubber belt and pulley was AT5 20teeth x 10 mm width.

E. Static Analysis

The static structural analysis of the various components was carried out in ANSYS software. The results are compiled below.

1. Triangular Frame: For the Frame the material is Mild Steel. The force applied was 20kN in radial inwards direction.

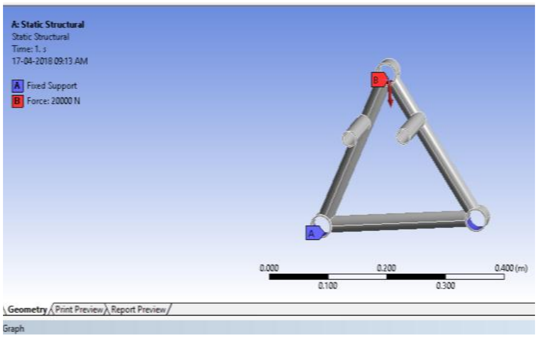

Fig11. Loading Conditions on Frame

Table1: Material Properties Of Frame

Material	Mild Steel
Density	7.87 g/cc
Yield Strength	370 M Pa
Thermal Conductivity	54 W/ m K
Poisson's Ratio	0.29

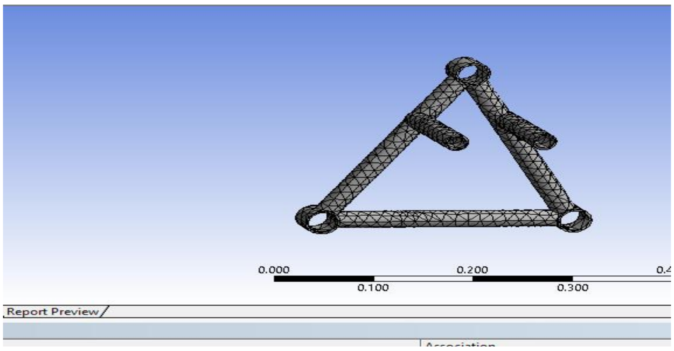

Fig12. Meshed model of triangular frame

Table2: Mesh Details Of Frame

Size function	Adaptive
Smoothing	Medium
Transition	Slow
Elements	10222
Nodes	5081

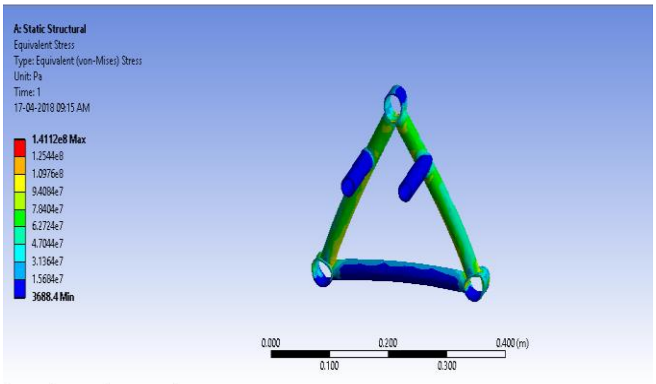

Fig13. Principal Stress on Frame

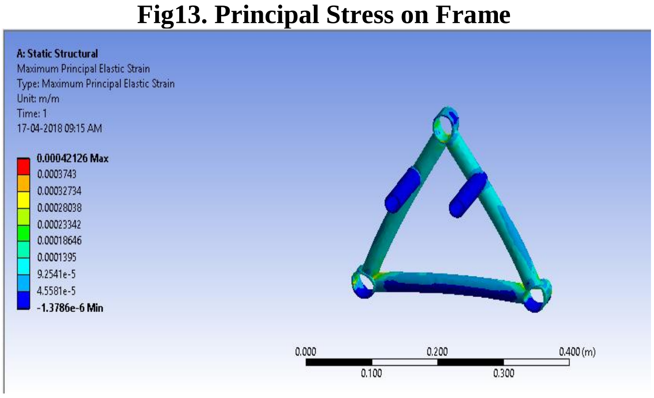

Fig14. Equivalent Stress on Frame

Table3: Analysis Output For Frame

Maximum Equivalent Stress	$1.41\text{x}10^{8}$ Pa
Minimum Equivalent Stress	3688.4 Pa
Maximum Principal Elastic Strain	0.00042126 m/m
Minimum Principal Elastic Strain	$-1.37\text{x}10^{-6}$ m/m

2. Shaft: The shaft material is MS. A reaction force of 3.5kN and moment of 5Nm is applied on the shaft. This is because the maximum torque output torque of motor is 5Nm.

Table4: Material Properties Of Shaft

Material	EN 24
Density	7.84 g/cc
Yield Strength	850 N/mm^2
Thermal Conductivity	40.5 W/ mK
Poisson's Ratio	0.35

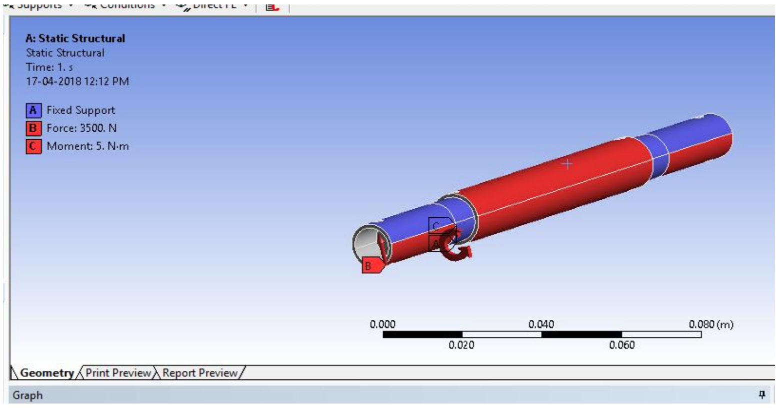

Fig15. Loading Condition on Shaft

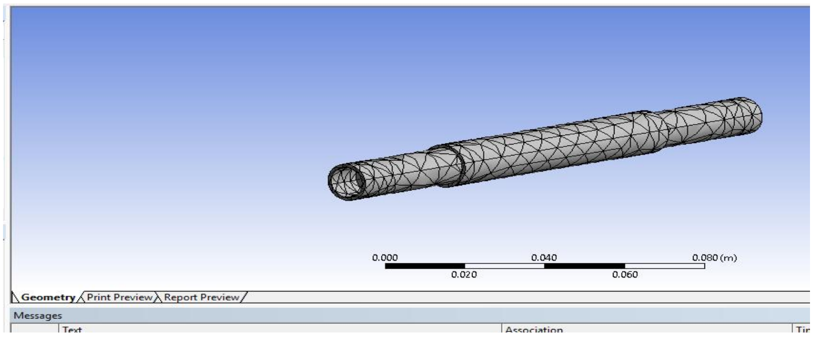

Fig16. Mesh model of shaft

Table5. Mesh Details For Shaft

Size function	Adaptive
Smoothing	Medium
Transition	slow
Elements	3087
Nodes	1492

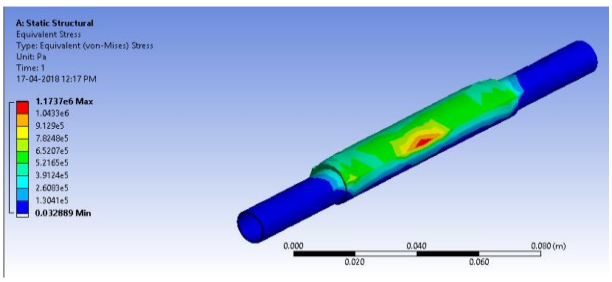

Fig17. Equivalent Stress on shsft

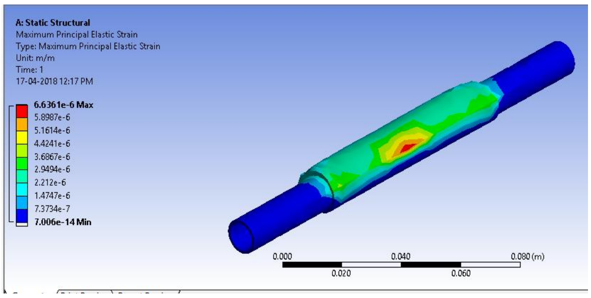

Fig18. Maximum Principal Strain on shaft

Table6: Output For Shaft

Maximum Equivalent Stress	1.17×10^{6} Pa
Minimum Equivalent Stress	0.03288 Pa
Maximum Principal Elastic Strain	6.63×10^{-8} m/m
Minimum Principal Elastic Strain	7.006×10^{-14} m/m

3. Roller: The roller is Aluminum 6 series and a moment of 5Nm is applied to it.

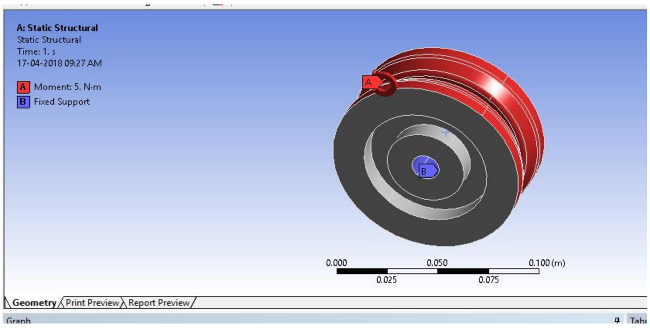

Fig19. Loading conditions on roller

Table8: Material Properties of Roller

Material	Aluminium 6082
Density	2.71 g/cc
Yield Strength	280 M Pa
Thermal Conductivity	180 W/mK

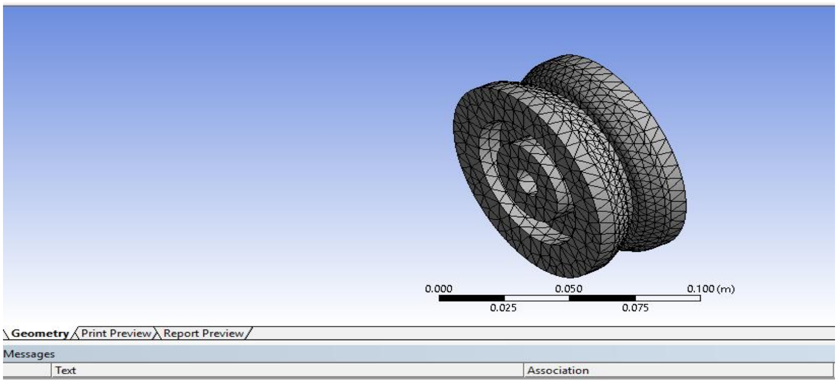

Fig20. Mesh of Roller

Table7: Mesh Details For Roller

Size function	Adaptive
Smoothing	Medium
Transition	Slow
Elements	15377
Nodes	9411

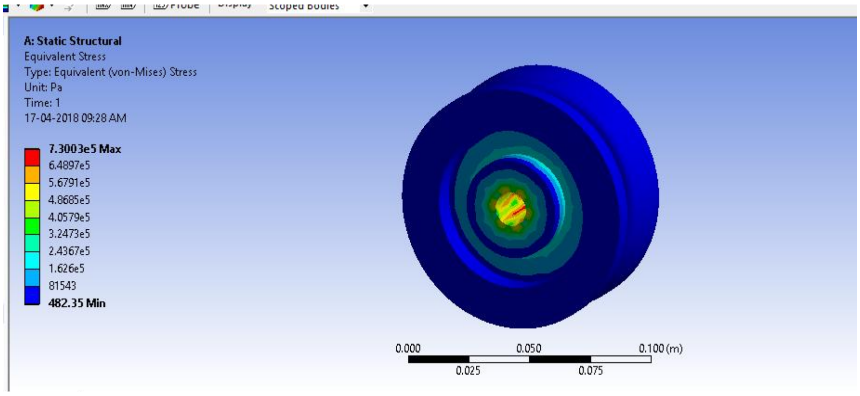

Fig21. Equivalent stress on roller

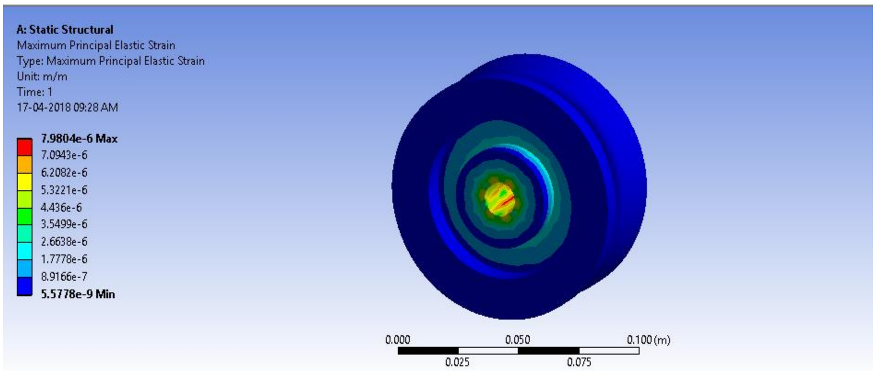

Fig22. Maximum Principal Strain on Roller

Table8: Ouput Of Analysis On Roller

Maximum Equivalent Stress	7.3×10^5 Pa
Minimum Equivalent Stress	482.35 Pa
Maximum Principal Elastic Strain	7.98×10^{-6} m/m
Minimum Principal Elastic Strain	5.57×10^{-9} m/m

V. Results

A. Fabrication of model

For fabrication of model, first the circuit was joint. The actual circuit is given below and for comparison refer Fig10.

Fig23. Actual Circuit

Once the circuit was connected, the next step was to mount the rollers, inside the shafts. The pulleys were also fitted alongside it and these three shafts were sandwiched between the triangular frames. The Belts were fitted on the pulleys and finally the motors on both the sides were coupled with the upper shaft using split pins and bush. This is demonstrated in the figure below.

Fig24. Hubless Wheel Fabrication Stage 1

Fig25. Hubless Wheel Fabrication Stage 2

The circuit was installed on the wheel finally.

Fig26. Hubless Wheel Fabrication Stage 3

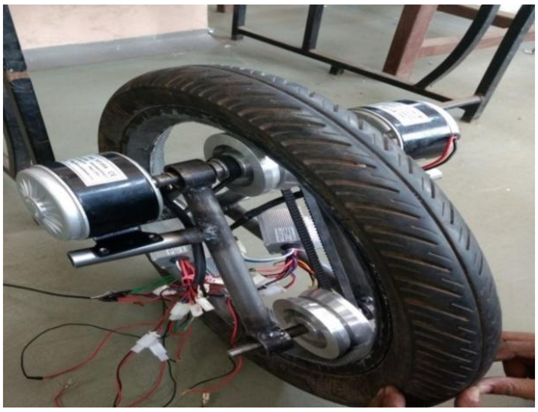

Fig27. Side view of Final hubless Wheel

B. Comparison of theoretical and Experimental parameters

1. Speed of wheel:

Dr=95 mm, Dw=408 mm

The speed of wheel was found by using above values and equations (1) to (5).

Table 9: Theoretical Wheel Speed

Motor speed (n_m) in rpm	Roller speed (n_r) in rpm	Wheel speed (n_w) in rpm	wheel speed in km/h
500	500	116.42	8.95
800	800	186.27	14.32
1200	1200	279.41	21.48
1500	1500	349.64	26.85
1800	1800	419.17	32.23
2000	2000	465.67	35.814
2300	2300	535.539	41.186
2650	2650	617.034	47.453

The experimental speed was found by suspending the wheel in air and running it at specific motor speed and then measuring the wheel speed using a laser tachometer. The values obtained experimentally are compiled in the table below.

Table 10: Experimental Speed Of Wheel

Motor speed (n_m) in rpm	Roller speed (n_r) in rpm	Wheel speed (n_w) in rpm	wheel speed in km/h
500	500	109.8	7.98
800	800	178.22	12.967
1200	1200	252.23	18.35
1500	1500	330.5	24.046
1800	1800	402.908	29.315
2000	2000	446.89	32.515
2300	2300	518.9	37.754
2650	2650	601.112	43.736

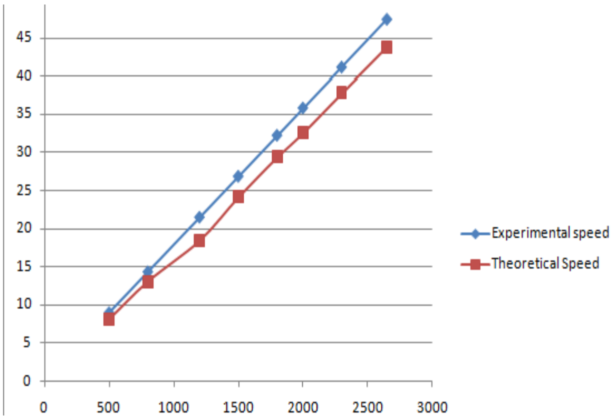

Fig28. Speed of Motor vs. Speed of hubless wheel

2. Torque of wheel (theoretical values):
By using equations 1, 2, 3, 4, 5 we get following values for torque at wheel.

TABLE 11: TORQUE OF WHEEL

Current (A)	**Voltage (V)**	**Power (W)**	**Speed of motor (rpm)**	**Motor Torque (Nm)**	**Torque at wheel (Nm)**
2.5	24	60	500	1.14	38.755
3.5	24	84	800	1.0026	34.061
5	24	120	1200	0.9549	32.305
7	24	168	1500	0.94	31.957
9	24	216	2200	0.93	31.62
10	24	240	2500	0.916	31.1411
12	24	288	3100	0.887	30.153
13.7	24	329	3600	0.872	29.642

To measure torque of wheel experimentally rope brake dynamometer was used. The wheel was suspended and the rope was wound around one of the shafts to find its torque. This torque was used to find the torque of the outer wheel. The values have been summarized below.

Table 12: Experimental Torque Of Wheel

Current (A)	**Voltage (V)**	**Power (W)**	**Speed of motor (rpm)**	**Motor Torque (Nm)**	**Torque at wheel (Nm)**
2.5	24	60	500	1.32	39.223
3.5	24	84	800	1.024	35.89
5	24	120	1200	0.967	33.43
7	24	168	1500	0.954	32.999
9	24	216	2200	0.9421	32.023
10	24	240	2500	0.90	31.143
12	24	288	3100	0.89	29.78
13.7	24	329	3600	0.887	25.67

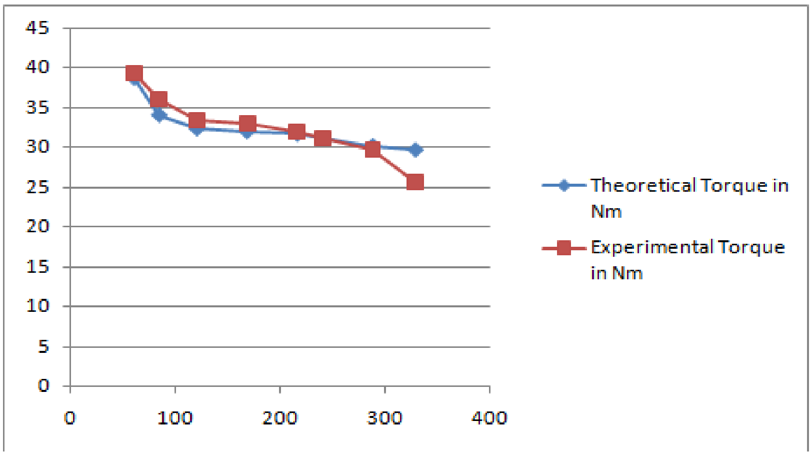

Fig29. Power(W) vs. Torque of hubless wheel

3. Discharge time (Theoretical):
The Theoretical discharge time was calculated simply by dividing the energy of the battery with the current provided by the battery at the particular instant.

Table 13: Theoretical Discharge Time

Energy of battery (mAh)	**Current (mA)**	**Discharge time (h)**
24000	2500	9.6
24000	3500	6.8
24000	5000	4.8
24000	7000	3.42
24000	9000	2.66
24000	10000	2.4
24000	12000	2
24000	13700	1.75

The Experimental Time of discharge was found by actually running the wheel at a particular current measured by a multimeter until the battery discharges. This took a lot of time, one reading was obtained in one day since the battery had to be charged to its full capacity before running again.

Table 14: Experimental Discharge Time

Energy of battery (mAh)	**Current (mA)**	**Discharge time (h)**
24000	2500	8.2
24000	3500	5.9
24000	5000	4.95
24000	7000	4.2
24000	9000	2.82
24000	10000	2.41
24000	12000	2.13
24000	13700	1.799

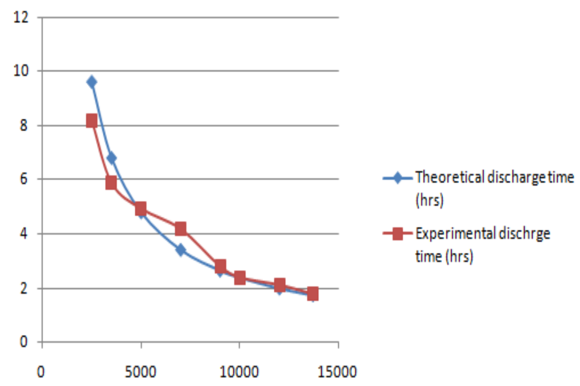

Fig30. Current (mA) vs. Discharge Time

VI. Conclusion

The electric hubless wheel was thus designed and manufactured. The theoretical values of speed, torque and discharge times are close to each other. This particular design can be used in two wheelers after modifications and by using optimized motors with higher wattage. Also suspension system may be installed after altering the design according to requirement. The wheel designed and manufactured in this project is only a prototype. There are several modifications possible such as provision of shock absorbers, proper braking system, mounting to connect it directly to the vehicle. Also, higher speeds can be achieved by using more efficient motors such as brushless motors or synchronous motors.

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