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DESIGN AND ANALYSIS OF ADJUSTABLE MULTI-NUT TIGHTENER AND REMOVER

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ABSTRACT

Tire plays a crucial role in the performance of a vehicle, but during an uncertain event such as tire puncture, replacing the punctured tire will take a lot of time before getting back on service. Removal of tire is really a tedious task when performed manually with tool provided by manufacturer. In order to aid easy removal of tire, a simple tool which can operate within the Pitch Circle Diameter (PCD) range of 100mm, 108mm and 114.3mm is designed, as the vehicles commonly being used are found to have wheels of these PCD range. The aim of the research work is to develop a pneumatic power/battery operated/manually operated for easy tightening and removal of the car wheel nut. The designing was done using Dassault Systems Solidworks software and analysis is done using Ansys Software. This product can be successfully used as standard tool nevertheless of the model of the vehicle. Also, it can be used in garages, workshops, service centers as well as emergency vehicles. The tool designed, will be easy to operate and can be carried anywhere needed.

Key words: Pneumatic, Scroll Plate, Pitch Circle Diameter, SolidWorks, ANSYS.

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1. INTRODUCTION

Transportation plays an important role in the economic growth and globalization. However, daily usage of vehicles often leads to wearing out of the vehicle tires which may lead to a punctured tire. It takes a lot of effort for an individual and consumes a lot of time for changing a car tire especially for women and senior citizens. This problem has been noticed by various researchers who in turn have developed their own version of the product. But the product developed by the researchers are only restricted to work for a single PCD (i.e. the products were not adjustable) [1-4]. The 'Design and analysis of adjustable multi-nut tightener and remover', aims at not only reducing the time and effort for an individual to replace the punctured/ worn out tires of a vehicle with ease.

It is understood from the past research done by other researchers that, very less work has been done on improving the existing mechanism for the removal and tightening of the car nut [5-8]. However there are very few studies on the said topic but no concrete proof of the actual working of the tool is not available. Moreover, there is no adequate literature to discuss the adjustable nature of the product.

2. METHODOLOGY

The assembly of the product is such that the adaptor of pneumatic power driven handgun will be connected to a shaft by means of socket. The shaft will carry there gears of varying diameters. At a time, set of four planetary gears will be connected to one of the three gears mounted on center shaft i.e. one sun gear will be in mesh with four planetary gears. The shaft on which the planetary gears are mounted are connected to a scroll plate having gear teeth on outer face by means of bearing, which has slots. This scroll plate is in mesh with a pinion gear which is provided to turn the plate as required. The shaft having planetary gears also accommodates a spring. The springs are provided to sustain backward compressive force exerted by the nut during operation. The shafts onto which planetary gears are mounted are provided with adapters at the end to which the sockets of various sizes can be attached [8]. These sockets will then be connected to the nuts of the wheel. When the pneumatic power driven hand gun will start to operate, it will drive the main gear of the arrangement which in-turn powers the four spur gears, which will either tighten or loosen the nut effortlessly depending upon the operators will.

The wheel nut removing and tightening is a very tedious affair and at the same time also very time consuming. So, speaking of the problem definition, this topic can have two perspectives.

2.1 Perspective 1

2.1.1 In Terms of Car Service Centers / Shop

- For a car service center or tire shop where there is continuous flow of vehicles, for tire related works, in which the centers have to quickly hand over the cars to the respective owners after change / repair of the worn out tires, where time is an important factor. Here the conventional method of manually loosening and tightening of the wheel nut takes a lot of human effort and time.

- Here the need for skilled workers is essential, but what if there is no availability of skilled personnel.

2.1.2 Car Owners

- It becomes difficult for women and senior citizens to manually loosen or tighten the nut of the wheel whose tire is punctured and if they have to replace it with a spare tire available in the back of their vehicles such as an ambulance carrying a patient or fire-tenders who have to douse an uncontrollable fire and are in hurry, cannot afford to waste time. But what if due to some unforeseen event like a tire puncture? The emergency services will get stopped. Manually removing the wheel nut will be very time consuming.
- In secluded locations or in hilly areas where there are no mechanics available for help during vehicle breakdown or during a punctured tire, the car driver/owner have to find a solution themselves to repair their car or fix their punctured tire, in such times it becomes difficult for them to loosen the nut and remove the tire themselves, fix new one and then tighten the nut again.

2.2 Perspective 2: Regarding the research work done so far by other researchers on similar topic.

- Researchers/product developers have developed products which are compatible for only one particular car and are not adjustable i.e. their application is only restricted to work for one particular wheel nut arrangement.
- The products designed/developed were not automated i.e. they are all manually operated which involves human effort.
- Their product has not been properly optimized and have a lot of weight and are large in size. Thus, not making the product portable.

3. DESIGN AND ANALYSIS

The following design is used to carry out research work.

Design

- According to the market survey carried out, 3 PCD were finalized, keeping those PCDs calculation is done and gear ratios are found. According to the Gear Ratios and calculations, designing is done of the spur gears.
- After considering all the weights acting on the shaft, outer diameter and thickness of the shaft is finalized. For fixing the gears a pin is used to fix them.
- A scroll plate is designed to ensure the radially expanding and contracting motion for varying the PCD. The slots are designed such that they are equivalent to the respective PCD.
- Keeping all the clearances and tolerances in mind and dimensions of the bearing, the casing of the mechanism is designed.
- Standard size of the wrench sockets are selected and designed accordingly.
- Complete design is done in Dassault Systems Solidworks 2020.

Design Calculations

The design calculations are shown in Table1.

Table 1 Notations of the terms used in calculations

Symbol	Meaning	Unit
Φ	Pressure Angle	°(degree)
G	Gear Ratio	-
D_p	Diameter of Pinion	mm
Z_p	Teeth on Pinion	-
m	Module	mm
σ_b	Bending Stress	N/mm^2
ϒ	Lewis Form Factor	-
b	Face Width	mm
F_b	Beam Strength	N
F_{eff}	Effective Force	N
N	Speed	R.P.M
P	Power	KW
F_t	Tangential Force	N
K_v	Velocity Factor	-
S	Service Factor	-
T	Torque	Nm
Q	Ratio Factor	-
K	Material Combination Factor	-
F_w	Wear Strength	N
F_r	Radial Force	N
F_N	Normal Force	N
D_g	Diameter of Gear	mm
Z_g	Teeth on Gear	-
Q	Ratio Factor	-
P_{ed}	Dynamic Equivalent Load	N
α	Contact Angle	°(degree)
L_{1O}	Life Of The Bearing For 90% Survival at 1mr	Hr
τ	Shear Stress	N/mm^2

As this project has 3 PCD's so the centre distance varies from 50mm, 54mm and 57.15mm for 100mm, 108mm, 114.3mm PCD wheels. The torque required to open one nut is 90 Nm [18], so calculation is based on point that every nut must experience torque more than 100 Nm for easy removal of the nut. The reason for selecting the spur gear is that the velocity ratio of spur gear is constant [1]. The material used for gear is EN8. Gear and pinion design calculations were performed keeping the above factors in mind and the values obtained were as follow.

For 100 PCD

Pitch circle Diameter for gear = 66.65 mm.

Pitch circle Diameter for pinion = 33.35 mm

Pressure angle (Φ) = 20°

$$(\text{Gear Ratio}) \quad = \frac{\text{PCD of Gear}}{\text{PCD of Pinion}} = \frac{66.65}{33.35} = 1.998 \approx 2 \qquad (1)$$

By Lewis form factor table,

No of teeth on pinion = $Z_p = 17$

No of teeth on gear = G x $Z_p = 34$ (2)

$$\text{Module(m)} = \frac{D}{zg} = \frac{66.65}{34} = 1.967 \approx 2\text{mm} \quad (3)$$

After calculation of each gear we get following values:

For Pinion

Teeth : 17

PCD (mm) : 33.35

Module (mm) : 2

Addendum (mm) : 2

Deddendum (mm) : 2.5

For Gears Resting On Centre Shaft:

The dimensions of gears resting on center shaft is shown in Table 2 and Mechanical properties is shown in Table3.

Table 2 Dimensions of gears resting on center shaft

Parameter	100 PCD	108 PCD	114.3 PCD
Teeth	34	38	42
PCD	66.65	74.67	80.95
Module	2	2	2
Addendum	2	2	2
Deddendum	2.5	2.5	2.5
Tool thickness	3.1	3.1	3.1
Gear Ratio	2	2.23	2.43

Table 3 Mechanical Properties (EN8/080M40) [3]

Ultimate tensile strength (S_{ut}) = 550 N/mm^2.
Yield strength (S_{yt}) = 280 N/mm^2.
Young's modules (E) = 200000 N/mm^2.
Poisson's ratio = 0.3.
BHN = 255 HB

Permissible Bending Stress:

As gear and pinion both are made up of same material

- For gear,

$$\boldsymbol{\sigma = \frac{1}{3} * Sut = \frac{550}{3} = 183.33}\ \text{N/mm}^2 \quad (4)$$

- For pinion,

$$\boldsymbol{\sigma = \frac{1}{3} * Sut = \frac{550}{3} = 183.33}\ \text{N/mm}^2 \quad (5)$$

When pinion and gear both are made up of same material then pinion is weaker in bending.

Beam Strength: [4]

$$F_b = m \times b \times \sigma_{b} \times Y \quad (6)$$

$$= 2 \times 20 \times 183.33 \times 0.469$$

$$= 3432.7\ \text{N}$$

Effective Load For Precise Estimation: [3-4]

$$F_{eff} = \frac{Ka * Km * Ft}{Kv} \quad (7)$$

As, $K_a = 1.25$, $K_m = 1.2$, $V = 24\ m/s^2$.

Input torque T = 480 N-m

So, each nut will experience Torque up to 120 N-m.

Speed = N = 300 rpm (pneumatic gun)

Speed = N = 300 rpm (pneumatic gun)

$$\text{Power (p)} = = \frac{2*3.14*N*T}{60} = \frac{2*3.14*300*480}{60} = 15\ \text{kw} \quad (8)$$

The factor of Safety Information is shown in Table 4. and Mechanical properties of EN19 is shown in Table 5.

Table 4 Factor of Safety Information

1< FOS < 1.25	Uniform load without shock
1.25 < FOS < 1.5	Medium start, Frequent shock
1.5 < FOS <1.75	Moderately heavy shock
1.75 < FOS < 2	Heavy shock

The FOS of gear pair is higher than required FOS therefore given pair of gears are safe.

Factual = Fact = $F_t \times K_v \times S$ = 625 x 0.533 x 2.25 = 749.5 N

$$Q = \frac{2G}{2G+1} = 1.42,\ K = 0.74 \ [3] \quad (9)$$

$$F_w = D_p \times q \times b \times K = 1701.2\ \text{N} \quad (10)$$

$F_r = 227.48$ N, $F_n = 665.11$ N

Pact < Fw therefore, Design is safe in wear

Shaft Material: For Centre shaft: Material of the shaft is 40Cr1M028 / 4140 / EN19

Table 5 Mechanical properties of EN19 [21]

Ultimate tensile strength (S_{ut}) = 655 N/mm^2.
Yield strength (S_{yt}) = 415 N/mm^2.
Young's modules (E) = 210000 N/mm^2.
Poisson's ratio = 0.3.
BHN = 219 HB

Outer Diameter = 25 mm.

Inner Diameter = 20 mm.

For Bearing

For center shaft Taper Roller Bearing is used as center shaft is subjected to radial as well as axial load.

L10 = 800 Hours

Bearing No. for Tapered Roller Bearing is SKF30205 (22)

For pinion shafts Ball Bearings are used as these shafts are subjected to radial load only.

L10 = 8364.93 Hours

Bearing No. for Ball Bearing is SKF W 6200-2RS1 (22)

For Spring

Applied load = 158 N

C = 6

Diameter of spring = 3 mm

Diameter of spring coil = 18mm

LIST OF MATERIALS

- Pneumatic power-based hand gun/battery operated 20v portable hand gun/T-Spanner.
- Shafts
- Spur Gear
- Taper roller bearing.
- Ball bearings.
- Mild steel casing.
- Nut bolts for casing.
- Scroll plate
- Locking pins.
- Spanners.
- Adapters.

Main shaft with Sun Gears and Basic Arrangement of Sun and Planet Gear Mechanism are illustrated in Figure 1 and Figure 2 respectively.

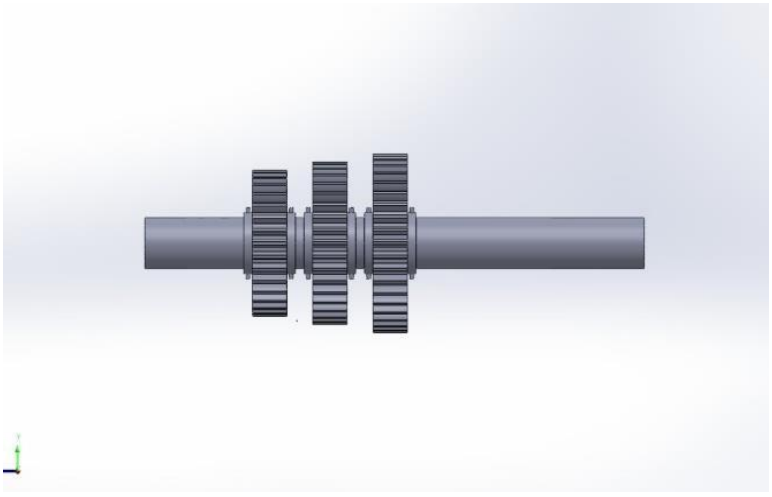

Figure 1 Main Shaft with Sun Gears

Figure 2 Basic Arrangement of Sun and Planet Gear Mechanism

The Mechanism with Casing and The Side view of mechanism casing and Pneumatic driven hand gun are depicted in Figure 3 and Figure 4 respectively.

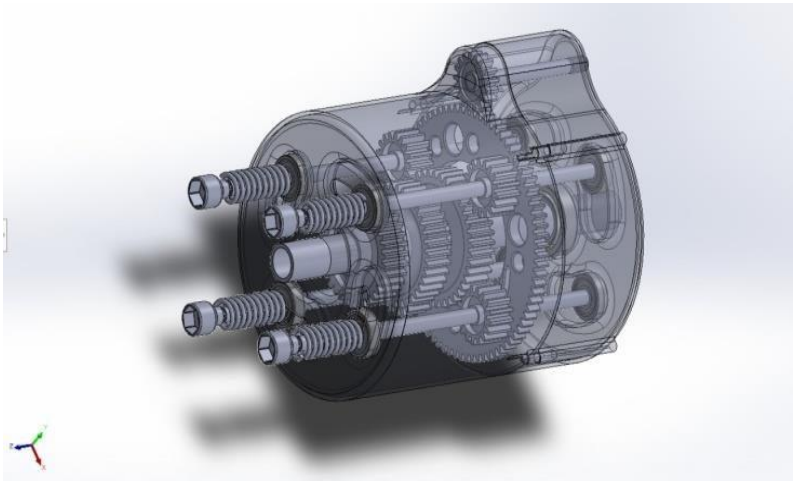

Figure 3 Mechanism with Casing

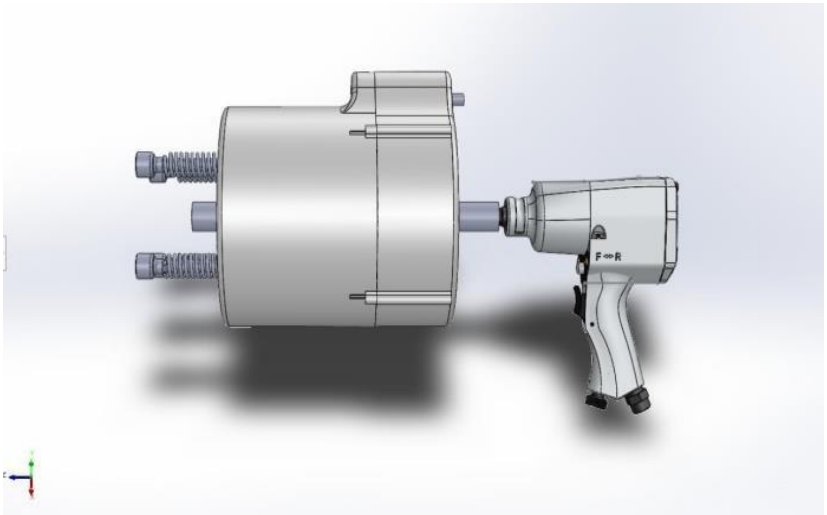

Figure 4 Side View of Mechanism Showing Casing and Pneumatic Power Driven Hand Gun

Figure 5 Scroll Plate Responsible For Radial Expansion

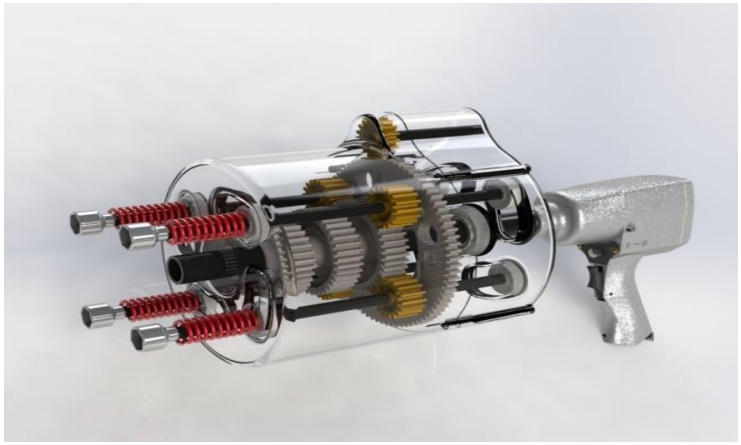

Figure 6 Final Assembly and Contraction Motion of the Mechanism.

The scroll plate responsible for radial expansion and construction motion of the mechanism and the final assembly are shown in Figure 5 and Figure 6 respectively.

ANALYSIS

- ANSYS is used for used for stress analysis of each and every component.
- Design and theoretical calculations were validated in Ansys workbench 2021R1.All the design was found to be safe, as the maximum von misses stress was lower that the material yield strength and favourable FOS was achieved.

The maximum deformation of shaft and the equivalent Von-mises of shaft are illustrated in Figure 7 and Figure 8 respectively.

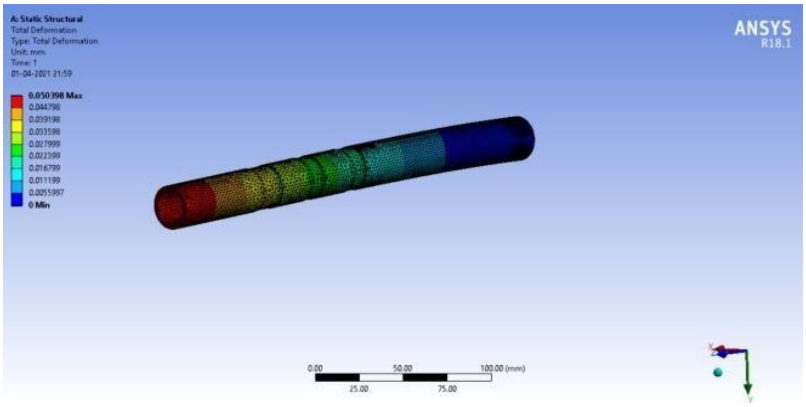

Figure 7 Maximum Deformation of Shaft

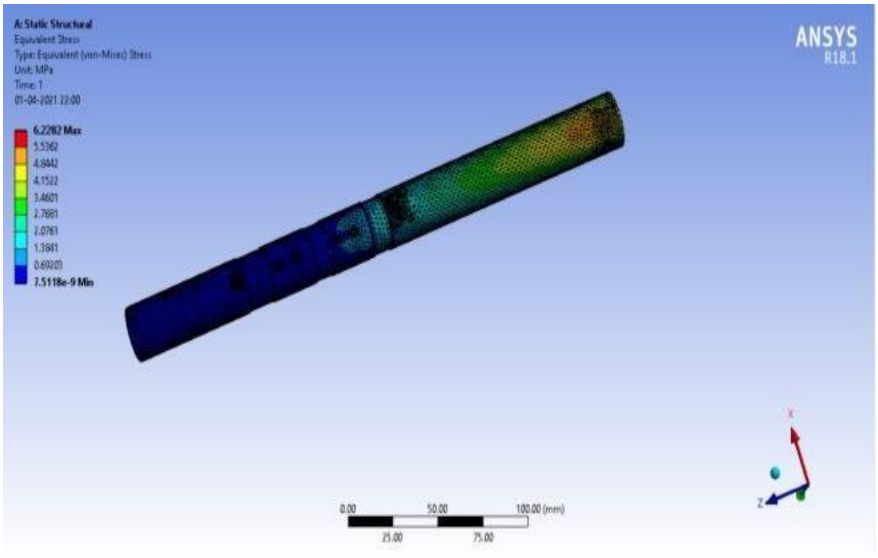

Figure 8 Equivalent Von-mises stress of shaft

The maximum deformation of one pair of gear and Equivqlent Von-mises of one pair of gear are depicted in Figure 9 and Figure 10.

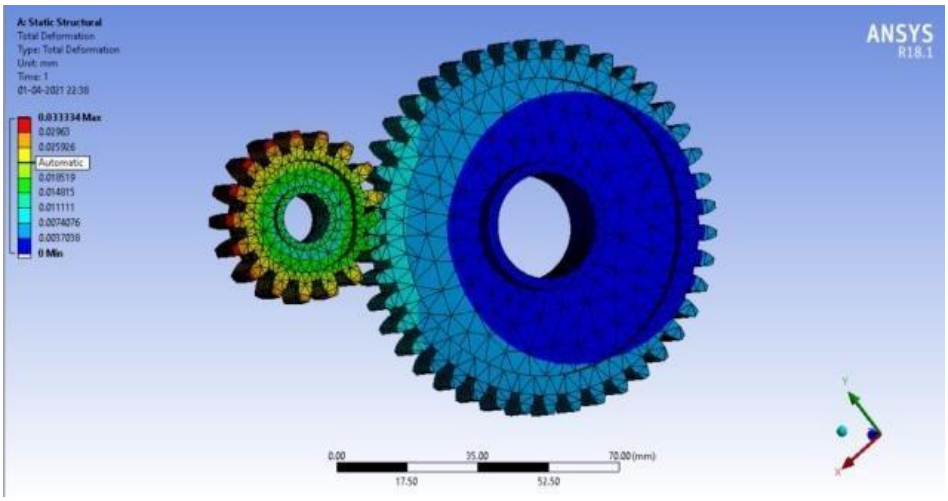

Figure 9 Maximum deformation of one pair of gear

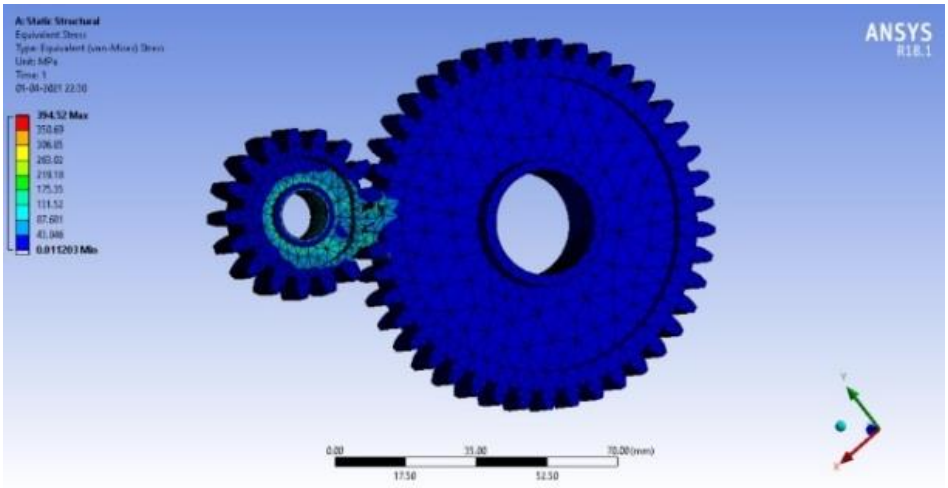

Figure 10 Equivalent Von-mises stress of one pair of gear

The maximum deformation all gears are in contact and Equivqlent Von-mises of all gears contact are illustrated in Figure 11 and Figure 12.

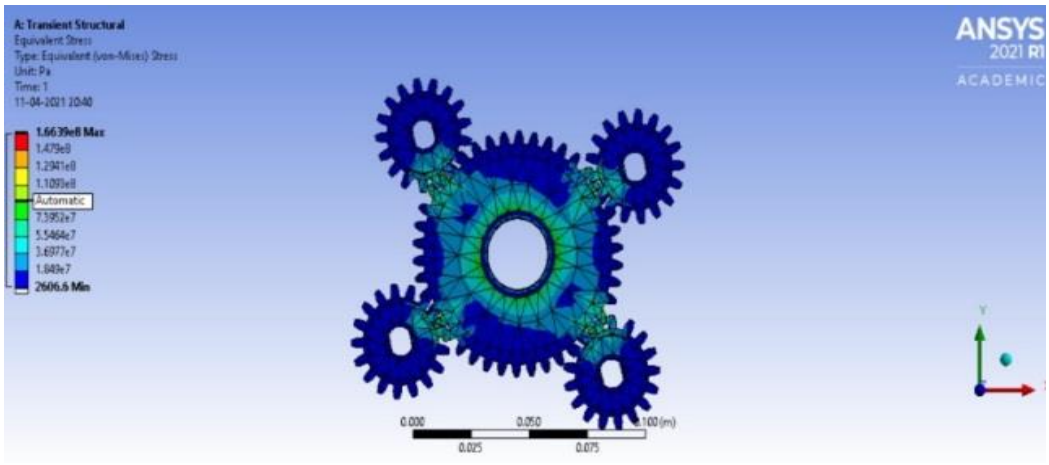

Figure 11 Maximum deformation when all gears are in contact

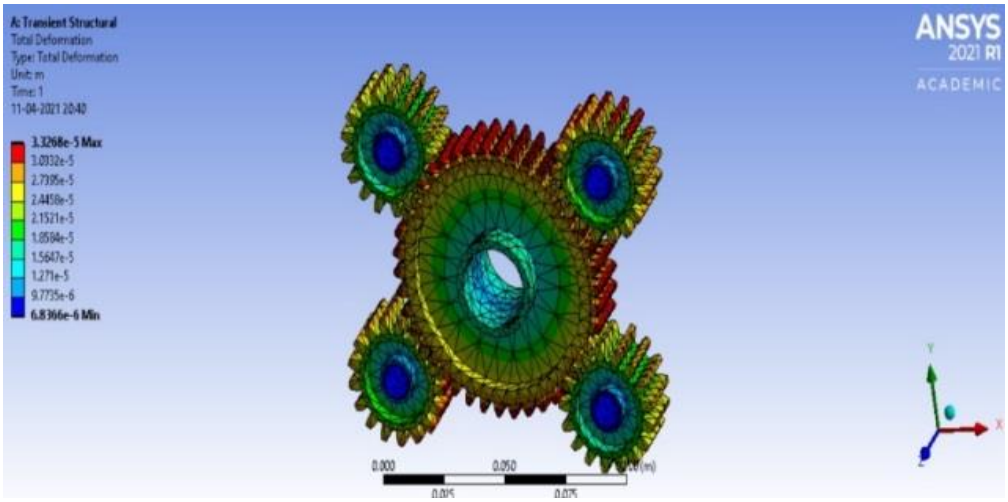

Figure 12 Equivalent Von-mises stress of all gears contact

4. CONCLUSION

The overall review of the paper is that the product developed can be used as a standard tool to work for a wide range of vehicles having PCD 100mm, 108mm and 114.3mm. The results obtained from calculation has shown that the mechanism is able to generate a torque which is more than sufficient to tighten or loosen all the four nuts at a time quickly. The factor of safety of gears has been found out to be 1.96 which is higher than the required value i.e. 1.75. The scroll plate with gear teeth which is incorporated in the mechanism plays a vital role towards the adjustable nature of the product which is a unique feature in comparison with the products developed so far. Analysis of all the components have shown positive results. However, development can be made to improve the design and quality of the product.

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