Design And Fabrication of Multi-Nut Impact Wrench

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Abstract*- A Multi-Nut Impact Wrench is a mechanism which can be used to Fasten/Loosen multiple nuts of a wheel simultaneously. It takes a lot of effort to Loosen/Fasten Lug-Nuts of a wheel. It is much more difficult for women and elderly people. One other way to go about this process is to use a Multi-Nut Impact Wrench. Multi-Nut Impact Wrench is a mechanism which involves a Planetary Gear system involving five gears. The gear in the center is the Sun Gear and the four Gears around it are Planetary in nature. Torque is applied on the main Sun Gear which is meshed to all four gears. This torque simultaneously gets equally distributed to all four gears. Thusfastening/Loosening of all nuts can be achieved with a single instance of application of torque. The mechanism mentioned above was fabricated and it was seen that the torque applied on the main shaft was getting equally distributed to the sub shafts, this ensures equal torques are applied on all the nuts of the wheel during fastening and all the nuts are fastened to the same degree.*

Keywords- Impact Wrench, Planetary Gear System, Multi-Nut, Pitch Circle Diameter, Lug-Nut

I. INTRODUCTION

In this 21st century modern day life, the principle objective of innovating a product is to extend a sense of convenience to the users of that product. When a car is taken into consideration, it no longer is a luxury, it is a necessity. There are advances being made to make the car as convenient as possible. It is inevitable that at some point in its usage a flat tyre occurs. Traditionally when a flat tyre occurs, the punctured wheel is swapped with spare set of wheels which involves the removal of the Lug-nuts of the wheel rim with a L-shaped wrench.

The problem with this process is, while removing the Lug-nuts of the wheel with a L-shaped wrench, it has to be carried out manually. This involves high application of torque to rotate the Lug-nuts. After the wheels are swapped, the nuts have to be fastened; there is a requirement for even higher application of torque as the Lug-nuts have to be tightened. It can be inferred that the process of manually fastening/loosening the Lug-nuts of the wheel requires high torque and can turn out to be much more difficult for women and the elderly. Therefore, there is a need for a device that can make this process convenient and ergonomic.

A Multi-Nut Impact wrench (MNIW) is a tool that is designed in such a way that it can be used to Loosen/Fasten all the nuts of a wheel simultaneously. It is also motorised with a help of an impact wrench, therefore eliminating the manual disadvantages of a L-Shaped wrench.

II. LITERATURE REVIEW

[1] Amol Bhange (2016) has proposed for a wheel nut removal tool which has ease of usage, is light in weight, compact and economical. He has designed a 6 in 1 all-nut-remover for automobile wheels. He has also argued against the use of air guns as effective means of tyre removal as it requires each nut to be removed individually and also because it requires high pressure air to be stored in a compressor which is hard to carry. He has effectively used planetary gear system to transmit torque to drive all gears of the tool which remove the nuts with lesser torque application and better efficiency.

[2] Nitesh L. Gomase has shown the design and fabrication of 4-wheel multiple-nut opening spanner for fastening and removing of all four nuts in a single hand motion. He has proposed a planetary gear mechanism to reduce effort and save time for removing all nuts at a time. He has also described the limitations of using high rotation power screws run by electric or pneumatic means. He has suggested motorization for reduction of effort, a mechanism for varying the pitch circle diameter as per the requirements of the car, torque convertor, use of different gear mechanism to increase efficiency.

[3] Abdulla (2013) has argued that since most of the countries today have at least one car per family the number of cars has increased drastically. He also says that a majority of mechanical problems are due to tyre related failures. One of which is improper fastening of lug nuts. This is due to the insufficient torque distribution to the lug nuts. This problem is compounded for old people because they have to use an L-shaped mechanical wrench which requires sufficient effort. He has therefore designed the ‘Vehicle all-wheel-nut remover’ to combat this problem.

[4] T. Thirumalai has observed that removing overtightened nuts from a car wheel requires immense amount of energy and would totally drain the battery of a cordless impact wrench. it's important that the nut is fastened within a fairly range. The shank of the bolt could break, or the threads may strip, providing no clamping force at all. It is therefore important to keep the nut tightened and the torque given to the nut limited.

[5] M. Savage and H.H. Coe have proposed that to optimise the design of compact spur gear reductions, the proportions of shafts and bearings that support spur gears have to be selected rather than only the meshing parameters. Many people started using computers to optimise compact gear mesh designs. Errichello (1989) had worked on bringing the determination of optimal gear design back to hand calculations. Since all of these methods depended on the gear parameters, it was imperative that the next step was to assume the entire gear system as one mechanism and optimise the proportions of individual components in relation to each other. The paper they wrote was to optimise design of a parallel shaft enclosed spur gear reduction system through a computer. They after finding successful values for designs suggested the use of such theory of spur gear system optimisation

III. DESIGN

PCD stands for the Pitch Circle Diameter. The PCD is one of the most important considerations that have to be taken while designing the MNIW because the centre distances between the gears have to be maintained in accordance with the PCD of the wheel. The value of the PCD varies for different manufacturers. With change in PCD of the wheel, the combinations of gears have to be varied to align with the PCD of the wheel. So, designing the Gears required for the MNIW working is possible only by keeping in consideration the PCD of the wheel on which the MNIW has work.
One such example is

Manufacturer	Model	PCD (mm)	Lug-Nut size (mm)
Maruti Suzuki	Hatch Backs	4×100	19
	Sedans	4×114.3	19
	SUV	5× 114.3	19

IV. DESIGN CALCULATIONS

Velocity Ratio

$$i = \frac{n_2}{n_1} = \frac{Z_2}{Z_1} = \frac{52}{49} = 1.06122$$

I. Identifying the weaker member

Lewis Form Factor

$$y_1 = 0.154 - \frac{0.912}{Z_1} \quad = 0.154 - \frac{0.912}{49} \quad = 0.09816 \quad \text{............ [eq. (23.116) DDHB]}$$

$$y_2 = 0.154 - \frac{0.912}{Z_2} \quad = 0.154 - \frac{0.912}{52} \quad = 0.1013 \quad \text{............ [eq. (23.116 DDHB]}$$

As the material for both Gear and pinion is Mild Steel, the allowable stress for both pinion and gear is considered to be 200MPa.
Therefore,

$$\sigma_{01} = \sigma_{02} = 200\text{MPa}$$

$$\sigma_{01}\ y_1 = 200 \times 0.09816 = 19.632$$

$$\sigma_{02}\ y_2 = 200 \times 0.1013 = 20.26$$

As per the above calculations, it can be inferred that both the pinion and gear are comparably stressed, with the Gear (Driven gear) being more stressed. Therefore, Design is based on the Driven Gear.

Design:

Tangential Tooth load

$$F_t = \frac{9550 \times 1000 \times 0.3 \times 1}{150 \times 24.5} = 779.5918\ \text{N}$$

$$F_t = \frac{9550 \times 1000 \times N \times C_s}{n \times r}$$

Lewis Tangential Tooth load

$$F_t = \sigma_0 \times b \times y \times p \times C_v$$

Where,

$$\sigma_0 = 200\text{MPa}$$
$$P = \pi \times m$$
$$b = 10 \times m$$
$$y = 0.154 - \frac{0.912 \times m}{d}$$
$$C_v = \frac{3}{3 + V_m} = 0.8863\ ^{m}/_{s}$$
$$V_m = \frac{\pi \times d \times n}{60 \times 10^3} = \frac{\pi \times 49 \times 150}{60 \times 10^3} = 0.3848\ ^{m}/_{s}$$

Substituting in above equation F_t

$$779.5918 = 200 \times 10 \times m \times \left(0.154 - \frac{0.912 \times m}{49}\right) \times \pi \times m \times 0.8863$$

$$0.13999 \leq 0.154m^2 - 0.0186m^3$$

To select an appropriate module, a trail and error method has to be performed by substituting ‘m’. The calculations should be done so that the resulting gear capacity should be more than induced load.

Trail 1: For m = 1

$$0.13999 \nleq 0.1354$$

Trail 2: For m = 1.5

$$0.13999 \leq 0.2837$$

Hence module 1.5 is selected

Checking for Stress

Allowable Stress: $(\sigma_{all}) = (\sigma \times C_v)_{all} = 200 \times \frac{3}{3+0.3848}$

$$\sigma_{all} = 177.2630\ \text{MPa}$$

Induced Stress: $(\sigma_{ind}) = \frac{F \times t_1}{b \times y_1 \times P}$

$$\sigma_{ind} = \frac{779.5918}{10 \times 1.5 \times \left(0.154 - \frac{0.192 \times 1.5}{49}\right) \times \pi \times 1.5}$$

$$\sigma_{ind} = 74.4584\text{MPa}$$

$$\sigma_{ind} \ll \sigma_{all}$$

hence design is safe

The induced value of stress is less than the allowable stresses. Therefore, it can be inferred that it is a safe design.

CHECKING

Dynamic Loading

$$F_d = F_t + \frac{21 \times V_m \times (F_t + (b \times C))}{(21 \times V_m) + \sqrt{F_t + (b \times C)}}$$

$$F_d = 389.7959 + \frac{21 \times 0.3848 \times (779.5918 + (15 \times 1400))}{(21 \times 0.3848) + \sqrt{779.5918 + (15 \times 1400)}}$$

$$F_d = 1927.8775\ \text{N}$$

Endurance test

$$F_{-1} = \sigma_{-1} \times b \times y \times m$$

$$\sigma_{-1} = 414\ \text{N/mm}^2 \text{ for BH=225}$$

$$y = \pi \times y = 0.4863$$

$$F_{-1} = 414 \times 10 \times 1.5 \times \pi \times 0.09816 \times 1.5$$

$$F_{-1} = 2872.5479\ \text{N}$$

$$F_d < F_{-1}$$

Hence the design is satisfactory and the module should be 1.5mm.

CAED MODEL

According to the design calculations, a CAED Model of a Spur Gear was designed.

Specifications of Gears

Specifications	Driver	Driven
Module	1.5	1.5
Addendum Circle Diameter	55mm	52mm
Dedendum Circle Diameter	49mm	45mm
Pitch Circle Diameter	52mm	49mm
Addendum	2mm	2mm
Dedendum	1.5mm	1.5mm
Total Depth	3.5mm	3.5mm
Face Width	16mm	9mm
Clearance	0.5mm	0.5mm

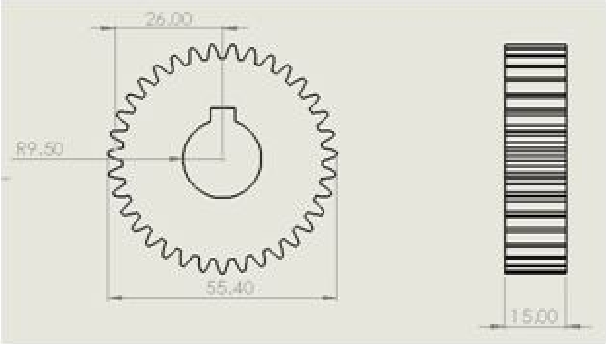


Fig. 2-D view of Driving Gear

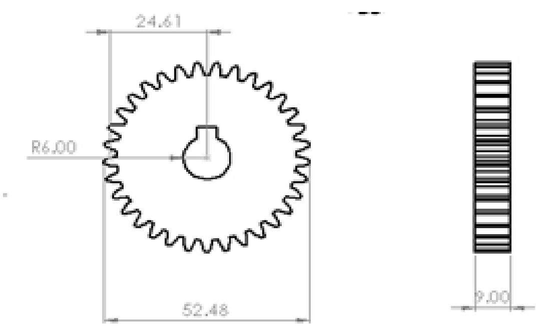


Fig. 2-D view of Driven Gear

2-D Drawing Views

The figures belowshow the 2-D views of the driven and the driving shaft respectively.

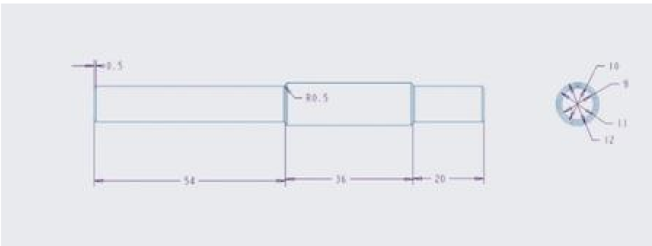


Fig.Driven Shaft

Fig. Driving Shaft

Specifications of shafts

	Driving Shaft	Driven Shaft
Overall length	90mm	110mm
Chamfer edges	0.5mm	0.5mm
Round radius	0.5mm	0.5mm
Inner diameter (ID)	16mm	9mm
Outer diameter (OD)	20mm	10mm
Central diameter	19mm	12mm

CAED Model of Plate

2-D Drawing Views

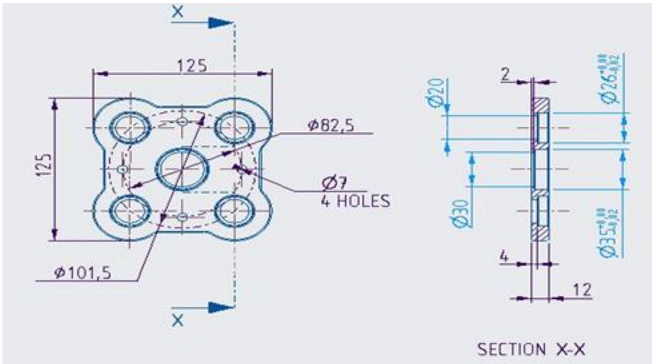
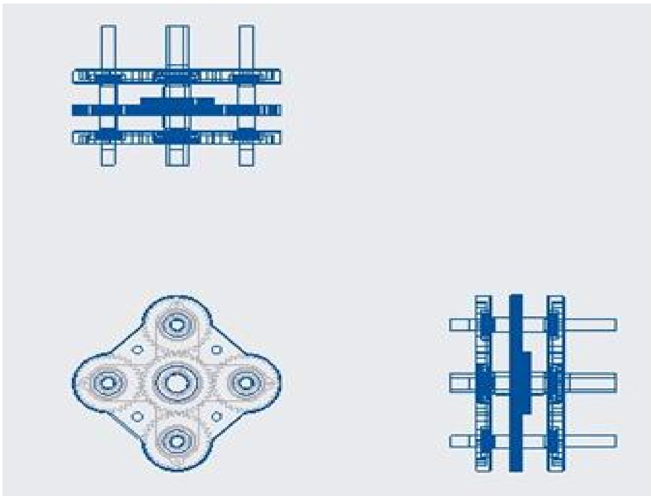


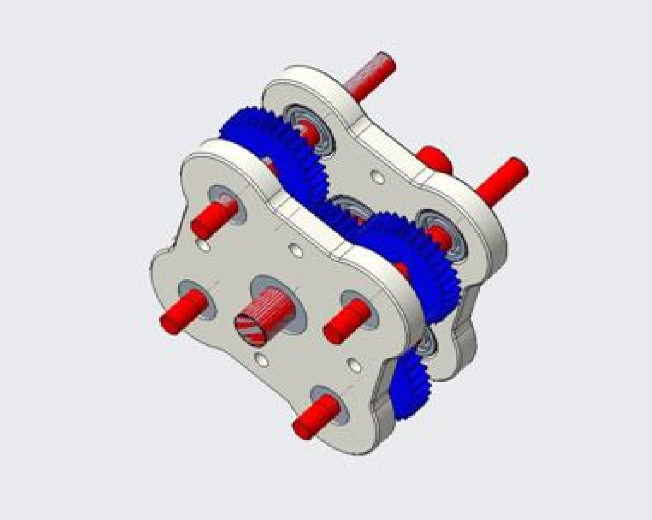
Fig. 7.10 2-D Drawing of a Plate

ASSEMBLY

The figure shows its 2-D drawing views.



2-D Drawing view of assembly of model



Assembly of entire model

FABRICATION

Fabrication of Plate requires cutting it to the designed shape and pressing of bearings into the holes. Laser Cutting, Wire Cutting, Drilling, Reaming, Flywheel Pressing, Hot pressing are the processes required to complete it. Fabrication of Shaft requires cutting it into appropriate length and milling it to lock it on one side and welding on the other side to completely lock the shaft in place. Bandsaw Metal Cutting, Step Turning, Arc Welding, Angle Grinding are the processes required to complete it.

Fabricated Plate

Driven and Driving Shaft

Assembly of MNIW

Front view of MNIW

Side view of MNIW

Bill of Material

Particulars	Trail 1 (Maruti Suzuki Celerio)	Trail 2 (Hyundai i-20)	Trail 3 (Maruti Suzuki Eeco)
L shaped wrench	113 sec	97 sec	107 sec
MNIW	58sec	70sec	65sec
Time saved of removing Lug Nut	55sec	27sec	42sec

V. RESULTS

Multi nut impact wrench of 100mm pitch circle diameter was designed using the software's PTC Creo v4.0 and SOLIDWORKS v18. By taking the material AISI 1045, for sun and planetary gears, design calculations were done. From the calculations we concurred that it was safe to use the designed gear system as the Factor of safety of planetary gear system was higher than the design factor of safety. If the handling time of the L-shaped wrench is considered this mechanism decreases the time taken to remove all the lug nuts. It also decreases the amount of force required to operate the Wrench depending upon the addition of torque multiplication mechanism. It can also be suggested that companies provide this mechanism as a standard tool provided with a new vehicle. The mechanism has been successfully fabricated and tested on Hyundai i10, i20, Maruti Suzuki swift, Eeco, Celerio, Alto.

The following trails where conducted to check the performance of the model.

Field Trails

Description	Quantity	Cost (INR)
Gears	5	650
Bearings	10	600
Sockets	8	300
Fabrication of Plate	4	1500
Fabrication of Shafts	5	750
Total	32	3800

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