DESIGN AND DEVELOPMENT OF A (5 IN 1) MULTI-LUG NUTS REMOVER AND TIGHTENER

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Abstract: The primary aim of this article is to develop a modified 5 in 1 multi-lug nuts remover and tightener device with a cordless direct current (D.C) electrical impact wrench attachment which provides it with the required turning torque for easy removal and tightening of lug nuts. SOLID WORKS was used for the design. The design was based on a PCD of 114.3 mm for most vehicle wheels thereby allowing all vehicles having a Pitch Circle Diameter (PCD) of 114.3 mm to use this device. This device is useful in places such as workshops, service stations and tire manufacturing companies. The calculations for the individual component parameters were performed using standard design equations. The gear design is based on the weaker gear. A mild steel spur gear was selected for the project because they are easy to design, manufacture and has a constant velocity ratio. An alloy steel chromium-vanadium was chosen for the shaft because it has good mechanical property (strength) and exhibits good weld-ability. A 3 mm thick cast steel plate was used to cover the entire assembly because it can withstand the forces of the gears and the shaft extensions. From the performance evaluation of the developed device, it takes 10 seconds to loosen five nuts, and 7 seconds to tighten the nuts in a single attempt and the loosening and tightening process were reduced by 93 and 95%, respectively compared to when using L shaped wrench.

Keywords: Development, multi-lug nuts, remover, tightener

Introduction

A multi-lug nuts remover and tightener is a specialized hand device with lug-nut sockets and long shaft used to remove lug nuts by taking advantage of different sized spur gears which greatly reduce the amount of time required for wheel removal and facilitates tightening of the wheel to the vehicle with reduced effort (Khurmi and Gupta, 2015). The added torque provided by the device permits anyone to loosen a lug nut with far less effort than the one required using L-wrench. Hence, the device provides a means for giving a far greater number of people the independence to change a tyre without having to wait for assistance. This lessens the time the user is stranded at the side of the road thereby reducing the time the user is exposed to the possibility of being struck by another vehicle or being accosted by persons with malevolent motives (Childs, 2014).

Different multi nut tightener/remover devices have been developed in the present decade having similar constructional features such as sun gear, planetary gear, shaft carrying the box spanner etc. (Azizul and Aziz, 2008; Sourabh, 2016; Mukhtar and Hussaine, 2014). Nurfarahin (2013) designed and fabricated a four-wheel opening spanner. In the work, each of the four nuts is losing/tighten individually by simultaneously applying the spanner/lever. Similarly, (Azman and Sulaiman, 2003), designed and fabricated a vehicle all-wheel-nut remover. Sirvabalan *et al*. (2014) designed and fabricated an adjustable unified wheel opener. Bevel gear arrangement was used for actuating the four socket spanners at a time. Twelve driven gears and one pinion gear were used. Somashekar and Mahendra (2018) in their work designed and fabricated a portable powered nut remover and tightener tool to remove and tighten the wheel nuts with easy maintenance, easy storage, easy to handle and using minimum available energy source from car battery.

Several other mechanisms have been designed in the past for car tyre tightening and removal among which are 6 in 1 all-nut remover for automobile wheels (Bhanage and Bhanage, 2016), four wheeler opening spanner, computer assisted impact wrench for a car wheel nuts puller, all wheel nut remover for automotive, heavy duty gears multi nuts removal device (Avinash and Bharaneedharan, 2014), spur gear in different geometric conditions, conceptual vehicle all wheel nuts remover, multi-lug nuts opener and tightener for four wheeler, cam-controlled planetary gear trains, multi-nut operating device using CATIA and ANSYS (Rahman and Aziz, 2008) tyre nut remover with 114 PCD.

The main aim of this work is to develop a modified multi-lug nuts remover and tightener with a cordless D.C electrical impact wrench attachment which provides it with the required turning torque for easy removal and tightening of vehicle wheel lug nuts.

Fig. 1: (a) Spider-type lug wrench (b) Torque wrench (c) Spherical lug nut

Materials and Methods

The nut remover was designed for a PCD of 114.3 mm, necessary gear and shaft parameter calculations were performed using standard equations and then designed in SOLIDWORKS before the fabrication process. Fig. 2 illustrates the flow chart adopted in developing and fabricating the product. The materials used for the design of the various machine components are based on the type of force that will be acting on them, expected work or function, the environmental conditions in which they will function, useful physical and mechanical properties, cost, and its availability in the local market.

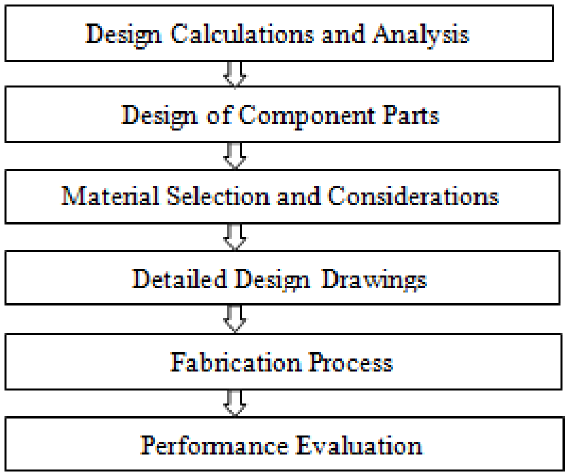


Fig. 2: Flow chart for the development of the device

Design calculations and analysis

The calculations for the individual component parameters were performed using standard design equations. Factor of Safety (FOS) of the design was checked and later the product was modelled using solid works. The work was designed for a wheel of PCD 114.3 mm, so that the center distance between gears had to be 57.15 mm. The torque required for removal of one nut is 85 N-m. Spur gear was selected for design because they are easy to design and manufacture with constant velocity ratio. Gear and pinion design calculations were performed and the values obtained were as follows:

Pitch Circle Diameter for Gear =

D_G = 76.3 mm

Pitch Circle Diameter for Pinion = D_P = 38 mm

Pressure Angle (ϕ) =20°

Velocity Ratio (VR) $= \frac{\text{PCD of Gear}}{\text{PCD of pinion}} = \frac{76.3\text{mm}}{38\text{mm}} = 2.00$

The gear design

The gear design is based on the weaker gear. To determine the weaker gear, a set of arbitrary tooth numbers were assumed such as 15 and 30, which satisfied a velocity ratio of 2:1. The gear and the pinion are made of same material (mild steel) having an endurance strength (S_o= 320MN/m^2).

Table 1 shows the table of form factors (y) for use in Lewis strength equation.

Table 1: Table of form factors

Component	No of teeth	S_o	Form factor (y)	$S_o y$
Pinion	15	320MN/m^2	0.092	29.44 MN/m^2
Gear	30	320MN/m^2	0.114	36.48 N/m^2

Since 29.44 MN/m^2 is less than 36.48 MN/m^2, the pinion is the weaker gear. Our design for strength is based on the weaker gear.

Torque transmitted by the pinion,

T = 85 Nm,

Diameter of pinion,

D_P= 38 mm = 0.038 m

Speed of the pinion,N_P= 550rpm

Transmitted force, $F = \frac{2T}{D} = \frac{2 \times 85}{0.038} = 4474\text{N}$

Pitch line velocity, $V = \frac{\pi dN}{60} = \frac{\pi \times 0.038 \times 550}{60} = 1.09\text{m/s}$

Power transmitted by pinion gear,

P = FV = 4474 x 1.09 = 4876.66W

Allowable tooth stress

Allowable tooth stress for the pinion for a speed of 1.09 m/s is given by:

$S_{\text{allowable}} = S_o\left(\frac{3}{3+v}\right) = 320 \times 10^6\left(\frac{3}{3+1.09}\right)$

= 234.72MN/m^2

Since the diameters are known, the following form of Lewis equation is used

$\left(\frac{1}{m^2 y}\right)_{\text{ind.}} = \left(\frac{sk\pi^2}{F}\right)_{\text{allow.}}$

$\frac{1}{m^2 y} = \frac{234.72 \times 10^6 \times 4 \times \pi^2}{4474}$

Allowable stress = 2.071MN/m^2

Where: $k \leq 4$

In order to find the module(m), form factor (y) is assumed to be 0.1

$$\frac{1}{m^2 y} = 2.071\text{MN/m}^2 = \frac{1}{m^2 \times 0.1} = 2.071\text{MN/m}^2$$

Therefore,

m = 2.197mm use 2.25mm as

standard modulem $= \frac{D_P}{N_P} \rightarrow N_P = \frac{D_P}{m} \rightarrow N_P = \frac{38mm}{2.25mm} = 16.888$

= say 17

$m = \frac{D_G}{N_G} \rightarrow N_G = \frac{D_G}{m} \rightarrow N_G = \frac{76.3mm}{2.25mm} = 33.911$

= approximately 34

Where: N_P= Number of teeth of the pinion, and D_P= Pitch circle diameter of the pinion; N_G= Number of teeth of the gear, and D_G= Pitch circle diameter of the gear.

From the table of form factor(y) for a number of teeth of 17 at 20° full-depth.

Y = 0.096 and m = 2.25 mm = 0.00225 m

$\frac{1}{m^2 y} = \frac{1}{0.00225^2 \times 0.096} = 2.058\text{MN/m}^2$ Induced stress

Since, the induced stress is less than the allowable stress, the design is satisfactory from the stand point of strength.

The value of k is reduced to

$k = 4\left(\frac{\text{Induced stress}}{\text{Allowable stress}}\right) = 4\left(\frac{2.058\text{MN}/m^2}{2.071\text{MN}/m^2}\right) = 3.97$

From Lewis equation,

Face width b = K.P_C = $k\pi m$ =3.97 $x\pi x$ 2.25 = 28.06 mm

From the design calculations above, the gear design parameters were obtained as,

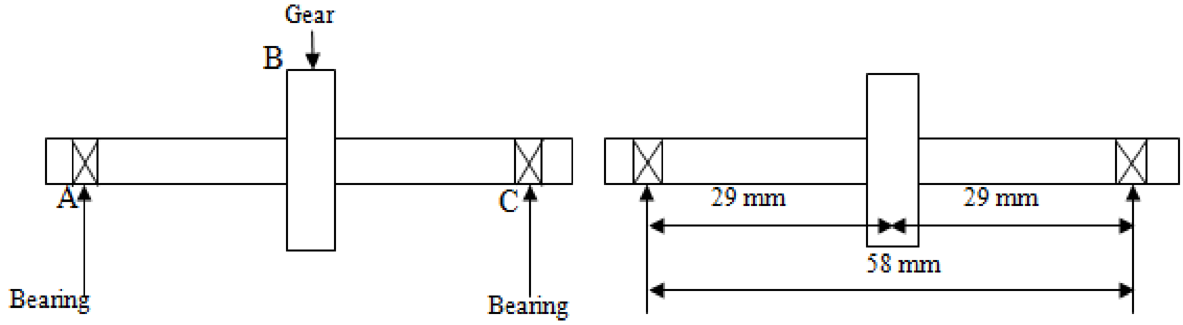
Face width b = 28.06 mm;

Module m =2.25 mm;

Number of teeth of pinion N_P = 17;

Number of teeth of gear N_G = 34

Design of Shaft



PCD of pinion = 38mm = 0.038m
Pressure angle (ϕ) = 20^o
Torque transmitted by pinion gear
T = 85Nm
Tangential force on pinion gear
$F_T = \frac{2T}{D_P} = \frac{2 \, x \, 85}{0.038} = 4473.68N$

Normal force acting on the tooth of the pinion
$W_N = \frac{F_T}{COS\phi} = \frac{4473.68}{COS \, 20} = 4760.80N$
Since the gear is mounted at the middle of the shaft, therefore, the maximum bending moment, M at the center of the gear,
$M = \frac{W_N . L}{4} = \frac{4760.80x \, 0.058}{4} = 69.03Nm$
Let d = diameter of the shaft.
The equivalent twisting moment

$T_e = \sqrt{M^2 + T^2}$

$T_e = \sqrt{69.03^2 + 85^2} = 109.5Nm$
For shaft without key way, the allowable shear stress (τ) is $55MN/m^2$

The equivalent twisting moment
$T_e = \frac{\pi \, x \, \tau x \, d^3}{16}$
$109.5 = \frac{\pi \, x \, 55x \, 10^6 \, x \, d^3}{16} =$
$10.799d^3 x 10^6$
d = 21.64 mm say 20 mm. (Shaft of 20 mm diameter was adopted).

To determine the factor of safety (FOS) of the device
The maximum moment was calculated using;
$M_{MAX} = PL$
Where, P is the tangential force on pinion gear = 4474N
L is the total length of shaft = 120 mm = 0.12 m
$M_{MAX} = 4474 \, x \, 0.12 = 536.88Nm$
Section modulus was calculated using;
$S = \frac{\pi d^3}{32} = \frac{\pi \, x \, 0.02^3}{32} = 7.85 \, x \, 10^{-7}Pa$

Maximum shear stress was calculated using;
$\tau_{MAX} = \frac{T.r}{J}$
Where: $J = \frac{\pi d^4}{64} = 7.85 \, x 10^{-9}$
$\tau_{MAX} = \frac{85 \, x \, 0.01}{7.85 \, x 10^{-9}} = 108MPa$

$FOS = \frac{\text{Maximum shear stress for material}}{\text{Maximum shear stress}} = \frac{320MPa}{108MPa} = 2.96$
For FOS greater than 1 indicates that the design is safe.

Table 2: Design calculations for gear and shafts

S/N	Design factors and consideration	Parameters
1.	Centre distance between gears	57.15 mm
2.	Torque required for removal of one nut	85Nm
3.	Pitch circle diameter (PCD) of wheel	114.3 mm
4.	Velocity ratio (V.R)	2
5.	Power transmitted by the pinion gear	4786.66W
6.	Torque transmitted by the driver gear	425Nm
7.	Available factor of safety (FOS)	2.96
8.	Power transmitted by the output shaft	4786.66W
9.	Percentage reduction in weight	93 & 95%
10.	Pitch circle diameter (PCD) of gear and pinion	76.3 & 38 mm
11.	Number of teeth of gear and pinion	34 & 17 mm
12.	Face width	28.06 mm
13.	Diameter of input shaft	20 mm
14.	Length of input shaft	120 mm

The ball bearing used in this project work was chosen considering the operating conditions, mounting arrangement, ease of mounting in the machine, allowable space, cost, availability, and other factors. Then the size of the bearing is chosen to satisfy the desired life requirement, fatigue life, grease life, noise, vibration, wear, and other factors (Fig. 3). An impact wrench with detent pin anvil, which can deliver a powerful forward and reverse torque was used. It is battery powered (Fig. 4).

Fig. 3: Bearing

Fig. 4: Impact wrench

The ball bearing used in this project work was chosen considering the operating conditions, mounting arrangement, ease of mounting in the machine, allowable space, cost, availability, and other factors (Table 3). From the measured turning torque required to loosening all five lug nuts at a time using torque wrench, an impact wrench of 520 Nm was selected (Table 4).

Table 3: Ball bearing specifications

Description	Specification
Inner diameter 17 mm	Basic dynamic load rating 8.06 KN
Outer diameter 35 mm	Basic static load rating 4.75 KN
Thickness 10 mm	Fatigue load limit 0.212 KN
Mass bearing 0.055 kg	Limiting speed 20,000 rev/min

Table 4: Specifications of impact wrench

Amps	7.5	Impact per minute	3100 rpm
Max torque	520 N.m	Weight	1.9 kg
No load speed	3300 rpm	Voltage	110v
Length	105 mm	Height	240 mm

Design Drawings

The design drawing reveals all the machine parts (input shaft), gear housing plate, driven (planetary gear), output shaft, socket wrench, pinion (driver) gear, and bearings (Fig. 5).

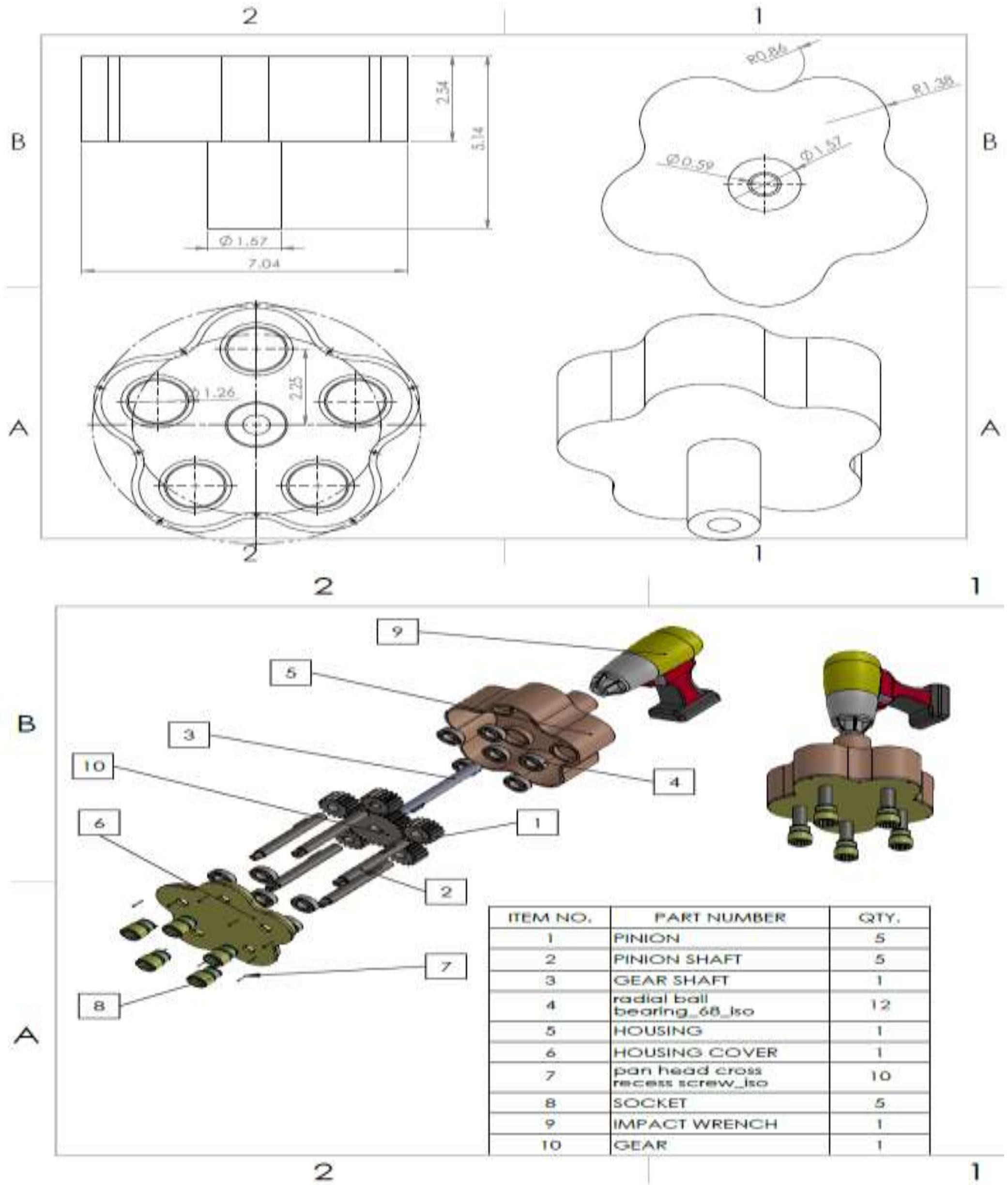


Fig. 5: Detailed design drawings

Fabrication process

Base and cover plate is used to cover the entire assembly, hold the gears and shafts mounted within it and to withstand the forces of the gears and the shaft extensions. It is a 3 mm plate made of cast steel (Plate 1). The bearing house was welded on this shaped metal plate at calculated points. A 3 mm thick metal plate made of cast steel which was used to construct the assembly casing. It was measured and cut out using hand cutting and grinding machine and hole of diameter 17 mm was drilled on it as shown in Plate 3.

Plate 1: Cast steel metal Plate (a) Cover (b) Base

The shaft was machined to the specification obtained from design calculations, and the gear was attached to the shaft at appropriate location using welding process as shown in Plate 2. The various components of the device were assembled to form the intended product. Lubricating grease was applied to the gear arrangement before the casing was finally closed for smooth operation of the device. Final surface finishes such as smoothening and painting was done to beautify the product and make it more attractive. Plate 3 and 4 depict the product asembly process and final product design.

Plate 2: Shaft and Gear attachment with welding process

Plate 3: Product assembly process

Plate 4: Final project assembly

Table 7: Project bill of materials

S/N	ITEM	DESCRIPTION	QTY	PRICE
1	Bearing	Ball bearing (ID 17 mm, OD 35 mm, W 10 mm)	12	# 3,600
2	Socket wrench	Size 21 mm	5	#1,500
3	Motor	(Impact wrench)	1	#28,000
4	Shafts	111 mm in length and 17 mm in diameter	6	# 4,200
5	Spur gear (driver)	Mild steel	1	#25,000
6	Spur pinion gear (driven)	Mild steel	5	
7	Metal plate (cast iron)	Housing		# 1,200
8	Hollow pipe	Cast iron (2 mm thick 200 mm length)	1	# 500
9	SOLIDWORKS Design	–		#10,000
10	Casing workmanship	–		# 5,000
11	Miscellaneous	–		# 5,000
			Total	**#84,000**

Table 8: Percentage reduction in time

Tool	Time (s)		Torque applied (Nm)
	To loosen five nuts	**To tighten five nuts**	
L-shaped wrench	140	135	425
Developed device (5 in 1 multi-lugs remover/tightener)	10	7	400
% reduction in time spent.	$\frac{140-10}{140}$ x 100% = 93%	$\frac{135-7}{135}$ x 100% = 95%	

Performance Evaluation

The performance evaluation was carried out after the design and fabrication process of the multi-lug nuts tighter and remover had been completed. This was done to determine the time taken to lose and tighten five-wheel nuts of car tyre. At the end of using the multi-lug nuts tightener and remover to carry out the operation, conventional tool (L shaped socket wrench) was also used; the two results were then compared to analyze the efficiency of the developed device. From the result obtained above, it clearly shows that the developed multi-lug nuts tightener and remover has reduced the time spent in the process of loosening by 93% and tightening by 95% with less application of torque compared to when the L-shaped wrench was used (Table 8).

Conclusion

A 5 in 1 multi lug nuts tightener and remover device with Pitch Circle Diameter (PCD) 114.3 mm which utilizes a planetary gear mechanism and powered by a torque wrench was successfully designed, developed, assembled and tested. The fabrication of the device is completed by Shaping, welding and fitting processes. The optimum operating speed of the device for lug nuts remover and tightening was found to be 550 rpm with an unscrewing time of 10 seconds and screwing time of 7 seconds with efficiencies of 93 and 95% respectively (Table 5). From the results obtained during the performance evaluation, it clearly shows that the device can conveniently remove and tighten five-wheel lug nuts of car tyres in a single attempt with reduced human effort input and time spent. Hence, the device can be operated by both men and women with ease. It can be successfully used as a standard device provided with a new vehicle. Also, it can be used in assembly line of automobiles, workshops and service stations.

Conflict of Interest

Authors have declared that there is no conflict of interest reported in this work.

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