MULTISTAGE EPICYCLIC LUG WRENCH

[1]Shinu Baby, [2] Nevin G Ninan, [3] Nithin George, [4] Salu Zachariah,

[5] Aju Zachariah Mani

[1,2,3,4] Scholar, [5]Assistant Professor, Department of Mechanical Engineering,

Saintgits College of Engineering (India)

ABSTRACT

Each and everyone have some kind of vehicle for their daily usage and those who don't have one, use any of the public transport. A common problem associated with all these vehicles is the removal and replacement of their wheels once they get damaged or flat. The lug nuts of heavy vehicles are removed by connecting a socket spanner to a long handle and then blowing this handle manually or with hammers. This takes a lot of human effort and may distort the fasteners and nuts. Although there are various mechanisms for removing lug nuts like lug wrenches, ratcheting socket wrench, impact wrenches, etc. but they are either time consuming, difficult to handle, non portable, power consuming or requires a lot of manual effort.

Our aim through this project is to reduce the human effort in unscrewing the lug nut. The huddle lies in the fact that the equipment to be designed must be light weight, portable and lower in power and time consumption. For this, in the present project a multistage epicyclic gear train device is designed to unscrew the lug nuts of vehicles. The device is very compact, simple in construction, easy to handle, reduces the unscrewing time to a considerable extend, portable and is user friendly.

Keywords: Case Hardened Alloy Steel, Gear Design, Gears, Multistage Gears, Torque

I. INTRODUCTION

Nowadays automobiles are an essential part of human life. We cannot imagine a world without them. Each and everyone have some kind of vehicle for their daily usage (whether it is a car or a bike) and those who don't have one use any of the public transport. Heavy vehicles like trucks are used to transport goods and other items. A common problem associated with all these vehicles is the removal and replacement of their wheels once they get damaged or flat. The tool set-up for each vehicle is a T-nut wrench and screw jack which is hard to use for a woman or teen to open their vehicle's lug nuts. Although there are various other mechanisms to unscrew lug nuts, they are either time consuming, non-portable or need a lot of human effort.

A lug nut or wheel nut is a fastener, specifically a nut, used to secure a wheel on a vehicle. Commonly used tool for lug nut removal is lug wrench. Lug wrenches may be L-shaped, or X-shaped. The form commonly found in car trunks is an L-shaped metal rod with a socket wrench on the bent end and a prying tip on the other end. Lug wrenches are much less expensive because they lack the ability to measure or limit the force used. Installing a wheel with a lug wrench thus requires a bit of rough guessing about proper tightness. Excessive force can strip threads or make the nuts very difficult to remove. Also, uneven torque between the various lug nuts, or excessive torque, can lead to warping of the brake rotor if the car is equipped with disc brakes. An improved form of the lug wrench is the ratcheting socket wrench, often called a ratchet**.**

There are also power tool versions of "air" ratchets which use compressed air power to drive air powered socket wrenches which tighten or loosen nuts or bolts. A second major variety of compressed air powered tools are impact wrenches which are used for common tasks such as lug nuts on wheels. Electric powered impact wrenches for the same tasks are not uncommon. Small cordless 12 Volt and 18 Volt impact drivers are often used today as powered ratchets to remove and install nuts and bolts. Hydraulic motor ratchets with their characteristic higher torque characteristics are rare outside of heavy industry.

An impact wrench is a socket wrench power tool designed to deliver high torque output with minimal exertion by the user, by storing energy in a rotating mass, then delivering it suddenly to the output shaft. Compressed air is the most common power source for impact wrenches, providing a low-cost design with the best power-to-weight ratio. A simple vane motor is almost always used, usually with four to seven vanes, and various lubrication systems, the most common of which uses *oiled air*, while others may include special oil passages routed to the parts that need it and a separate, sealed oil system for the hammer assembly. Most impact wrenches drive the hammer directly from the motor, giving it fast action when the fastener requires only low torque. Electric impact wrenches are available, either mains powered, or for automotive use, 12-volt, 18-volt or 24-volt DC-powered. Recently, cordless electric impact wrenches have become common, although typically their power outputs are significantly lower than corded electric or air-powered equivalents. Some industrial tools are hydraulically powered, using high-speed hydraulic motors, and are used in some heavy equipment repair shops, large construction sites, and other areas where a suitable hydraulic supply is available. Hydraulic impact wrenches have the advantage of high power-to-weight ratio. But these are not portable. Some of the drawbacks of pneumatic power systems include high cost, require large size compressors to generate high torque and large power consumption. Disadvantages of electrical power systems include inability to operate at low speeds, physically large, expensive to produce and high maintenance cost.

Hence an attempt was made to design a simple device to unscrew the lug nuts of heavy vehicles using epicyclic gear trains which can be hand operated, portable, less expensive and low weight. Objective of the current work also included the development of a solid model of the device in Solid Works as per the design and to conduct structural analysis of the developed model in ANSYS.

In the current work we use gears to design a system that reduces the manual effort. Gears were invented by the Greek mechanics of Alexandria in the third century B.C., were considerably developed by the great Archimedes, and saw wide use in the Roman world. They found two main applications: in heavy-duty machines such as mills and irrigation wheels, where they transmitted considerable power, and in small-scale water-clocks, calendrical instruments and automata which could be of extraordinary sophistication, incorporating the differential and perhaps the hypoid gear [1]. In the current work our objective was to design a multistage speed reducer so that initial input torque given is minimum. A detailed overview of the design of a new two-stage cycloidal speed reducer with tooth modifications can be found in [2]. The effects of the design parameters of involute gears generated by rack-cutters and also a general algorithm for the kinematic synthesis of spur and helical gears can be found in [3].

Planetary gear sets possess numerous advantages over their parallel-axis counterparts in terms of their power density, tolerance insensitivity and noise attributes in addition to their kinematic flexibility. One potential disadvantage of planetary gear sets is power losses due to multiple planet branches, resulting from an increased number of gear meshes and bearings. The power losses of a planetary gear set can be grouped in two categories based on their dependence on load. Load-dependent (mechanical) power losses are induced by friction in external and internal gear mesh contact interfaces as well as at planet bearings while load-independent (spin) losses are associated with drag of the carrier assembly and gears, bearing viscous losses and oil-air pocketing at gear mesh interfaces. With the assumption that power losses of these components are independent of each other, a methodology that implements a family of models to predict total power loss of planetary gear sets including primary mechanical and spin loss components is proposed in [4].

II. EXPERIMENTAL METHODOLOGY

We had to design an epicyclic gear train device which reduces the mechanical leverage in unscrewing lug nuts. It should be compact, easy to handle, have low weight and should be able to produce the desired output torque with least human effort. For heavy vehicles like buses and trucks maximum torque required to unscrew lug nuts is 1000Nm. So if we use a single stage epicyclic gear train, the system will be of large size, heavy and difficult to handle. So we have to use a multistage epicyclic gear system for torque multiplication.

In order to construct a multistage epicyclic gear train, initially we need to find the output of a single stage. So to find the number of rotations of the output shaft for a given input rpm, output torque and the number of stages required to produce the required torque, motion analysis and torque analysis was done [5]. After finding the number of stages required and the output of each stage, we had to find the spur gear data required for the design calculations. So formulas for the dimensional calculation of spur gear in terms of diametral pitch (P) and number of teeth (N) were used.

These spur gear data were then used for the design of the system. For design three different materials were considered. These include case hardened alloy steel, cast iron and bronze. These materials were then checked for dynamic, static and wear tooth loads. For safe design static and wear tooth loads should be more than dynamic tooth load [6]. Next, we had to create a model of the device. So, using Solid Works a model of the required device was created. First, different components including sun gear, planet gears, ring gear, shaft, connecting bar, handle, etc. were generated as different parts and then assembled to have the required device.

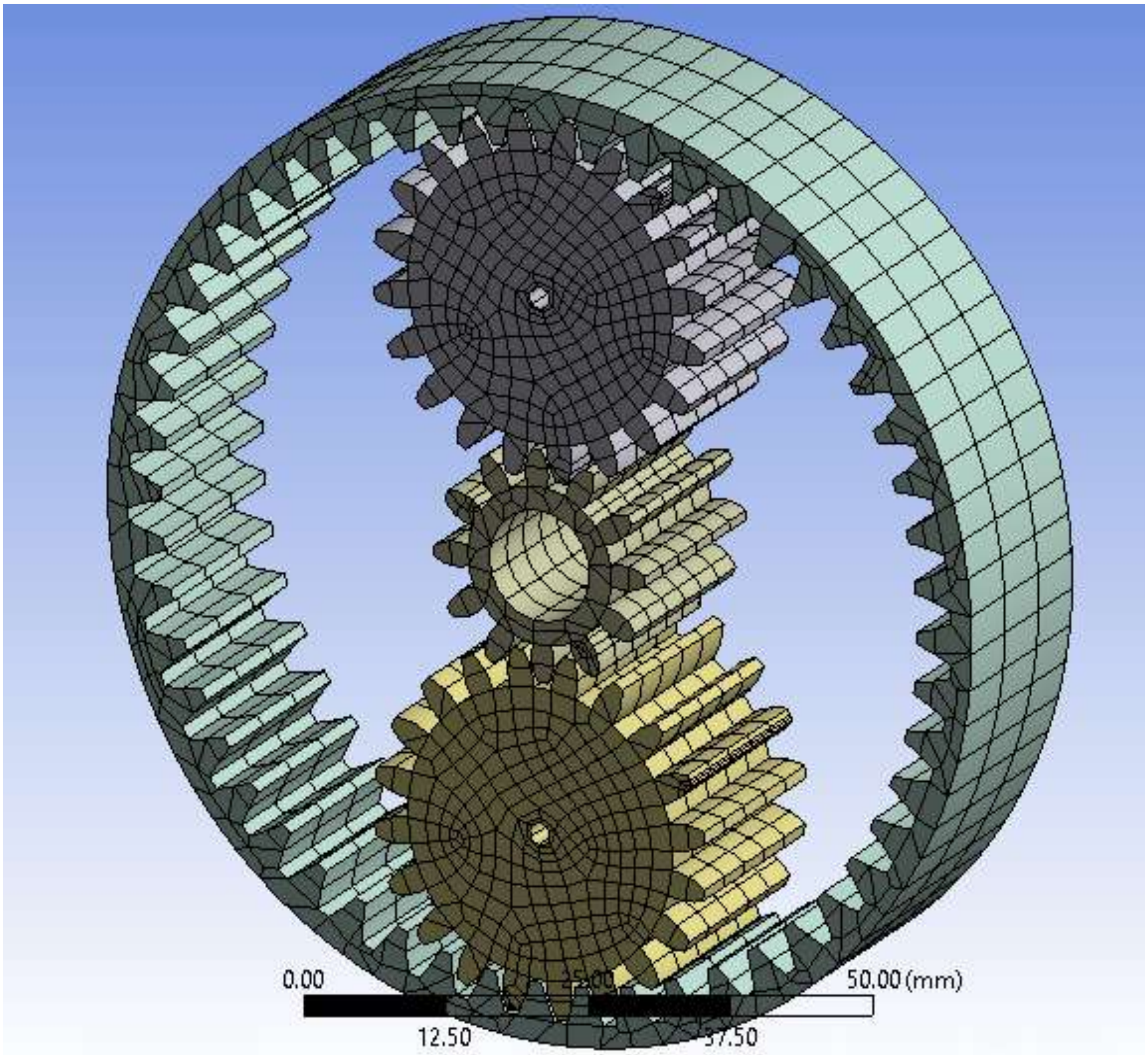

Fig. 1: Meshed view of section of the device being analyzed

Finally, static structural analysis of the created model was done in ANSYS for case hardened alloy steel, cast iron and bronze to find the equivalent stress, equivalent strain and total deformation of the device for various input conditions. Fig. 1 shows a meshed view of the section being analyzed. This was done to find whether the material used for design was safe.

III. RESULTS AND DISCUSSIONS

3.1 Velocity of Arm & Number of Stages

Data obtained from the motion analysis and torque analysis of the system is show in the Table 1. From the table it is clear that for an input velocity of 20rpm the velocity of the arm reduces to 3.75rpm in a single stage. So the velocity ratio of the system is found to be 0.1875. Results of torque analysis shows that three stages of epicyclic gear train are required to produce the desired torque output. Gear ratio of the system is 5.33. Table 2 shows the input and output velocities and torques for each of the three stages. For an input torque of 10Nm and 20Nm, the output at the end of third stage is 1517.22Nm and 3034.44Nm respectively.

Table 1: Results of velocity and torque analysis

Input velocity = 20rpm	**Input torque = 10Nm**
Parameters	**Magnitude**
No. of stages	3
Output velocity at the end of stage one	3.75rpm
Output velocity at the end of stage three	0.13182rpm
Maximum output torque	1517.22Nm
Velocity ratio	0.1875
Gear ratio	5.33

Table 2: Input and output velocities and torques for each stage

		Stage		
		1	2	3
Velocity (rpm)	Input	20	3.75	0.703
	Output	3.75	0.703	0.13182
Torque (Nm)	Input	10	53.33	284.495
	Output	53.33	284.495	1517.22
	Input	20	106.667	568.99
	Output	106.667	568.99	3034.44

3.2 Spur Gear Design Data

In the present project, design of spur gear using three different materials was analysed for satisfying different design requirements. The materials used include case hardened alloy steel of BHN 650, cast iron of BHN 225 and bronze of BHN 80. Gears were tested for dynamic, static and wear tooth loads. Table 3 shows results of spur gear design using different materials. From the Table.3 it is clear that the static and wear tooth loads for bronze and cast iron are less than the dynamic tooth load. But for the design to be safe, static and wear tooth loads should be more than the dynamic tooth load. So it is not safe to use bronze and cast iron as gear material in the design. But in the case of case hardened alloy steel the static and wear tooth loads are more than the dynamic tooth load. So case hardened alloy steel is safe for design.

Table 3: Dynamic, static and wear tooth loads for different materials

Material	Dynamic tooth load (N)	Static tooth load (N)	Wear tooth load (N)
Bronze	2118.749	437.310	142.439
Cast iron-Grade 35	2118.750	359.015	449.092
Case hardened alloy steel	2118.774	2197.370	2428.725

3.3 Solid Model

Fig. 2 shows the model of the multistage epicyclic gear train device design to unscrew the lug nut of vehicles. The device works on hand power. Whenever a lug nut is to be removed, a socket is attached to the lug nut and the output shaft of the device is connected to the socket. Then the input shaft is rotated by means of a handle. The input torque now gets multiplied in each of the three stages, thus providing the necessary torque at the output shaft required to unscrew the lug nut with least human effort. The outer ring serves as the casing for the device, so no additional casing is required. Since the device is compact and is of less weight it can be easily handled and is portable.

Fig. 2: Multistage epicyclic lug wrench

3.4 Structural Analysis Data

The model of the device created was structurally analysed in ANSYS for equivalent stress, equivalent strain and deformation for three different materials (i.e. case hardened alloy steel cast iron and bronze). Table 4 shows the maximum and minimum values of stress, strain and deformation for each of the different materials. From Table.4 it is clear that the equivalent strain, equivalent stress and total deformation for case hardened alloy steel is much lower than cast iron and bronze. This may be due to the better material properties and strength of case hardened alloy steel compare to the other two. Alloy steel is case hardened by carburizing, quenching and tempering, which increases their fatigue resistance, toughness, hardness and wear resistance. The maximum equivalent stress of alloy steel is less than its ultimate stress, but it is not so in the case of bronze and cast iron. So alloy steel is structurally safe for design, which is in agreement with numerical calculation.

Table 4: Maximum and minimum values of stress, strain and deformation

Parameter		Material		
		Bronze	Cast iron	Alloy steel
Equivalent Elastic Strain	Minimum	1.2389×10^{-15}	7.286×10^{-16}	1.3391×10^{-16}
	Maximum	2.3401×10^{-2}	2.2215×10^{-2}	4.0830×10^{-3}
Equivalent(von-Mises)Stress (MPa)	Minimum	7.037×10^{-11}	3.2785×10^{-11}	1.1503×10^{-11}
	Maximum	2.375×10^{3}	2.3898×10^{3}	8.3853×10^{2}
Total Deformation (mm)	Minimum	0	0	0
	Maximum	2.2537×10^{-1}	2.1230×10^{-1}	3.9019×10^{-2}

Equivalent stress distribution obtained from static structural analysis of the section of the device for case hardened alloy steel, bronze and cast iron are show in figures 3, 4 and 5 respectively. From figures 3, 4 and 5 it is clear that the maximum stress is minimum in the case of case hardened alloy steel. Also, for alloy steel the maximum stress is below its ultimate stress, but it is not so in the case of bronze and cast iron. So alloy steel is safe for design.

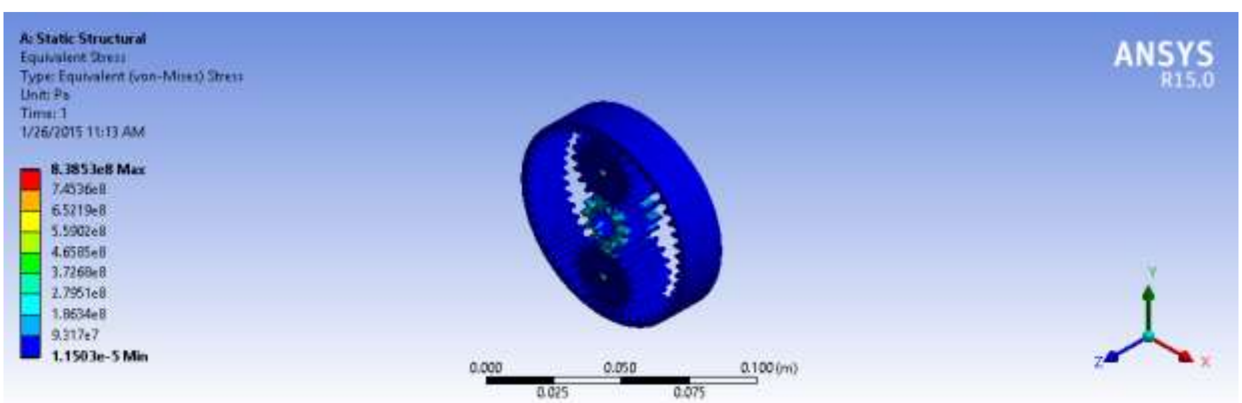

Fig. 3: Equivalent stress distribution for case hardened alloy steel

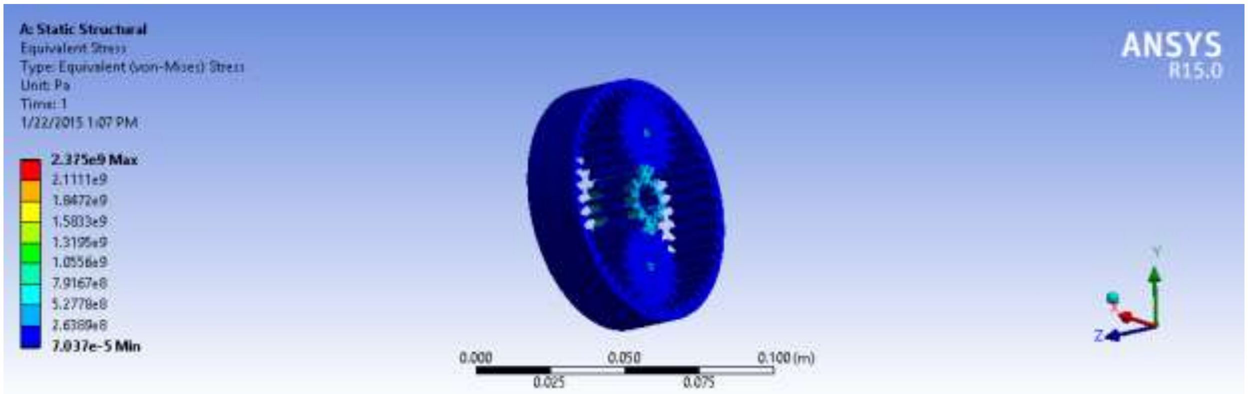

Fig. 4: Equivalent stress distribution for bronze

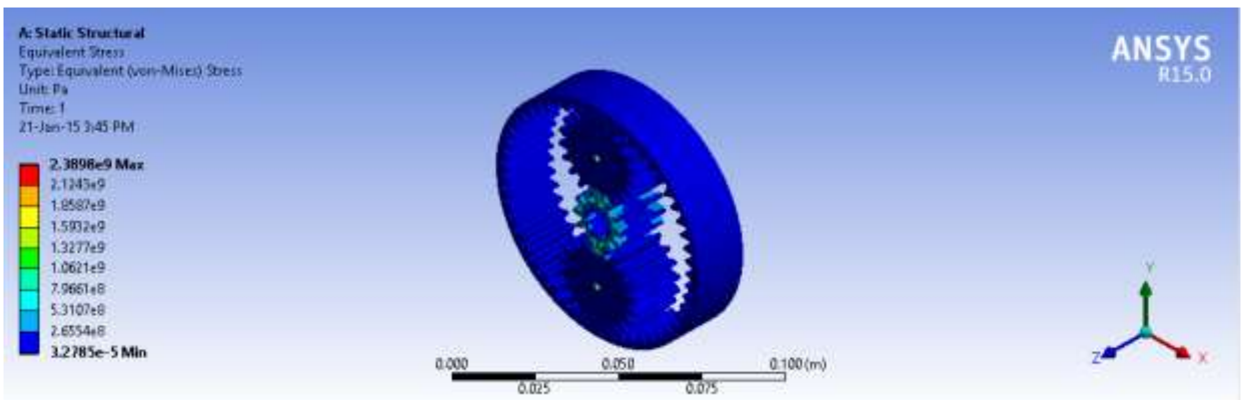

Fig. 5: Equivalent stress distribution for cast iron

IV. CONCLUSIONS

A mechanical device for unscrewing the lug nuts of vehicles was design using multistage epicyclic gear trains. The device offers better advantage over pneumatic, electric and hydraulic impact wrenches as it is hand operated and does not require any external power other than a little human effort. The device is compact, portable and is of less weight, so it can be easily handled. The use of the device can be extended to unscrewing nuts and bolts which are difficult to remove other than the lug nuts.

A model of the device was created in the Solid Works and it was analyzed in ANSYS to find its equivalent stress, equivalent strain and total deformation.

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Biographical Notes

Mr. Shinu Baby is presently pursuing B. Tech final year in Mechanical Engineering Department from Saintgits College of Engineering, Pathamuttom, Kottayam, India.

Mr. Nevin G Ninan is presently pursuing B. Tech final year in Mechanical Engineering Department from Saintgits College of Engineering, Pathamuttom, Kottayam, India.

Mr. Nithin George is presently pursuing B. Tech final year in Mechanical Engineering Department from Saintgits College of Engineering, Pathamuttom, Kottayam, India.

Mr. Salu Zachariah is presently pursuing B. Tech final year in Mechanical Engineering Department from Saintgits College of Engineering, Pathamuttom, Kottayam, India.

Mr. Aju Zachariah Mani is working as an Assistant Professor in Mechanical Engineering Department, Saintgits College of Engineering, Pathamuttom, Kottayam, India.