

Design & Analysis of Parking Brake System of Car

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ABSTRACT:-Without pulling or pushing the lever, the parking brake will not work. Also, sometimes due to negligence or in emergency conditions, we humans often forget to apply parking brakes. This may lead to rolling of vehicle in case of slopes and collision with other vehicles in parking area. Sometimes if service brake fails parking brakes are used as a emergency brake to stop the vehicle. This Project provides a new concept design of the parking brake system that has simple and low-cost characteristics. This paper deals with designing, analysis and fabrication of new parking braking system of car. This new parking brake system also referred to as brake by-wire, replace conventional parking brake hand lever with a electronic switch. This occurs by replacing conventional linkages with electric motor-driven units. The braking force is generated directly by high performance DC motors and gear reduction by which parking brake is applied.

KEYWORDS: - Parking brake, Automatic parking brake system, Finite element analysis (FEA)

I. INTRODUCTION

Brakes are one of the most important safety systems in a motor vehicle. The main functions of brakes system are to decelerate the vehicle, to maintain the vehicle's speed during downhill operation and finally to park the vehicle stationary either on a flat or slope road condition. The first two functions are related to the service brakes, while the last function is referred to the secondary or parking brakes. Conventional parking brake actuation involves the human interference. Without pulling or pushing the lever, the parking brake will not work. Also, sometimes due to negligence or in emergency conditions, we humans often forget to apply parking brakes. This may lead to rolling of vehicle in case of slopes and collision with other vehicles in parking area. Constant enhancements in active safety and improvements with respect to the reliability and comfort of operation mean that mechanical handbrakes are increasingly being replaced by new other systems and this giving birth to new ideas of parking brake techniques.

An new parking brake system involves a 12 v dc motor, spur gear and worm gear. A power and torque from the motor is transmitted to spur gear and worm gear an worm gear works as a anti lock mechanism and at output shaft of worm gear cable wire is attached and at that cable wounds two times to the out shaft and thus cable wire is get locked and thus the parking brake is applied. As a result the mechanical hand brake is eliminated and we get more space at the front side of the drivers cabin and thus the problem of required force of pushing and pulling hand brake is totally eliminated by this new parking brake system.

II. EXISTING PARKING BRAKE SYSTEM

There are typically three types of parking brake systems available in today's vehicle namely, fully mechanical (conventional), electro-mechanical (EMPB) and electric (EPB) parking brake system.

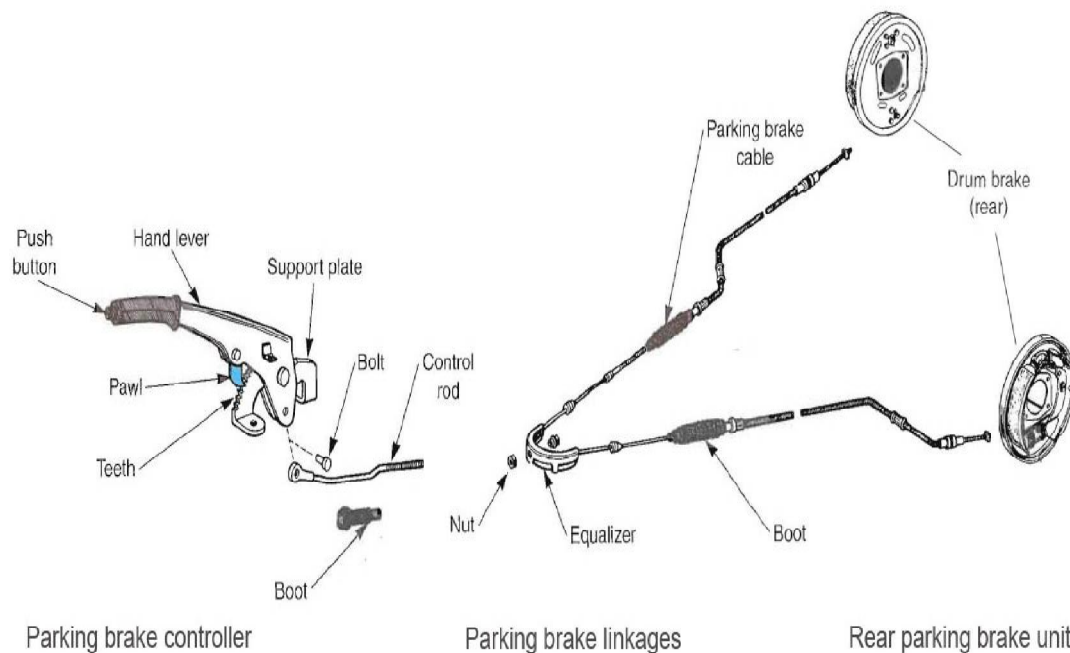


Fig.1 Example of Parking Brake System (Rear drum brake unit)

Each of the design types has its own advantages and disadvantages. For instance, the conventional parking brake system is relatively cheap compared to EMPB and EPB. However, the disadvantages of conventional parking brake over EMPB and EPB are the driver has to apply a significant amount of force to pull or to press the stick and center lever types or pedal type, respectively, the system cannot prevent vehicle rollaway that due to insufficient clamping force when park on a slope road, and the system cannot alert the driver if he/she forgot to engage or disengage the parking brake system. Nevertheless the conventional parking brake system is still favored by most car makers due to its simple design and low manufacturing cost. In general, a conventional parking brake system can be divided into three parts, namely parking brake controller, parking brake linkages, and rear parking brake unit as shown in the *figure.1*

III. DESIGNED PARKING BRAKE SYSTEM

After the identification of the problem and after carrying out extensive literature survey, it is essential to mention the research method for the perfect solution of the problem. So in relevant to this, the current chapter explains the various methods in detail. The various methods mentions in this chapter are Analytical, Simulation, and Experimental; further validation of the results by these methods has been carried out. For designed parts detailed design is done and dimensions there obtained are compared to next dimensions which are already available in market.

The various research methods are as follows:-

3.1 Analytical Method:-

In Analytical method design of various components and their related calculations required are calculated and carried out as follows.

- Design of various components or parts of new designed parking brake system, which includes. Design of spur gear, Design of worm gear and selection of proper dc motor, Design of output shaft.

As per from the industries data required condition, The complete two stage or complete system should be fitted in a one frame and it should compact & feasible in size, The whole system should be fitted in compact box, which has size of 200×200×100 mm.

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Hand Brake should be applied in 1 sec & in this cable wire travel distance should not exceed 60 mm and load required to apply brakes is 222 N.

We know

$$\therefore F = \frac{T}{d}$$

Torque = Force \times Distance

$$T = F \times d$$

$$\dots\dots\dots d = 2r$$

Here material used is steel case carburized

We have

$$\text{Shear stress } \tau = 115 \text{ N/mm}^2$$

As taken F.O.S = 2

$$\text{Shear stress allowance } \tau = \frac{115}{2} = 57.5 \text{ N/mm}^2$$

We have,

$$T = \frac{\pi \tau d^3}{16}$$

$$F \times d = \frac{\pi \tau d^3}{16}$$

$$F \times 2r = \frac{\pi \tau 2r \times 2r \times 2r}{16} \dots\dots\dots d = 2r$$

$$r = 2.21716 \text{ mm}$$

$$d = 2r = 2 \times 2.21716$$

$$d = 4.43432 \text{ mm}$$

We take diameter as 10mm for more safety purpose

➤ Considering output shaft diameter & Cable wire length = 60 mm

d = 10mm and r = 5mm

• We have circumference of circle

$$= 2\pi r$$

$$= 2 \times \pi \times 5$$

$$= 31.4 \dots\dots\dots \text{in 1 revolution}$$

$$= 2 \times 31.4 \dots\dots\dots \text{Because the cable wire wound around the shaft 2 times}$$

$$= 62.8 \dots\dots\dots \text{in 1 sec}$$

This satisfies the required condition of the company that cable wire travel distance should not exceed 60 mm.

Total distance travel

$$= 60 \text{ mm}$$

For 2 revolution in sec,

$$2 \times 60 = 120 \text{ R.P.M}$$

Thus we get required speed at the output shaft 120 R.P.M

The Out shaft diameter of Motor is 10 mm.

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Table.1 Input / Output values

Input (12v motor)	Output
Motor Power = 0.35 kw	Speed of out Shaft = 120 r.p.m
Speed of Motor = 7000 r.p.m	

Therefore now we have Input speed & output speed

- Input speed = 7000 R.P.M
 - Output speed = 120 R.P.M
- ∴ Speed Ratio = Input speed / Output speed
= 7000 / 120
= 58.33

1:58....Gear Ratio for this speed reduction is required

Now the whole system is divided In two stage, If the speed reduction not be reduced, Then going for three stage, Four stage if essential.

3.2 Proposed design system:

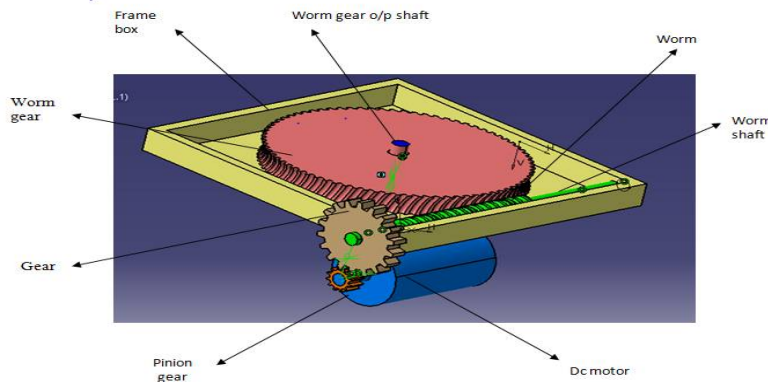


Fig.2 3d model of complete assembly of new parking brake designed system

3.3 Design of Spur Gear

• 1st Stage

Choosing spur gear,

Module $m = 1\text{mm}$

Numbers of teeth on pinion $T_p = 18\text{mm}$

Pressure angle $\phi = 20^\circ$

By calculating we get required dimensions of spur gear as in the table 3.1

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Table 2. Gear Terminology (Dimension)

Dg = 60 mm	Dp = 20 mm
Tg = 54	Tp = 18
G.R = 3	m = 1 mm

The material selected for spur gear and properties is selected from standard table

- Material for spur gear:- Structural steel
- Ultimate tensile strength (σ_{ut}) = 460 N/mm² or MPa.

The allowable static stress(σ_0) for steel gear is approximately one third of ultimate tensile strength (σ_{ut}) i.e.

$$\sigma_0 = \frac{\sigma_{ut}}{3} = \frac{460}{3} = 153.33 \text{ N/mm}^2 \text{ or MPa.}$$

But in our case as both the pinion and gear is made up of same material structural steel, The static allowable stress from the material (σ_{ut}),

We have,

$$\sigma_{op} = 153.33 \text{ N/mm}^2 \text{ \& } \sigma_{og} = 153.33 \text{ N/mm}^2$$

∴ Now using the Lewis equation for the pinion, we get tangential tooth load acting on the tooth (or beam strength of the tooth)

$$W_{Tp} = (\sigma_{op} \times Cv) b \times \pi m \times y_p = (153.33 \times 0.29040) 10.545 \times \pi \times 1 \times 0.1033$$

$$W_{Tp} = 152.280 \text{ N.}$$

The tangential component (W_T) induces a bending stress which tends to break the tooth. As the radial component (W_R) induces a compressive stress of relatively small magnitude, Therefore its effect on the tooth may be neglected. Hence the bending stress is used as the basis for design calculations.

- The bending stress on the pinion can be find out by following formula

$$\sigma_{bp} = \frac{W_T}{b \times m \times j} = \frac{152.380}{10.545 \times 1.11 \times 0.34404} = 37.8389 \text{ N/mm}^2$$

(j) Geometry factor = 0.34404 is taken from standard table

- Torque acting on the pinion

$$Tp = \frac{P \times 60}{2 \times \pi \times Np} = \frac{350 \times 60}{2 \times \pi \times 7000} = 477.4648 \text{ N-mm}$$

- Torque acting on the gear

$$Tg = \frac{P \times 60}{2 \times \pi \times Ng} = \frac{350 \times 60}{2 \times \pi \times 2333.33} = 1432.3969 \text{ N-mm}$$

- Tangential load acting on the gear tooth (W_{Tg})

$$W_{Tg} = (\sigma_{op} \times Cv) b \times \pi m \times y_g = (153.33 \times 0.29040) 10.545 \times \pi \times 1 \times 0.13711$$

$$W_{Tg} = 202.2520 \text{ N}$$

- The bending stress on the gear.

$$\sigma_{bg} = \frac{W_T}{b \times m \times j} = \frac{202.25037}{10.545 \times 1.11 \times 0.34404} = 50.2239 \text{ N/mm}^2$$

3.4 Design of worm gear

- **2nd Stage**

Now,

We have,

Input speed from the motor = 7000 r.p.m

Gear ratio of spur gear = 3

$$\therefore \text{Speed ratio} = \frac{\text{Input speed}}{\text{output speed}}$$

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$$3 = \frac{7000}{\text{output speed}}$$

Output speed = 2333.33 r.p.m. i.e. the speed of gear (Ng).

This output speed from gear shaft is transmitted to worm as an input speed. Therefore from input and output speed we get required gear ratio for worm gear is 19.4

- 20° normal pressure angle worm gear is assumed for which the lead angle should not exceed 25° (Table 5.6) and Z_2 minimum is 21 (Table 5.7).
- Allowing 6° lead per thread of the worm, the worm could have 4 or less teeth. $Z_1 = 4$ or quadruple threaded worm is assumed
- Assuming module m is 2 mm.
- Necessary data is taken from the standard table.

➤ **Choosing phosphor bronze for the worm gear and heat treated C45 steel for the worm,**

The phosphor bronze is widely used for worm gears in order to reduce wear of the worms which will be excessive with cast iron or steel.

The allowable static stress (σ_0) = 84 MPa is taken from standard table.

By calculating we get required dimensions of worm gear as in the table 3

Table 3. Worm Gear Terminology (Dimension)

Diameter of worm (D_w) = 16.0712 mm	Diameter of worm gear (D_g) = 154.95 mm
Numbers of teeth on worm (Z_1) = 4	Numbers of teeth on worm gear (Z_2) = 78
G.R = 19.44	m = 2 mm

- Torque acting on the worm

$$T_w = \frac{P \times 60}{2 \times \pi \times N_w} = \frac{350 \times 60}{2 \times \pi \times 2333.33} = 1432.3965 \text{ N-mm}$$
- Tangential force acting on the worm

$$W_{T_w} = \frac{T_w}{D_w/2} = \frac{1432.3965}{16.0712/2} = 178.256 \text{ N}$$
- Torque acting on worm gear

$$T_g = \frac{P \times 60}{2 \times \pi \times N_g} = \frac{350 \times 60}{2 \times \pi \times 120} = 27852.1150 \text{ N-mm}$$
- Tangential force acting on the worm gear

$$W_{T_g} = \frac{T_g}{D_g/2} = \frac{27852.1150}{154.95/2} = 358.0538 \text{ N}$$

IV. FEA OF DIFFERENT PARTS OF NEW DESIGNED SYSTEM

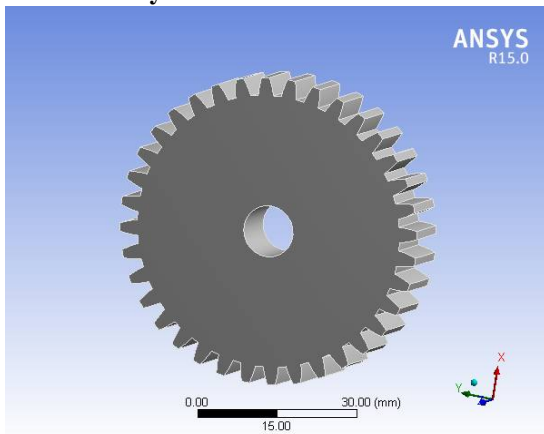
After doing all mathematical analytical calculations, designing and checking for safe design, In Simulation method 3d modeling (CATIA V5) and Analysis (ANSYS workbench) of following components is done based on which experimental method is carried out.

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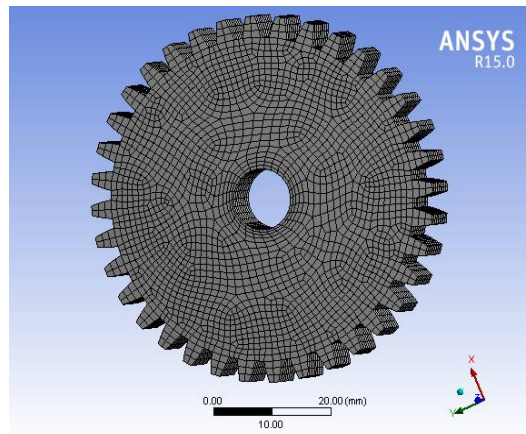
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➤ Geometry:- Gear



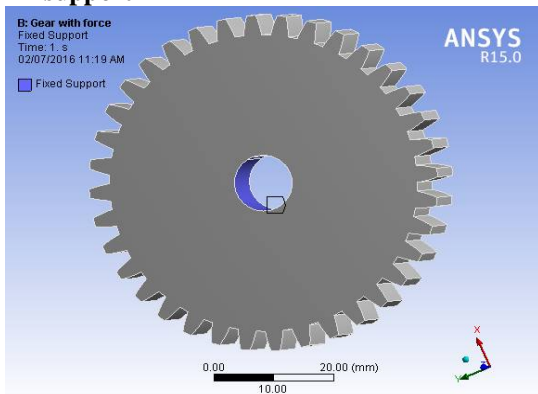
Mesh



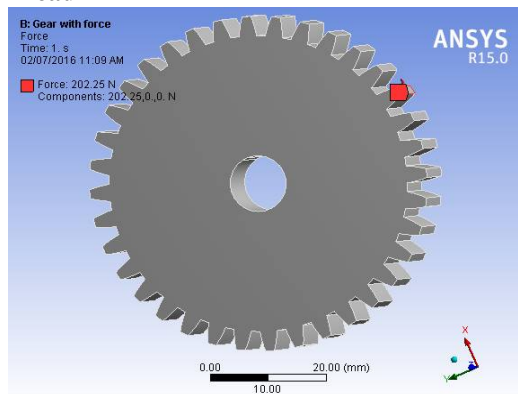
The geometry spur gear (bigger gear) is modeled in CATIA V5 as per the dimensions calculated and designed safely in analytical method and imported 3d model of gear from CATIA V5 in ANSYS workbench for analysis purpose, The meshing properties of gear & its nodes and elements is shown below

Statistics	
<input type="checkbox"/> Nodes	88580
<input type="checkbox"/> Elements	19170

Fix support

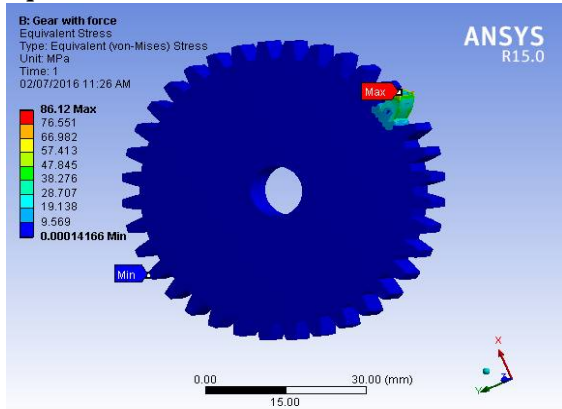


Load

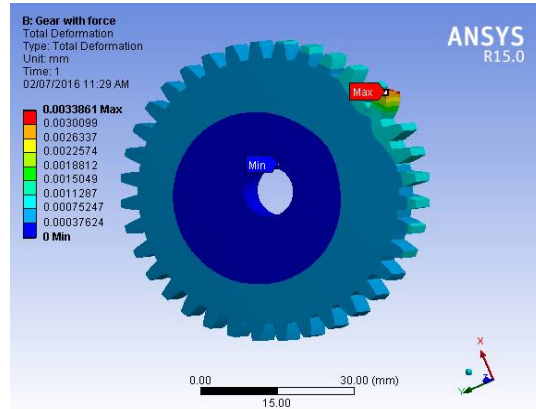


The fix support is applied at the shaft hole of the gear along whole periphery at the inner side of the gear & the load is applied on the tooth of the gear

Results: Gear by applying load
Equivalent stress



Total deformation

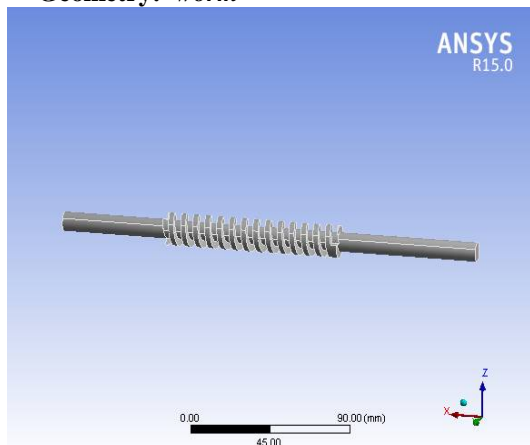


The results getting from ANSYS by applying force of 202.25 N on the tooth, we get results of equivalent stress and total deformation and answer are validated with Allowable static stress (σ_0) is taken out from standard properties of material selected Structural steel

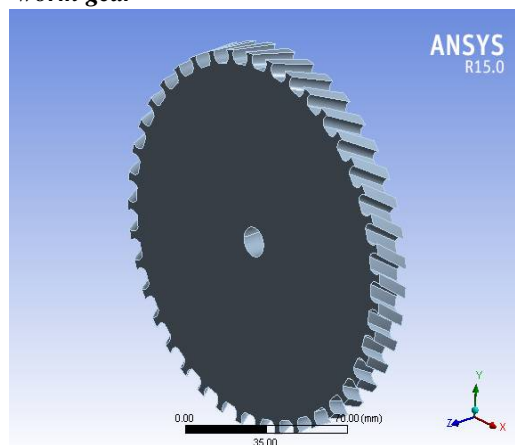
Equivalent stress = 86.21 N/mm ² From ANSYS	Allowable static stress $\sigma_0 = 153.33$ N/mm ² From Standard table of properties of material
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From above results we get total deformation of the tooth to the next tooth of the worm gear and also gives equivalent stress of maximum stress and minimum stress as shown in the images above, And by validating with the material allowable static stress we can say the design is safe and now we can go for manufacturing purposes.

➤ **Geometry:- worm**



worm gear



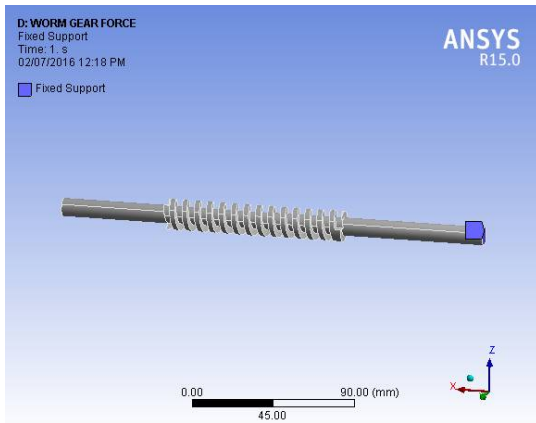
The 3d model of worm n worm gear is created in CATIA V5 and imported in ANSYS workbench for Analysis purpose.

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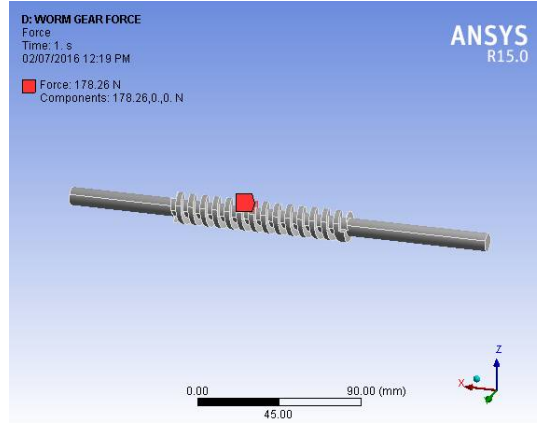
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Fix support



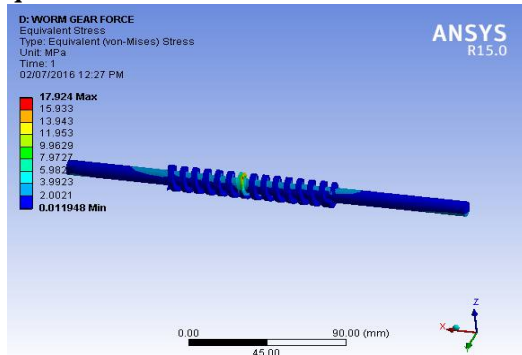
load



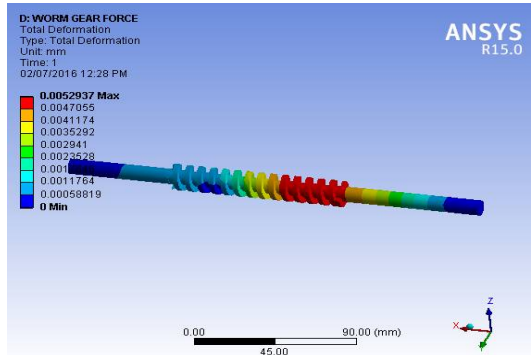
The fix support is applied at one end of the worm shaft of the along whole periphery at the outer side of the worm shaft & the load is applied on the tooth of the worm as shown.

Results: worm by applying load

Equivalent stress



Total deformation



The results getting from ANSYS by applying force of 178.26 N on the tooth, we get results of equivalent stress and total deformation and answer are validated with Allowable static stress (σ_0) is taken out from standard properties of material selected.

Equivalent stress = 17.924 N/mm²
From ANSYS

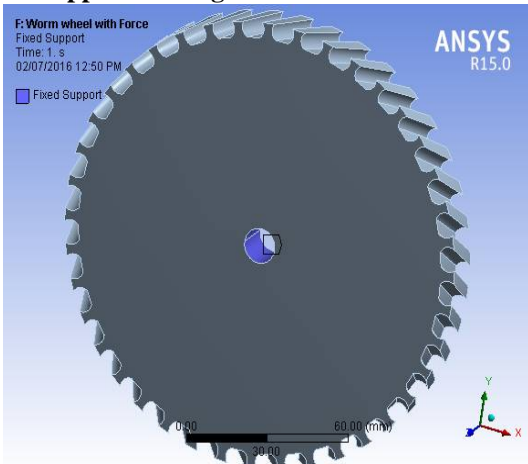
Allowable static stress σ_0 = 153.33 N/mm²
From Standard table of properties of material

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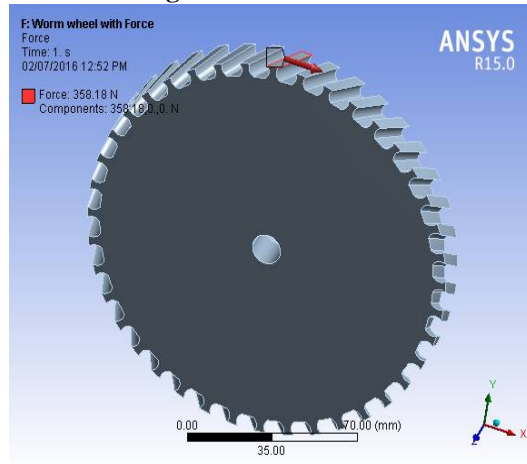
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Fix support worm gear



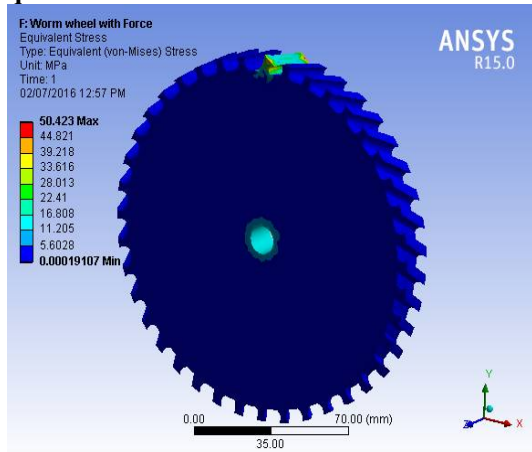
load on worm gear tooth



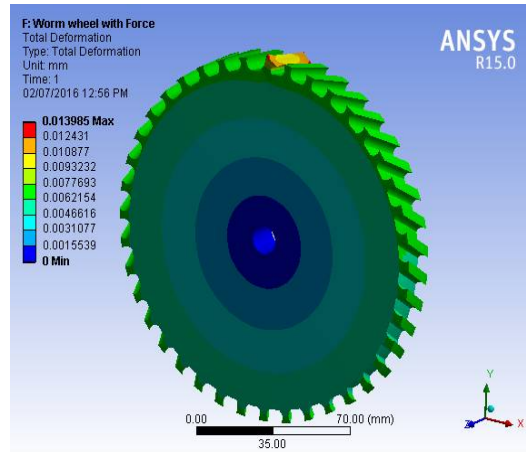
The fix support is applied at the shaft hole of the worm gear along whole periphery at the inner side of the gear & the load is applied on the tooth of the worm gear

Results: worm gear by applying load

Equivalent stress



Total deformation



The results getting from ANSYS by applying force of 358.18 N on the tooth, we get results of equivalent stress and total deformation and answer are validated with Allowable static stress (σ_0) is taken out from standard properties of material selected phosphor bronze. The results are obtained are mentioned in the below table.

Equivalent stress = 50.423 N/mm ² From ANSYS	Allowable static stress $\sigma_0 = 84$ N/mm ² From Standard table of properties of material
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V. EXPERIMENTAL METHOD

After analytical method and after analyzing all components of new parking brake system and validating the values of both methods successfully. Here now part comes in picture of performing its actual working of new system and it is initially at primary level the working of parking brake system is performed in experimental method.

The experimental is carried out and performed at its initial and primary level on small car that is maruti Suzuki 800 is a type of small hatch back. The new designed system is fitted in the car by some doing arrangements at the front

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side of the drivers cabin by removing seat next to the driver seat as per the required designed conditions, so that the complete new designed system should be consoled in to the one frame compact box size of 200×200×100 mm under the seat, so that we get required free space at the front side of the car by eliminating hand lever which occupies more space at the front side and which ergonomically is not so perfect by considering anthropometric human body considerations.



Fig. a. free space



Fig. b. Hand lever

The above all images shows front seat removal and removal of hand lever and shows free space available after removal of hand lever and also shows how much it occupies more space at the front side of the car cabin.

As the power is drawn from car batteries and it is given or transmitted to dc motor as shown in the images. As dc motor transmitted power 7000 rpm to the two stage gear box that is of spur gear and worm gear here in which is consoled in the housing as shown in the image, At the output shaft of the worm gear a hole is drilled of 10 mm at centre of the shaft and in this worm gear output shaft hole a copper cable wire as a primary cable is inserted as shown in the image above and other end of the cable wire is connected to equalizer and further equalizer is connected to the two secondary parking brake cable as right side cable and left side cable which further connected to the rear brake drum brake lever.

A designed system is given with a ON-OFF forward reverse push button of N- type. As the ON button is pressed the power is drawn from the car batteries and it is transmitted to the dc 12v motor which as a power of 350 watt and speed of 7000 rpm is further transmitted to the two stage gear box. The two stage gears has spur gear and worm gear as worm n worm gear acts as a anti lock mechanism to the new designed parking brake system. As we have input and output speed required as per the designed system. The speed at the output shaft of the worm gear is 120 rpm at which a hole is drilled of 10mm at the centre in that hole a cable wire is inserted as shown in the image. As button is pressed the output shaft of the worm gear starts rotating and cable wire inserted starts to wound around the shaft two times which stretches the equalizer and thus the parking brake is applied as shown in the image below in a working of new designed parking brake system

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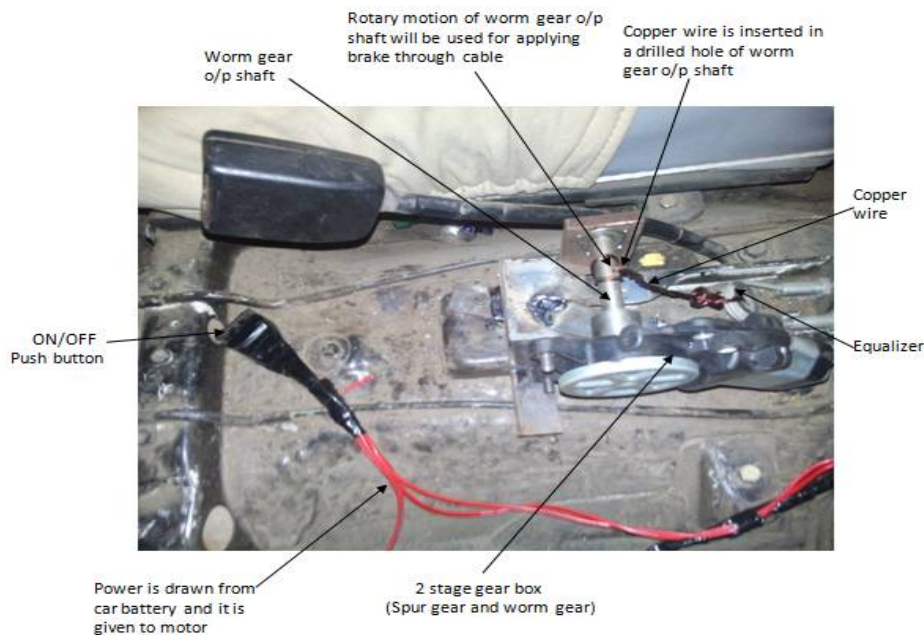


Figure.3. Working of new designed parking brake

As the push button is pressed again OFF mode is activated as the dc motor is of type of reversible dc motor the two stage gears spur gear and worm gear starts rotating in opposite direction, where the copper wire inserted in the output shaft hole of worm gear which is stretched starts un winding along from the periphery of the worm gear output shaft to a set of required wire length of 60 mm and un stretches the equalizer and thus the parking brake releases as shown in the above *Figure.3.* in a working of new designed parking brake system

VI. CONCLUSION

- In new designed parking brake system the hand lever is totally eliminated
- The issue of pulling and pushing the hand lever and applying force to the hand lever is completely removed or taken away
- In new designed parking brake system we get more free space available at the front side of the drivers cabin.
- As more space available at the front side of the drivers cabin we can introduce a new seat or a child seat as case in the smaller cars
- Braking action will be activated and deactivated only by just pressing ON-OFF switch
- Worm n worm gear acts as a locking mechanism for applying brakes.
- New designed parking brake system has complete automatic operation for easy drivability and safety.

VII. FUTURE SCOPE

- Further modification may be done to use same as emergency braking system.
- System can be modified to apply parking brake automatically when is engine gets turns off

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