# An Investigation on effect of change in material of gear pair used in rear wiper mechanism of vehicles

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Abstract— In four wheeler automobiles the driver is continuously monitoring the rear side of the vehicle through a mirror while driving. In the rainy season it becomes difficult to visualize the rear side image. Hence, now a days a rear wiper is used. Existing rear wiper mechanism is using steel gear pair for speed reduction. It's weight and cost is more. It also required lubrication so that solution is found out that to replace the metal gears by plastic gears. It is expected to accommodate plastic gears within available space. Different materials are used for finite element analysis to obtained contact stresses and feasible material is taken for the manufacturing. Fatigue life is calculated from this numerical stresses values of feasible material. Number of cycles are obtained from the S-N curve and compared this number of cycles with experimental results and validated. Aim of this study, is that weight and cost of the mechanism is reduced also plastic material is feasible solution to replace metal gears in rear wiper mechanism.

Keywords— Rear wiper mechanism, analytical design for gear pair, numerical analysis, experimental validation.

#### I. INTRODUCTION

This paper deals with automobile rear wiper system. In four wheeler automobiles, the driver is continuously monitoring the rear side of the vehicle through a mirror while driving. In the rainy season it becomes difficult to visualize the rear side image. Hence, now a days a rear wiper is used. Current rear wiper mechanism makes use of two stage speed reduction achieved through gears. In first stage worm gear is used and in second stage uses a pinion and sector gear. Also in an automobile a rear wiper system should perform good wiping to operate silently. In existing mechanism, material used for pinion gear is of bright mild steel and that of sector gear is of low carbon steel. As the metal cost and weight is more, automotive industries are focused on use of plastic materials for gear manufacturing. There are following advantages of plastic gears over metal gears such as self lubricating, light in weight, corrosion resistance, easy of mass production. Now a days, some plastic materials like Acetal, Nylon, Nylon 6, Nylon6/6 glass filled are used for gear manufacturing because of their good properties[3][5].

As applied load is higher, wear rate decreases and as wear rate decreases the service life of plastic gears increase[5]. When modification in gears are made which affect the load shearing distribution but not affect contact ratio and sliding Prof . L.V.Awadhani

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velocity of gears[3]. As flexibility in plastic gears, there is no separation during engagement of mating gears[4].Fatigue occurs due to rolling contact and repeated loading[6].finite element method is widely used to calculate contact stresses. There are two methods to obtained stresses generated in mating gears. First is to apply concentrated load directly which calculates the bending stress but not contact stresses. Second method is by applying torque on gears after modeling the gear pair which calculates the value of contact stresses.[1]

In this study, plastic materials mentioned earlier are used for the contact stresses analysis by applying the torque to gear pair in ANSYS 14.5. Out of these plastic materials best result is taken and decided to manufacturing of gear pair and validated experimentally by calculating fatigue life.

# A.Components used in the mechanism

Existing rear wiper mechanism is consists of permanent magnet dc motor, worm and worm wheel, sector and pinion gear pair, and spindle to which blade is attached as shown in fig 1. Permanent magnet dc motor is run at 2880 rpm with 12V supply to drive the mechanism. An armature is use as rotating member and placed in magnetic field which carries current along this conductor due to which mechanical force is exerted. This is the working principle of all dc motors. Permanent magnet creates magnetic field inside the yoke. Construction of dc motor is simple. These types of motor are used in windshield wipers ,starter motor in automobiles .Also, motors are use when there is no need to control speed of motor by field control.

In the first stage, the mechanism speed reduction is achieved through worm and worm gear. A single start (one spiral) worm is used. This can be an advantage when it is desired to eliminate any possibility of the output driving the input. In the existing mechanism number of teeth on the worm are 9 and number of teeth on worm gear are 60. Therefore, speed of the motor is reduced by this gear pair. Speed of the motor is 2880 rpm. This input speed is reduced upto 48 rpm at worm wheel. This can be calculated as 2880/60=48 rpm. In the second stage, The speed of the sector gear and pinion gear is same as that of worm wheel because the sector gear is attached to worm wheel. 20° Involute teeth

Nomenclature	
Ø	Pressure angle
m	Module
h <sub>a</sub>	Addendum
$\mathbf{h}_{\mathrm{f}}$	Deddendum
с	Clearance
$\mathbf{h}_{\mathbf{k}}$	Working depth
h	Whole depth
S	Tooth thickness
а	Centre distance
d <sub>p</sub> '	Pitch circle diameter
Zp	Number of teeth on pinion
Zg	Number of teeth on gear
d <sub>b</sub>	Base circle diameter (d <sub>b</sub> )
do	Outside circle diameter
r <sub>b1</sub>	Base circle radius of pinion
r <sub>b2</sub>	Base circle radius of gear
r <sub>o1</sub>	Outside circle radius of pinion
r <sub>o2</sub>	Outside circle radius of gear
Cr	Contact ratio
1	length of arch
$\mathbf{p}_{\mathbf{b}}$	Pitch of base circle
Е	Modulus of elasticity
μ	Poisson's ratio

profile is used for pinion and sector gears. Number of teeth on the sector gear considered as full gear are 18 and number of teeth on the pinion gear are 11. Fig.1 shows rear wiper mechanism.



Fig.1 Rear wiper mechanism.

## II. ANALYTICAL DESIGN FOR GEAR PAIR

Involute gear pair is used in existing wiper mechanism consists of 11 number of teeth pinion gear mesh with sector gear which is considered as whole tooth profile having 18 number of teeth rotates at 48 rpm and produces a torque of 8000 N-mm at the end of spindle. Motor rotates at 2880 rpm and torque is 600 N-mm. As the speed decreases, torque increases. Material used for pinion gear is of bright mild steel and that of sector gear is of low carbon steel Therefore Gears are design on the basis of beam strength and wear strength. For pinion gear young's modulus and poisons ratio is 201 Gpa and 0.3 respectively. For sector gear young's modulus and pressure angle for involute gears profile is taken as 20°. By using standard equations for gears such as lewi's equation and

bukingham's equation, module is estimated from the standard size of module as m=2.

# A. Dimensions for gears

Based on specifications of motor, gears are designed and module is estimated as 2mm and pressure angle is 20° for given involute gear profile. As there is space constrains at the rear wiper mechanism, the dimensions are kept to be same for plastic gear pair as that of steel gear pair. Following are the dimensions of gear pair on the basis of standard assumptions of module size.

1)Addendum( $h_a$ ) = 2mm 2)Deddendum( $h_f$ ) = 2.5mm 3)Clearance(c) = 4mm 4) Working depth $(h_k) = 4mm$ 5) Whole depth(h) = 4.5 mm 6)Tooth thickness(s) = 3.141mm 7)Tooth space = 3.141mm 8)Fillet radius = 0.8mm 9)Centre distance(a) = 29mm 10)Pitch circle diameter( $d_p$ ') i) for pinion  $(d_{p1}) = 22mm$ ii) for gear  $(d_{p2}') = 36$ mm 11)Face width (b) = 6mm 12)Base circle diameter (d<sub>b</sub>) i) for pinion $(d_{b1}) = 20.67$ ii) for gear  $(d_{h2}) = 33.82$ 13) Outside circle diameter  $(d_0)$ i) for pinion $(d_{o1}) = 26$ mm ii) for gear  $(d_{o2}) = 40$ mm

#### B. Contact ratio(Cr)

It is necessary for spur gear to transmit rotation continuously that there should be contact between atleast one gear tooth pair.[1]

Contact ratio is the ratio of the arc of action (l) to the base circle pitch  $(P_b)$ . It is the ratio that represents the average number of teeth are in contact when gears are in mesh and revolved. It is represented by the formula given below.[1]

$$contact\ ratio\ = \frac{l}{p_b} \tag{1}$$

Where, l is the length of the line of action l is given by,

$$l = \sqrt{r_{o2}^2 - r_{b2}^2} + \sqrt{r_{o1}^2 - r_{b1}^2} - asin\emptyset$$
(2)

And base circle pitch is given by,

$$p_b = \pi * m * \cos \emptyset \tag{3}$$

Therefore, Contact ratio=1.41

Now, the contact ratio is 1.41 means that two pairs of teeth are contacting for 41% of a revolution and one pair of teeth are contacting for rest 59%. Contact ratio greater than 1 is preferred for external spur gears.

#### III. NUMERICAL ANALYSIS

Contact stresses are determined by using finite element method. Dimensions of gears are taken from analytical design. Therefore the CATIA model is prepared and imported this model in ANSYS 14.5 for analysis of contact stresses. The plastic materials are use such as Acetal, Nylon, Nylon 6, Nylon6/6 glass filled for the analysis. Boundary condition are decided from actual loading torque comes on gear pair. and applied same torque for the analysis i.e. 2000 N-mm. Results are obtained for given plastic materials.

## A. Contact stresses analysis for plastic gear pair

Acetal material is use first for the contact stresses analysis. Material properties for acetal, young's modulus and poisson's ratio is 2.6 Gpa and 0.35 respectively. To solve solution numerically part is to be descritise with help of mashing. Better meshing type gives accuracy in the results. Tetrahedron element meshing is used for its good meshing quality. It is basically use to solve mechanical parts such as gears. This type of meshing achieved solution faster. Number of nodes are 11539 and number of element are 6053. Hence boundary conditions are applied such as as contact region is no separation and frictionless support is given at the bore diameters of the gears. After this torque is applied of 2000 N-mm and result is obtained the stresses values as 52.63 mpa. This value is very close to allowable stress value for acetal i.e 65 mpa hence material is going to fail almost for gear pair.

Now by applying same boundary conditions to same gear pair another material is taken for the contact stress analysis i.e.Nylon. Material properties for Nylon, young's modulus and poisson's ratio is 2.9 Gpa and 0.38 respectively. Result is obtained the stresses values as 51.85 mpa. This value is very close to allowable stress value for Nylon i.e 62 mpa hence this material is also going to fail for gear pair.

Now, another material is taken for the contact stress analysis i.e.Nylon6. it is having properties as young's modulus and poisson's ratio is 2.3 Gpa and 0.41 respectively. Result is obtained the stresses values as 51.45 mpa. This value is also close to its allowable stress value for Nylon6 i.e 62 mpa hence this material is also going to fail for gear pair.

Now,Nylon6,6 30% glass filled material is taken for analysis of contact stresses.It is having properties as young's modulus and poisson's ratio is 10 Gpa and 0.41 respectively. It is observed that, for Nylon 6,6 glass filled material, value of contact stresses is 60.82 which less than that of allowable stresses value i.e. 160 to 210 mpa. It is said to be that Nylon6,6 glass filled material is safe for design the gear pair. Hence this material is selected for further manufacturing of sector gear and pinion gear. Contact stresses are as shown in fig 2.



Fig.2 contact stresses in Nylon6,6 30% glass filled gear pair

## B. Comparison of contact stresses values

Values of contact stresses are compared as shown in table1. It is cleared from the table1 that acetal, Nylon and Nyln6 materials are almost going failed for torque of 2000 N-mm where Nylon6,6 glass filled material is giving safe value of contact stresses numerically at torque of 2000 N-mm. Therefore Nylon6,6 30% glass filled is safe material for manufacturing of sector gear and pinion gear.

TABLE I. COMPARISON OF CONTACT STRESSES VALUES

Materials	Stress values (N/mm <sup>2</sup> ) (By ANSYS)	Allowable tensile strength (N/mm <sup>2</sup> )	Remark
Acetal	52.63	65	Almost failed
Nylon	51.85	62	Almost failed
Nylon 6	51.45	69	Almost failed
Nylon 6,6 30% glass filled	60.82	160-210	Safe design

C. Fatigue analysis by using numerical stresses values

Fatigue life is almost become necessary for gear components under repeated loading. Standard S-N curve (Stress vs Number of cycles) for Nylon 6,6 30% glass filled material is considered [2]. The value of stresses is 60.82 mpa. It is clear from the curve, fatigue life of gear pair is obtained that number of cycles are around 7,00,000-8,00,000 cycles. So that this value of fatigue life will be compare with experimental fatigue life in terms of number of cycles.

# IV. EXPERIMENTAL ANALYSIS

Sector and pinion gear are manufactured by using Nylon 6,6 30% glass filled material with dimensions given in analytical design. The fig.3(a) and (b) shows metal gear pair and plastic gear pair respectively.



Fig3 (a)Metal gear pair and (b) plastic gear pair.

# A. Weight and cost analysis

As objective of this study is concerned that to reduce weight as well as cost of mechanism. Reduction in weight and cost of gear pair is shown in table II. By means of this overall cost of mechanism is reduced.

TABLE II. REDUCTION IN WEIGHT AND COST OF GEAR PAIR

Materials	Part	Cost (Rs.)	Weight (Grams)
Steel	i)Sector gear	16/-	65
	ii) Pinion gear	15.5/-	25
	Total	31.5/- Rs.	90 grams
Nylon 6,6,30% glass filled	i)Sector gear	5/-	10
	ii) Pinion gear	3/-	5
	Total	8/- Rs.	15 grams

## B. Experimental tests

There are Indian standard IS:7827 (part II) for testing wind screen wipers performances[8]. It consists of three parts such as wiper motors, driving mechanism, wheel box and wiper system consists of arm and blades. The test conducted under this Indian standard are as follows.

1)visual examination
 2)No load test
 3)low voltage test(starting test)

4)stalling test
5)parking test
6)continuous torque test
7)Noise test
8)vibration test
9)Endurance test

Criteria for acceptance is mentioned as per the specifications and standard. From above number of test, Endurance test gives fatigue life of rear wiper mechanism so that this test is discussed further.

# C. Endurance test

This test is carried out under following test conditions as per IS7827 standard [8].

- For this test ambient temperature should not be more than 40°.
- During the test 13.5 i.e. ± 2% of 12 V voltage is provided,
- By using in-built switch test cycle time should be of 7 minutes. This includes water spray 330sec wet +30 sec dry + 60 sec park. Total duration 250 Hrs.

Now, with satisfying the above test conditions, acceptance criteria for the test is

- motor should meet all drawing specification after end of test.
- During testing, no water entry shall be observed inside vehicle from glass sealing.
- Noise level should not cross 50dB at the end of test[7].

Experimental set up of this test is such that samples of rear wiper mechanism with plastic gear pair are taken for conducting the test and it is installed at the rear panel of vehicle. Voltage is supplied as 13.5 V and current of 1.2 A to DC motor. At no load condition speed is measured at the spindle is between 38 rpm to 48 rpm running satisfactorily as per the criteria given in IS7825. When load is applied as torque of 600 N-mm then speed get reduces and is between 33 rpm to 43 rpm again the mechanism is running satisfactorily as per the criteria given in IS7825.Finally 2000 N-mm torque is applied and speed of the mechanism is observed as above 25 rpm as per criteria given in IS782 and also the mechanism running satisfactorily.Noise level is observed between 43 dB to 48dB which is lower than that of 50 dB accepted value. Hence endurance test is passed satisfactorily for rear wiper mechanism wiping system.

It is observed that mechanism is running under the given specifications and satisfying all acceptance criteria required for mechanism. There is no mechanical and electrical failure is observed during test.

## D. Fatigue analysis (experimental)

As there is no failure observed during the test. Therefore fatigue life is calculated as maximum duration for the test is 250 hours. Hence Number of cycles are calculated 7,05,000 cycles which is close to that of value of number of cycles got from numerical analysis i.e7,00,000 cycles .So it is proved that the plastic material Nylon 6,6 glass filled material is suitable to replace metal gear pair in rear wiper mechanism.

## V. CONCLUSION

Rear wiper mechanism is studied and replaced the metal gear pair with plastic gear pair successfully.

- We have designed the gear with plastic material and investigate the effect on gear pair with different materials at the same load condition and its working satisfactorily.
- Because of this replacement, cost is reduced by 74% and weight is reduced by 84%.
- Fatigue life of mechanism is observed to be 7,00,000 cycles
- Therefore, Nylon6,6 glass filled is feasible material for replacing the metal gear in rear wiper mechanism of vehicles.

## ACKNOWLEDGEMNT

We would like to thank Mr. Rajesh Patil for his help and insight on this research.

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