Design and Development of Nylon 66 Plastic Helical Gears in Automobile Application

Ashish N. Taywade
Department of Mechanical Engineering,
Bapurao Deshukh College of Engineering,
Wardha,Maharashtra, India.

Dr. V. G. Arajpure
Department of Mechanical Engineering,
Dr.Bhausaheb NadurkarCollege of Engineering,
Yavatmal,Maharashtra,India

Abstract- This paper deals with the idea of gear designing and development for automobile application. Basically the driver and driven gear material plays vital role for the better performance in wear. Replacement of metal gears by plastic gear is continuing in automobiles, appliances and machinery due to its merits of low noise, less wear, self lubrication, economical considerations, light weight, simple design and manufacturing. Due to thermal wear acetal gear failed, so to overcome the problem of acetal gear the nylon 66 is better option due to its superior properties and it also meet extreme performance challenges. Tooth load is calculated with help of Lewis equation & dynamic tooth load is calculated with help of Buckingham equation. Static analysis of the gear is done to find the Von-mises stress on the tooth of the gear in while meshing.

Key Words: Nylon66, Buckingham equation, Lewis equation, Hertzian stress, hob

I. INTRODUCTION

Gearing is one of the most important components in mechanical power transmission system and are generally used in power, motion transmission and in most industrial rotating machinery and work under different loads and speeds. Due to their high degree of reliability and compactness, it is possible that gears will predominate as the most effective means of transmitting power in future machines. In addition, the rapid shift in the industry from heavy industries such as shipbuilding to industries such as automobile manufacture and office automation tools will necessitate a refined application of gear technology.

Historically, they were limited to very low power transmissions such as clocks, printers and lawn sprinklers. Today's stronger, more consistent engineering polymers and its better control of the molding process, now makes it possible to produce larger, more precise gears that are compatible with higher horsepower. It also opens new opportunities for smaller and more efficient transmissions in many products.

The driver and driven material plays a key role in the wear performance. When nylon is used as the driver, the acetal gear fails due to thermal wear [3]. The wear can be divided into three phases: an initial running in, a nearly linear and a final fracture phases. Hence to overcome the limitations of acetal, Nylon 66 may find substitute due to their superior properties

II. NEED OF THIS RESEARCH WORK

A lot of work has been carried out on the wear analysis of metal gear. But very few researchers have worked on the study of wear behavior of plastic gear and nobody has touched to the topic undertaken for study. Hence the designed, development of plastic (Nylon 66) gear is undertaken for study.

For acetal against acetal gears, it was found that the acetal gear wear rate increased dramatically. When the load reached a critical value for a specific geometry and the gear surface showed slow wear, with a low specific wear rate if the gear was loaded below this critical value. It was found that the surface temperature was the dominant factor influencing the wear rate. The study of molded gear performance is important for economic reasons because it can be mass- produced at a fraction of the cost compared to machine gears [3].Since accurate molded gears are now available, it is necessary to learn more about the performance of these gears under different operating conditions. The study of molded gear performance is important for economic reasons because it can be mass-produced at a fraction of the cost compared to machined gear

The main focus of the current research is comprising the following points:-

- To select the appropriate material for plastic gear.
- To design the plastic helical gear analytically so that it should meet the requirement of existing metal gear.
- To develop the plastic helical gear by choosing one of the gear manufacturing processes, here gear is generated by Gear Hobbing Method.

- To develop models of helical gear using PRO-E.
- To calculate contact stresses using ANSYS and compare the results with Hertzian theory.
- To compare stresses of both metal and plastic gear using ANSYS.

III. MATERIAL SELECTION

To achieve their intended performance of gear, durability and reliability, the selection of a suitable gear material is very important. A vast amount of knowledge and experience have been accumulated in plastic engineering. In the interest of time and economy there is usually a well-known material that will adequately suit the user's purpose. The most widely used plastic for gear is nylon, which is available in many different forms. Nylon66 is a generic designation for a family of synthetic polymers known generically as aliphatic polyamides. The automobile sector is marked by a constraint shift towards plastics. Especially, Thermoplastics has some wider range of applications in it. The current day to day application of nylon 66 is very limited than it is to be. The materials used for the manufacture of gears depend upon the strength and service conditions like wear and noise etc.. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The plastic materials have corrosion resistance, low electrical and thermal conductivity, easily formed into complex shapes, wide choices of appearance, colours and transparencies. The introduction of plastic materials was made it possible to reduce the weight of the rotating spares without any reduction on load carrying capacity and stiffness. The final selection should be based upon an understanding of material properties and application requirements.

Comparison between steel and Nylon66

Sr.No.	Properties	Steel	Nylon 66
1	Hardness	106.8	118-120
2	Tensile Strength(N/mm^2)	67.70	85
3	Flexural Yield Strength (MPa)	40	145-310
4	Elongation At Brake (%)	13	5-640
5	Melting Point (Celsius)	1470	260
6	Thermal Conductivity (w/m-k)	46	0.53
7	Tensile Modulus (MPa)	240	5500
8	Density (Kg/m^3)	7860	1400
9	Yield Stress (N/mm^2)	285	82.8
10	Poisons Ratio	0.3	0.39

IV. DESIGN METHODOLOGY

Gear design Based on "AGMA" procedure: The design of helical gear is almost similar to spur gear design with slight modifications in Lewis and Buckingham equations due to helix angle. The theoretical design calculations are performed using the input parameters such as power for engine, pinion speed, gear ratio, helix angle, pressure angle, Speed of Pinion, Gear Ratio, Helix Angle, Minimum centre. According to Lewis equation, the beam strength of helical gear tooth is given by,

$$S_b = m \times b \times \sigma_b \times Y$$

Sr No	Specification	Pinion gears	Driver Gears
1	Tooth profile	Involute	Involute
2	Material	Nylon66	Nylon66
3	Normal Module	1.5	1.5
3	Normal Pressure angle	20^0	20^0
4	Helix angle	20^0	20^0
5	Direction of helix	LH	RH
5	Number of teeth	66	15
6	Pitch circle Diameter	105.35	23.94
7	Operating centre distance(mm)	65.5	65.5

Center to center distance :-

$$a = \frac{mn\,(Zp+Zg)}{2cos\Psi} = \frac{1.5\,(15+66)}{2cos20} = 64.65mm$$

Speed ratio :-

$$i = \frac{Zg}{Zp} = \frac{66}{15} = 4.4$$

Torque on pinion, T_p:-

$$P = \frac{2\pi N p T p}{60\times1000} = \frac{2\pi\times900\times Tp}{60\times1000}$$

$$T_p = \frac{2.687\times60\times1000}{2\pi\times900} = 3.95 \text{ N-m}$$

T_p =3.95 N-m

Torque transmitted by gear, M_t

$$M_t = \frac{60\times10^3\times2.687}{2\pi\times900} = 28509.95 \text{ N-mm}$$

ISSN: 2278-0181
Vol. 3 Issue 9, September- 2014

$P_t = \frac{2(Mt)}{dp} = \frac{2(2850.95)}{23.94}$ = 2381.78 N

In helical gear the resultant force *F* acting on the tooth is resolved into three components viz,

1) Tangential force component, F_t
2) Radial force component, Fr
3) Axial force component, F_a as shown in figure.

They are related as follows:-

1) Tangential force component, F_t :-

$F_t = \frac{2(Mt)}{dp} = \frac{2\times 28509.95}{23.94}$ = 2381.78 N

2) Radial force component, F_r:-

$F_r = F_t\left[\frac{\tan\varphi_n}{\cos\psi_n}\right] = 2381.78\left[\frac{\tan 20}{\cos 20}\right] = 922.53$ N

3) Axial component, F_a :-

$F_a = F_t (\tan\psi) = 2381.78(\tan 20) = 866.89$ N

Since both gears are made of the same material the pinion is weaker than gear

Bending Strength

$S_b = m \times b \times \sigma_b \times Y$

S_b =3162.470 N

Dynamic load,

$P_d = \frac{e n_p Z_p b r1 r2}{2530\sqrt{r^2+r^2}} =$

P_d=18.937 N

Effective load on gear tooth:-

$P_{eff} = C_s P_t + P_d \cos\varphi_n \times \cos\psi_n$

P_{eff} =2589.39 N

Sb≥Peff

3162.470 > 2589.39

Hence design is safe.

Wear Failure:

By using Hertzian stress

$S_{c(application)} = \sqrt{\frac{W(r+1)}{f\ D_{pr}} \times \frac{0.7\ E1E2}{(E1+E2)\cos\varphi\sin\varphi}}$

Where,

W = tangential driving load,

T_p= pinion torque,

Dp_p= pinion pitch diameter,

f = face width,

r = gear ratio = N_g/N_p,

E_1, E_2=moduli of elasticity of mating gear materials,

Φ= pressure angle

$S_{c(application)} = 59.488$

$S_{c(allowable)} = S_{c(graph)} \times Kj$

$KJ = \frac{Ck}{Ck_s}$

$C_k = \sqrt{\frac{0.70}{\left(\frac{1}{E_1}+\frac{1}{E_2}\right)\cos\varphi}} = 36.311$

$Kj = \frac{36.311}{639} = .0568$

$S_{c(allowable)} = 3000 \times 0.0568 = 170.474$ MPa

$S_{c(application)} < S_{c(allowable)}$

59.488 < 170.474

V. GEAR DEVELOPMENT

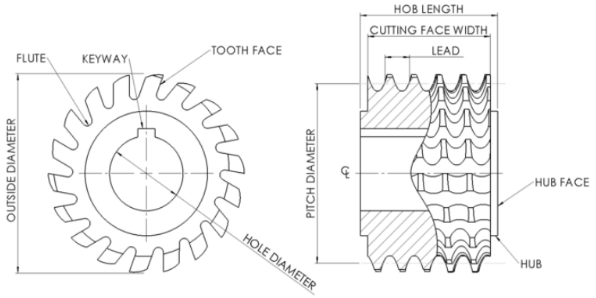
A wide variety of machines are used to cut gear teeth. The cutting tool may be threaded and gashed. If so, it is hob, and the method of cutting is called hobbing. Hobbing uses a hobbing machine with two skew spindles, one mounted with a blank workpiece and the other with the hob. The angle between the hob's spindle and the workpiece's spindle varies, depending on the type of product being produced. For example, if a spur gear is being produced, then the hob is angled equal to the helix angle of the hob; if a helical gear is being produced then the angle must be increased by the same amount as the helix angle of the helical gear. The two shafts are rotated at a proportional ratio, which determines the number of teeth on the blank

The hob is the cutter used to cut the teeth into the workpiece. It is cylindrical in shape with helical cutting teeth. These teeth have grooves that run the length of the hob, which aid in cutting and chip removal. There are also special hobs designed for special gears such as the spline and sprocket gears.

The time required to make a hobbing cut can be calculated from the following formula:

$$\text{Hobbing time, min} = \frac{no.of\ gear\ teeth \times (face + gap)}{no.of\ hob\ threads \times feed \times hob\ rpm}$$

The reason for adding the gap to the face width is the fact that a hob has to travel a certain distance in going into cut and out of it.



VI. OUTCOMES OF LITERATURE SURVEY

In last few years, a number of polymer gears have been researched all over the world. One of the superior polymers is nylon 66 which is used in gear manufacturing. The various research works carried out on analysis of plastic gear wear are as follows:

Calabrese, A., Davoli, P., et al[1]This paper are described the results, in terms of measured noise, of the substitution of steel timing gears with plastic ones, that is with a material whose characteristics can reduce the gear meshing noise at source. Experimental tests is performed on the engine (without combustion) to compare the noise emission with steel and plastic gears

The noise emission is measured in terms of sound power, sound intensity and sound pressure with a real-time analyzer, at different speeds. The results obtained allow one to appreciate and quantify the reduction of noise level due to the substitution of steel gears with plastic ones.

C.J.Hooke et al [2] suggests that of the nylon 66 composites, only those reinforced with short glass fiber appears to be of any significant value. These may have low coefficient of friction, which means that they could be used for relative high duty applications without the temperature becoming excessive (over 2000C). This however is at expense of life and it appears unlikely that components made from these materials will have live in excess of 107cycles.

Crippa, G., Davoli, P. et al [3] this paper deals with the application of a carbon-fiber-reinforced polyamide as material for the gears of the timing drive in C.I. engines. Plastic gears have been manufactured with the injection-molding technique previously, analyzed and optimized by computer simulation. Laboratory tests have been performed on the engine itself, with different loads and revolving speeds. The results obtained by means of these experiments give important data concerning the capabilities of carbon-fiber-reinforced plastics as material for timing gears and for similar applications.

Kapelevich, A. and McNamara, T, [4] has developed unique methodology for designing plastic gears to enhance strength and life while allowing size and wear reduction. This new approach, trade named Direct Gear Design (DGD), optimizes the gear geometry to impart superior drive performance versus traditional gear design methods. This paper explains the alternative approach and demonstrates its effectiveness in several small engine applications.

Kapelevich, A.et al [5] this paper presents Direct Gear Design - an alternative method of analysis and design of involute gears which separates gear geometry definition from tool selection to achieve the best possible performance for a particular product and application. This method has successfully been applied for a number of automotive applications. Some examples are presented at the end of the paper.

K. Mao, et al [7] drawn conclusion that the nylon gear friction and wear performances are completely different when compared to that of acetal gear and the gear failures are mainly root and pitch fractures instead of surface wear. It is very interesting to see the different wear and failure behavior when running dissimilar material, especially when acetal as driver against nylon showing better performance compared with the situation reversed.

Ming-Haung Tsai et al [8] suggests a multi-tooth contact analysis using finite element method to calculate the static transmission errors and load sharing of plastic spur gear.

M.S.Zaamout [9] has investigated polymer at low applied static loads and without impact loading, NylatronGS seems to be the highest wear resistive polymer, than Nyloil, Nylon66 followed by GFNylon66. When the statically applied loads are greater than (80 N), the above classification changes to Nylon66, NylatronGS, Nyloil and finally GFNylon66.

N.A.Wright et al [10] has invented a new method, co-ordinate measurement technique which is capable of providing detailed information on wear rates of gears as a function of roll angle, and hence load, sliding speed and slip ratio.

Shastri, D.et al [12] this paper commences with a general overview of the methodologies on proper gear material selection to improve performance with optimize cost (including of design & process), weight and noise. We have materials such as SAE 8620, 20MnCr5, 16MnCr5, Nylon, Aluminium, etc. used on Automobile gears. We have process such as hot & cold forging, rolling, etc. This paper also focuses on uses of Nylon gears on Automobile as Speedo-gears and now moving towards the transmission gear by controlling the backlash. It also has strategy of gear material cost control.

W. Li et al [13] suggests analysis shows the contact force is higher at the beginning of the tooth engagement (access) when compared to the end of the tooth engagement (recess). This higher contact force in the access mesh causes the driven gear wear fast. Acetal against nylon shows much better performance due to the root wear rate being much lower than that in the tip.

VI. TOOLS USED

PRO-E: - It is used to create a complete 3D digital model of the component. The models consist of 2D and 3D solid model data which can also be used downstream in finite element analysis

ANSYS: - It is software which provides finite element analysis (FEA), in this methodology any component under consideration is discredited into small geometric shapes and the material properties are analyzed over these small elements.

VII. CONCLUSION

This paper suggests selection of appropriate of plastic, the simple gear design and development of gear by suitable manufacturing process. Since the bending stress of existing metal gear is more than Nylon 66 and bending strength is more than Effective load on gear tooth hence the design is safe. This work will help to use the Nylon 66 helical gear for small automobile application and also gives the idea of selection of appropriate plastic material so that it can withstand the desired load and may use for various applications also.

REFERENCES

[1] Calabrese, A., Davoli, P., and Quaranta, S., "Noise Reduction with Plastic Gears: a Case History for Diesel Engines," SAE Technical Paper 954149, 1995.

[2] C.J.Hooke ,S.N.Kukureka et al, The friction and wear of polymers in non-conformal contacts, wear 200(1996),83-94.

[3] Crippa, G., Davoli, P., Gorla, C., and Quaranta, S., "Nylon Gears for Engine Timing Drives: Design and Experimental Tests," SAE Technical Paper 1993-25-0635, 1993.

[4] Kapelevich, A. and McNamara, T., "Plastic Gearing for Small Engine Applications," SAE Technical Paper 2006-32-0038, 2006, doi: 10.4271/2006-32-0038.

[5] Kapelevich, A. and McNamara, T., "Direct Gear Design® for Automotive Applications," SAE Technical Paper 2005-01-1817, 2005, doi: 10.4271/2005-01-1817.

[6] K. Mao, W. Li et al, Polymer gear surface thermal wear and its performance prediction, Tribology International 43(2010), 433-439.

[7] K. Mao , W. Li et al, Friction and wear behaviour of acetal and nylon gears, wear 267,(2009),639-645.

[8] Ming-Haung Tsai,Yieng-Chieng Tsai ,A method for calculating static transmission errors of plastic spur gear using FEM evolution, Finite Element Analysis and design ,27,(1997),345-357.

[9] M.S.Zaamout, The Wear Behaviour of Nylon-66 and its Composites Under Impact Loading, JKAU: Eng. Sci., vol. 16 no. 1, pp. 85-101.

[10] N.A. Wright, S.N. Kukureka, Wear testing and measurement techniques for polymer composite gears, Wear (2001), 1567-1578.

[11] S. Senthilvelan, R. Gnanamoorthy, Effect of rotational speed on the performance of unreinforced and glass fiber reinforced Nylon 6spur gear 28(2007), 756-762.

[12]Shastri D.Ramamurthy S.,and ParabP.,"STRATEGIES FOR AUTOMOBILE SELECTION," SAE Technical-28-0055, P2008, doi: 10 4271/2008-28-0055.

[13] W. Li , A. Wood , R. Weidig , K. Mao, An investigation on the wear behaviour of dissimilar polymer gear engagements,Wear,271(2011),2176-2183

[14] J. Sukumaran et al, Modeling gear contact with twin-disc setup, Tribology International, 49, (2012)1-7.