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COMPARISON OF BENDING STRESSES IN SPUR GEAR DUE TO THE BACKLASH PROVIDED BY DIFFERENT METHODS

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ABSTRACT

Bending stresses are one of the failure modes of gear teeth. Backlash is difference between tooth space & mating gear tooth thickness. Backlash is necessary to avoid jamming, to make lubrication. It can be provided two methods. Either by reducing tooth thickness or by increasing center distance. In both situations bending stresses are affected. In this work finite element analysis of spur gear is done to study the effect of backlash on bending stresses. Initially a gear without backlash is modeled using AutoCAD software. Finite Element analysis is done by meshing the model with 8 node quadrilateral element. Software ANSYS is used for the analysis. The finite element results are compared with the analytical values of bending stress. As the error was very less, same element & mesh density is used throughout this work. Further models were prepared for gear with reduced tooth thickness for backlash. Then the bending stresses were determined using ANSYS. Stresses are also determined by increasing centre distance. Comparison of maximum Von Mises stresses & maximum deformation is done to study the effects of both methods.

Keywords - backlash, bending stress, centre distance, finite element analysis, tooth thickness

I. INTRODUCTION

1.1 Bending stresses in gears

There are several failure mechanisms for spur gears. Bending failure of the teeth is one of the main failure modes. Fatigue or yielding of a gear tooth due to excessive bending stresses is one important gear design considerations. In order to predict fatigue and yielding, the maximum stresses on the tensile and compressive sides of the tooth, respectively, are required.

1.2 Backlash in gears

Backlash is the amount by which the width of a tooth space exceeds the thickness of the engaging tooth on the pitch circles. In other words, when the sum of the thickness of two teeth out of mating gears on operating pitch circle would be less than circular pitch, it is said those two gears are engaged with backlash, meaning there is a gap between teeth of two mating gears.

The basic purpose of designing backlash is to prevent locking the gears, as well as to prevent coming into contact in both side of one tooth simultaneously. A little of backlash is desirable to make necessary gap for lubrication & partially expansion of gears. Also, the amount of backlash should not be increased exceedingly, because the backlash causes high manufacturing costs.

In general, there are two ways for providing backlash in mating gears.

1. Reducing tooth thickness
2. Installing two mating gears in a distance which would be more than the standard center distance.

1.3 Previous work

Literature review is done to know the earlier work done by the researchers in this area. It is seen that lot of work is done in this area.

V. Spitas et al. [1] used non-dimensional modeling to decrease the number of independent design variables in conjunction with Boundary Element Analysis and photo-elasticity measurements to compare the bending strength of all AGMA and FZG designs in the region of their intended use.

Alexander L. Kapelevich and Yuriy V. Shekhtman [2] described an approach to the tooth parameters' tolerancing and tool profile definition.

Andrzej Kawalec et al. [3] presented comparative analysis of tooth-root strength evaluation methods used within ISO and AGMA standards and verifying them with developed models and simulations using the finite element method (FEM).

Mahesh. Badithe et al. [4] studied the effect of different shaped holes in reducing stress concentration.

Konstandinos G. Raptis et al. [5] studied the calculation of maximum stress at gear tooth root when the meshing gears are loaded at their most unfavorable contact point (highest point of single-tooth contact-HPSTC), using both numerical and experimental methods.

Shweta Nayak and Swetaleena Mishra [6] studied the effects of addendum modification on root stress in involute spur gears with various pressure angles.

Alireza Dastan [7] studied the concept of backlash in spur gears and the method of its creation. He used the concept of the Highest Point of Single Tooth Contact (HPSTC) which is the most critical loading point in gears

Use finite element based software is also done by many researchers now a days. It is seen that few researchers have studied the effect of backlash on bending stresses in spur gears but nobody has done a comparative study of providing backlash by increasing centre distance & by reducing tooth profile on bending stresses in gears.

Shweta Nayak and Swetaleena Mishra [6] studied the effects of addendum modification on root stress in involute spur gears with various pressure angles. Alireza Dastan [7] studied the concept of backlash in spur gears and the method of its creation. He used the concept of the Highest Point of Single Tooth Contact (HPSTC) which is the most critical loading point in gears.

1.4 Purpose of the work

The purpose of the work is to compare the two methods of providing backlash with reference to the bending stresses.

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1.5 Contributions

Based on outcome of the analysis, backlash providing method may be selected for a specific situation.

II. PROBLEM DEFINITION

The stress field at the spur gear tooth root will be analyzed using a two-dimensional finite element solid model. The study will be for gears geometries used in the reduction gearing arrangement as shown in Fig. 1.

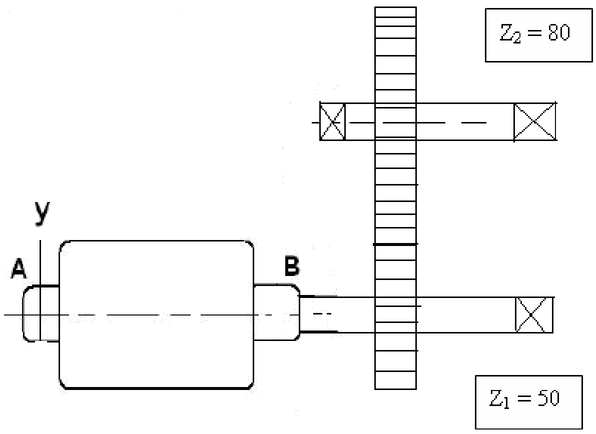

Figure 1 Gearing Arrangement of the problem considered

Table 1 Specification of Gears

Gear	**Speed**	*Rpm*	**Teeth**	*Nos.*	**P.C.D.**	*mm*
Pinion	n_1	750	Z_1	50	d_1	150
Gear	n_2	397	Z_2	80	d_2	240

As both the pinion & gear are made of same material, pinion is weaker. So the stress analysis of the pinion is carried out.

Parameters:

Motor Power (P) = 15 HP (8 Pole, Speed 750 Rpm)

Face Width (b) = 20 mm

Module (m) = 3 mm

Pressure angle = 20^{o}

Calculation of tangential force

As the tangential force is responsible for bending stress, the same is calculated as below.

The forces between Gear No. 1 & 2 are calculated in the following way.

$F_t = \frac{P}{V}$ where, F_t is tangential force in Newton, P is power in Watts, & V is the pitch line velocity in m/s.

P = 15 H.P x 746 = 11190 Watts.

$$V = \frac{\pi . d_1 n_1}{60}$$

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d_1 = 150 mm = 0.15 m (Given)

$$V = \frac{\pi \text{ x } 0.15 \times 750}{60}$$

V = 5.89 m/s

$$F_t = \frac{11190}{5.89}$$

$\mathbf{F_t}$ **= 1899.83 N ≈ 1900 N**

III. ANALYTICAL BENDING STRESSES (σ)

Bending stress is calculated analytically using the equation (1) as below :

$$\sigma = \frac{F_t}{b.m.J} = \frac{1900}{20x3x0.45778} = 69.17 \text{ Mpa} \quad \text{..............................(1)}$$

Above solution is obtained by taking geometry factor with reference to load applied at HPSTC.

IV. FINITE ELEMENT ANALYSIS

Finite Element Analysis is done by using software ANSYS. Fig. 2 shows meshed model of teeth with load & boundary condition. For meshing 8 quadrilateral elements are used. Bending stress obtained by FEM is nearly equal to analytical bending stress.

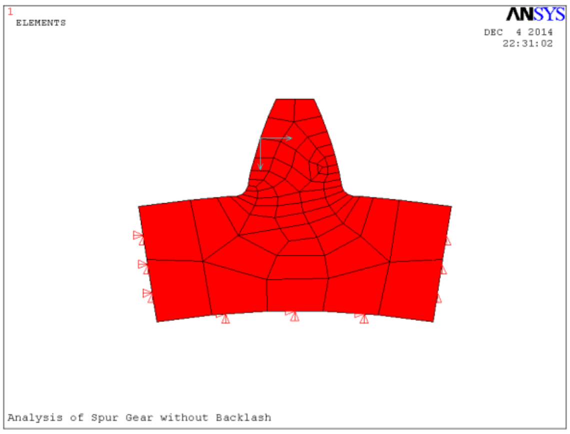

Figure 2 Teeth with Load & boundary conditions

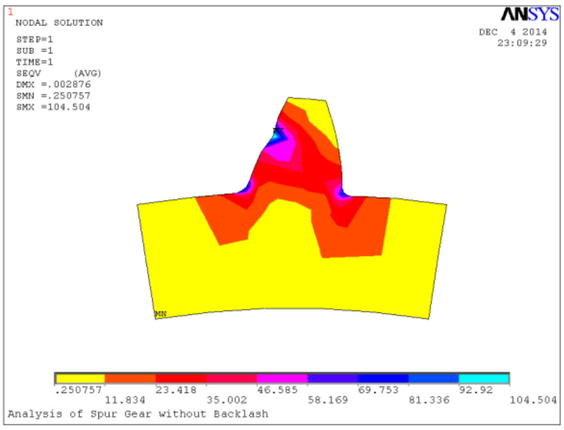

Figure 3 Bending Stresses (Von Mises)

V. Making backlash by reducing tooth thickness

Here Operating Pressure Angle = $\phi_1 = \phi - (\tan\phi - \tan\phi_H + \frac{\pi}{2N} - \frac{B}{4R_p})$ where B is final amount of backlash divided up into equal parts on each gear.

Table 2 Backlash (by reducing tooth thickness)& operating pressure angle

Sr. No.	Amount of Backlash (B) in mm	ϕ_1 (°)	F_t (N)	$F_r = F_t$ X TAN ϕ_1 (N)
1	0.15	18.88326	1900	649.895
2	0.20	18.90235		650.602
3	0.25	18.92145		651.310
4	0.30	18.94054		652.017
5	0.35	18.95963		652.725
6	0.40	18.97872		653.433

VI. MAKING BACKLASH BY INCREASING CENTRE DISTANCE

ϕ_H = involute pressure angle at HPSTC, r_H = HPSTC circle radius

Table 3 Backlash (by increasing center distance)& operating pressure angle

B (in mm)	r_H (in mm)	ϕ_H (in degrees)	ϕ_1 (in egrees)	F_r (N)	F_t (N)
0.1835	75.5259	21.0687	19.98984	691.1619183	1900
0.3675	75.78907	21.57921	20.0001	691.5472005	
0.5559	76.0539	22.07846	20.01022	691.9272747	
0.7448	76.32325	22.57168	20.02028	692.3051439	
0.9381	76.59349	23.05344	20.03017	692.6766748	
1.1318	76.8696	23.5316	20.04006	693.0482524	

VII. RESULTS AND DISCUSSIONS

Table 4 shows the comparison of max. Von Mises stresses & max. deformation obtained by providing backlash by reducing the tooth thickness & by increasing the centre distance.

Table 4 Comparison of methods of providing backlash on stresses & deformation

Backlash provided by Reducing the tooth thickness			Backlash provided by Increasing center distance		
Amount of Backlash (in mm)	Max. Von Mises Stress (MPa)	Max. Deformation (in mm)	Amount of Backlash (in mm)	Max. Von Mises Stress (MPa)	Max. Deformation (in mm)
0.15	90.996	0.00296	0.1835	120.464	0.003106
0.2	91.422	0.003	0.3675	128.849	0.00339
0.25	103.667	0.00305	0.5559	148.837	0.00372
0.3	107.612	0.0031	0.7448	168.73	0.004046
0.35	106.375	0.00315	0.9381	177.437	0.00436
0.4	107.404	0.0032	1.1318	234.229	0.004862

Effect on maximum Von Mises stresses & Maximum deformation:

7.1 By reducing tooth thickness

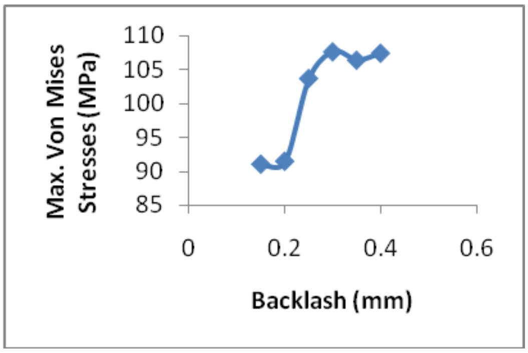

Figure 4 Effect of backlash (by reducing tooth thickness) on max. Von Mises stresses

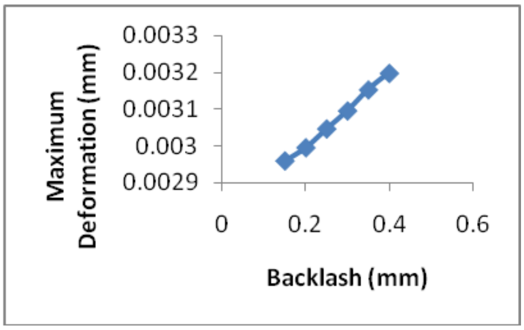

Figure 5 Effect of backlash (by reducing tooth thickness) on max. deformation

Here initially max. Von Mises stresses increases by very small amount with increase in backlash but afterwards there is much increase in stresses. Max. deformation increases as backlash increases.

7.2 By increasing centre distance

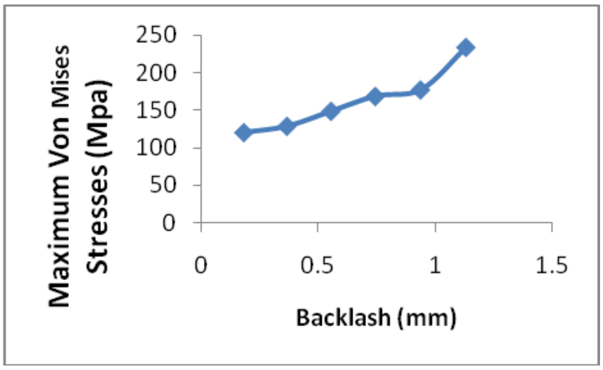

Figure 6 Effect of backlash (by increasing centre distance) on Max. Von Mises stresses

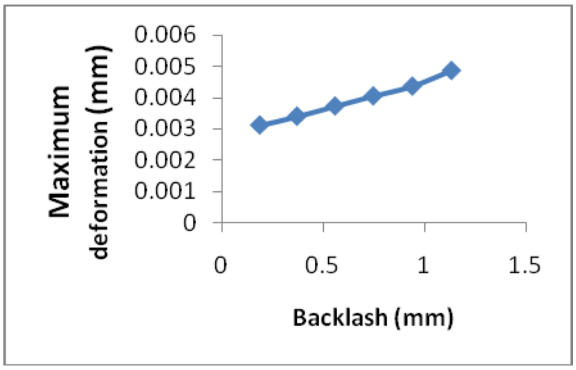

Figure 7 Effect of backlash (increasing centre distance) on Max. deformation

Here it is seen that as backlash increases Maximum Von Mises stresses increases almost linearly. Theses stresses are almost directly proportional to backlash.

VIII. CONCLUSIONS

Following are the conclusions.

- In the tooth thickness reduction method, as backlash increases maximum Von Mises stresses increase slightly initially. But afterwards there is much increase in these stresses with increase in backlash. At the end, it nearly remains constant.

- In the tooth thickness reduction method, as backlash increases, maximum deformation increases. Maximum deformation is almost directly proportional to backlash.
- In increasing centre distance method, as backlash increases Maximum Von Mises stresses increase. These stresses are almost directly proportional to backlash.
- In increasing centre distance method, the maximum deformation increases as backlash increases. This increase is almost linear.
- Maximum Von Mises stresses and maximum deformation both are more in case of backlash provided by increasing the centre distance than the corresponding values obtained by providing backlash by reducing the tooth thickness. Hence providing backlash by reducing tooth thickness is good.

IX. ACKNOWLEDGEMENT

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