Finite element analysis of profile modified spur gear

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Abstract: This paper describes a general Finite Element Analysis of a Spur Gear under desirable loading conditions and the effect of load during the meshing of gear is shown for the fillet foundation. The results are compared with that of various profile modified spur gears. The modified profiles are designed based on the relocation of the Cutting Rack while manufacturing the gear. The designs were confirmed by a number of trials and comparison of their analysis with that of a regular Spur Gear. When the Cutting Rack's axis line or pitch line is moved away from the pitch circle of the gear, the achieved modified gear is known as positively corrected gear, whereas when the same is moved towards the center of the gear, and it intersects with the pitch circle of the gear, the modified gear is known as negatively corrected gear. Spur Gears can be described as the most basic type of gear, largely used in the modern world. Gears were adopted into various mechanism which were earlier attained by use of wheels or belts. The advantage of gears being the teeth of a gear prevent slippage made their value known throughout the globe and their usage along with time increased, efficiency improved and more variety of gears came into existence with many different variations. One such variation with respect to spur gears was the Profile Modification of the teeth. The teeth being cut with an involute profile had a lot of advantages, but along with them came some disadvantages which needed improvisation. For instance, at higher speeds the gears have noise related issues and vibrations caused due to conjugation of non-involute profiles and occurrence misalignments. Solution to that came with a type of profile medication known as S-Modification.

In the case of S- Gearing Modification, the profile was generated in such a way that the tooth already consisted of an undercut. That is, some material was already removed from the base of the tooth which was the general starting location for all the issues that came with meshing of gears. To achieve this, the cutting rack was placed along the cutting line in such a way that its axis, or its pitch line, intersected with the pitch circle of the required gear. This gave us a tooth profile with an undercut with which there were no more issues related to noise at high speeds, as at the location where the non-involute profiles started to mesh, the respective material was already removed. This also caused reduction in weight of the gear, and thus reducing chances of misalignments greatly. However, the flaw that followed was lowering of power transmission capacity. The other type of modification in the same way was moving away the pitch line of the rack from the pitch circle of the gear, and this was called S+ Modification. As a result, a thicker, stronger tooth profile will be obtained. Even though the weight of the gear box will increase, the power transmitting capacity of the gear will improve appreciably. In this work, such profiles for various factors of modification were generated and analysed on ANSYS.
Structural and compared to that of a regular Spur gear with no modification.

### II. DESIGN SPECIFICATIONS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Gear</th>
<th>Pinion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch circle diameter (mm)</td>
<td>500</td>
<td>100</td>
</tr>
<tr>
<td>Number of teeth</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Module (mm)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Addendum (mm)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Dedendum (mm)</td>
<td>6.25</td>
<td>6.25</td>
</tr>
<tr>
<td>Clearance (mm)</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>Tooth thickness (mm)</td>
<td>7.854</td>
<td>7.854</td>
</tr>
<tr>
<td>Fillet radius (mm)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Face width (mm)</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

### III. FEA ANALYSIS OF STRESSES ON GEAR TOOTH AND MODIFIED GEAR TOOTH PROFILES USING ANSYS

The material properties are as given below:

AISI no. 17-7PH Precipitation-Hardenable steel

UTS = 1450MPa, Yield Strength = 1310MPa

The force acts at the line of contact (during meshing of gears) as shown in fig. 4.

### IV. TOTAL DEFORMATION AND STRESS IN REGULAR SPUR GEAR

Fixed supports were given as boundary condition to the surfaces shown in fig. 4.

Maximum Deformation: 0.0025854 mm (At the Tooth Top)
Maximum Equivalent Stress analyzed: 119.22MPa
Minimum Equivalent Stress analyzed: 0.0008MPa

V. PROFILE MODIFICATION

To avoid undercutting, the practice which is now universally adopted is what is known as the "profile correction" of gear tooth. When a standard, uncorrected pinion is cut by the rack, the pitch line is tangent to the pitch circle of the pinion at the normal pitch point P. When, however, the rack is withdrawn, this situation alters. The rack reference line MM is no longer a tangent to the pitch circle. Instead, it is away by an amount equal to $xm$ millimetres. To effect this, the cutter is withdrawn by a specified distance so that the addendum line of the rack-type cutter or hob just touches the point of tangency when the cutting action begins.

This amount $xm$ is the profile correction of the gear and the coefficient $x$ is known as the “correction factor”. Positively corrected gear is known as S-plus gear and negatively corrected gear as S-minus gear.

\[ x = 14 - \frac{z}{17} \]  

VI. PARAMETERS

In a corrected gear, the following parameters remain unaltered:
- Base circle diameter $d_1 = d \cos a$  
- Pitch circle diameter $d = mz$  
- Circular pitch $p = \frac{(\pi)rm}{3}$

The following parameters change:

- Tip circle diameter $da$ becomes bigger by an amount of $(+2xm)$ in case of S-plus gears and smaller by $(-2xm)$ in case of S-minus gears.

(a) Correction factor $x= +1.0$
(b) Correction factor $x= +0.5$
(c) Correction factor $x= 0$
(d) Correction factor $x= -0.5$

In a positively corrected gear, the addendum is increased by an amount of $xm$ and the dedendum is correspondingly decreased by the same amount. The reverse is true in case of the negatively corrected gears. Normally, the root-fillet becomes smaller in case of positively corrected gears. This has a detrimental effect on stress concentration problems. Negative correction weakens the teeth and the tooth strength decreases. However, this detrimental effect is largely nullified in case of gears with a greater number of teeth. One effect of the positive correction is to make the tooth more and more pointed as the correction factor increases. Consequently, the top land becomes correspondingly smaller and ultimately results in a pointed tip. This phenomenon is termed as “peaking”. The peaking limit sets a boundary to the amount of positive correction that may be applied. The profile of a positively corrected tooth (i.e. its face and flank) is composed of that portion of the involute which is farther away from the base circle than in case of an
ordinary gear. Moreover, positive correction results in greater tooth thickness at the root. All these aspects combine to make a positively corrected tooth look thicker at the bottom and pointed at the top—more or less like an inverted V.

VII. POSITIVE CORRECTION

Fig. 9 Deformation (x=0.25)

Max. Def. Value: 0.0013903 mm

One effect of the positive correction is to make the tooth more and more pointed as the correction factor increases. Consequently, the top land becomes correspondingly smaller and ultimately results in a pointed tip. This phenomenon is termed as “peaking”. The peaking limit sets a boundary to the amount of positive correction that may be applied.

VIII. NEGATIVE CORRECTION

x = -0.25

Max. Def. Value: 0.0054034 mm (At the Tooth Top)

Minimum Deformation: 0mm (In the center of gear)

Fig. 11 Deformation (x=-0.25)

Table II. Results

<table>
<thead>
<tr>
<th>Profile Correction Value (mm)</th>
<th>Max. Def. Value (mm)</th>
<th>Max. Stress Value (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>x = 0.50</td>
<td>0.001098</td>
<td>112.5</td>
</tr>
<tr>
<td>x = 0.67</td>
<td>0.002096</td>
<td>112.2</td>
</tr>
<tr>
<td>x = -0.50</td>
<td>0.012855</td>
<td>128.0</td>
</tr>
<tr>
<td>x = -0.3527</td>
<td>0.007554</td>
<td>130.0</td>
</tr>
</tbody>
</table>

CONCLUSION

The modifications help in meeting with necessary requirements. The positively corrected profile modify the gear with thicker base, strengthening the gear tooth against undercutting and also improving its load carrying capacity appreciably. That, however, increases the weight of the gearbox. On the other hand, the negatively corrected gear profile have modified pre-existing undercut, due to which any chances of interference and further undercutting can be avoided. In this case, the load carrying capacity reduces, which is a drawback.
References


