1 Tooth contact analysis in planetary gears

1.1 Executive summary
Below, the effect of planet carrier deformation and sun gear twist on the contact pattern in planetary gears are shown.
The effect of gear corrections is considered too.

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1.3 Document change record

<table>
<thead>
<tr>
<th>Revision</th>
<th>Dated</th>
<th>Who</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2011-10-07</td>
<td>HD</td>
<td>Original document</td>
</tr>
</tbody>
</table>

1.4 Abbreviations

[ ] Units

1.5 References

[1] KISSsoft 03-2011

## 2 Basic example date

2.1 System data

Side I=left side

Side II=right side

View: always from I to wards II

Sense of rotation of planetary carrier and sun gear: clockwise.

Powerflow: Input on planetary carrier, output on sun shaft

The system consists of a planetary carrier driven from the left side, supported on two bearings.
The sun gear (red) drives the sun shaft which is on the right side of the system.
Carrier and sun are rotating clockwise.

2.2 Basic data

Let us use some example gear data as shown below:
Figure 2.2-1 Example gear data

Figure 2.2-2 Load settings
2.3 Planet carrier deformation

From the FEM analysis of the planet carrier, the tilting of the planet pin is known. Let us assume that it is tilted in the tangential plane by 100um over the planet face width (see red, dashed line) with respect to the theoretical axis (red, solid line) which is parallel to the gearbox axis (blue, solid line).

![Figure 2.3-1 Tilting of planet pin in deformed planet carrier](image)

3 Gear modifications

3.1 Profile modifications

First, add profile modifications on e.g. sun and planet using the sizing function in KISSsoft, similar to the below:

<table>
<thead>
<tr>
<th>Gear</th>
<th>Type of modification</th>
<th>Value [µm]</th>
<th>Coefficient 1</th>
<th>Coefficient 2</th>
<th>Status</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun gear</td>
<td>Tiprelief, progressive</td>
<td>21.000</td>
<td>0.966</td>
<td>7.0000</td>
<td>active</td>
<td></td>
</tr>
<tr>
<td>Sun gear</td>
<td>Rootrelief, progressive</td>
<td>21.000</td>
<td>0.966</td>
<td>7.0000</td>
<td>active</td>
<td></td>
</tr>
<tr>
<td>Planets</td>
<td>Tiprelief, progressive</td>
<td>48.000</td>
<td>0.566</td>
<td>7.0000</td>
<td>active</td>
<td></td>
</tr>
<tr>
<td>Planets</td>
<td>Rootrelief, progressive</td>
<td>48.000</td>
<td>0.6422</td>
<td>7.0000</td>
<td>active</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 3.1-1 Example profile modifications](image)

3.2 Lead modifications

For the lead modifications we need at least
- crowning on the planetary gears to compensate any error in alignment
- helix angle correction in the planetary gear to compensate the carrier deformation, we will apply the same correction on both flanks (flanks are not tapered)
- helix angle modification to compensate for the twist of the sun gear
- helix angle modification on the sun gear note to compensate the helix angle modification of the planet

To find the helix angle modification of the planet, use the opposite value of the torsional wind up of the planet carrier as shown in fifth line below. Also, let us add 20um crowning on the planet.
To compensate the helix angle correction of the planets, the sun gear needs to be corrected two (!) times by the same amount minus it’s own torsional wind up giving a value of about as shown below:

<table>
<thead>
<tr>
<th>Gear</th>
<th>Type of modification</th>
<th>Value [µm]</th>
<th>Coefficient 1</th>
<th>Coefficient 2</th>
<th>Status</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun gear</td>
<td>Tip relief, progressive</td>
<td>21.0000</td>
<td>0.3901</td>
<td>7.0000</td>
<td>active</td>
<td></td>
</tr>
<tr>
<td>Sun gear</td>
<td>Root relief, progressive</td>
<td>21.0000</td>
<td>0.3901</td>
<td>7.0000</td>
<td>active</td>
<td></td>
</tr>
<tr>
<td>Planets</td>
<td>Tip relief, progressive</td>
<td>42.0000</td>
<td>0.3669</td>
<td>7.0000</td>
<td>active</td>
<td></td>
</tr>
<tr>
<td>Planets</td>
<td>Root relief, progressive</td>
<td>42.0000</td>
<td>0.3669</td>
<td>7.0000</td>
<td>active</td>
<td></td>
</tr>
<tr>
<td>Planets</td>
<td>Helix angle modification, parallel</td>
<td>100.0000</td>
<td>0.6422</td>
<td>7.0000</td>
<td>active</td>
<td>( \alpha_1 = 90.0 \rightarrow \beta_{\text{off}} = 0.073 \text{ right} )</td>
</tr>
<tr>
<td>Planets</td>
<td>Crowning</td>
<td>20.0000</td>
<td></td>
<td></td>
<td>active</td>
<td></td>
</tr>
</tbody>
</table>

**4 Tooth contact analysis**

**4.1 Active flank**

Note that in our system, for the sun, the right flank is active. Choose the setting accordingly in the tab “Contact analysis”.

**4.2 Considering sun gear twist**

To consider the sun gear twist, choose the below setting. Note that side II is the “right” side in our gearbox. The inner diameter of the sun gear and the torsional wind up of the sun gear are then considered.

**Figure 3.2-1 Helix angle modification on the planet to compensate the carrier twist and crowning**

**Figure 4.1-1 Selecting active flank on sun**

**Figure 4.2-1 Torque side of sun gear**
4.3 Considering planet pin tilting

The planet tilting leads to a deviation error of the planet pin axis with respect to the ring gear axis of \( f_{\Sigma \beta} = 100 \mu m \).

The sun gear remains parallel to the ring gear, so, \( f_{\Sigma \beta} \) is zero.

![Tilting of sun and planet (deviation error) with respect to ring gear](image1)

Enter the values as shown below:

<table>
<thead>
<tr>
<th>Axis alignment</th>
<th>Sun - Tail gear</th>
<th>Planets - Tail gear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation error of axis</td>
<td>( f_{3\beta} )</td>
<td>0.0000 ( \mu m )</td>
</tr>
<tr>
<td>Inclination error of axis</td>
<td>( f_{2\beta} )</td>
<td>0.0000 ( \mu m )</td>
</tr>
</tbody>
</table>

![Input of planet tilting due to carrier deformation](image2)

4.4 Other settings

For the ring gear, we neglect any deformation due to the torque, we select “not considered”.

Use the sizing function to calculate the accurate coefficient of friction.

Neglect any pitch error.

Set the load for the calculation to nominal load.

![Other settings in tooth contact analysis](image3)

4.5 Results

4.5.1 General results

KHbeta values can be found in the “Results”
Results

Sun gear - Planets

<table>
<thead>
<tr>
<th>min</th>
<th>max</th>
<th>Delta</th>
<th>μ</th>
<th>sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission error</td>
<td>-220.697 μm</td>
<td>-210.367 μm</td>
<td>10.330 μm</td>
<td>-216.439 μm</td>
</tr>
<tr>
<td>Stiffness curve</td>
<td>23,150 N/mm/μm</td>
<td>40,113 N/mm/μm</td>
<td>16,956 N/mm/μm</td>
<td>29,214 N/mm/μm</td>
</tr>
<tr>
<td>Line load</td>
<td>0.509 N/mm</td>
<td>880.512 N/mm</td>
<td>880.003 N/mm</td>
<td>396.934 N/mm</td>
</tr>
<tr>
<td>Torque Gear 1</td>
<td>3176.930 Nm</td>
<td>3186.703 Nm</td>
<td>9.783 Nm</td>
<td>3182.083 Nm</td>
</tr>
<tr>
<td>Torque Gear 2</td>
<td>4679.645 Nm</td>
<td>4772.070 Nm</td>
<td>92.425 Nm</td>
<td>4730.092 Nm</td>
</tr>
<tr>
<td>Loss power</td>
<td>0.027 W</td>
<td>62.13 W</td>
<td>121.8 W</td>
<td>62.186 W</td>
</tr>
<tr>
<td>Mach temperature</td>
<td>79.324</td>
<td>107.176</td>
<td>28.153 *</td>
<td>56.685 *</td>
</tr>
<tr>
<td>Lubricating film</td>
<td>0.075 μm</td>
<td>0.355 μm</td>
<td>0.276 μm</td>
<td>0.124 μm</td>
</tr>
<tr>
<td>Hardcast stress</td>
<td>1646.456 N/mm²</td>
<td>1646.456 N/mm²</td>
<td>1019.182 N/mm²</td>
<td>1019.182 N/mm²</td>
</tr>
<tr>
<td>Safety against interlocking</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse contact ratio under load</td>
<td>1.28</td>
<td></td>
<td>0.775 μm</td>
<td>1.514 μm</td>
</tr>
<tr>
<td>Overlap ratio under load</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total contact ratio under load</td>
<td>1.28</td>
<td>(min 0.775, μ 1.514, max 1.275)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KHbeta = (minmax/μmm)</td>
<td>1.16</td>
<td></td>
<td>(minmax = 731.696 N/mm, μmm = 632.384 N/mm)</td>
<td></td>
</tr>
</tbody>
</table>

Remarks:
The report contains only the important graphics.
The other graphics can be found in menu 'Graphics' -> 'Contact analysis'.

Contact patterns
The contact patterns can be found using the following graphics:

Figure 4.5-1 Results summary including KHbeta value

Figure 4.5-2 Graphics for contact patterns, here: sun-planet contact, patterns on sun gear (Gear A of mesh)
4.5.2 Influence of increasing crowning

Increased crowning has the positive effect that if the misalignment of the planet pin is different to the expected value (e.g. in case of different loads or in case of machining errors), the contact is still good in the sense that higher misalignment of the pin can be tolerated. However, in general, a higher crowning leads to a smaller contact ellipse resulting in a poor KHbeta value. So, crowning should be minimized but sufficient to account for misalignment.
Figure 4.5-4 Tooth contact patterns, crowning on planet of 20um
4.5.3 Influence of changing helix angle correction

A change in helix angle corrections allows to move the centre of the contact from one side to another as shown below. The – fairly optimal (in the sense that the contact pattern is in the middle of the face width – contact pattern with helix angle modification of -100um on the planet, may be moved to side I or side II when increasing/decreasing the value to e.g. -50um and -150um respectively:

<table>
<thead>
<tr>
<th>KHbeta</th>
<th>Crowning=20um on planet</th>
<th>Crowning=80um on planet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun-planet mesh</td>
<td>1.16</td>
<td>1.65</td>
</tr>
<tr>
<td>Planet ring gear mesh</td>
<td>1.20</td>
<td>1.74</td>
</tr>
</tbody>
</table>
Figure 4.5-6 Helix angle correction of -50um and 20um crowning
In comparison to Figure 4.5-4 Tooth contact patterns, crowning on planet of 20um, it can be seen that the centre of the contact has move to side I or side II.

4.5.4 Optimisation
The optimization of the tooth contact patterns remains responsibility of the user, based on his experience.