INFLUENCE OF THE LINEAR TIP RELIEF MODIFICATION IN SPUR GEARS AND EXPERIMENTAL EVIDENCE

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Application of interest

Gear Box for Aerospace vehicles

- high performance
- low weight

Spur Gears
Tip Relief Modification

What is Tip Relief Modification?

Material removal along the involute profile at the tip of the tooth

What is the use of Tip Relief Modification?

- Better meshing engagement of tooth pairs
- Transmission Error trace modified (PPTE reduced)
Tip Relief Modification

Roll Angle parameterization

Material removal along normal direction

Geometrical definition of Tip Relief Modification

- Tip Relief Topography (either Linear or Parabolic)
- Start Tip Relief $P_s$ (related Roll Angle)
- Max. material removal at the top $v_e$
Linear Tip Relief Modification

• It produces a low PPTE, very useful in terms of whining noise, especially for Spur Gears, so this kind of modification is very appreciated.

• It generates a sharp edge at the Tip Relief start Point. Even though the angle is very flat, the solid elastic Contact Pressure solution is singular.
Linear Tip Relief Modification

• Nominal Contact Pressure solution

If the contact zone encompasses one or both the start relief points, Contact Pressure rises to infinity.
Numerical models produce **not stable results** (mesh depending) when the $P_s$ is inside the Contact Region.
Why not to accept sharp edge and singular contact pressure

• Every technological process can not produce a perfectly sharp edge

• The angle at the tip relief start point is so flat that the surface roughness has to be considered for defining the corner region

• After a short run in the material necessarily yields or wears, and sharp edges should be blunted
Micro pitting prediction model needed

- If $C^2$ (even $C^1$) continuity condition is satisfied the Hertz Contact Pressure is accepted to be the nominal stress for Micro-Pitting material resistance prediction.

- If $C^0$ continuity condition is satisfied only, a nominal Contact Pressure stress value is not available.
Definition of an effective regular profile

**Golden Rules** to fulfill for *effective profile* definition

- The profile need to satisfy $C^1$ continuity (enough in terms of well defined Contact Pressure and its regularity)
- The profile in the zone of $P_s$ has a curvature influenced by the *roughness parameters* (such as $R_a$)
- The profile has to reproduce the *nominal profile as much as possible* (for example not near $P_s$)
- The method must to be *simple*
Data for the definition of an effective regular profile

Experimental data available: 800 profiles points inside the design tolerance band, on which define the effective profile.
Definition of an effective regular profile

$2R_a$ related boundaries offset with reference to nominal design

maximum Radius Linear-Fillet-Linear, with parabolic fillet
Definition of an effective regular profile

Strong curvature step, but $C^1$ condition fulfilled
Definition of an effective regular profile

Quite narrow statistical distribution of fillet Radii
Contact Pressure Results

- Numerical stable results
- Different combinations for statistical sake, then statistical results variation
- Very high Contact Pressure found
Contact Pressure Results

Profile and related points, plus Acquisition limits

Nominal Modification, plus acquisition points

Contact Pressure evolution on the profile

Contact Pressure rise due to “sharp edges” in contact
Experimental Evidence

Experimental equipment for Profile and Roughness detection

Equipment scheme for “horizontal tooth flank” displacement
Experimental Evidence

- Micro-Pits found
- Evidence of opposite Rolling-Sliding combinations, from Pits’ borders
- Micro-Pitting lines
Conclusion

• A simple method to perform a regression to a regular profile, in the case of singular nominally profile, was shown and experimentally validated.

• The only micro-geometry parameter leading the regression is the roughness $R_a$, around the Start Relief Point.

• Numerical simulations were performed and micro-pitting evidence provided for the high contact pressure found.

• The coincidence found is good.