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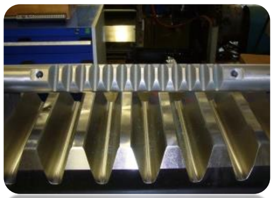



TIP RELIEF AND "SEMI-TOPPING" OF GEAR RACK TOOTH PROFILE

The profile of flank of the basic rack of 14 ½, 20- or 25-degree pressure angle involute is a straight line, inclined from the vertical by the pressure angle (PA). The British Standard (BS 436) which refers to 20 deg. PA involute only, unlike the American AGMA (and German DIN) standard, quotes tip relief of up to 0.02" maximum starting at 0.6" maximum depth from tooth tip (*values in unit module or diametrical pitch*). To our knowledge, all standards other than the BS imply that any tip relief or modification of the involute profile is beyond the scope of the standard.

Heavily loaded teeth of a driven spur gear are deflected in the direction of motion; hence every unloaded tooth is slightly behind its correct position in relation to the loaded teeth.

Similarly, every unloaded tooth of a driving spur gear is slightly ahead of its correct position in relation to the loaded teeth.

Consequently, two unloaded teeth that are about to make contact are out of step by an amount equal to the sum of the deflections of a pair of loaded teeth. In a pair of gears with accurately pitched teeth of accurate form, every tooth engagement would occur with impact.

Helical gears do not require tip relief for the reason that makes it imperative in spur gears, but in every type of gear it is preferable to prevent contact extending quite to any edge, and so some tip relief is desirable.

The above comments refer to cylindrical gear pairs operating at pre-determined fixed centers. In the instance of a rack and pinion pair, the need for tip relief (and in some instances the more excessive "semi-topping") is more imperative owing to:-

a) **The increased difficulty in ensuring rigidity of mounting.**

b) **The difficulty often encountered to ensure true alignment of mesh.**

c) **The frequent instances of operation with pinion fully into mesh (dual flank contact) with anti or "minimum" backlash drives typically on X, Y and Z axes.**

d) Those applications where the pinion axis has to follow that of a rack whose straight form is purposely "bent" in order to traverse in variable planes.

Noise and vibration during running is an indication of errors in mesh of pitch or form of teeth. All gears have such errors, and whether they lead to objectionable noise (and wear) depends on their magnitude, the speed, and the noise amplifying characteristics of their mounting. Absence of tip relief on straight tooth gears (and gear racks) is enough to explain noise.

The application of gears fully in mesh, in particular gear rack with small diameter pinions, leads to the phenomena where the rack tooth tip is in contact in the root of pinion tooth near the "base" diameter of the pinion (from where the involute commences) and a "wedging" action can ensue. This again demands tip relief to avoid/remove tooth contact away from the "base" diameter of the pinion.

APPLICATION OF TIP RELIEF (20deg. PA)

From the outset, being heavily involved in the machine tool industry sector, HRS applied tip relief according to the then British Standard 436-1940 Class A2 – Precision Cut and Class B – High Class Cut Gears, i.e. 0.01" relief, commencing 0.5" from tooth tip, i.e. 0.5" from basic pitch line. Units of *"unit normal metric module or diametrical pitch"*.

The gradual entry into other less precise and less demanding industry sectors realized the need to increase the amount of tip relief to the maximum specified in the standard for Class C – Commercial Cut Gears, i.e. 0.02" relief, commencing 0.6" from tooth tip, i.e. 0.4" from basic pitch line.

This maximum level of tip relief has been retained in the later British Standards 436: Part 1 : 1967 (Diametrical Pitches) and Part 2: 1970 (Metric Modules). With few, specific exceptions (see below) this relief was retained by HRS until December 2001 when **"semi-topping"** began to be applied, in addition to the tip relief, on all new 20 degree PA tool purchases.

The "few, specific exceptions" where relief other than BS maximum relief referred to above, includes those customers who by their own experience had developed rack tooth designs incorporating increased tip relief and/or "semi-topping". These customers refer mainly to stair lift applications where there is difficulty in ensuring rigidity and alignment of the drive pinion and mesh with racks "bent" to follow the profile of the stair incline. This includes rack bent to internal and external gear shapes- also the equivalent of a "crown" gear (bevel gear with zero-degree apex angle).

A separate drawing lists these pitches and relief/semi-topping.

The **"semi-topping"** incorporated Dec2001 by HRS, together with the existing BS maximum tip relief was, in the absence of any known standard recommendations, established as a compromise. It was a compromise of the considered requirements, existing client demands and after the review of the few competitors, who also incorporated various, unspecified degrees of semi-topping. The amount of **"semi-topping"** was **45 degree chamfer giving 0.159 relief commencing 0.25 from tooth tip.**

Note: - 45 degree chamfer is often stipulated for "tip easing". The relief of 3 and 3.1/2DP (8 and 7 module) has since been restricted as below:

Pitch Range	Type of Relief	Amount of Easing	**Actual Relief
		(unit normal pitch)	(unit normal pitch)
Coarser than 3DP/8mod	BS Tip Relief Only	0.02 relief, start 0.6 from tip	0.02
3DP/8mod	Tip Relief + Semi-Top	*45-deg chamfer, 0.19 from tip	0.1345
3.1/2DP/7mod	Tip Relief + Semi-Top	*45-deg chamfer, 0.21 from tip	0.1466
20 to 4DP/1 to mod incl'e	Tip Relief + Semi-Top	45-deg chamfer, 0.25 from tip	0.1706
Finer than 20DP/1mod	Semi-Top Only	45-deg chamfer, 0.25 from tip	0.1590

***The nominal amount of relief from semi-topping is restricted to that of the 4DP/6module pitch i.e. 0.063"/1.5mm respectively from rack tooth tip. The actual amount of easing from tooth tip depends on the depth of cut (actual pitch-line to back).**

****For practical purposes, the consideration of Semi-Topping alone – "0.159 relief"** (i.e. **ignoring the BS blended 0.02 relief commencing at 0.6 from tooth tip - at 0.25 depth, the "blend" is only 0.01 pro rata relief) is sufficiently accurate enough for most calculations of tip relief.**

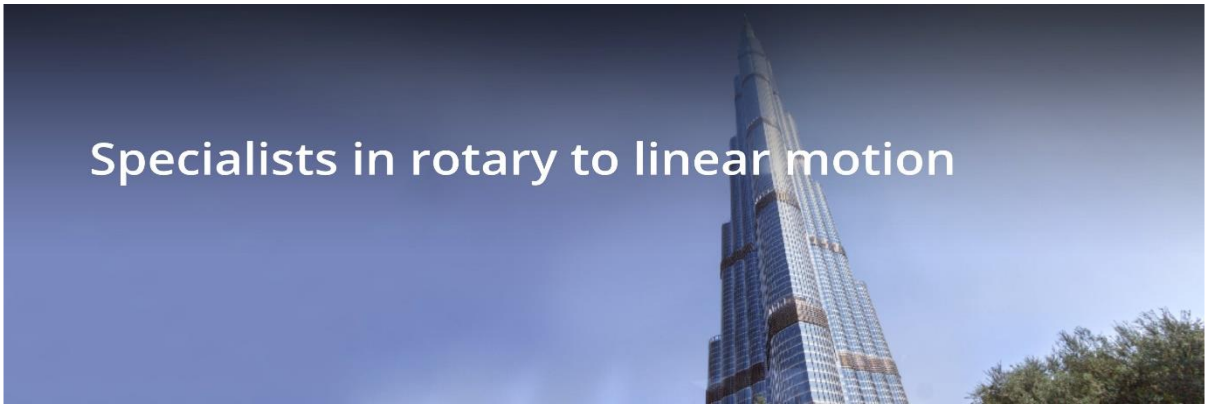
Since HRS introduction of semi-topping of 45 degree, 0.25 from tip, other rack producers have listed alternative amounts of "semi-topping".

APPLICATION OF TIP RELIEF. (14 ½ degree PA)

This "obsolete" PA still included in AGMA 201.02 August 1968 through which states "not recommended for new designs" can be more susceptible to the phenomena of tooth wedging owing to the smaller PA and the earlier onset of undercutting/interference of drive pinion profile. (Any gear having less than 32 teeth requires profile modification ("correction") whereas 20-degree PA, gears having less than 17 teeth require profile modification). Prior to December1999 all 14 ½ degree tooling had no tip relief. The subsequent increased experience of X, Y and Z axis drives prompted the application of tip relief as defined in the 14 ½ PA "composite" tooth system, i.e., 0.06" relief commencing 0.62" from the tip of the tooth.

SUMMARY

For gear designers and system integrators one of the typical issues that arises in noise and/or vibration originating from the gear meshing. In some applications, the mesh efficiency is not important. However, most applications attempt to minimize the noise and vibration in order to meet system and environmental requirements. HRS is an originator and leader of gear rack manufacturer's by incorporating tip relief and semi-topping as a standard feature of our gear rack production process. This results in gear rack systems that run smoother and quieter resulting in a better performing end product system.



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