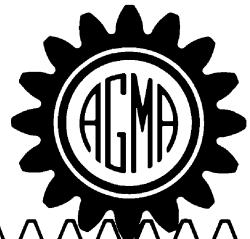


The Ultimate Motion Graph for “Noiseless” Gears

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American Gear Manufacturers Association



TECHNICAL PAPER

The Ultimate Motion Graph for “Noiseless” Gears

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

The innovation was to develop a gear geometry that reduces or eliminates gear noise and increases the strength of gears. Gear noise is a common problem in all bevel and hypoid gear drives. A variety of expensive gear geometry optimizations are applied daily in all hypoid gear manufacturing plants, to reduce gear noise. In many cases those efforts have little success. Additional expensive finishing operations (lapping after the grinding) are applied to achieve the goal of quiet and strong gearsets. The ultimate motion graph is a concept for modulating the tooth surfaces that uses a physical effect to cancel out the dynamic disturbances that are naturally generated by all up-to-date known kind of gears. The ultimate motion graph also eliminates the sensitivity of gears against deflection under load or displacements because of manufacturing tolerances. Lower dynamic disturbances will also increase the dynamic strength.

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The Ultimate Motion Graph for “Noiseless” Gears

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Design Practice Today

According to classic design, gearsets have three principal types of tooth form modifications. The type of tooth modification depends to the highest degree on the possible flank form modifications versus the conjugate flank form.

The intent of flank modifications is to provide a limited contact area under no load or light load which provides insensitivity to gear housing tolerances, inaccuracies in the gear members and assembly, as well as deflections. The corrections keep the contact pattern inside the boundaries of the teeth and, therefore, prevent edge contact. For cutting bevel gears there are three mechanisms to create modifications that have the intent to locate the bearing contact. Those modifications are called "crowning".

The first element is lengthwise crowning which is a circular modification along the face width. If a ring gear is cut to the conjugate theory and a circular modification is applied to the pinion the result of the interaction between pinion and gear after cutting is shown in **Figure 1**. Length crowning can be generated by modifying the cutter radius vs. the theoretical conjugate radius. For example, by reducing the length radius on a

convex flank, clearance will be provided towards the heel or toe end of the tooth. Similarly, length crowning can be generated by tilting the face cutter head around the flank line tangent and by a corresponding change of the blade angles. The so-called Ease-Off represents the interaction between pinion and gear roll position by roll position, across the whole flank surface. Pinion and gear are rotated from contact line to contact line about discrete angles with respect to their ratio. If we visualize this process, it becomes clear that a contact between the two mating flanks exists only in theoretical conjugate points. If no crowning were applied to the case shown in Figure 1, the Ease-Off topography would be a flat surface on top of the presentation plane with zero deviation in the ordinate direction [1]. The Ease-Off presentation plane is an axial projection of the gear tooth like the outline of the gear tooth in a cross-sectional, two-dimensional blue print.

In case of crowning, generally only one point or one line will remain, where the Ease-Off topography is zero.

If it is one point, then this location is called the “mean point”. The mean point is the only location inside the entire flank area where the ratio is

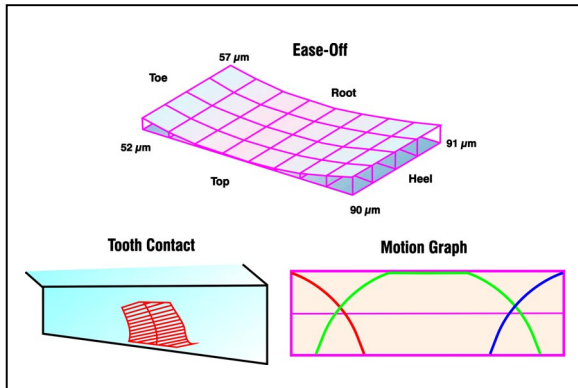


Figure 1: Ease-Off with lengthwise crowning

accurate and no acceleration or deceleration occurs; it is a conjugate point. In case of a contact in line between Ease-Off and presentation plane, this line is called "mean line". The mean line can cross many contact lines as shown in Figure 1, or it might be identical to one contact line. It can (but does not have to) be identical to the path of contact (see also [2]).

The second element to generate crowning is a profile modification on the tool. A concave curvature on the cutting edge of a blade (versus a straight edge) will take stock off on top and flank and cause a circular profile crowning. **Figure 2** presents a profile crowning that results in a high bias contact if it is the only or the dominating correction.

The third element of flank crowning is a flank twist from toe to heel. **Figure 3** shows the classic flank twist. The most commonly used methods to obtain an Ease-Off as shown in Figure 3 is a cutter tilt around the root angle axis and a corresponding change of the machine root angle. Other methods are the use of modified roll

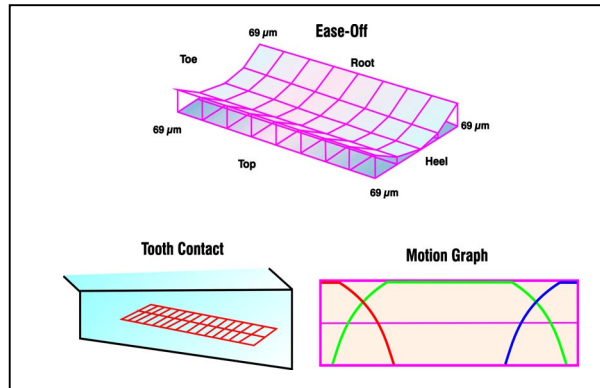


Figure 2: Ease-Off with profile crowning

and helical motion [1]. All real bevel and hypoid gear applications used in power transmissions (and many cylindrical gears) use a combination of all three types of crowning.

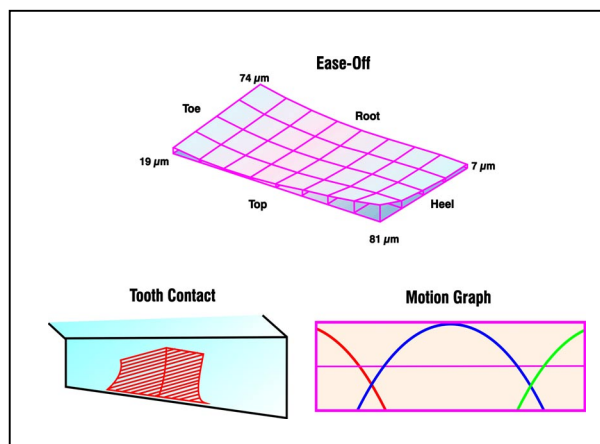


Figure 3: Flank twist with bias out contact

In case of face milling, there is no basic machine set-up that provides conjugate flank geometry. Cutting in the root line plane and rolling in a plane that matches the pitch line can only be approximated for gears with a tapered tooth depth. The elements of flank form correction are used in the gear design of tapered depth tooth systems to eliminate the systematic deviations from conjugate to some extent and leave a desired crowning characteristic. Principally, this

leads to similar flank corrections that were once applied to face hobbed gearsets with a uniform tooth depth design.

Research Project to Develop Tooth Contact and Single Flank Characteristics for Quiet Rolling Gearsets

The subject of a research project conducted at The Gleason Works was the development of a ground rear axle drive that has a noise characteristic similar to a very high quality lapped gearset.

The selected vehicle is one of the most sensitive passenger cars available. It has a rigid beam-style axle mounted basically without any isolation directly to the chassis. The one-piece propeller shaft transmits any kind of stimulation towards the front part of the cabin. Grinding developments done in the past for this vehicle never succeeded. In order to analyze the noise characteristic of the vehicle, airborne noise measurement instruments, speed pick-up as well as pressure gages to determine the exact load situation, were installed in the vehicle. The principle of a laboratory and vehicle measurement loop was successfully applied in the past for grinding developments used in independent and isolated rear axles of expensive luxury vehicles. This closed loop system is shown in **Figure 4**.

The same technique was applied during the actual research project to the most challenging conditions of the mentioned mid-size sedan.

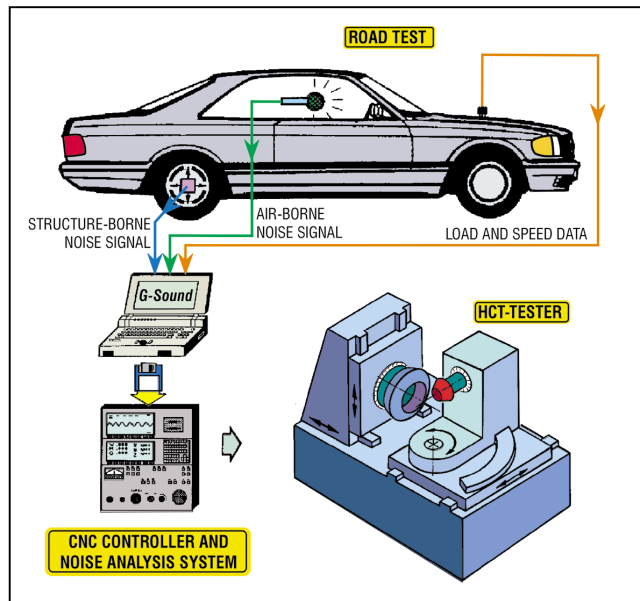


Figure 4: Closed loop between tester and vehicle measurements

The design for the gears was done by using the **Universal Motion Concept (UMC)** on the pinion. Higher order kinematic freedoms up to the 4th order were applied to achieve the best possible result in noise, sensitivity and adjustability. The grinding of the actual parts took place on a UMC capable free form grinding machine. During the development phase, highly accurate single flank and structure borne noise test equipment was used to pre-qualify the gearsets and to establish a correlation between vehicle and test machine.

There are several reasons to prefer an advanced grinding process compared to the conventional lapping process. The heat-treat deflections, which are very difficult to control, basically do not have any influence on the final ground flank form. The parts do not need to be stored and built in pairs anymore, which reduces logistical effort and cost. The ground flank form is very easy to