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Hypoloid™ Gears with Small Shaft Angles and Zero to Large Offsets

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Abstract

Beveloid gears are used to accommodate a small shaft angle. The manufacturing technology used for beveloid gearing is a special set up of cylindrical gear cutting and grinding machines.

A new development, the so called Hypoloid gearing addresses the desire of gear manufacturers for more freedoms. Hypoloid gear sets can realize shaft angles between zero and 20° and at the same time allow a second shaft angle (or an offset) in space which provides the freedom to connect two points in space.

The first application of Hypoloids is found in all wheel driven vehicles that use traditionally a transfer case with a pinion/idler/gear arrangement or a chain. In those cases, the exit of the transfer case needs to be connected with the front axle. The obstacle here is the fact that the propeller shaft between the transfer case and the front axle will require two CV joints, because the front axle input point has a vertical offset and is shifted sideways with respect to the transfer case exit. The tight packaging of modern vehicles requires the possibility to offset the two connecting points of a front propeller shaft. However the penalty for such a design is the cost of two CV joints as well as the reduced efficiency of the front drive train, which could range between 0.5% and 2% of the power that flows through the front axle.

Beveloids can realize an angle in one plane, which in most cases is not sufficient to connect the two points in question without the additional requirement of two CV joints. Only the newly developed Hypoloids can connect those two points due to the shaft angle and the additional offset and obsolete the use of CV joints.

The Hypoloid technology not only reduces cost and increases efficiency, it also has an enhanced performance compared with beveloids with straight teeth. The curved Hypoloid teeth enhance the NVH characteristic and show less contact displacement under load. Flank form generation, tooth contact analysis, Ease-Off calculation and coordinate measurement with corrective feed back are already possible with today's cutting and grinding machines.

The Hypoloid technology does not apply only to automotive drive trains. All of the mentioned advantages apply also to aircraft as well as general gearbox manufacturing.

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Introduction

If two shafts are neither parallel nor perpendicular, but include a small angle in the plane that is defined by the axis of rotation, then two possible gearing solutions are known to accomplish a motion transmission.

One possible solution is called beveloids. Beveloids are manufactured like cylindrical gears using for example a hobbing process for soft manufacturing and a threaded wheel grinding for hard finishing. Shaft angles between 0° and 15° can be realized according to the Beveloid method which results depending on the ratio in gear pitch angles between 0° and 7.5° , or in case of the combination of one conical gear with one conventional cylindrical gear, the maximal required pitch angle might be as high as 15° [1,2].

The second possibility is the application of angular spiral bevel gears. The ratio in most real applications is close to miter which results in pitch angles between 0° and 7.5° .

The described gearsets are generally used in automotive transfer cases to transmit rotation and torque from the output shaft of a transmission to the front axle of an all wheel driven vehicle.

The mechanical function of both tapered cylindrical gears (Beveloids) and spiral bevel gears is to provide an angle between the shafts in the plane that their two axes define. In most cases concerning all-wheel drive vehicles, this will still require two constant velocity joints or two universal joints (one on each end of the drive shaft) in order to connect the output shaft of the gear box with the input shaft of the front axle, which commonly have different vertical locations.

In order to connect 2 points in space, like in the case of a propeller shaft between the output of a transfer case and a front axle input, it is necessary to provide one angle and a linear offset or two angles in perpendicular planes. Hypoid gears represent such a general valid solution of input/output shaft orientation in three dimensional space. However, the

features of today's hypoid gear designs do not cover the case of low shaft angle and high offset. The different hypoid theories applied today do not even allow gear engineers to design low shaft angle gears with any offset. The common hypoid theories rely on a flat or conical generating gear as the basis for basic setting and tool parameter calculation [3]. Shaft angles close to and including 90° combined with ratios of 2.5 and higher lead to gear pitch cone angles of 68° and higher, and pinion pitch cone angles of 22° and lower. This leads to a typical ring gear whose cone is close to a plane, with a tangent plane to the pitch cone, which is close enough to the pitch cone in the neighborhood of the contacting line. This allows to apply certain amounts of hypoid offset, derived in the pitch cone tangent plane in the traditional hypoid theory. The traditional theory fails in cases of high hypoid offsets (close or equal to half the ring gear diameter). The traditional hypoid theory also fails in cases of low ratio (close to 1.0). In cases of high ratios, worm gear drives can be used to realize a 90° shaft angle and an offset of half the gear diameter plus half the worm diameter (like center distance in cylindrical gearing). In the case of low ratios, crossed helical gears can be used to achieve any desired shaft angle combined with an offset equal to the center distance of those crossed helical gears.

The freedom of any small shaft angle (e.g., 0° to 20°) combined with any offset between zero and the sum of half the mean pitch diameters of the two members will for the first time be possible by applying the Hypoloid system.

The basics of hypoloids

The generating principle is applied between the driving pinion and the driven gear. Although in most cases, pinion and gear might have the same number of teeth, the gear is used as a generating gear. The new method even goes one step further and uses a non-generated gear with straight or curved tooth profile as generating gear for the pinion. In bevel and hypoid gears the non-generated principle is generally only used in cases when the ring gear

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pitch cone angle is 68° and higher. The Hypoloid method derives, in a first step, bevel gear machine basic settings for a non-generated gear member. Those settings are used to derive, in a second step, the basic settings for a bevel gear generator in order to manufacture the pinion. The cutter head for the pinion cutting (positioned by the basic settings and rotated around the cradle axis) represents one tooth of the non-generated gear member on which the pinion rolls during the generating roll process.

The principle of applying a non-generated gear member in order to generate the mating pinion is the only technique that delivers a precise conjugate relationship between pinion and gear, even if the axes of the two members are not in one plane. A conjugate basic geometry also requires the pitch cone to be parallel to the root cone. It has been observed that in case of low shaft angle spiral bevel gear sets, the tooth depth was calculated to be taller at the toe (reverse tooth taper) in order to fulfill the requirements of completing (matching tooth thickness and opposite member slot width). One element of the Hypoloid geometry is a parallel depth tooth design, which will lead to more optimal tooth proportions than a reverse taper and also fulfill the requirement of parallelism between pitch line and root line. If the axes of the two members are in two parallel planes, the distance between the planes is defined as offset. In the case of conical pitch elements of the two members, this offset is commonly called hypoid offset.

One member is defined as a pinion (which is the generated member) and one member is defined as a gear (which is the non-generated member). In spite of the traditional definition, Hypoloid gears and pinions can have a similar number of teeth. It is even possible that the pinion has a higher number of teeth than the gear.

The conjugacy between the two members is only the basis for the generating principle. In order to make the gearset insensitive to tolerances in manufacturing and assembly, a located contact is achieved using flank surface crowning in the direction of the tooth profile, the lead and the path of contact.

If the non-generating process of the gear member is performed with straight cutting blades, then the generation of a pinion tooth will cause additional

profile curvature versus an involute (or more precisely defined as spherical involute or octoid). The additional pinion profile curvature can cause undercut in the pinion root area and a pointed topline. To reduce the additional profile curvature in the generated pinion, it is possible to manufacture the non-generated gear teeth with curved blades. If the gear cutter blades are formed like the involute of a similar generated gear, then the pinion tooth profiles will be regular involutes without additional profile curvature, without additional undercut in the root area and with no pointed topline versus a standard profile. It is also possible to approximate the involute function of the gear blade profile with circular or parabolic shape functions. This will achieve a similar effect and reduce the complexity of blade grinding or grinding wheel dressing kinematics.

The adjustment of the offset is done in two steps, starting from the spiral bevel non-generated gear design. The axis of the spiral bevel gear set lies in a horizontal plane (Figure 1). The first step to offset the pinion relative to the gear is to move the pinion axis in a vertical direction. A positive offset for pinions with left hand spiral direction means a down movement of the pinion, if the view is directed onto the front of the pinion and if the pinion is located to the right (gear to the left). The rule for positive offset is identical to hypoid gear sets. The amount of the down movement is identical to the amount of offset. However, this vertical movement would increase the center distance (e.g. at the center of the face width) as well as the diameter of the pinion (of the same amount then the center distance increase). In contrast to regular hypoid pinions where the diameter is also increased (in case of a positive offset) the diameter increase of the Hypoloid pinions would be larger than required to compensate for the increasing pinion spiral angle. This is the reason for the correction of the pinion diameter, accomplished by a second movement of the pinion axis in a horizontal plane towards the gear. The amount of this movement is determined such that the original center distance is re-established. A pinion diameter increase, because of the spiral angle increase due to the offset is not required (would lead to a small addendum modification) but can be introduced in order to achieve a minimal impact of the hypoid offset onto the pinion profile.