Design of Involute Spur Gears with Asymmetric teeth & Direct gear Design

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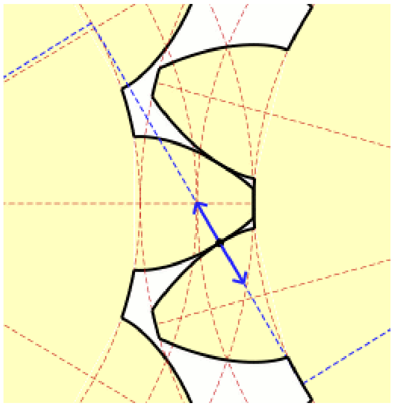
Abstract-- Design of gears with asymmetric teeth that enables to increase load capacity, reduce weight, size and vibration level. . standard tool parameters and uses nonstandard tooth shapes to provide required performance for a particular custom application. This makes finite element analysis (FEA) more preferable than the Lewis equation for bending stress definition. This paper does not describe the FEA application for comprehensive stress analysis of the gear teeth. It sents the engineering method for bending stress balance and minimization.

Introduction

Conventional involute spur gears are designed with symmetric tooth side surfaces . It is well known that the conditions of load and meshing are different for drive and coast tooth's side. Application of asymmetric tooth side surfaces enables to increase the load capacity and durability for the drive tooth side. Therefore, the geometry and design of asymmetric spur gears represents an important problem. There are several articles about involute gears with asymmetric, or so-called, buttress teeth . They consider the low pressure angle profile (as a rule 20°) for the drive side and high pressure angle profile for the coast side teeth. Such an approach enables to decrease the bending stresses and keeps contact stresses on the same level as for symmetric teeth with equal pressure angle. However, this design is accompanied by raising mesh stiffness, increasing noise and vibration with frequency of the cycle of meshing. It does not affect the load capacity limited by contact stresses.

Modern gear design is generally based on standard tools. This makes gear design quite simple (almost like selecting fasteners), economical, and available for everyone, reducing tooling expenses and inventory. At the same time, it is well known that universal standard tools provide gears with less than optimum performance and—in some cases—do not allow for finding acceptable gear solutions. Application specifics, including low noise and vibration, high density of power transmission (lighter weight, smaller size) and others, require gears with nonstandard parameters. That's why, for example, aviation gear transmissions use tool profiles with custom proportions, such as pressure angle, addendum, and whole depth. The following considerations make application of nonstandard gears suitable and cost-efficient: • CNC cutting machines and CMM gear inspection equipment make production of nonstandard gears as easy as production of standard ones. • Cost of the custom cutting tool is not much higher than that of the cutting tool for standard gears and can be amortized if roduction quantity is large enough. • The custom gear performance advantage makes a product more competitive and justifies larger tooling inventory, especially in mass production. • Gear grinding is adaptable to custom tooth shapes. • Metal and plastic gear molding cost largely does not depend on tooth shape. This article presents the direct gear design method, which separates gear geometry definition from tool selection, to achieve the best possible performance for a particular product and application.

Involute gear



Two involute gears, the left driving the right: Blue arrows show the contact forces between them. The force line runs along a tangent common to both base circles. (In this situation, there is no force, and no contact needed, along the opposite common tangent not shown.) The involutes here are traced out in converse fashion: points (of contact) move along the *stationary* force-vector "string" as if it was being unwound from the left *rotating* base circle, and wound onto the right *rotating* base circle.

The **involute gear** profile is the most commonly used system for gearing today. In an involute gear, the profiles of the teeth are *involutes of a circle*. (The involute of a circle is the spiraling curve traced by the end of an imaginary taut string unwinding itself from that stationary circle called the base circle.)

In involute gear design contact between a pair of gear teeth occurs at a single instantaneous point (see figure at right). Rotation of the gears causes the location of this contact point to move across the respective tooth surfaces. The path traced by this contact point is known as the Line of Action (also called

Pressure Line or Line of Contact). A property of the involute tooth form is that if the gears are meshed properly, the line of action is straight and passes through the Pitch Point of the gears. When this is true, the gears obey the Fundamental Law of Gearing:

The Pressure Angle is the acute angle between the line of action and a normal to the line connecting the gear centers. The pressure angle of the gear is a function of the involute tooth shape and pairs of gears must have the same pressure angle in order for the teeth to mesh properly.

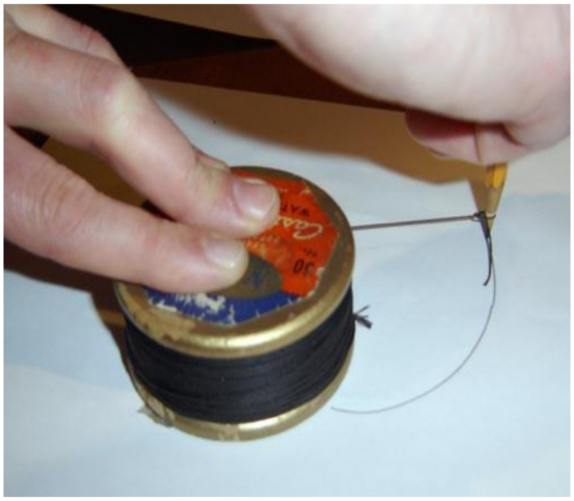
While any pressure angle can be manufactured, the most common stock gears have a 20° pressure angle, with 14½° and 25° pressure angle gears being much less common Increasing the pressure angle increases the width of the base of the gear tooth, leading to greater strength and load carrying capacity. Decreasing the pressure angle provides lower backlash, smoother operation and less sensitivity to manufacturing errors

The Involute Curve, Drafting a Gear in CAD and Applications

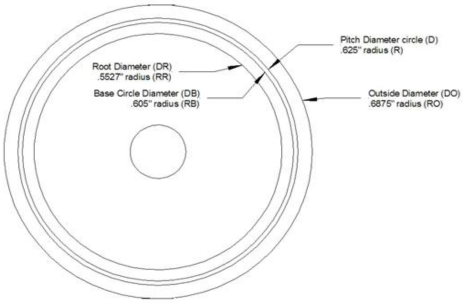
Most of us reach a point in our projects where we have to make use of gears. Gears can be bought ready-made, they can be milled using a special cutter and for those lucky enough to have access to a gear hobber, hobbed to perfect form. Sometimes though we don't have the money for the milling cutters or gears, or in search of a project for our own edification seek to produce gears without the aid of them. This article will explain how to draw an involute gear using a graphical method in your CAD program that involves very little math, and a few ways of applying it to the manufacture of gears in your workshop.

The method I describe will allow you to graphically generate a very close approximation of the involute, to any precision you desire, using a simple 2D CAD program and very little math. I don't want to run though familiar territory so I would refer you to the Machinery's Handbook's chapter on gears and gearing which contains all the basic information and nomenclature of the involute gear which you will need for this exercise.

When we talk about gears, most of us are talking about the involute gear. An involute is best imagined by thinking of a spool of string. Tie the end of the string to a pen, start with the pen against the edge of the spool and unwind the string, keeping it taut. The pen will draw the involute of that circle of the spool. Each tooth of an involute gear has the profile of that curve as generated from the base circle of the gear to the outside diameter of the gear.



Drawing a gear



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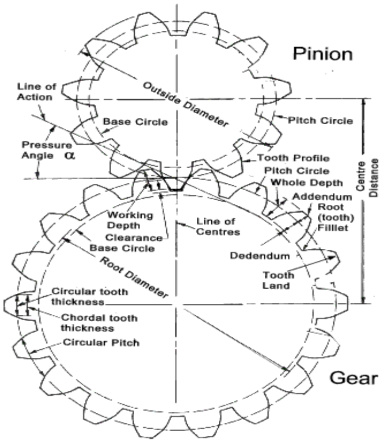

Spur Gear design:

The spur gear is is simplest type of gear manufactured and is generally used for transmission of rotary motion between parallel shafts. The spur gear is the first choice option for gears except when high speeds, loads, and ratios direct towards other options. Other gear types may also be preferred to provide more silent low-vibration operation. A single spur gear is generally selected to have a ratio range of between 1:1 and 1:6 with a pitch line velocity up to 25 m/s. The spur gear has an operating efficiency of 98-99%. The pinion is made from a harder material than the wheel. A gear pair should be selected to have the highest number of teeth consistent with a suitable safety margin in strength and wear.

A **direct-shift gearbox** commonly abbreviated to **DSG**,is an electronically controlled dual-clutch multiple-shaft manual gearbox, in a transaxle design – without a conventional clutch pedal, and with full automatic,or semi-manual control. The first actual dual-clutch transmissions derived from Porsche in-house development for 962 racing cars in the 1980s.In simple terms, a DSG is two separate manual gearboxes (and clutches), contained within one housing, and working as one unit. It was designed by BorgWarner,and was initially licensed to the Volkswagen Group, with support by IAV GmbH By using two independent clutches,a DSG can achieve faster shift times, and eliminates the torque converter of a conventional epicyclic automatic transmission**.**

Transverse DSG

At the time of launch in 2003- it became the world's first dual clutch transmission in a series production car,in the German-market Volkswagen Golf Mk4 R32 and shortly afterwards, worldwide in the original Audi TT 3.2; and for the first few years of production, this original DSG transmission was only available in transversely orientated front-engine, front-wheel-drive — or Haldex Traction-based four-wheel-drive vehicle layouts.The first DSG transaxle that went into production for the Volkswagen Group mainstream marques had six forward speeds (and one reverse), and used wet/submerged multi-plate clutch packs (Volkswagen Group internal code: DQ250, parts code prefix: 02E). It has been paired to engines with up to 350 N·m (260 lb·ft) of torque,and the two-wheel-drive version weighs 93 kg (210 lb). It is manufactured at Volkswagen Group's Kassel plant,with a daily production output of 1,500 units.

"S" mode

The floor selector lever also has an **S** position.When **S** is selected, "sport" mode is activated in the DSG. Sport mode still functions as a fully automatic mode, identical in operation to **"D"** mode, but upshifts and downshifts are made much higher up the engine rev-range. This aids a more sporty driving manner, by utilising considerably more of the available engine power, and also maximising engine braking. However, this mode does have a detrimental effect on the vehicle fuel consumption, when compared to **D** mode. This mode may not be ideal to use when wanting to drive in a 'sedate' manner; nor when road conditions are very slippery, due to ice, snow or torrential rain — because loss of tyre traction may be experienced (wheel spin during acceleration, and may also result in roadwheel locking during downshifts at high engine rpms under closed throttle). On 4motion or quattro-equipped vehicles this may be partially offset by the drivetrain maintaining full-time engagement of the rear differential in 'S' mode, so power distribution under loss of front-wheel traction may be marginally improved.

S is highlighted in the instrument display, and like **D** mode, the currently used gear ratio is also displayed as a number.

R ***position of the floor-m"R"***

ounted shift lever means that the transmission is in "reverse". This functions in a similar way to **D**, but there is just one 'reverse gear'. When selected, **R** is highlighted in the instrument display.

Manual mode

Additionally, the floor shift lever also has another plane of operation, for **manual** mode, with spring-loaded **"+"** and **"−"** positions. This plane is selected by moving the stick away from the driver (in vehicles with the driver's seat on the right, the lever is pushed to the left, and in left-hand drive cars, the stick is pushed to the right) when in **"D"** mode only. When this plane is selected, the DSG can now be controlled like a manual gearbox, albeit only under a sequential shift pattern.

In most (VW) applications, the readout in the instrument display changes to **6 5 4 3 2 1**, and just like the automatic modes, the currently used gear ratio is highlighted or emboldened. In other versions (e.g. on the Audi TT) the display shows just **M** followed by the gear currently selected, e.g. **M1**, **M2** etc.

To change up a gear, the lever is pushed forward (against a spring pressure) towards the **"+"**, and to change down, the lever is pulled rearward towards the **"−"**. The DSG transmission can now be operated with the gear changes being (primarily) determined by the driver. This method of operation is commonly called "tiptronic". In the interests of engine preservation, when accelerating in Manual/tiptronic mode, the DSG will still automatically change up just before the redline, and when decelerating, it will change down automatically at very low revs, just before the engine idle speed (tickover). Furthermore, if the driver calls for a gear when it is not appropriate (e.g.: requesting a downshift when engine speed is near the redline) the DSG will not change to the driver's requested gear.

Current variants of the DSG will still downshift to the lowest possible gear ratio when the kick-down button is activated during full throttle whilst in manual mode. In Manual mode this kick-down is only activated by an additional button at the bottom of the accelerator pedal travel; unless this is pressed the DSG will not downshift, and will simply perform a full-throttle acceleration in whatever gear was previously being utilised.

Advantages and disadvantages

Advantages

- Better fuel economy (up to 15% improvement) than conventional planetary geared automatic transmission (due to lower parasitic losses from oil churning)and for some models with manual transmissions;
- No loss of torque transmission from the engine to the driving wheels during gear shifts;

- Short up-shift time of 8 milliseconds when shifting to a gear the alternate gear shaft has preselected;
- Smooth gear-shift operations;
- Consistent shift time of 600 milliseconds, regardless of throttle or operational mode;

Disadvantages

- Achieving maximum acceleration or hill climbing, while avoiding engine speeds higher than a certain limit (e.g. 3000 or 4000 RPM), is difficult since it requires avoiding triggering the kick-down-switch. Avoiding triggering the kick-down-switch requires a good feel of the throttle pedal, but use of full throttle can still be achieved with a little sensitivity as the kick-down button is only activated beyond the normal full opening of the accelerator pedal.
- Marginally worse overall mechanical efficiency compared to a conventional manual transmission, especially on wet-clutch variants (due to electronics and hydraulic systems);
- Expensive specialist transmission fluids/lubricants with dedicated additives are required, which need regular changes;
- Relatively expensive to manufacture, and therefore increases new vehicle purchase price;
- Relatively lengthy shift time when shifting to a gear ratio which the transmission ECU did not anticipate (around 1100 ms, depending on the situation);
- Torque handling capability constraints perceive a limit on after-market engine tuning modifications (though many tuners and users have now greatly exceeded the official torque limits.; Later variants have been fitted to more powerful cars, such as the 300 bhp/350Nm VW R36 and the 272 bp/350 Nm Audi TTS.
- Mechatronic units in earlier models are prone to problems and requires replacement units

Conclusions

The basic geometric theory of the gears with asymmetric teeth has been developed. This theory allows to research and design gears independently from generating rack parameters. It also provides wide variety of solutions for a particular couple of gears that are included in the area of existence. The asymmetric tooth geometry allows for an increase in load capacity while reducing weight and dimensions for some types of gears. It becomes possible by increasing of the pressure angle and contact ratio for drive sides.

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