Spur Gear Design Applications and Analysis

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1. Gear Nomenclatures

Some of the basic but important nomenclatures/terminologies for gears are as follows:

- Pitch Circle: Tangent point of mating gears
- Pinion is the smaller of the two mating gears, and the larger gear of the set is called the gear
- Circular Pitch, p: Distance between two similar points on the adjacent teeth as measured on the pitch circle, i.e., summation of two distances: tooth thickness and the space between two adjacent teeth
- Diametral Pitch, P: The ratio of the number of teeth on the gear to its pitch diameter, D. It is used in the FPS system.
- Module, m: Used in the metric system only, and it is inverse of the diametral pitch, P
- Addendum, a: radial distance between the outside diameter of the teeth and the pitch circle
- Dedendum, b: radial distance between pitch circle and root circle diameter
- While Depth, h: summation of addendum and dedendum of the tooth
- Backlash: distance between tooth thickness and clearance space between two adjacent teeth

2. Types of Machine Tool Gears

In general, some of the types of gears used in machine tool applications are mentioned below:

- Spur Gear
- Helical Gear
- Herringbone Gear
- Worm Gears

In machine tool applications, spur gear has numerous advantages, as mentioned below:

- It is very easy to manufacture quality spur gears using simpler machine tools
- Easy of Assembly and removal
- Spur gears do not create any axial thrust on the shaft
- It costs much less to manufacture and quality control spur gears compared to other forms of gears
- For low-speed and high-torque applications, spur gears are very suitable

3. Gear Classifications

Gear Manufacturing Associations (AGMA) establish gear classifications per standard 390.02. This standard specifies the selection and specification of gears for industrial uses and applications. Gears are assigned AGMA numbers, which combine quality numbers and heat treatment processes applied to manufacture them. For example, a gear specified by number 9-H-16 means gear quality number 9, with hardness 335 to 375 BHN.

AGMA quality numbers range from 3 to 15. The higher the number, the more precise the gear. For indexing purposes, I always used quality number 10 to control the turret's accuracy. For Gear Box applications, class 9 reduces the sound and accuracy of running. For higher-speed gear, class 9 or better must be used to control runout tolerances, which is twice the eccentricity of the gear pitch circle.

Other qualities of the gears include tooth-to-tooth spacing tolerance, profile tolerance, total composite tolerance, lead tolerance, and others, detailed in the AGMA standard 390.02.

For machine tool applications, gear surface finish is important and should be understood properly. The surface finish is achieved by the grinding process during manufacturing after hardening is completed. Several errors, such as pitch error, lead error, etc., can be controlled precisely by the accurate grinding process. Higher speeds of rotation, vibration effects, and noise reduction for gears can be controlled by dynamic balancing of gears.

Almost all the gears in machine tool applications are heat-treated to increase load-carrying capacity. Gear hardening is obtained either by the surface hardening process or through the hardening process. Thru hardening of steel is done using oil quenching to a specified hardness. Hardening can also be done using carburizing or nitriding process. The surface hardening is done to enhance the wear rate of the gears. Next is the induction hardening process using electric coils. It is a very effective process but costly compared to other hardening processes. Flame hardening is also used to harden the gears depending on the gear materials (See Fig.1 also for tooth nomenclatures).

American Standard 14 1/2-degree full-depth tooth: The total depth of the tooth equals 2.157/Diametral Pitch (DP). 14 1/2 degrees is the pressure angle of the teeth. This particular full-depth tooth form helps avoid undercutting the teeth if the number of teeth is comparatively high. Undercutting becomes excessive when the number of teeth is less than 22, as per AGMA. In general, a full-depth tooth is suitable when the number of teeth in a gear is higher than 32.

American Standard 20- and 25-degree full-depth tooth: The pressure angle for this tooth is 20 or 25 degrees. The addendum, dedendum, and total depth are the same for the 14 1/2-degree pressure angle tooth form. A larger pressure angle makes the tooth form thicker at the root of the teeth. Hence, it is stronger than 14 1/2 degree teeth form. Undercutting becomes excessive if the number of teeth for 20-degree and 25-degree tooth forms is less than 14. Other formulae are the same as those for 14 1/2 degrees.

American Standard 20-degree stub tooth: For this type of tooth, the total depth becomes 1.8/DP. A shorter depth and higher pressure angle make the tooth stronger than another tooth form. The length of contact between teeth is shorter than 20 degrees for full-depth teeth. That reduces strength and increases sound during running. Full depth tooth form is normally preferred to stub tooth form. Shorter tooth increases the quality of the teeth.

Fellows Stub Tooth: Another similar tooth form is recommended by Fellows Gear Shaping company, called fellows stub tooth system. The pressure angle is still 20 degrees. The teeth are designated as 4/6, 6/8, 8/10 etc. The numerator is used to denote or calculate the number of teeth thickness, and the denominator is used to calculate the depth of the tooth.

Long and Short Addendum Tooth Form: Sometimes, the outside diameter of the pinion is recommended for higher durability requirements. This also avoids undercutting and excessive interference during running. To keep the center distance the same, the outside diameter of the gear is reduced. The increase is normally equal to or less than one addendum. If increment of center distance between gears is not an issue, the enlarged pinion can work with standard gear, i.e., the gear outside diameter is as per standard dimension.

Full Fillet Radius Tooth Form: The pressure angle could be 14 1/2, 20, or 25 degrees. The only difference is increased full depth, higher than standard depth. The fillet radius at the root of the tooth is full radius eliminating chance of stress concentration or chance of durability failure.

Module Tooth System: In the metric system, the module is defined as pitch diameter divided by the number of teeth (D/T). In the inch system, diametral pitch (DP) is defined as the number of teeth divided by pitch diameter (T/D) Hence, Module (m) = 1/DP. The pressure angle for the metric system could be same as in the inch system i.e. 14 1/2, 20 or 25 degrees.

The Standard for Full Depth Spur Gear Proportions;

Diametral Pitch, DP: Number of teeth/pitch diameter = N/D

Pitch Circle Dosimeter = D

Outside Diameter (OD) = (N=2)/DP

Circular Pitch = 3.1416/DP

Tooth Thickness, t = 1.5708/DP

Addendum, a = D/T

Dedendum, b =1.157/DP

Working Depth, h_w = 2/DP

Whole Depth, H_W = 2.157/DP

Clearance, c = 0.157/DP

Circular Tooth Thickness, t = DP/2

Pressure Angle is denoted by α =14 1/2 degrees

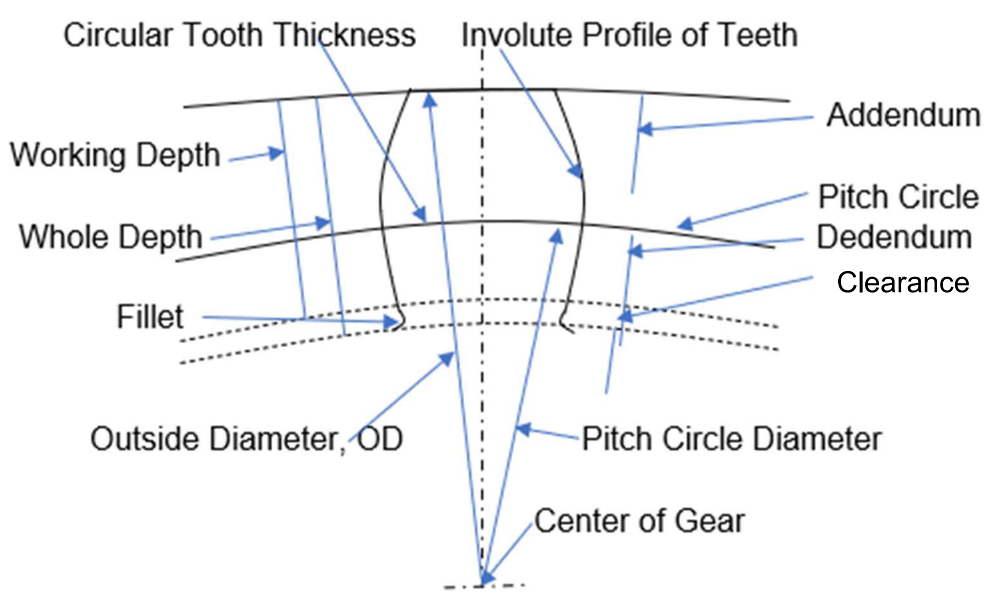


Fig 1. Spur Gear Tooth Nomenclatures

4. Spur Gear Design Considerations

Spur Gears transmit power between two parallel shafts. The gear set transmits power without creating axial thrust on the support bearings mounted on the shaft. Only radial loads are created. Spur gears are used in machine tool applications very often for several applications. Ground and heat-treated gears can be used for high speeds and power transmission without much problem. Spur gears can be manufactured very easily, and there are several types of tooth configurations, such as 14 1/2-degree,20-degree full-depth tooth, and 20-degree stub tooth.

I always used 14 1/2-degree tooth for machine tool applications. There are special advantages of spur gears over other possible types of gear arrangements and they are as follows:

- No axial thrust
- Less costly
- Quick and simple manufacturing
- Widely and easily available

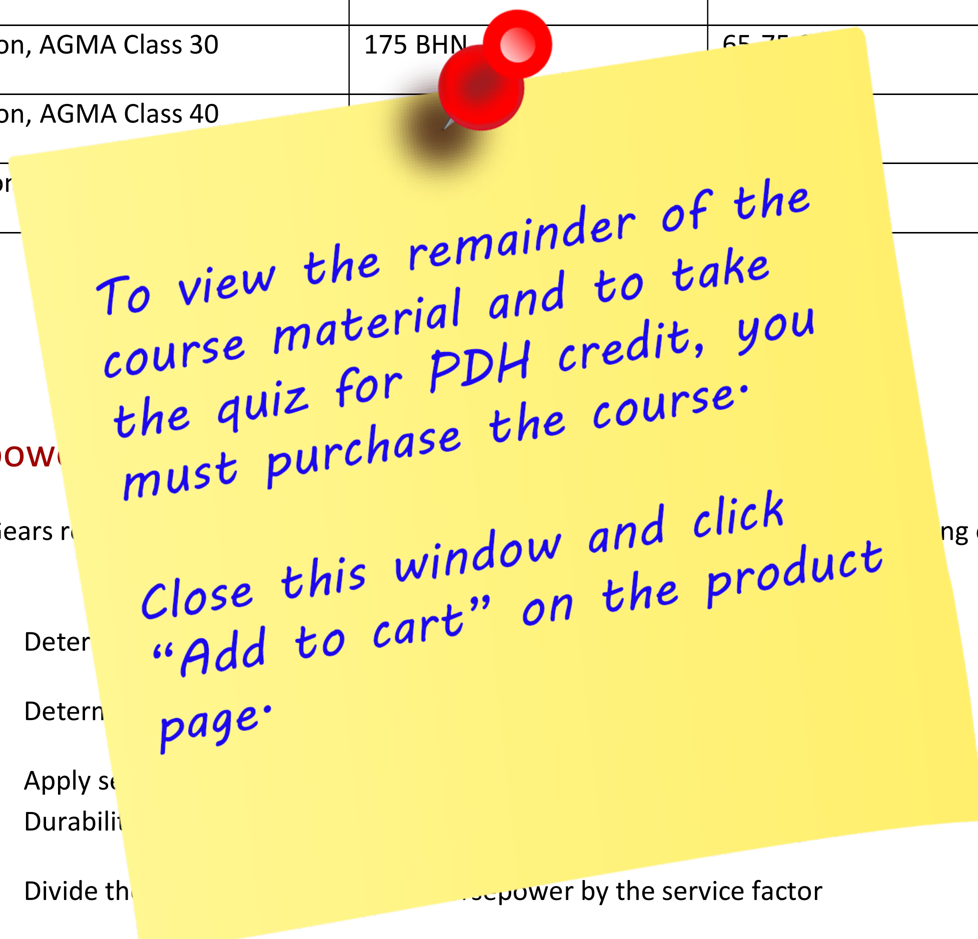
Spur gear materials could be cast steel, alloy steel, carbon steel, or phenolic resins. Materials must be selected to have enough durability and strength for the application. Such gears can be hardened to a specified hardness number using oil or water quenching, carburizing, nitriding, or induction hardening processes.

Spur gears can be manufactured in various types, such as 14 1/2-degree, 20-degree full depth, 20-degree stub tooth, and 25-degree. They can also be manufactured in both inch and module systems.

5. Spur Gear Materials and Heat Treatment

The selection of materials will depend on the strength and durability requirements of the gear system. The material could be cast iron, cast steel, carbon and alloy steel, plastics, etc. Depending on the requirements, steel materials could be thoroughly hardened, or induction hardened. The steel hardening process includes oil or water quenching. Gear teeth can also be case carburized and normalized to add higher toughness to the teeth. The author has successfully used SAE 1020, Nitride Steel, SAE 1040, Class 30 or 40 Cast Iron for spur gear in machine tool applications. The allowable contact stress for the gear/pinion depends on the type of material used and the heat treatment applied. Allowable bending Stress of the material is also required to calculate the horsepower rating of the gear and pinion set. Some typical values are shown below:

Type of material	Hardness value	Contact Stress, PSI, S_{ac}
Thorough Hardened Steel	300 BHN	120-135,000
Thorough Hardened Steel	440 BHN	170-190,000
Case Carburized Steel	55 R_c	180-200,000
Flame or Induction Hardened Steel	50 R_c	170-190,000
Cast Iron, AGMA Class 30	175 BHN	[illegible]
Cast Iron, AGMA Class 40	[illegible]	[illegible]
Tin Bron[illegible]	[illegible]	[illegible]



6. Horsepow[illegible]

Philadelphia Gears r[illegible] ng of the spur gears:

- Deter[illegible]
- Detern[illegible]
- Apply s[illegible] on the Durabili[illegible]
- Divide th[illegible] power by the service factor
- Lower of the two-horsepower ratings (Durability and strength) is the service rating of the set, which must be higher than the required horsepower to be transmitted

Strength horsepower dictates premature failure of the gear tooth due to power and speed transmission. It dictates the weakness of the gear tooth against power transmission. On the other hand, durability strength dictates the wear rating of the gear. During power or speed transmission.

This dictates the speed capability of the gear. Let us take an example. The strength calculations will be dependent on the equations provided by Philadelphia Engineers. For more than single-speed gearboxes,

Spur gears are needed for shifting purposes to change gears as necessary. Other gears are constant mesh gear sets and cannot have sliding motion. These equations and factor values could be different for