Bevel Gear Design, Analysis and Applications

An Online Continuing Education Course for Engineers

Course Number: M-2100

Credit: 2 Hours / 2 PDH / 2 CPD

Bevel Gear Design, Analysis and Applications

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1. Objectives

- Familiarity with different types of Bevel Gears
- Advantages and Disadvantages of Bevel Gears
- Common Bevel Gear Nomenclatures for Design Calculations
- Gear Classifications and Bevel Gear Design Considerations
- Bevel Gear Material and Heat Treatment Process
- Design Strength and Wear Rate of Bevel Gears
- Design Horsepower Calculation for bevel Gears
- Gear Tooth Failure Mechanism
- Gear Force and Stress Analysis
- Gear Shaft and Support Bearing Analysis
- Cause and Mitigation of Gear Noise

2. Introduction

This Course is primarily devoted to the design of different types of bevel gears and their analysis and properties. Any gear has to resist bending stresses during load transmission. Teeth fail due to such bending loads. Pitting and premature wear occur due to excessive loads and speeds. Failure of the teeth due to stress occurs when bending stress goes beyond the material's allowable stresses, and surface failure occurs when contact stress at the contact point exceeds the endurance limit of tooth material. Lubrication of teeth is also very important and significant to enhance gear life.

In this course, we will learn about the following aspects of bevel gear design and applications:

- Various types of bevel gears
- Nomenclatures of bevel gear sets as per AGMA
- The strength Horsepower of bevel gear sets
- Durability Horsepower of bevel gear sets
- Bevel Gear Set Design Principles
- Bevel Gear Teeth Forces
- Design strength and Wear rate considerations for Gears in general
- Bevel Gear Noise Reductions

Proper use, strength calculations, Prevention of excessive wear and pitting failures of gear teeth, gear materials, noise mitigation, lubrication methods, etc., have been recommended by the American Gear Manufacturers Association (AGMA) for a long time in the United States. Whenever required, AGMA practices have been mentioned in this course also.

This course simplifies AGMA-recommended procedures, but important procedures have been simplified for practicing design engineers. The focus of this course has been to explain the behavior and application of bevel gears. Previous courses by this author explained similar procedures for spur and helical gears.

It is hard to imagine a production machinery or automobile transmission, without having a set of gears in it. Gear is a basic mechanical element for speed or torque management. This is also a fact that even today, designers and manufacturers are constantly working to improve the gear design and manufacturing process to produce the best set of bevel gears for various applications throughout the airline, marine applications, earth moving equipment, and machine tool industries. The gear design started way back right from the Renaissance time and it is still going on as we speak.

At this point, several types of gears and gear arrangements have been used in machine design. The author has also been associated with several such gearbox designs using spur, helical, bevel, and worm gears throughout his professional career over fifty years. The present course will reflect some of those experiences to help future designers design helical gears. The author, during his time, always depended on feedback and help from several gear manufacturers such as Philadelphia Gear Corporation, Arrow Gear Corporations, etc., to name a few. The contents of this course are very much guided by the inputs received from gear manufacturing companies with comments from the author.

The contents have been put together to focus on two aspects: bevel gear design principles and applications to be applied for machine tool industries and automobile applications. The course will contain force analysis, durability analysis, and noise reduction for gear applications and will also contain the methods to design gears for durability analysis techniques. The principles of gear nomenclatures and manufacturing will be covered in brief since designers are not required to know that, and the gear manufacturers will help the designers to that extent.

The simple shortcut formulas for designing bevel gears of various types will be demonstrated in this course. It will demonstrate the methods and processes that the author used to design gears and gearboxes for machine tool applications only. For various applications, durability, strength, horsepower of bevel gear sets, noise reduction, etc, are very pertinent requirements that designers have to satisfy. Bevel gear design principles will be explained very briefly for a typical torque reducer that the author has applied in the indexing unit of a CNC turning center. Many of the contributors are very well-known in the gear industry, such as Darle Dudley, Elliott Buckingham, Gene Shipley, Prof. M F Spotts, and many others.

The contents should help the designers to a great extent in applying the design principles for their design efforts. Details of gear classifications as per the American Gear Manufacturers Association (AGMA) will be briefly explained as and when necessary. In general, the designers need to know the design approach and design process for gears for machine tools and marine and automobile applications where durability, cost, and noise reduction are very important design considerations.

Applications, examples, and design discussions will be limited to helical gears, which are mostly used in machine tools. Helical gears are also very suitable and cost-effective for applications such as heavy earth-moving equipment, ship engines, automobile transmissions, etc.

There are several types of bevel gear arrangements in use for power transmission, such as

- Straight Teeth Bevel Gears
- Spiral Teeth Bevel Gears
- Zerol Bevel Gears
- Hypoid Gears
- Spiroid Gear

Straight teeth bevel gears are used when power needs to be transferred between two shafts, which are at right angles to each other. The speed ratio between shafts could be one, more than one, or less than one, depending on the number of teeth for the driver and driven gear. The pitch line velocity should be less than 1000 feet/minute. Straight-tooth bevel gears are more economical than spiral teeth bevel gears, which provide higher performance than straight-teeth bevel gears. When the input gear and output gear have the same number of teeth and right angle to each other, the gears are called **Miter Gears** which are normally used to change the direction of the shafts holding the gears. Bevel Gears with an outside diameter of 100 inches have been manufactured at the Philadelphia Gear Corporation.
For pitch line velocities higher than 1000 fpm and reduced noise level, spiral bevel gears are used in place of straight teeth bevel gears. Teeth have a spiral shape. The axial thrust created by Zerol bevel gears is less than that created by spiral teeth bevel gears. Zerol bevel gears have curved teeth, but the spiral angle of teeth is zero. It is a patented form of teeth, and sometimes, it is used in place of spiral bevel gear. For automobile applications, hypoid gears are used where the pinion shaft centreline is offset for the gear centreline as required by the drive line arrangements. These gears are called hypoid gears. Every differential gear set in an automobile uses hypoid gears. Because of the offset, tooth action consists of rolling and sliding, similar to worm gears' teeth action. Philadelphia Gear Corporation has the capability of cutting bevel gears with a minimum diameter pitch equal to 16 and a maximum gear weight of up to 10000 lbs.

Straight Teeth bevel gears are cot on conical-shaped blanks where the apex of gear and pinion axes meet at the same point. That makes the teeth tapered, i.e., tooth thickness at the inside of the blank is less than the thickness at the outer periphery of the tooth. Hence teeth become weaker at the inner side of the blank. Gear Teeth are comparatively weaker at the inner point since the thickness is less. To protect the gear teeth from breaking at the inside point, contact at the tooth center is maintained while assembling. To protect the teeth at the inner side, gears are married together in a machine, and the backlash is properly designed for the pair of gears (See Fig. 1 for Miter Gear Arrangement).

The selection of gear material for bevel gears is very important since the tooth thickness is not the same throughout the tooth. The materials could be cast iron, alloy steel, carbon steel, bronze, phenolic, etc. Bevel gears made out of alloy or carbon steel can be hardened as per the specifications. The larger gears can be flame-hardened and normalized. Smaller gears can be flame-hardened, induction-hardened, case-carburized, or thorough-hardened, depending on the material of the gear. To keep the contact patch in the middle of teeth, larger gear teeth form can be coniflex tooth form. The coniflex gear teeth are more rounded in the middle of teeth and provide a better tooth contact patch and the contact patch remains in the middle of teeth instead of being at the tip of the teeth. It reduces the stress in the teeth and enhances the life of the gear. Coniflex tooth form also reduces noise at higher pitch line velocities (See Fig. 2, Fig. 3, and Fig. 3A also).

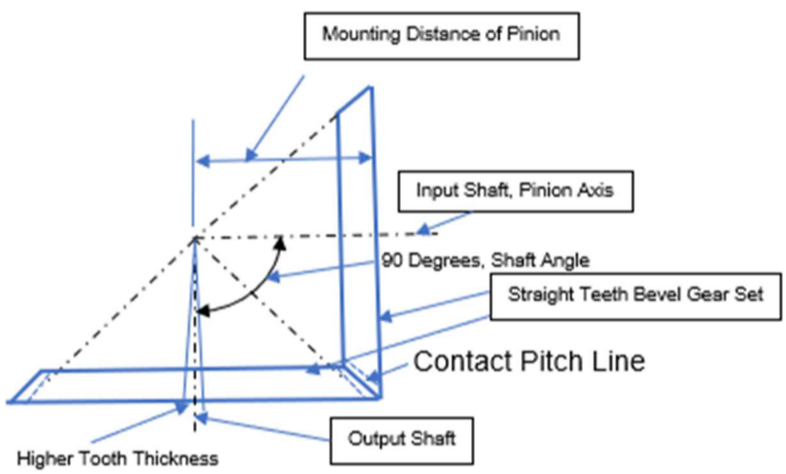
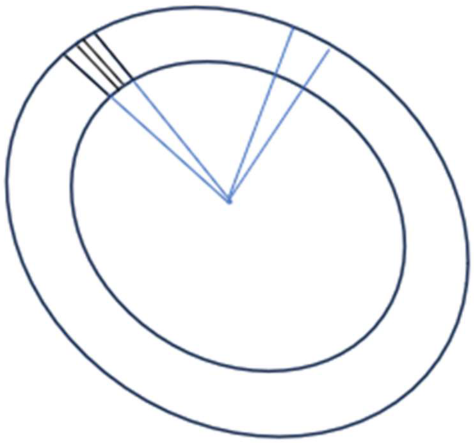


Fig. 1. Miter Set of Bevel Gears



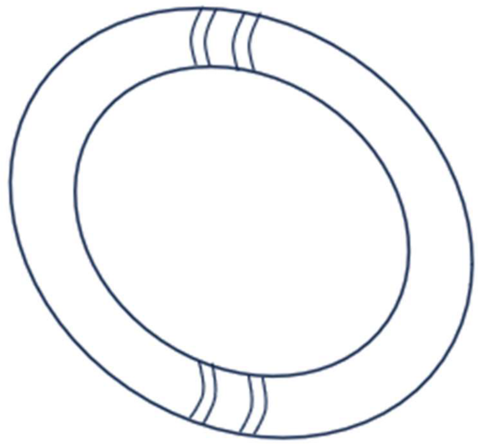
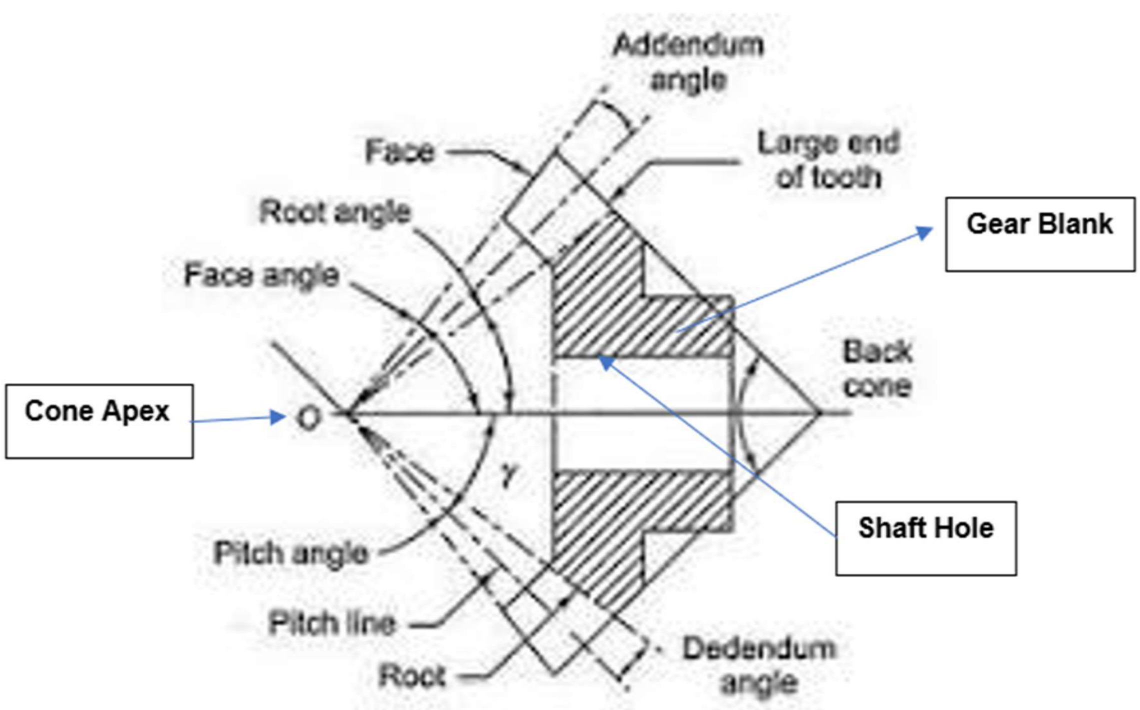


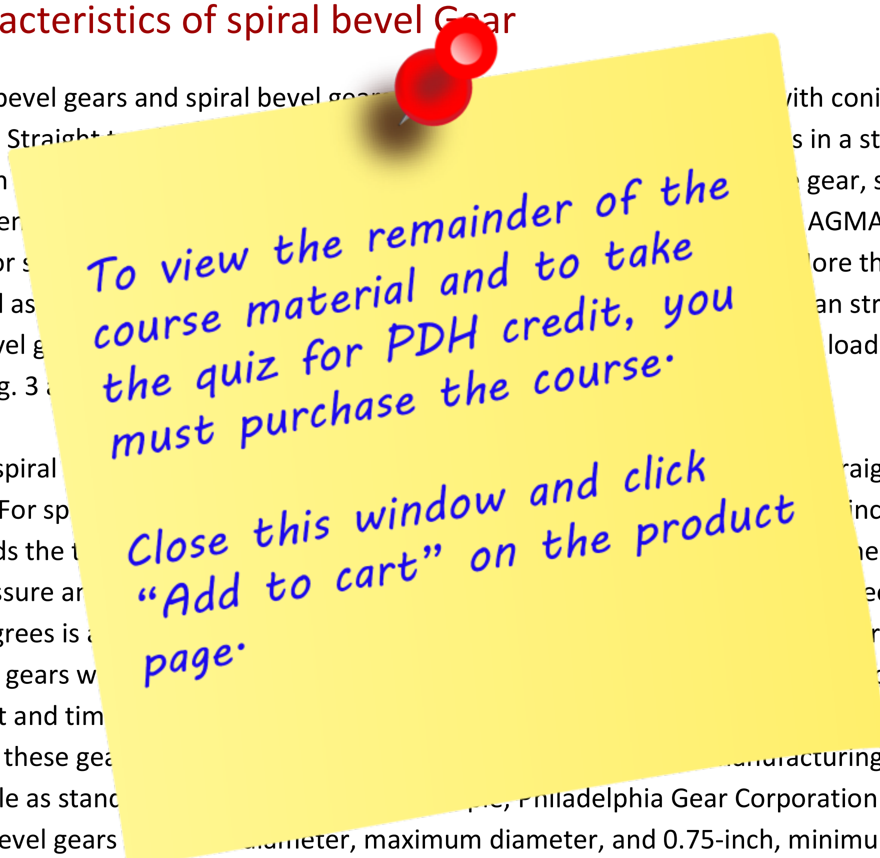
Fig. 2. Straight Teeth Bevel Gear *Fig. 3. Spiral Teeth Bevel Gear*



Source: [Jayesh Srivastava](#)/Internet Course on Bevel Gears, Modified
Fig.3A. Bevel Gear Nomenclatures

Standard available gears must be used to keep the cost of manufacturing very low. Standard ratios such as 1:1, 1.333:1, 1.5:1, 2:1, 4:1, etc. are available. The use of the standard gear saves time and money. To use standard bevel gears, design engineers need to use established ratio, diametral pitch, face, and cone distance. Design engineers can consult the manufacturer's handbook to get further details on each gear set. Standard gears, gear, and pinion, up to 36-inch pitch diameter, are made out of SAE 4140 or 4620 alloy steel, heat treated.

3. Characteristics of spiral bevel Gear



Straight teeth bevel gears and spiral bevel gea ... ith conical configurations. Straig ... s in a straight-line path, and when ... gear, spiral bevel teeth form is ger ... AGMA also. The contact ratio for s ... ore than one tooth shares the load as ... an straight bevel gear. Spiral bevel g ... loading is more gradual (See Fig. 3 ...

Because of its spiral ... aight bevel pinion of similar size. For sp ... increases, contact spreads towards the t ... e tip of the teeth. The pressure ar ... eeth. The spiral angle of 35 degrees is ... r and pinion set, standard bevel gears w ... ossible to reduce the cost and tim ... ies of manufacturing these gea ... anufacturing company and what is available as stand ... , Philadelphia Gear Corporation can manufacture bevel gears ... iameter, maximum diameter, and 0.75-inch, minimum diameter.

As mentioned earlier, materials for gears vary from company to company and as specified by the requirements. The hardness and toughness required for the gears dictate the material to be used for the gear and pinion. Gears up to 36–40-inch diameter can use SAE 4620, alloy steel, which can be case carburized and hardened. If the gear diameter is more than 36-40 inches, SAE 4140 alloy steel can be used, and this material can be nitride or flame-hardened as required. Small pinions can use SAE 4140 also and flame hardened. Materials such as ductile iron, phenolic, and bronze can be used. In case of case carburization, nitriding, and flame hardening, normalizing is required to increase the toughness of the gear teeth. After the hardening process, gears are subjected to an oil quenching process to minimize distortion of the teeth. Generally, pinions are hardened to 50-60 Rc, and gear hardness is less than that of pinion.