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American National Standard

Design, Rating and Application of Industrial Globoidal Wormgearing (Metric Edition)

ANSI/AGMA 6135-A02



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American National Standard

Design, Rating and Application of Industrial Globoidal Wormgearing (Metric Edition)

ANSI/AGMA 6135-A02

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Approved March 20, 2003

ABSTRACT

This standard provides guidelines for the design, rating and application of globoidal wormgearing mounted with axes at a 90 degree angle. Specific definitions for globoidal wormgearing terms are presented, along with formulas for determining the geometric sizes of the major features for the worm and gear. Design considerations, design procedures, gear blanks and self-locking conditions are also discussed. Procedures for rating the load capacity of globoidal wormgearing are included.

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Contents

	Page
Foreword	iv
1 Scope	1
2 Symbols, terms and definitions	2
3 General design considerations	9
4 Gearset design	13
5 Self-locking	16
6 Adjustments and contact patterns of globoidal wormgearing	16
7 Run-in procedures	16
8 Rating and efficiency	17
9 Gear blank design	27

Annexes

A Basic assembly procedure	29
B Analysis of gearing forces, worm bending stress and deflection of globoidal wormgearing	32
C Backlash measurement	37
D Service factors	39
E Overhung load factors	41
F Reducer efficiency	43
G Formulas for rating factors	45

Figures

1 Worm and gear mesh in central plane	3
2 Gearset central plane	4
3 Relationship of central plane and transverse plane	5
4 Gearset transverse plane	6
5 Pitch circles	7
6 Lead angle, normal and axial pressure angles	7
7 Contact lines – Hindley design	10
8 Contact lines – Full contact design	10
9 Hindley design, 101.60 mm C.D., 10:1 ratio, 3 threads, 30 teeth	17
10 Hindley design, 101.60 mm C.D., 30:1 ratio, 1 thread, 30 teeth	18
11 Full contact design, 101.60 mm C.D., 30:1 ratio, 1 thread, 30 teeth	19
12 Gear blank types	27
13 Typical gear blank configuration minimum rim thickness	28

Tables

1 Symbols used in design of industrial globoidal wormgears	2
2 Recommended number of gear teeth	13
3 Basic pressure factor, Z_W	20
4 Ratio correction factor, Z_U	21
5 Face width and materials factor, Z_m	21
6 Velocity factor, Z_v	22



Foreword

[The foreword, footnotes and annexes, if any, in this document are provided for informational purposes only and are not to be construed as a part of ANSI/AGMA Standard 6135-A02, *Design, Rating and Application of Industrial Globoidal Wormgearing (Metric Edition)*.]

This standard revises, combines and supersedes two previous independent standards: ANSI/AGMA 6030-C87, *Design of Industrial Double-Enveloping Wormgears*, and ANSI/AGMA 6017-E86, *Rating and Application of Single and Multiple Reduction Double-Enveloping Worm and Helical-Worm Speed Reducers*. It presents guidelines and practices for the design, rating and application for industrial globoidal wormgearing.

This Standard has been revised to conform with the ANSI (American National Standard Institute) style manual, to add metric dimensions and expand the definitions section.

The first draft of ANSI/AGMA 6135-A02 was made in December, 2000. It was approved by the AGMA membership in October 2001. It was approved as an American National Standard on March 20, 2003.

Suggestions for improvement of this standard will be welcome. They should be sent to the American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, Virginia 22314.

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American National Standard – Design, Rating and Application of Industrial Globoidal Wormgearing (Metric Edition)

1 Scope

This standard provides guidelines for the design, rating and application of globoidal wormgearing mounted with axes at a 90 degree angle. This type of gearing is called double enveloping wormgearing in the United States, but the term globoidal is more commonly used worldwide.

This standard discusses the two main categories of globoidal wormgearing manufactured in industry today: the traditional Hindley designs, and the more recently developed full contact designs. The standard presents the formulas for calculating general gearset proportions for the globoidal designs and a rating procedure for Hindley designs. It does not provide a detailed or complete procedure for the design of gearsets and the cutting tools required.

Globoidal wormgearing of the Hindley design has been used in industrial applications for over 200 years. The manufacturers of Hindley wormgearing have each designed and built their own tooling to manufacture the gearing. The Hindley design uses a common base circle to form all of the tooth profiles. The worm thread is generated by a cutting edge (line) rotating in a single plane.

The more recently developed full contact designs do not use a constant base circle to form the tooth profiles. The worm thread is generated in multiple planes by a generating surface. The manufacturers of full contact gearing have each conducted their own research, and the details of their designs are proprietary to each company. This design may

provide increased load carrying capability over the Hindley design, but a standard rating method for full contact designs has not been established.

1.1 Types of reducers

This standard provides information pertaining to globoidal wormgear speed reducers of the following specific types:

- single reduction reducers incorporating globoidal wormgearing;
- multiple reduction reducers incorporating globoidal wormgearing in each stage of reduction;
- the wormgear portion of multiple reduction reducers incorporating globoidal wormgearing with other types of gearing.

1.2 Speed limitation

The velocity factor table in this standard provides data for sliding velocities up to 30 meters per second. For velocities in excess of 30 meters per second, the manufacturer should be consulted.

Where the sliding velocity of the worm thread exceeds 10 meters per second, additional consideration must be given to the lubrication of gears and bearings. Special lubricants and a pressurized lubrication system may be required.

1.3 Included ratios

The input power formulas for globoidal wormgearing apply for ratios of 3:1 and greater. Engineering practice dictates that ratios in excess of 74:1 should be discussed with the manufacturer.

1.4 Exceptions

Wildhaber plane enveloping globoidal gearing is not covered in this standard.

This standard does not pertain to globoidal wormgearing used as speed increasers. For such applications, the manufacturer should be consulted.

1.5 Intended use

The equations and values presented provide a general approach to design and rating. Deviations from the methods and values stated in this manual may be made when justified by experience, testing or more specific analysis. It is intended for use by experienced gear designers capable of selecting reasonable values based on their knowledge of the

performance of similar designs and the effect of such items as lubrication, deflection, manufacturing tolerances, metallurgy, residual stresses and system dynamics. It is not intended for use by the engineering public at large.

1.6 References

The following standards contain provisions which, through reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

ANSI/AGMA 2004-B89, *Gear Materials and Heat Treatment Manual*

ANSI/AGMA 6001-D97, *Design and Selection of Components for Enclosed Gear Drives*

ANSI/AGMA 6110-F97, *Standard for Spur, Helical, Herringbone and Bevel Enclosed Drives*

ANSI/AGMA 9005-D94, *Industrial Gear Lubrication*

2 Symbols, terms and definitions

2.1 Symbols

The symbols, terms and definitions, when applicable, conform to ANSI/AGMA 1012-F90, *Gear Nomenclature, Definitions Of Terms With Symbols*. See table 1.

NOTE: The symbols and terminology used in this standard may differ from other AGMA standards. The user should not assume that familiar symbols can be used without careful study of table 1.

Table 1 - Symbols used in design of industrial globoidal wormgears

ISO Symbols	Description	Units	First used	Ref. para.
a	Center distance	mm	Eq. 2	2.2
b_{f1}	Length of flat on outside diameter of worm	mm	Eq. 22	2.2
b_1	Worm face width	mm	- -	2.2
b_2	Gear face width	mm	- -	2.2
b_{1eff}	Effective worm thread length	mm	Eq. 21	2.2
c_1	Clearance in the worm	mm	Eq. 13	2.2
c_2	Clearance in the gear	mm	Eq. 14	2.2
d_{a1}	Worm throat diameter in transverse plane	mm	Eq. 17	2.2
d_{a2}	Gear throat diameter in central plane	mm	- -	2.2
d_b	Base diameter (Hindley design)	mm	Eq. 20	2.2
d_{e1}	Worm outside diameter	mm	- -	2.2
d_{e2}	Gear outside diameter	mm	- -	2.2
d_{f1}	Worm root diameter in transverse plane	mm	Eq. 3	2.2
d_{f2}	Gear root diameter in central plane	mm	- -	2.2
d_{w1}	Worm pitch diameter in transverse plane	mm	Eq. 2	2.2
d_{w2}	Gear pitch diameter in central plane	mm	Eq. 4	2.2
h_{am1}	Addendum of worm thread	mm	Eq. 12	2.2
h_{am2}	Addendum of gear tooth	mm	Eq. 12	2.2
h_{fm1}	Dedendum of worm thread	mm	Eq. 15	2.2
h_{fm2}	Dedendum of gear tooth	mm	Eq. 16	2.2
h_w	Working depth of tooth	mm	Eq. 11	2.2
h_1	Whole depth of worm thread	mm	Eq. 10	2.2
h_2	Whole depth of gear tooth	mm	Eq. 10	2.2
j_x	Backlash	mm	- -	2.2
m_a	Axial module	mm	Eq. 6	4.7

(continued)

Table 1 (concluded)

ISO Symbols	Description	Units	First used	Ref. para.
m_n	Normal module	mm	Eq. 9	4.9
n_1	Rotational speed of worm	rpm	Eq. 27	--
P_1	Input power rating	kW	Eq. 27	8.1.3
p_{n1}	Normal circular pitch	mm	Eq. 8	2.2
p_{t2}	Circular pitch	mm	Eq. 5	2.2
r_{f2}	Gear root form radius	mm	Eq. 24	2.2
r_{g1}	Worm throat form radius	mm	Eq. 25	2.2
r_{g2}	Gear throat form radius	mm	Eq. 26	2.2
s_{n2}	Normal gear tooth thickness	mm	--	2.2
s_k	Minimum amount of gear bronze below tooth root	mm	--	9.3
s_{mx1}	Axial worm thread thickness	mm	--	2.2
s_{mx2}	Axial gear tooth thickness	mm	Eq. 20	2.2
s_{n1}	Normal worm thread thickness	mm	--	2.2
u	Gear ratio	--	Eq. 1	2.2
V_g	Sliding velocity	mps	Eq. 28	8.1.4
Z_m	Face width and material factor	--	Eq. 27	8.1.3
Z_u	Ratio correction factor	--	Eq. 27	8.1.3
Z_v	Velocity factor	--	Eq. 27	8.1.3
Z_w	Basic pressure factor	--	Eq. 27	8.1.3
z_2	Number of teeth in gear	--	Eq. 1	4.1
z_1	Number of threads in worm	--	Eq. 1	4.2
α_n	Normal pressure angle	degrees	Eq. 19	2.2
α_x	Axial pressure angle	degrees	Eq. 19	2.2
δ_{m1}	Lead angle at pitch point	degrees	Eq. 7	2.2

2.2 Terms and definitions

addendum, h_{am1} , h_{am2} : The addendum of the worm thread and gear tooth is the radial distance from the pitch circle to the addendum circle on the worm and gear, respectively. See figures 1, 2 and 4.

addendum circle, gear: The gear addendum circle coincides with the tops of the gear teeth and is defined in the central plane. See figures 1 and 2.

addendum circle, worm: The worm addendum circle coincides with the top of the worm thread and is defined in the transverse plane. See figure 4.

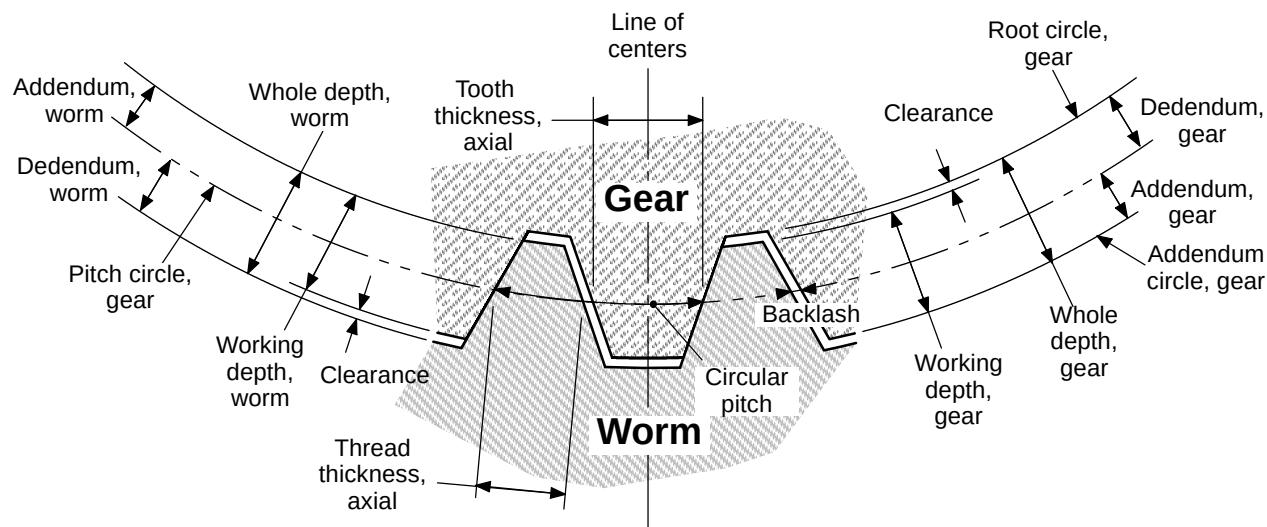


Figure 1 - Worm and gear mesh in central plane

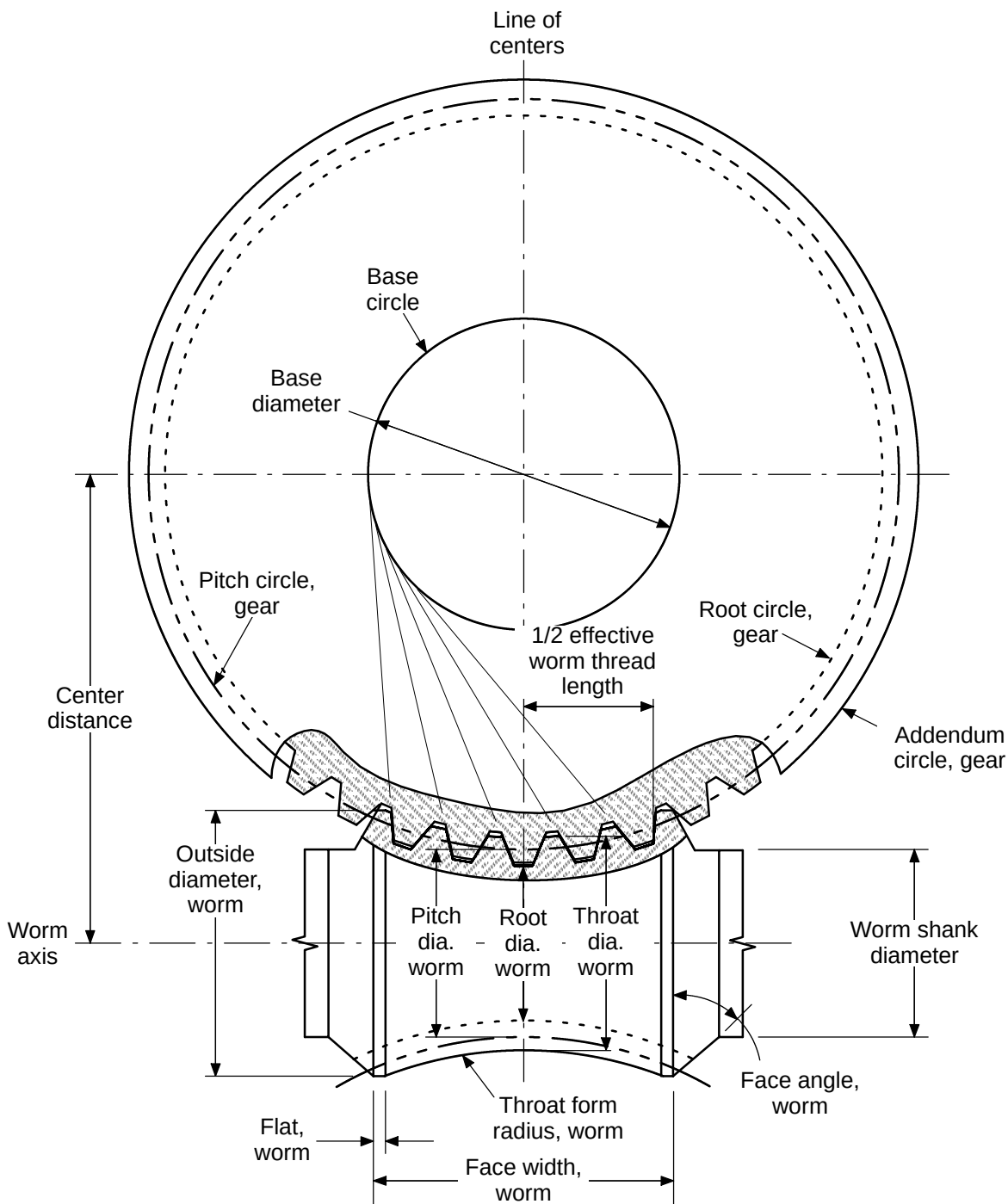


Figure 2 - Gearset central plane

backlash, j_x : The backlash is the amount by which the circular pitch exceeds the worm thread and gear tooth thickness. See figure 1 and annex C.

base circle: The base circle is the tangent circle of two generating lines of the tooth of the worm cutter. For the Hindley design, the generating lines are cutting lines which lie in the central plane. They are the cutting edges of the worm cutter. See figure 2.

For full contact designs, the generating lines are the generatrices of cutting planes or cutting cones.

base diameter, d_b : The base diameter is the diameter of the base circle. See figure 2.

center distance, a : The center distance of the gearset is the shortest distance from the axis of the worm to the axis of the gear. See figure 2.

central plane: The central plane is the plane perpendicular to the gear axis and contains the worm axis and the line of centers. See figures 1, 2 and 3.

circular pitch, p_{t2} : The circular pitch is the length of the arc along the gear pitch circle between two corresponding successive gear tooth flanks measured in the central plane. See figure 1.

circular pitch, normal, p_{n1} : The normal circular pitch is a theoretical value and is defined as the circular pitch times the cosine of the lead angle at the pitch point.

clearance, c_1, c_2 : The clearance is the amount by which the whole depth of the worm threads and gear teeth exceeds the working depth. The clearance is measured in the central plane. See figure 1.

dedendum, h_{fm1}, h_{fm2} : The dedendum of the worm thread and gear tooth is the radial distance from the root circle to the pitch circle on the worm and gear respectively. See figure 1.

effective worm thread length, b_{1eff} : The effective worm thread length is two times the distance from

the transverse plane to the point on the thread where theoretical contact with a gear tooth first occurs. It is measured parallel to the worm axis. See figure 2.

face angle, gear: The gear face angle is the angle of the beveled surface between the gear face and the gear outside diameter. See figure 4.

face angle, worm: The worm face angle is the angle of the beveled surface between the worm shank diameter and the worm outside diameter. See figure 2.

face width, gear, b_2 : The gear face width is the distance between the faces of the gear measured parallel to the gear axis. See figure 4.

face width, worm, b_1 : The worm face width is the distance across the worm flats measured parallel to the worm axis. See figure 2.

flats, gear: Gear flats are the surfaces included on the outside diameter of the gear. Gear flats avoid sharp edges at the intersections of the gear face angles and the throat form radius. See figure 4.

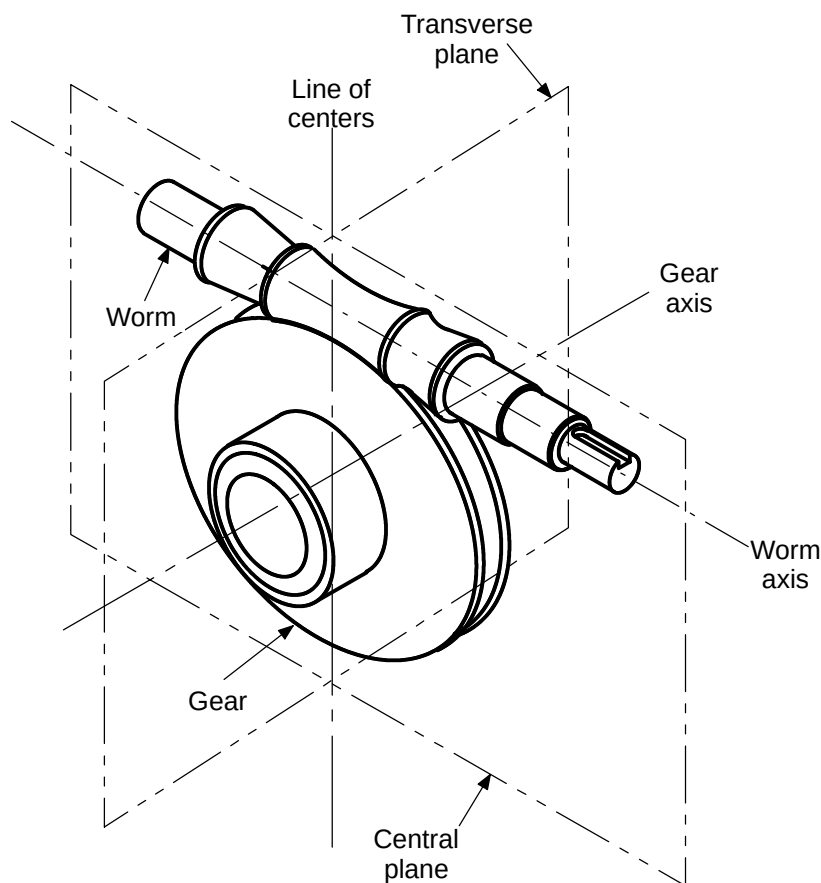


Figure 3 - Relationship of central plane and transverse plane

flats, worm, b_{f1} : Worm flats are the surfaces included on the outside diameter of the worm. Worm flats avoid sharp edges at the intersections of the worm face angles and the throat form radius. See figure 2.

gear: The gear is the toothed output member. The gear increases in diameter from the central plane toward both sides generally conforming to the curvature of the worm. Other commonly used terms to describe this component include wormwheel and wormgear. For purposes of this standard, the term gear is used. See figures 3 and 4.

gear axis: The gear axis is the axis of rotation of the

gear. The gear axis lies in the transverse plane. See figures 3 and 4.

gear face: The gear faces are the flat sides of the gear. See figure 4.

root form radius, gear, r_{f2} : The gear root form radius is the root radius generated by the hob. It is shown in the transverse plane and provides clearance for the tips of the worm threads. See figure 4.

lead angle at the pitch point, δ_{m1} : The lead angle at the pitch point is the angle formed between the tangent to the trace of the pitch point on the worm thread surface and a line perpendicular to the worm axis. The lead angle varies through the length and the depth of the worm. See figure 6.

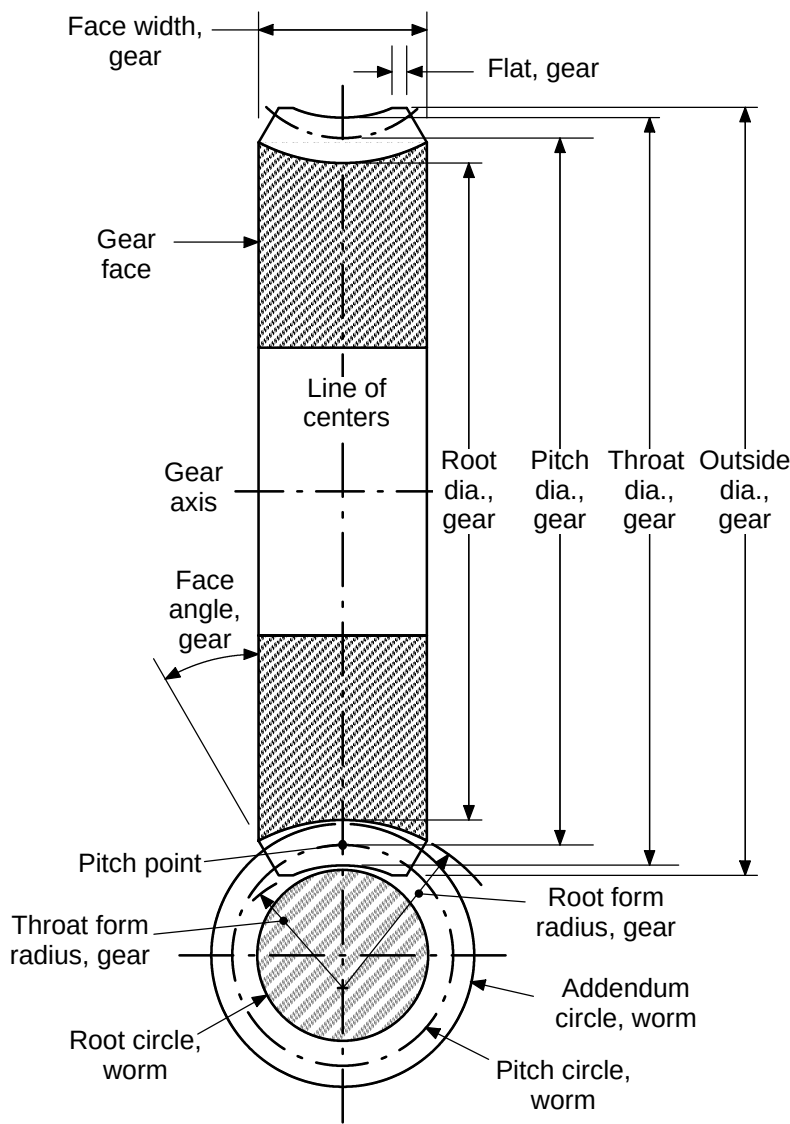


Figure 4 - Gearset transverse plane

line of centers: The line of centers connects the center of the worm pitch circle and the center of the gear pitch circle. The line of centers is formed by the intersection of the central plane and the transverse plane. See figure 3.

outside diameter, gear, d_{e2} : The gear outside diameter is the maximum diameter of the gear blank measured at the gear flats. See figure 4.

outside diameter, worm, d_{e1} : The worm outside diameter is the maximum diameter of the worm blank measured at the worm flats. See figure 2.

pitch circle, gear: The gear pitch circle is the reference circle used for determination of gear tooth proportions. The gear pitch circle lies in the central plane. See figures 1, 2 and 5.

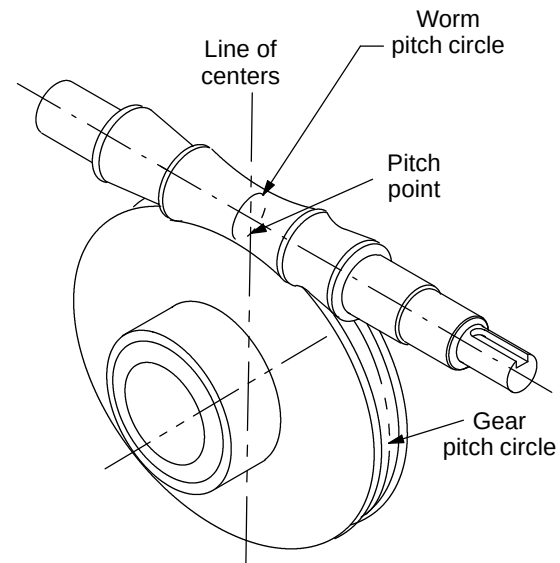


Figure 5 - Pitch circles

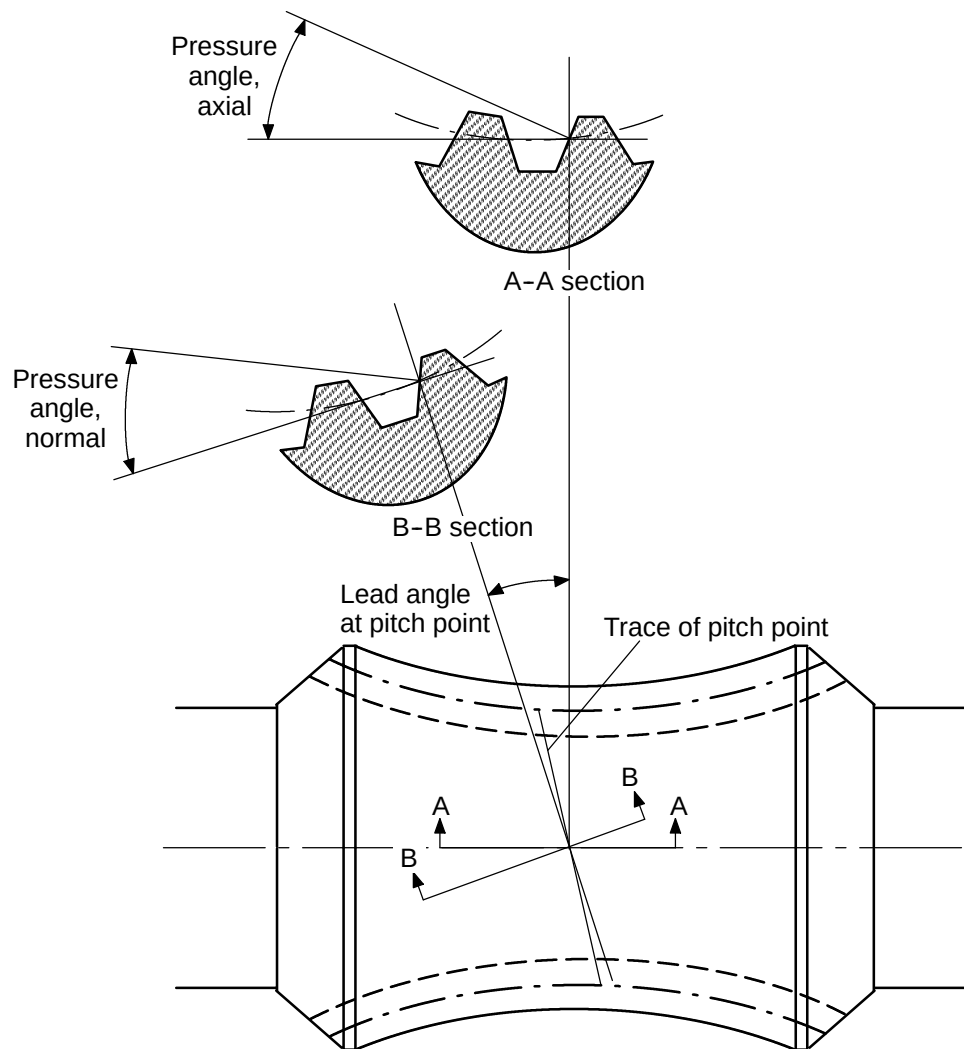


Figure 6 - Lead angle, normal and axial pressure angles

pitch circle, worm: The worm pitch circle is the reference circle used for determination of worm thread proportions. The worm pitch circle lies in the transverse plane. See figures 4 and 5.

pitch diameter, gear, d_{w2} : The gear pitch diameter is the diameter of the gear pitch circle. See figure 4.

pitch diameter, worm, d_{w1} : The worm pitch diameter is the diameter of the worm pitch circle. See figure 2.

pitch point: The pitch point is the common point of the worm pitch circle and the gear pitch circle and is on the line of centers. See figures 4 and 5.

pressure angle, axial, α_x : The axial pressure angle is the pressure angle in the central plane. It is the angle at the pitch point formed between the projection of the normal of the worm thread surface in the central plane and a line parallel to the worm axis in the central plane. See figure 6.

pressure angle, normal, α_n : The normal pressure angle is the pressure angle in the normal plane. It is the angle at the pitch point formed between the normal of the worm thread surface and the tangent plane of the pitch surface. See figure 6.

ratio, u : The gearset ratio is the number of teeth in the gear divided by the number of threads in the worm.

root circle, gear: The gear root circle coincides with the bottoms of the gear tooth spaces and is defined in the central plane. See figures 1 and 2.

root circle, worm: The worm root circle coincides with the bottom of the worm thread space and is defined in the transverse plane. See figure 4.

root diameter, gear, d_{f2} : The gear root diameter is the diameter of the gear root circle. See figure 4.

root diameter, worm, d_{f1} : The worm root diameter is the diameter of the worm root circle. See figure 2.

thread: The thread is the tooth element of the worm. It forms a helix along the worm face width. The thread advances one or more axial pitches for each worm revolution, with additional threads required for each additional pitch advance.

thread thickness, axial, s_{mx1} : The axial worm thread thickness is the length of arc between two sides of a worm thread measured on the gear pitch circle. See figure 1.

thread thickness, normal, s_{n1} : The normal worm thread thickness is the length of arc between two

sides of a worm thread in a plane normal to the thread surface passing through the pitch point at the center of the thread.

throat diameter, gear, d_{a2} : The gear throat diameter is the diameter of the gear addendum circle. See figure 4.

throat diameter, worm, d_{a1} : The worm throat diameter is the diameter of the worm addendum circle. See figure 2.

throat form radius, gear, r_{g2} : The gear throat form radius is the radius of the throat surface of the gear blank in the transverse plane. See figure 4.

throat form radius, worm, r_{g1} : The worm throat form radius is the radius of the throat surface of the worm blank in the central plane. See figure 2.

tooth thickness, axial, s_{mx2} : The axial gear tooth thickness is the length of arc between the two sides of a gear tooth measured on the gear pitch circle. See figure 1.

tooth thickness, normal, s_{n2} : The normal gear tooth thickness is the length of arc between the two sides of a gear tooth in a plane normal to the tooth surface passing through the pitch point at the center of the gear tooth.

transverse plane: The transverse plane is the plane perpendicular to the worm axis, and contains the gear axis and the line of centers. See figures 3 and 4.

whole depth, h_1, h_2 : The whole depth is the total depth of a tooth space or thread space. It is the radial distance between the addendum circle and the root circle. See figure 1.

working depth, h_w : The working depth is the depth of engagement of the worm thread and gear tooth. See figure 1.

worm: The worm is the threaded input member. The worm has one or more threads, also called leads or starts. The threaded area of the worm has a throat which increases in diameter from the transverse plane toward both ends generally conforming to the curvature of the gear. See figures 2 and 3.

worm axis: The worm axis is the axis of rotation of the worm. The worm axis lies in the central plane. See figures 2 and 3.

wormgearing: Wormgearing refers to gearsets consisting of a worm and a gear.

3 General design considerations

Successful application of globoidal wormgearing begins with an understanding of the unique characteristics of this type of gearing and a consideration of the requirements for the application. This clause discusses both the Hindley and full contact designs.

3.1 Characteristics of wormgearing

Globoidal wormgearing consists of a threaded input member (worm) driving a larger toothed gear at right angles. By restraining the rotating worm axially, the gear is made to turn. As the worm rotates through the gear tooth, lines of contact progress from the outer edges of the face width of the gear tooth toward the center where they exit the mesh. As shown in figures 7 and 8, these contact lines are approximately perpendicular to the direction of rotation of the worm providing a favorable lubrication condition. At any given instant there will be several teeth in contact transmitting the power, where the number of teeth in contact is a function of pitch (tooth size) and worm length. Finer pitches will increase the number of teeth in contact but decrease the working depth. The worm length is limited by the pressure angle where the outermost thread cannot wrap around the gear to a point of interference with the gear teeth.

The Hindley gearset design has approximately 1/8 of the gear teeth in contact with the worm thread at any given instant. The loaded gear teeth are in varying positions along the worm thread as shown in figure 7. At any instant in time, each loaded tooth has one or two contact lines on its face. The contact lines sweep across the entering half of the gear tooth face and converge at the tooth centerline.

The full contact gearset design has approximately 1/8 of the gear teeth in contact with the worm thread at any given instant. The loaded gear teeth are in varying positions along the worm thread as shown in figure 8. At any instant in time, each loaded tooth has two contact lines on its face. The contact lines originate from each side of the gear tooth and progress toward the center where they converge. This design makes full use of the gear tooth by spreading the contact stress over a wider area.

The movement of lines of contact as the tooth progresses through the mesh results in an area of contact marking on each gear tooth. The stresses developed along the lines of contact are surface and subsurface stresses related to the load, the relative

radii of curvature of the worm thread and gear tooth, the distribution of load between the teeth, and the sliding friction forces caused by the rotation of the worm and the materials. When designing gearsets, consideration should be given to maximizing both the total length of contact lines and the relative radii of curvature between the worm and gear.

3.2 Application

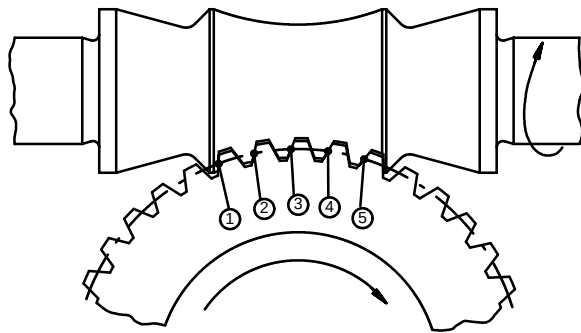
The design of globoidal wormgearing may be tailored to the type of load and speed being transmitted. For transmission of power at higher speeds, a relatively fine pitch gear tooth should be used, while high torques at low speeds require larger worm diameters and coarser pitches. When smoothness of transmission with low noise and vibration is a requirement, finer pitches are preferred. For general design when the application is not predefined, a balanced design approach would be appropriate.

3.3 Ratios

Globoidal wormgearing is generally limited to ratios of 3:1 through 100:1; however, ratios outside this range are possible when due consideration is given to the design and application. The ratio is the number of teeth in the gear divided by the number of threads in the worm. Ratios above 30:1 are usually produced with a single-thread worm and ratios lower than 30:1 favor the use of multiple threads. Generally, the larger the center distance, the greater the number of threads that should be selected. However, there can be exceptions.

In the design or selection of ratios requiring multiple thread worms, there are two tooth combination systems that can be used. One is the even number system where the number of teeth in the gear can be evenly divided by the number of threads in the worm, for example $40/2 = 20:1$. The hunting tooth ratio system uses a combination of gear teeth and worm threads where the number of teeth in the gear is not evenly divisible by the number of threads of the worm, for example $39/2 = 19.5:1$. Over the years, there has been a difference of opinion of the benefit of one system over the other. Use of state-of-the-art manufacturing equipment, tools, and technology has resulted in either of the two systems performing suitably in virtually all types of applications.

In designs requiring precision motion transmission, or in designs that are extremely cost sensitive, further investigation of the hunting tooth system versus even number system may be required.



Gear teeth in mesh

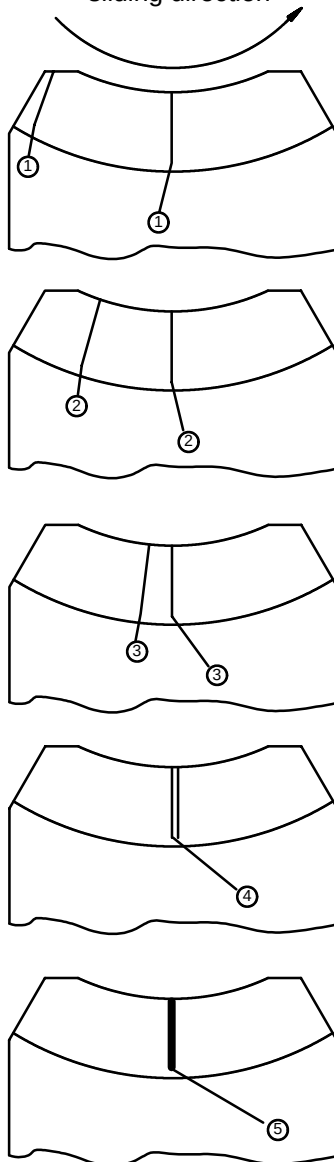
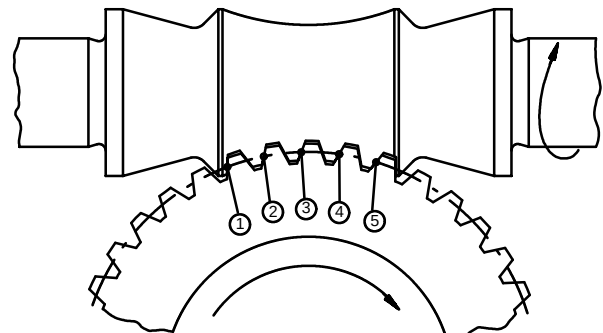
Worm thread
sliding directionLines of contact on
successive gear teeth

Figure 7 - Contact lines - Hindley design



Gear teeth in mesh

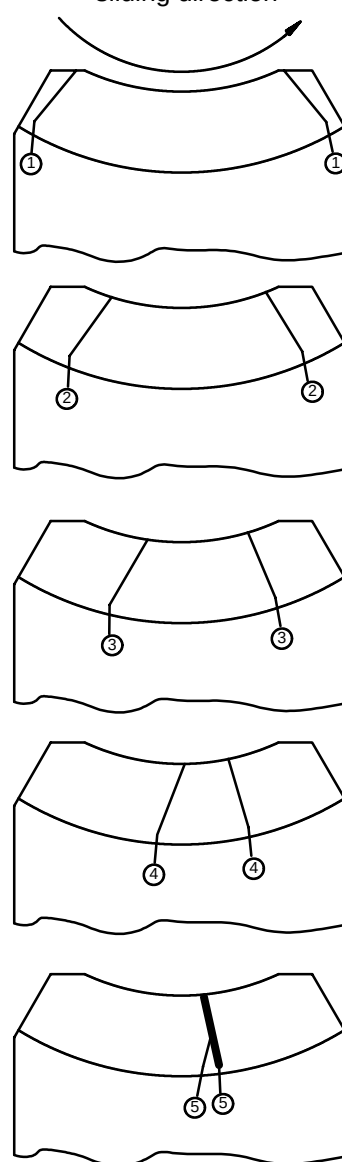
Worm thread
sliding directionLines of contact on
successive gear teeth

Figure 8 - Contact lines - Full contact design

3.4 Accuracy

Satisfactory performance of wormgearing depends on the accuracy of manufacturing even when an application has no special requirements for indexing, noise level or accuracy.

3.4.1 Worm accuracy

The accuracy of worm dimensions (i.e., runout, lead variations, profile variations, and thread spacing variations for multiple worms) are most important because the worm is the harder member and, as such, will not correct for these variations during run-in. In addition, the worm is subject to many more stress cycles than the gear.

3.4.2 Gear accuracy

The gear is usually made from the softer material and, as such, any initial minor tooth spacing variations as well as minor profile variations will be greatly reduced within a few hours of operation. However, excessive gear tooth runout will tend to accelerate the gear every half revolution causing contact area variations and increased stresses. Excessive face runout or wobble, either in hobbing or mounting of the gear, will also cause the gear contact area to shift across the face, causing the gear to accelerate and decelerate during each revolution.

3.5 Backlash

Gearsets have backlash (clearance) to allow for free running with lubrication between the worm threads and gear teeth. Backlash also allows for expansion of the worm threads and the gear teeth during operation, and for manufacturing tolerances of the worm and gear including tooth thickness and runout.

Backlash should be kept to a minimum in the design of the assembled gearset to minimize dynamic loading of the gear teeth and worm threads in load reversal applications. Gearset backlash will increase slightly after initial operation and run-in (see clause 7) and gradually over the life of the gearset as wear occurs.

3.5.1 Gearset backlash

Gearset backlash is defined as the rotational gear movement at a specified radius with the worm and gear on designed center distance, properly positioned and the worm held stationary. This value is generally converted to arc minutes or degrees. See table C.1 in annex C.

Backlash of worm gears is not defined as holding the gear stationary and rotating the worm because the amount of worm rotation becomes a function of ratio, and is not indicative of the clearance between the worm threads and gear teeth. The worm rotation resulting from gearset backlash is easily calculated by multiplying the gearset backlash measured at the gear (in arc minutes or degrees) by the ratio of the gearset. See annex C for backlash measurement.

Gearset backlash is usually specified by the manufacturer as a range (minimum to maximum) in units of arc minutes or degrees, and varies depending on the size of the gearset and the manufacturing processes used to produce the worm and gear. The backlash is specified and measured on the designed center distance with the worm and gear correctly positioned (see annex A). Each manufacturer specifies the backlash ranges for their various product lines and generally includes this information in their product catalog. Manufacturers may offer a range of options for reduced backlash.

The purchaser often specifies the maximum acceptable gearset backlash for a specific application.

3.5.2 Assembled backlash

When a gearset is assembled into a reducer or as part of a machine, the resulting rotational movement of the gear with the worm held stationary (assembled backlash) will be affected by the gearset backlash, manufacturing tolerances, and design clearances of the housing and mounting components. These include:

- Worm bearing endplay: The bearing endplay or clearance for tapered roller bearings results in axial and radial movement of the worm. Bearing endplay adds directly to the backlash of the gearset to increase assembled backlash. Angular contact (ball) bearings usually do not have endplay.
- Gear bearing endplay: Tapered roller bearings on the gearshaft operate at slow speed and are generally set with zero clearance to slightly preloaded. Even if there is a slight amount of endplay in the gear bearings, it will have very little effect on reducer backlash.
- Housing center distance: The manufacturing tolerance on housing center distance will affect backlash. If the housing center distance is greater than the design center distance (open condition), reducer assembled backlash will increase. If it is