



American
Gear Manufacturers
Association®

AGMA 929-B22
(Revision of AGMA 929-A06)

AGMA Information Sheet

Calculation of Bevel Gear Top Land, Slot Widths and Cutter Edge Radii

AGMA 929-B22

**American
Gear
Manufacturers
Association*****Calculation of Bevel Gear Top Land, Slot Widths and Cutter Edge Radii***

AGMA 929-B22

[Revision of AGMA 929-A06]

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ABSTRACT

This information sheet supplements ANSI/AGMA ISO 23509 with calculations for bevel gear top land and guidance for selection of cutter edge radius for determination of tooth geometry. It integrates various publications with modifications to include face hobbing. It adds top land calculations for non-generated manufacturing methods. It is intended to provide assistance in completing the calculations requiring determination of top lands and cutter edge radii for gear capacity in accordance with ANSI/AGMA 2003.

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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 AGMA 929-B22, *Calculation of Bevel Gear Top Land, Slot Widths and Cutter Edge Radii*.]

The Bevel Gearing Committee recognized the need for additional equations to aid in the design of bevel gears. The equations for geometry factors found in the annex of ANSI/AGMA 2003-C10 require detailed information on the proposed cutting tool before a proper calculation can be performed. In addition, the minimum top land thickness is required to aid in determining the maximum case depth allowed on carburized bevel gears. The equations required for these values were not published in AGMA documentation, but could be found, for some cases, in the publications listed in the bibliography of this information sheet. AGMA 929-A06 expands on those equations to include gears manufactured with the face hobbing cutting method.

The equations in this document may yield different values for top land thicknesses and tooth depth at the toe and heel than obtained on commercially available software. The pinion top land thickness is reduced by curvature added to the pinion, a natural consequence of the non-generated gear member having no profile curvature on the teeth. For the gear member, the non-generating process cuts a root line tangent to the gear root cone, a root line that does not wrap around the root cone as in the generated case. This leaves the toe and heel ends of the tooth slots shallow compared to the generated gear case, and the gear tooth space at the ends of the teeth narrower. The non-generated gear is the imaginary generating gear for the pinion. So the pinion teeth, which fit in the non-generated gear tooth slots, are thinner at the ends than their generated gear counterparts.

The cutter edge radii calculated in this document are based on the geometrical conditions as presented. The blades have manufacturing flats. Blade manufacturers have standard blade edge radii and manufacturing tolerances for their products, which should be considered when sourcing non-standard radii. It is recommended to work closely with the blade supplier to ensure design specifications and sourced product specifications are consistent.

AGMA 929-B22 replaces AGMA 929-A06. The main changes include calculations anywhere along the face width instead of just toe, mean, and heel.

The first draft of AGMA 929-B22 was made in January 2010. It was further developed based on 14FTM13 authored by B. Bijonowski. AGMA 929-B22 was approved by the Technical Division Executive Committee (TDEC) in August 2022.

The AGMA Bevel Gearing Committee wishes to dedicate this new revision to the memory of Ted Krenzer, long time employee of The Gleason Works and the U.S. delegate to ISO TC 60/ WG 13.

Suggestions for improvement of this information sheet will be welcome. They may be submitted to tech@agma.org.

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American Gear Manufacturers Association –

Calculation of Bevel Gear Top Land, Slot Widths and Cutter Edge Radii

1 Scope

This information sheet provides a set of equations for the calculation of bevel gear top land and guidance on cutter edge radius. It integrates the equations in ANSI/AGMA ISO 23509, *Bevel and Hypoid Gear Geometry*, and Gleason publication SD3124B, *Formulas for Cutter Specifications and Tooth Thickness Measurements for Spiral Bevel and Hypoid Gears*, with modifications to include face hobbing, and additions for the top land calculations for non-generated manufacturing methods, to achieve compatibility between publications.

It is intended to provide assistance in completing the calculations requiring determination of top lands and cutter edge radii in ANSI/AGMA 2003, *Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zerol Bevel and Spiral Bevel Gear Teeth*.

Annexes are provided for additional related information and calculation examples.

2 Symbols, terminology and definitions

2.1 Symbols and terminology

The equations in this information sheet are written in terms generally used for hypoids. See Table 1.

For other gears, the nomenclature from ANSI/AGMA ISO 23509 is used.

NOTE: Some of the symbols and terminology contained in this document may differ from those used in other documents and AGMA standards. Users of this information sheet should assure themselves that they are using the symbols, terminology and definitions in the manner indicated herein.

Table 1 – Symbols and terms

Symbol	Term	Units	Where first used
a	Offset	mm	Eq (13)
a_p	Offset in the pitch plane	mm	Eq (15)
b_1, b_2	Face width of pinion, wheel	mm	Eq (1), Eq (2)
c	Clearance	mm	Eq (62)
d_{e1}, d_{e2}	Outer pitch diameter, pinion, wheel	mm	Eq (9), Eq (10)
d_{m1}, d_{m2}	Mean pitch diameter, pinion, wheel	mm	Eq (7), Eq (8)
h_{ac1}	Pinion addendum at the chamfer starting point	mm	Eq (214)
h_{aci1}	Pinion addendum at the inner end chamfer	mm	Eq (203)
h_{ai1}, h_{ai2}	Inner addendum, pinion, wheel	mm	Eq (102), Eq (103)
h_{aiadj1}, h_{aiadj2}	Adjusted inner addendum, pinion, wheel	mm	Eq (106), Eq (107)
h_{am1}, h_{am2}	Mean addendum, pinion, wheel	mm	Eq (64), Eq (64)

Symbol	Term	Units	Where first used
h_{fm1}, h_{fm2}	Mean dedendum, pinion, wheel	mm	Eq (58), Eq (59)
h_{infcv1}, h_{infcv2}	Limit tooth height for interference concave, pinion, wheel	mm	Eq (122), Eq (127)
h_{infcx1}, h_{infcx2}	Limit tooth height for interference convex, pinion, wheel	mm	Eq (124), Eq (126)
j_{en}	Outer normal backlash allowance	mm	Eq (51)
k_E	Wheel rotation factor	- -	Eq (65)
m_{mn}	Mean normal module	mm	Eq (26)
p_n	Mean normal circular pitch	mm	Eq (50)
q_{x2}	Generating angle at involute curvature, wheel	degrees	Eq (42)
R_1, R_2	Cone distance at range variable, pinion, wheel	mm	Eq (1), Eq (2)
R_{c1}	Pinion cone distance at chamfer starting point	mm	Eq (193)
R_{e1}, R_{e2}	Outer cone distance, pinion, wheel	mm	Eq (1), Eq (2)
R_{e21}	Wheel cone distance of pinion outer boundary	mm	Eq (18)
R_{i21}	Wheel cone distance of pinion inner boundary	mm	Eq (19)
R_{m1}, R_{m2}	Mean cone distance, pinion, wheel	mm	Eq (3), Eq (4)
R_{x2}	Cone distance for involute lengthwise curvature point where normal circular pitch and slot width is a maximum, wheel	mm	Eq (39)
r_{bicv1}	Normal pinion concave base radius at inner end	mm	Eq (197)
r_{bicv21}	Normal wheel concave base radius of pinion inner boundary	mm	Eq (200)
r_{bicx1}	Normal pinion convex base radius at inner end	mm	Eq (198)
r_{bicx21}	Normal wheel convex base radius of pinion inner boundary	mm	Eq (199)
r_{naci1}	Normal pinion outside (tip) radius at the inner end chamfer	mm	Eq (204)
r_{naci21}	Normal wheel radius of pinion inner boundary at tooth chamfer (non-generated only)	mm	Eq (205)
r_{nipt1}	Normal pinion pitch radius at inner end	mm	Eq (195)
r_{nipt21}	Normal wheel pitch radius of pinion inner boundary	mm	Eq (196)
r_{a02R1}, r_{a02R2}	Maximum roughing blade edge radius which can be manufactured, pinion, wheel	mm	Eq (137), Eq (136)
r_{a02cv1}, r_{a02cv2}	Maximum finishing blade edge radius concave, defined by maximum roughing blade edge radius and minimum stock allowance, pinion, wheel	mm	Eq (140), Eq (143)
r_{a02cx1}, r_{a02cx2}	Maximum finishing blade edge radius convex, defined by maximum roughing blade edge radius and minimum stock allowance, pinion, wheel	mm	Eq (141), Eq (142)
r_{a011}, r_{a012}	Maximum blade edge radius for no running interference, pinion, wheel	mm	Eq (98), Eq (99)

Symbol	Term	Units	Where first used
r_{a021}, r_{a022}	Maximum blade edge radius that can be manufactured, pinion, wheel	mm	Eq (98), Eq (99)
r_{a031}, r_{a032}	Maximum blade edge radius to avoid mutilation, pinion, wheel	mm	Eq (98), Eq (99)
r_{a0cv11}, r_{a0cv12}	Maximum blade edge radius for no running interference concave, pinion, wheel	mm	Eq (128), Eq (131)
r_{a0cx11}, r_{a0cx12}	Maximum blade edge radius for no running interference convex, pinion, wheel	mm	Eq (129), Eq (130)
r_{a0max1}, r_{a0max2}	Maximum blade edge radius, pinion, wheel	mm	Eq (98), Eq (99)
r_{a0cv31}, r_{a0cv32}	Maximum blade edge radius to avoid mutilation concave, pinion, wheel	mm	Eq (159), Eq (161)
r_{a0cx31}, r_{a0cx32}	Maximum blade edge radius to avoid mutilation convex, pinion, wheel	mm	Eq (158), Eq (160)
r_{a0rh1}, r_{a0rh2}	Roughing cutter edge radius, pinion, wheel	mm	Eq (139), Eq (138)
r_{bicv1}, r_{bicv2}	Inner base radius - concave, pinion, wheel	mm	Eq (112), Eq (115)
r_{bicx1}, r_{bicx2}	Inner base radius - convex, pinion, wheel	mm	Eq (113), Eq (114)
r_{c0}	Cutter radius	mm	Eq (22)
r_{fincv1}, r_{fincv2}	Maximum finishing blade edge radius concave, pinion, wheel	mm	Eq (144), Eq (147)
r_{fincx1}, r_{fincx2}	Maximum finishing blade edge radius convex, pinion, wheel	mm	Eq (145), Eq (146)
r_{i1}, r_{i2}	Original inner pitch radius, pinion, wheel	mm	Eq (100), Eq (101)
r_{ai1}, r_{ai2}	Inner outside radius, pinion, wheel	mm	Eq (110), Eq (111)
r_{iadj1}, r_{iadj2}	Adjusted inner pitch radius, pinion, wheel	mm	Eq (108), Eq (109)
S_{A1}, S_{A2}	Stock allowance, pinion, wheel	mm	Eq (91), Eq (90)
S_{acn1}	Pinion normal top land at chamfer starting point	mm	Eq (190)
$S_{acn\Delta1}$	Desired pinion normal top land at chamfer starting point and pinion inner end	mm	Eq (191)
S_{aen1}, S_{aen2}	Outer normal top land, pinion, wheel	mm	Eq (185), Eq (188)
S_{ain1}, S_{ain2}	Inner normal top land, pinion, wheel	mm	Eq (183), Eq (186)
S_{amn1}, S_{amn2}	Mean normal top land, pinion, wheel	mm	Eq (184), Eq (187)
S_{anci1}	Normal pinion top land at inner chamfer	mm	Eq (210)
S_{ni1}	Normal pinion circular thickness at inner end	mm	Eq (201)
S_{ni21}	Normal wheel circular thickness of pinion inner boundary	mm	Eq (202)
S_{mn1}, S_{mn2}	Mean normal circular thickness at pitch line, pinion, wheel	mm	Eq (51), Eq (51)
t_{c1}	Length of chamfer	mm	Eq (194)
W	Finishing point width, wheel (Unitool and single sided)	mm	Eq (69)
W_{B1}, W_{B2}	Finishing blade point, pinion, wheel	mm	Eq (95), Eq (94)

Symbol	Term	Units	Where first used
W_{BR1}, W_{BR2}	Roughing blade point, pinion, wheel	mm	Eq (93), Eq (92)
W_{e1}, W_{e2}	Outer slot width, pinion, wheel	mm	Eq (78), Eq (77)
W_{eff}	Effective wheel point width	mm	Eq (72)
W_{i1}, W_{i2}	Inner slot width, pinion, wheel	mm	Eq (81), Eq (80)
W_{m1}, W_{m2}	Mean slot width, pinion, wheel	mm	Eq (79), Eq (64)
W_{max1}, W_{max2}	Maximum slot width, pinion, wheel	mm	Eq (89), Eq (88)
W_{min1}, W_{min2}	Minimum slot width, pinion, wheel	mm	Eq (87), Eq (86)
W_{r1}, W_{r2}	Roughing point width, pinion, wheel	mm	Eq (91), Eq (90)
W_{x1}, W_{x2}	Slot width at R_{x2} (maximum pinion, wheel slot width)	mm	Eq (83), Eq (82)
y	Amount of fillet mutilation permitted	mm	Eq (154)
z_0	Number of blade groups	- -	Eq (26)
z_2	Number of wheel teeth	- -	Eq (28)
α_{aciv1}	Pinion concave pressure angle at inner end tooth chamfer	degrees	Eq (206)
α_{aciv21}	Wheel concave pressure angle of pinion inner boundary at tooth chamfer (non-generated only)	degrees	Eq (209)
α_{acix1}	Pinion convex pressure angle at inner end tooth chamfer	degrees	Eq (207)
α_{acix21}	Wheel convex pressure angle of pinion inner boundary at tooth chamfer (non-generated only)	degrees	Eq (208)
α_{BX2}	Inside blade angle wheel cutter (non-generating)	degrees	Eq (48)
α_{cv1}	Normal pressure angle, concave pinion	degrees	Eq (48)
α_{cx1}	Normal pressure angle, convex pinion	degrees	Eq (49)
α_{icv1}	Inner pinion pressure angle - concave	degrees	Eq (116)
α_{icx1}	Inner pinion pressure angle - convex	degrees	Eq (117)
β_{e1}, β_{e2}	Outer spiral angle, pinion, wheel	degrees	Eq (35), Eq (37)
β_{e21}	Wheel spiral angle at pinion outer boundary	degrees	Eq (24)
β_{i1}, β_{i2}	Inner spiral angle, pinion, wheel	degrees	Eq (36), Eq (38)
β_{i21}	Wheel spiral angle at pinion inner boundary	degrees	Eq (25)
β_{m2}	Mean spiral angle, wheel	degrees	Eq (22)
β_{x2}	Spiral angle at cone distance R_{x2}	degrees	Eq (43)
$\Delta c_1, \Delta c_2$	Change in clearance, pinion, wheel	mm	Eq (52), Eq (53)
$\Delta h_{ai1}, \Delta h_{ai2}$	Change in inner addendum, pinion, wheel	mm	Eq (104), Eq (105)
Δf	Width of blade flat	mm	Eq (136)
$\Delta W_{min1}, \Delta W_{min2}$	Difference between minimum slot width and blade point, pinion, wheel	mm	Eq (152), Eq (153)
$\Delta \alpha_2$	Normal tilt of finishing cutter non-generated	degrees	Eq (48)

Symbol	Term	Units	Where first used
$\Delta\Sigma$	Shaft angle departure from 90 degrees	degrees	Eq (11)
δ_{ac1}	Pinion chamfer angle	degrees	Eq (215)
δ_{f2}	Wheel root angle	degrees	Eq (12)
δ_1, δ_2	Pitch angle, pinion, wheel	degrees	Eq (7), Eq (8)
θ_{f1}, θ_{f2}	Dedendum angles, pinion, wheel	degrees	Eq (58), Eq (12)
μ_1, μ_2	Range variable, pinion, wheel		Eq (5), Eq (6)
μ_{c1}	Pinion range variable at chamfer starting point		Eq (189)
μ_{e1}, μ_{e2}	Range variable at heel, pinion, wheel		Eq (18), Eq (37)
μ_{e21}	Wheel range variable of pinion outer boundary		Eq (20)
μ_{i1}, μ_{i2}	Range variable at toe, pinion, wheel		Eq (19), Eq (38)
μ_{i21}	Wheel range variable of pinion inner boundary		Eq (21)
μ_{m1}, μ_{m2}	Range variable at mean, pinion, wheel		Eq (3), Eq (4)
μ_{x2}	Wheel range variable at involute curvature		Eq (40)
v	Lead angle of cutter	degrees	Eq (26)
ρ_b	Epicycloid base circle radius	mm	Eq (28)
ρ_{icv1}, ρ_{icv2}	Inner profile radius of curvature concave, pinion, wheel	mm	Eq (118), Eq (121)
ρ_{icx1}, ρ_{icx2}	Inner profile radius of curvature convex, pinion, wheel	mm	Eq (119), Eq (120)
ρ_{P0}	Crown wheel center to cutter center distance	mm	Eq (27)
Σ	Shaft angle	degrees	Eq (11)
$\Sigma\alpha$	Included pressure angle	degrees	Eq (49)
ξ	Angle between wheel root plane and plane in which taper is specified	degrees	Eq (73)
ζ_m	Pinion offset angle in axial plane	degrees	Eq (13)
ζ_{mp}	Offset angle in pitch plane, pinion and wheel	degrees	Eq (14)
$\Omega_{cv1}, \Omega_{cv2}$	Intermediate blade mutilation value concave, pinion, wheel	mm ²	Eq (154), Eq (157)
$\Omega_{cx1}, \Omega_{cx2}$	Intermediate blade mutilation value convex, pinion, wheel	mm ²	Eq (155), Eq (156)

2.2 Definitions

This clause provides supplemental definitions for bevel gear cutter and cutting method terminologies referred to in this information sheet. The list of definitions given here is not intended to be all-inclusive. For more detailed information regarding a particular cutter design or cutting method, the user is encouraged to consult the cutter manufacturer's data or machine tool manufacturer.

2.2.1 Bevel gear cutter terminology

alternate blade. Any multiple blade face cutter having successive blades that cut on opposite sides of a tooth space.

blade flat. A flat land on the tip end of blades required for blade manufacturing control, see Figure 4.

blade point. The length across the tip end surface of a blade or tool (measured along a radius of a circular cutter), bounded by the extension of the cutting edge and non-cutting edge of the blade, see Figure 4.

blade, inside. A blade of a circular face cutter with a cutting edge that produces the convex side of a tooth surface, see Figure 4.

blade, outside. A blade of a circular face cutter with a cutting edge that produces the concave tooth surface, see Figure 4.

coast side. The side of a tooth flank that is in contact with the opposite flank of the mate when the gear set is driven in the reverse direction.

drive side. The side of a tooth flank that is in contact with the opposite flank of the mate when the gear set is driven in the forward direction.

effective gear point width. Effective point width is one half of the difference of the outside minus the inside point diameters of a cutter. The effective point width is not equal to the slot width produced on the part when indexing motion occurs between drive and coast side generation. For spread blade cutters, the effective point width equals the actual cutter point width. When indexing accounts for part of the slot width, the effective point width can be negative.

fillet mutilation. Fouling of tooth fillet by the non-cutting side of the blade tip. This is caused by a tool edge radius or a blade point which is too large.

point width. One half of the difference between the inside and outside point diameters of an alternate blade cutter.

2.2.2 Bevel gear cutting method terminology

completing. A machining process where the tooth space is completed in one machining setup. Unlike single side, single setting, or fixed setting methods where the tooth space roughing and finishing are carried out in separate machining setups.

cutter tilt. A change in the relative position between workpiece and cutter, measured as an angle in the normal, or axial, or both planes of the workpiece.

Formate. A term describing non-generated gear members whose teeth have surfaces of revolution, and straight profiles in their normal sections. Pinions generated to run with such gears are called Formate pinions.

non-generated method. A gear cutting process where the tooth space is machined without generating motion (see Formate). The tooth surfaces are formed by the sweep of a straight-sided cutting tool and thus have straight profiles in any normal section.

single setting. A finishing method, which is a variation of the spread blade method. Refers to a method for finishing one side of gear teeth at a time using one alternate-blade circular face-mill cutter with a point width slightly narrower than the slot width, which is uniform along the tooth length. Machine settings are not altered between the cutting operations of the two sides of the teeth.

single side. A cutting method, which uses an alternate blade cutter to separately, cut the profiles on each side of a tooth space, with independent machine settings.

spread blade. A cutting method which uses a circular face cutter with alternate inside and outside blades to cut both sides of a tooth space at the same time.

Unitool. A method for producing pairs of spiral bevel, zerol bevel or hypoid gears using the same single face mill cutter for both members. The cutters used with this method are designated as Unitool cutters.

Versacut. A process, which requires very few cutters to accommodate a wide variety of spiral bevel gears. The cutters used with this method are designated as Versacut cutters.

3 Input data

The equations in this information sheet are intended to be as general as possible. Many of the calculations require knowledge of the specific cutting method used in manufacture.

The tables in this clause describe the data necessary to complete the calculations of this information sheet. In most cases the values can be obtained from the calculations detailed in ANSI/AGMA ISO 23509. Many of those calculations are duplicated in Clause 4 where needed.

NOTE: These values may not agree with commercial software.

3.1 Input variables

Table 2 contains all the input variables necessary for the calculations used in this information sheet.

Table 2 – Input variables

Symbol	Term	Units
Σ	Shaft angle	degrees
a	Hypoid offset	mm
z_1, z_2	Number of teeth, pinion, wheel	--
m_{mn}	Mean normal module	mm
b_1, b_2	Face width, pinion, wheel	mm
R_{e1}, R_{e2}	Outer cone distance, pinion, wheel	mm
R_{m1}, R_{m2}	Mean cone distance, pinion, wheel	mm
α_{cv1}	Concave pinion normal pressure angle	degrees
α_{cx1}	Convex pinion normal pressure angle (always negative)	degrees
β_{m2}	Wheel mean spiral angle	degrees
δ_1, δ_2	Pitch angle, pinion, wheel	degrees
θ_{f1}, θ_{f2}	Dedendum angle, pinion, wheel	degrees
c	Clearance	mm
h_{am1}, h_{am2}	Mean addendum, pinion, wheel	mm
h_{fm1}, h_{fm2}	Mean dedendum, pinion, wheel	mm
s_{mn1}, s_{mn2}	Mean normal circular thickness, pinion, wheel	mm
r_{c0}	Cutter radius	mm
z_0	Number of blade groups (face hobbing)	--
α_{BX2}	Inside blade angle, wheel cutter (non-generating)	degrees
W	Wheel finishing point width (Unitool and single setting)	mm
S_{A1}, S_{A2}	Stock allowance, pinion, wheel	mm
y	Amount of fillet mutilation permitted	mm
Δf	Width of blade flat	mm

3.2 Wheel rotation factor

Input variable k_E is based on the cutting method to be used in manufacture (See 4.5.2).

3.3 Suggested default values for variables

Table 3 contains some suggested default values for variables not described in ANSI/AGMA ISO 23509. Other values may be used if experience dictates.

Table 3 – Suggested default values for input variables

Symbol	Term	Units	Suggested default
α_{BX2}	Inside blade angle of wheel cutter (non-generated wheel only)	degrees	Average pressure angle
S_{A1}	Stock allowance, pinion	mm	For completing, use 0.000
			For rough and finish, use actual or see Annex B
S_{A2}	Stock allowance, wheel	mm	For completing, use 0.000
			For rough and finish, use actual or see Annex B
y	Amount of fillet mutilation permitted	mm	0.05
Δf	Width of blade flat	mm	0.20
r_{c0}	Cutter radius (straight bevel gears)	mm	254000
	Cutter radius (all other bevel gears)		See ANSI/AGMA ISO 23509 Annex D

4 Calculations

4.1 General geometry

Many of the following formulas are presented in function notation. These formulas are expressed as functions of pinion and wheel range variables, μ_1 and μ_2 , respectively. Within the pinion and wheel tooth boundaries, the valid range for μ_1 and μ_2 is between 0 and 1, where 0 is located at the heel of the tooth, and 1, at the toe of the tooth. By changing the value of range variables, tooth geometry at different points of interest can be calculated. Table 4 displays the values for range variables, μ_1 and μ_2 , at inner, mean, outer, and involute lengthwise curvature, where top land calculations are typically required.

Function notation defined in this document has the form $F_a\{x\}$, where F_a is the name of the function and x , the argument. Braces $\{ \}$ are exclusively used for the function notation to distinguish it from ordinary trigonometric and involute functions, which use parentheses $()$. A detailed explanation of function notation is given in Annex A.

Table 4 – Point of interest, μ_1 and μ_2 , along pitch cone

Point of interest	Value of range variable	
	Pinion	Wheel
Inner (Toe)	$\mu_{i1} = 1.0$	$\mu_{i2} = 1.0$
Mean	μ_{m1}	μ_{m2}
Outer (Heel)	$\mu_{e1} = 0.0$	$\mu_{e2} = 0.0$
Involute lengthwise curvature	μ_{x1}	μ_{x2}

Range variable for pinion cone distance R_1

$$\mu_1 \{R_1\} = \frac{R_{e1} - R_1}{b_1} \quad (1)$$

Range variable for wheel cone distance R_2

$$\mu_2 \{R_2\} = \frac{R_{e2} - R_2}{b_2} \quad (2)$$

Pinion range variable at mean, μ_{m1}

$$\mu_{m1} = \mu_1 \{R_{m1}\} \quad (3)$$

Wheel range variable at mean, μ_{m2}

$$\mu_{m2} = \mu_2 \{R_{m2}\} \quad (4)$$

Pinion cone distance located at point μ_1

$$R_1 \{\mu_1\} = R_{e1} - \mu_1 b_1 \quad (5)$$

Wheel cone distance located at point μ_2

$$R_2 \{\mu_2\} = R_{e2} - \mu_2 b_2 \quad (6)$$

Pinion mean pitch diameter, d_{m1}

$$d_{m1} = 2R_{m1} \sin \delta_1 \quad (7)$$

Wheel mean pitch diameter, d_{m2}

$$d_{m2} = 2R_{m2} \sin \delta_2 \quad (8)$$

Pinion outer pitch diameter, d_{e1}

$$d_{e1} = 2R_{e1} \sin \delta_1 \quad (9)$$

Wheel outer pitch diameter, d_{e2}

$$d_{e2} = 2R_{e2} \sin \delta_2 \quad (10)$$

Shaft angle departure from 90 degrees, $\Delta\Sigma$

$$\Delta\Sigma = \Sigma - 90^\circ \quad (11)$$

Wheel root angle, δ_{f2}

$$\delta_{f2} = \delta_2 - \theta_{f2} \quad (12)$$

Pinion offset angle in axial plane, ζ_m

$$\zeta_m = \arcsin \left[\frac{2a}{d_{m2} + d_{m1} \frac{\cos \delta_2}{\cos \delta_1}} \right] \quad (13)$$

Offset angle in pitch plane, pinion and wheel, ζ_{mp}

$$\zeta_{mp} = \arcsin\left(\frac{\sin\zeta_m \sin\Sigma}{\cos\delta_1}\right) \quad (14)$$

Offset in the pitch plane, a_p

$$a_p = R_{m2} \sin\zeta_{mp} \quad (15)$$

4.2 Determination of spiral angles

4.2.1 Pinion inner and outer spiral angles

In order to determine pinion inner and outer spiral angles, it is necessary to determine wheel spiral angle at wheel cone distances R_{i21} and R_{e21} of inner and outer pinion boundary points, see Figure 1.

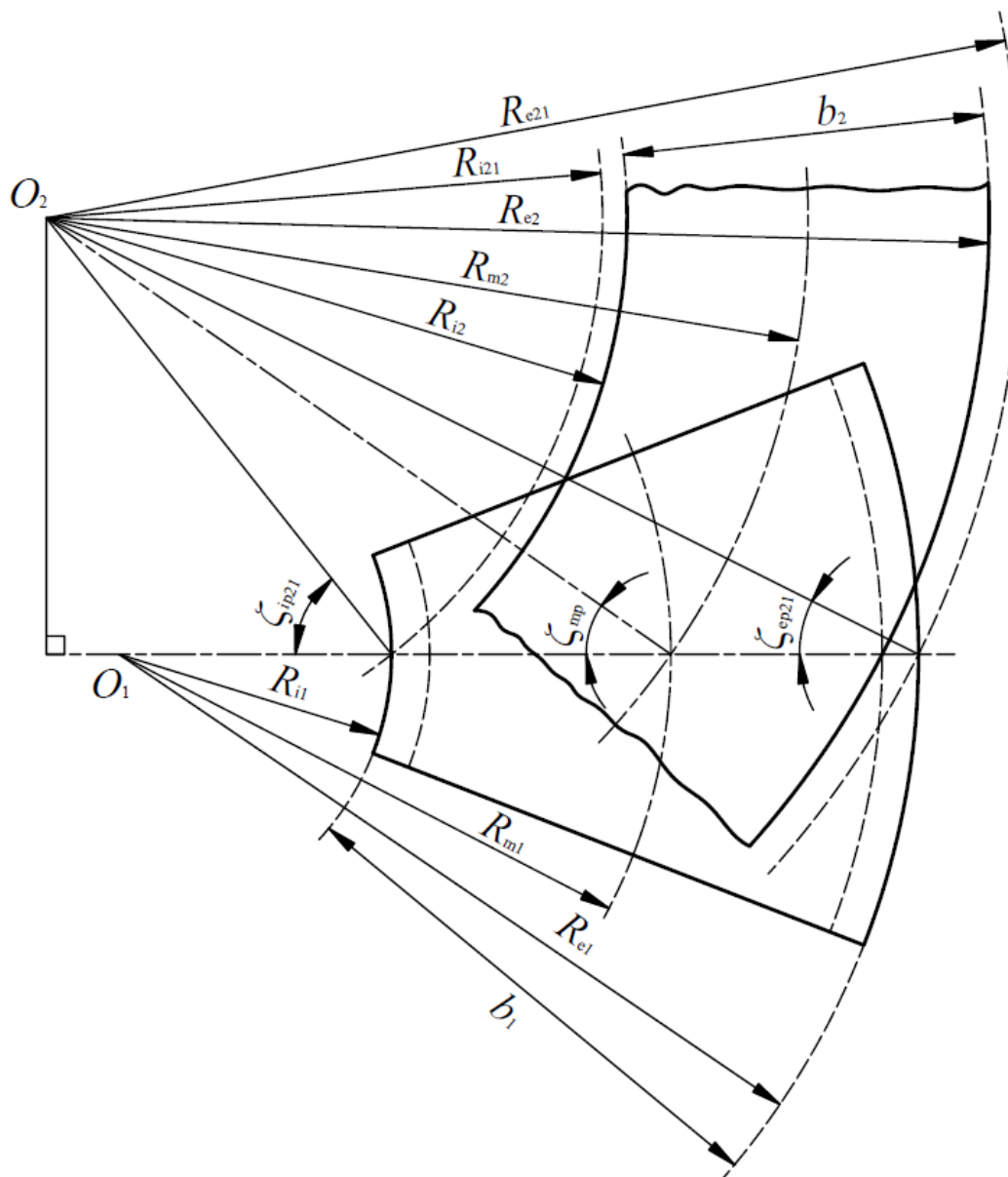


Figure 1 – Determination of pinion spiral angle in pitch plane

Wheel cone distance of pinion boundary at point μ_1

$$R_{21}\{\mu_1\} = \sqrt{R_{m2}^2 + [(\mu_1 - \mu_{m1})b_1]^2} - 2R_{m2}(\mu_1 - \mu_{m1})b_1 \cos \zeta_{mp} \quad (16)$$

Wheel point $\mu_{21}\{\mu_1\}$ of pinion boundary at point μ_1

$$\mu_{21}\{\mu_1\} = \mu_2\{R_{21}\{\mu_1\}\} \quad (17)$$

Wheel cone distance R_{e21} of pinion outer boundary, where R_{e21} may be greater than R_{e2}

$$R_{e21} = R_{21}\{\mu_{e1}\} \quad (18)$$

Wheel cone distance R_{i21} of pinion inner boundary, where R_{i21} may be smaller than R_{i2}

$$R_{i21} = R_{21}\{\mu_{i1}\} \quad (19)$$

Range variable for wheel cone distance R_{e21}

$$\mu_{e21} = \mu_2\{R_{e21}\} \quad (20)$$

Range variable for wheel cone distance R_{i21}

$$\mu_{i21} = \mu_2\{R_{i21}\} \quad (21)$$

Face milling

Wheel spiral angle at point μ_2 along pitch cone

$$\beta_2\{\mu_2\} = \arcsin \left[\frac{2R_{m2}r_{c0} \sin \beta_{m2} - R_{m2}^2 + R_2^2\{\mu_2\}}{2R_2\{\mu_2\}r_{c0}} \right] \quad (22)$$

Wheel generating angle at point μ_2 along pitch cone

$$q_2\{\mu_2\} = \frac{r_{c0} \cos(\beta_2\{\mu_2\})}{R_2\{\mu_2\} - r_{c0} \sin(\beta_2\{\mu_2\})} \quad (23)$$

Wheel spiral angle at point μ_{e21}

$$\beta_{e21} = \beta_2\{\mu_{e21}\} \quad (24)$$

Wheel spiral angle at point μ_{i21}

$$\beta_{i21} = \beta_2\{\mu_{i21}\} \quad (25)$$

Face hobbing

Lead angle of cutter, ν

$$\nu = \arcsin \left(\frac{z_0 m_{mn}}{2r_{c0}} \right) \quad (26)$$

Crown gear to cutter center distance, ρ_{P0}

$$\rho_{P0} = \sqrt{R_{m2}^2 + r_{c0}^2 - 2R_{m2}r_{c0} \sin(\beta_{m2} - \nu)} \quad (27)$$

Epicycloid base circle radius, ρ_b

$$\rho_b = \frac{\rho_{P0}}{1 + \frac{z_0}{z_2} \sin \delta_2} \quad (28)$$

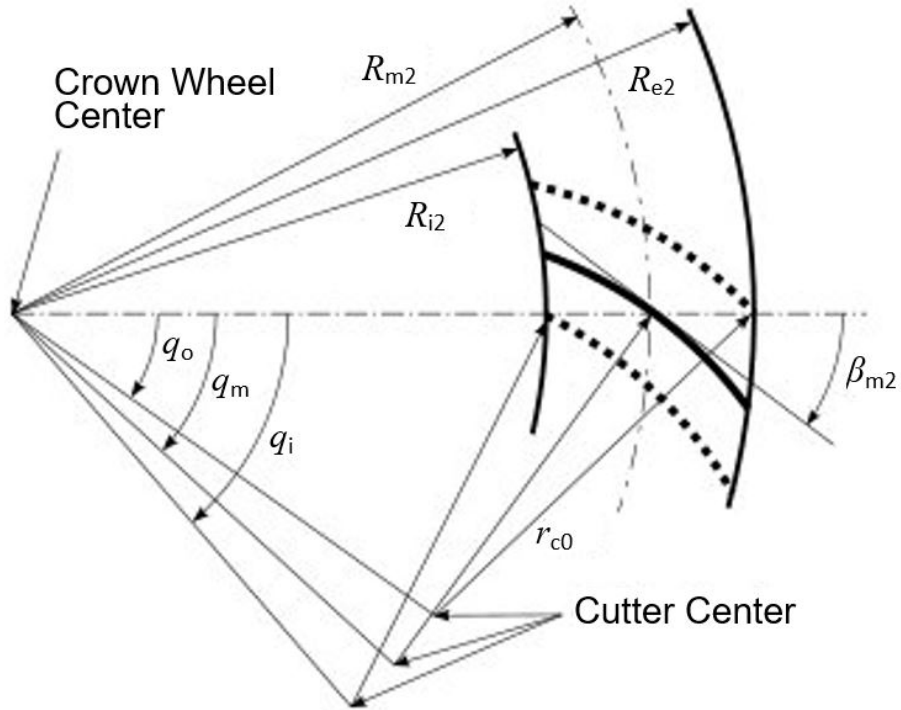


Figure 2 – Generating angles

Wheel generating angle at point μ_2 along pitch cone

$$q_2 \{ \mu_2 \} = \arccos \left[\frac{R_2^2 \{ \mu_2 \} + \rho_{P0}^2 - r_{c0}^2}{2 R_2 \{ \mu_2 \} \rho_{P0}} \right] \quad (29)$$

Wheel spiral angle at point μ_2 along pitch cone

$$\beta_2 \{ \mu_2 \} = \arctan \left[\frac{R_2 \{ \mu_2 \} - \rho_b \cos(q_2 \{ \mu_2 \})}{\rho_b \sin(q_2 \{ \mu_2 \})} \right] \quad (30)$$

Wheel spiral angle at point μ_{e21}

$$\beta_{e21} = \beta_2 \{ \mu_{e21} \} \quad (31)$$

Wheel spiral angle at point μ_{i21}

$$\beta_{i21} = \beta_2 \{ \mu_{i21} \} \quad (32)$$

Face hobbing and face milling

Pinion offset angle in pitch plane of wheel boundary point μ_2 along wheel pitch cone

$$\zeta_{p2} \{\mu_2\} = \arcsin \left(\frac{a_p}{R_2 \{\mu_2\}} \right) \quad (33)$$

Pinion spiral angle of wheel boundary point μ_2

$$\beta_{12} \{\mu_2\} = \beta_2 \{\mu_2\} + \zeta_{p2} \{\mu_2\} \quad (34)$$

Pinion outer spiral angle, β_{e1}

$$\beta_{e1} = \beta_{12} \{\mu_{e21}\} \quad (35)$$

Pinion inner spiral angle, β_{i1}

$$\beta_{i1} = \beta_{12} \{\mu_{i21}\} \quad (36)$$

4.2.2 Wheel outer and inner spiral angles

Wheel outer spiral angle, β_{e2}

$$\beta_{e2} = \beta_2 \{\mu_{e2}\} \quad (37)$$

Wheel inner spiral angle, β_{i2}

$$\beta_{i2} = \beta_2 \{\mu_{i2}\} \quad (38)$$

4.3 Cone distance for involute lengthwise curvature

Cone distance for involute lengthwise curvature point R_{x2} , where normal circular pitch and slot width are at maximum.

Face milling

$$R_{x2} = \sqrt{R_{m2}^2 - 2R_{m2}r_{c0} \sin \beta_{m2} + 2r_{c0}^2} \quad (39)$$

$$\mu_{x2} = \mu_2 \{R_{x2}\} \quad (40)$$

Face hobbing

Iterate for wheel cone distance and spiral angle at involute lengthwise curvature.

First trial

$$\mu_{x2} = \mu_{m2} \quad (41)$$

Generating angle at point μ_{x2}

$$q_{x2} = q_2 \{\mu_{x2}\} \quad (42)$$

Wheel spiral angle at point μ_{x2}

$$\beta_{x2} = \beta_2 \{\mu_{x2}\} \quad (43)$$

Change μ_{x2} until

$$|q_{x2} - \beta_{x2}| \leq 0.001 \quad (44)$$

For the second trial make

$$\mu_{x2} = \mu_{x1} + 0.001 \quad (45)$$

For third and subsequent trials interpolate.

End of iteration

Wheel cone distance at point μ_{x2}

$$R_{x2} = R_2 \{ \mu_{x2} \} \quad (46)$$

Wheel spiral angle at involute lengthwise curvature β_{x2}

$$\beta_{x2} = \beta_2 \{ \mu_{x2} \} \quad (47)$$

4.4 Additional geometry calculations

For non-generated wheels normal tilt of finishing cutter, $\Delta\alpha_2$

$$\Delta\alpha_2 = \alpha_{BX2} - \alpha_{cv1} \quad (48)$$

Included pressure angle, $\Sigma\alpha$

$$\Sigma\alpha = \alpha_{cv1} - \alpha_{cx1} \quad (49)$$

Mean normal circular pitch, p_n

$$p_n = \pi m_{mn} \quad (50)$$

Outer normal backlash, j_{en}

$$j_{en} = \left[p_n - (s_{mn1} + s_{mn2}) \right] \frac{R_{e2} \cos \beta_{e2} \cos \left(\frac{\Sigma\alpha}{2} \right)}{R_{m2} \cos \beta_{m2}} \quad (51)$$

Change in clearance

Pinion

$$\Delta c_1 = \frac{j_{en} R_1 \{ \mu_{i1} \} \cos \beta_{i1}}{R_{e1} \cos \beta_{e1}} \frac{1}{\sin \alpha_{cv1} - \sin \alpha_{cx1}} \quad (52)$$

Wheel

$$\Delta c_2 = \frac{j_{en} R_2 \{ \mu_{i2} \} \cos \beta_{i2}}{R_{e2} \cos \beta_{e2}} \frac{1}{\sin \alpha_{cv1} - \sin \alpha_{cx1}} \quad (53)$$

If Δc_1 is greater than $0.75c$, or if Δc_2 is greater than $0.75c$, reduce j_{en} or increase clearance c .

Increment in generating angle, $\Delta q\{\mu_2\}$

$$\Delta q\{\mu_2\} = |q_2\{\mu_{m2}\} - q_2\{\mu_2\}| \quad (54)$$

Pinion cone distance of wheel boundary at point μ_2

$$R_{12}\{\mu_2\} = R_{m1} + R_2\{\mu_2\} \cos(\zeta_{p2}\{\mu_2\}) - R_{m2} \cos(\zeta_{mp}) \quad (55)$$

Pinion point μ_{12} of wheel boundary at point μ_2

$$\mu_{12}\{\mu_2\} = \mu_1\{R_{12}\{\mu_2\}\} \quad (56)$$

Generated wheels have slightly deeper teeth at the toe and heel ends than non-generated wheels, which is caused by the relative rolling action between cutter and work piece. Non-generated wheels do not reach the theoretical depth at both tooth ends; this depth reduction is calculated by:

$$\Delta h_2\{\mu_2\} = \frac{[b_2(\mu_{m2} - \mu_2)]^2 \tan \Delta \alpha_2}{2r_{c0} \cos^2 \beta_{m2}} + \frac{R_2\{\mu_2\} \sin^2(\Delta q\{\mu_2\})}{2 \tan \delta_{f2}} \quad (57)$$

Dedendum along pitch cone

Pinion

$$h_{f1}\{\mu_1\} = h_{fm1} + (\mu_{m1} - \mu_1) b_1 \tan \theta_{f1} \quad (58)$$

Non-generated wheel

$$h_{f2}\{\mu_2\} = h_{fm2} + (\mu_{m2} - \mu_2) b_2 \tan \theta_{f2} - \Delta h_2\{\mu_2\} \quad (59)$$

Generated wheel

$$h_{f2}\{\mu_2\} = h_{fm2} + (\mu_{m2} - \mu_2) b_2 \tan \theta_{f2} \quad (60)$$

Sum of pinion and wheel dedendum at point μ_2 along pitch cone

$$\Sigma h_f\{\mu_2\} = h_{f1}\{\mu_{12}\{\mu_2\}\} + h_{f2}\{\mu_2\} \quad (61)$$

Addendum along pitch cone

Pinion

$$h_{a1}\{\mu_1\} = h_{f2}\{\mu_{21}\{\mu_1\}\} - c \quad (62)$$

Wheel

$$h_{a2}\{\mu_2\} = h_{f1}\{\mu_{12}\{\mu_2\}\} - c \quad (63)$$

4.5 Slot width calculations and blade specifications

4.5.1 Mean wheel slot width

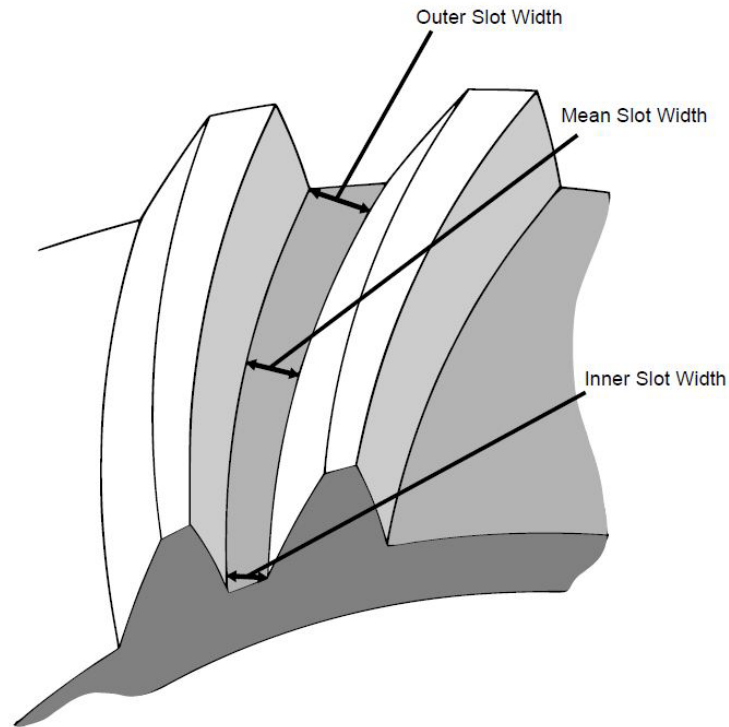


Figure 3 – Slot width, inner, mean and outer

Mean wheel slot width, W_{m2}

$$W_{m2} = p_n - s_{mn2} - \frac{\Sigma h_f \{ \mu_{m2} \}}{2} (\tan \alpha_{cv1} - \tan \alpha_{cx1}) - (h_{am1} - h_{am2}) \tan \left(\frac{\Sigma \alpha}{2} \right) \quad (64)$$

4.5.2 Wheel rotation factor, k_E

Face hobbing

Gleason or Klingelnberg

$$k_E = 1.0 \quad (65)$$

Oerlikon not using roughing blade

$$k_E = 1.0 \quad (66)$$

Oerlikon using a roughing blade

$$k_E = 1.3 \quad (67)$$

Face milling

Spread blade

$$k_E = 0.0 \quad (68)$$