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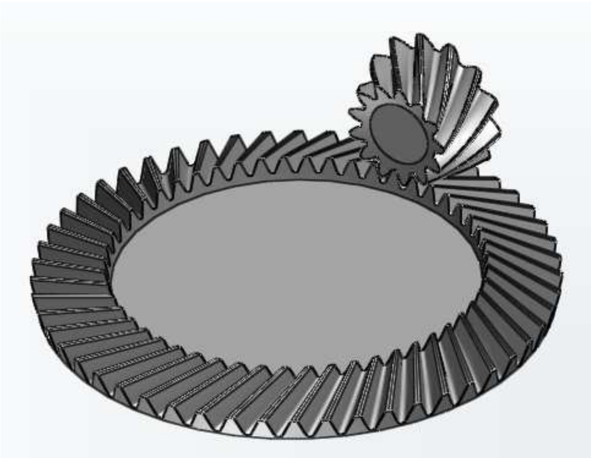
Bevel gear rating along AGMA2003 in KISSsoft



The bevel gear rating methods as implemented in KISSsoft software have been extended for the Release 09-07 and now include the bevel gear rating along AGMA2003-B97, American National Standard for "Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zerol Bevel and Spiral Bevel Gear Teeth".
Below, some comments are given with respect to the differences between the bevel gear rating along ISO10300 and AGMA2003. Furthermore, some of the verification calculations performed are illustrated.
It is shown that the safety factors calculated for different given gear pairs differ considerably depending on the rating method (ISO10300 or AGMA2003) are used. The gear designer should be aware of these differences.
A comparison of the KISSsoft software to calculation example as given in AGMA2003 and a comparison of KISSsoft software to another software has shown that the calculation has been implemented correctly.

Table of contents

1 On the bevel gear rating along AGMA2003

1.1 A comparison to ISO10300

Albeit the principles of the calculation procedures as given in AGMA2003 and ISO10300 respectively are similar, the two methods give different resulting safety factor for a given gear set. The differences are due to certain factors which have different values, e.g. the load distribution factor KHβ, the size factors Zx and Yx and the crowning factor Zxc.

The load distribution factor KHβ (describing the load distribution along the face width) depends – for both methods – on the type of support of both pinion and wheel shaft. Following AGMA2003, KHβ is furthermore increased as a function of the face width, in ISO10300, there is no such relationship. AGMA2003 also uses the crowning factor Zxc (for an optimised spiral bevel gear, this factor is equal to 1.5, otherwise it is 2.0 or higher) which is not used in ISO10300. The ISO10300 uses a constant factor of 1.5 to calculated the support factor Khbee from the load distribution factor. ISO10300 uses a transverse load factor Khα and uses only 85% of the face width for the calculation of the stresses. The above combined results in higher K factors if ISO10300 is used, especially for small to medium size bevel gears. As the factor Zxc as used in AGMA2003 is considered only for the contact stress but not for the root stresses, the difference in stress levels calculated along ISO10300 and AGMA2003 is considerable, especially for the bending stresses (see section below for an example).

For AGMA2003, the size factor pitting, Zx varies from 0.5 to 1.0 for a range of the face width from 12.7mm to 114.3mm, whereas for the ISO10300, the factor remains constant and equal to 1.0 for the same range. The size factor for bending, Yx varies from 0.5 to 1.0 for a range of the module from 1.6mm to 50mm, whereas for the ISO10300, the factor varies only in the range of 0.8 to 1.0 for the module range from 5.0mm to 25mm. The stresses calculated along AGMA2003 (flank and root stresses) are therefore lower for smaller bevel gears compared to the ISO10300 method.

The geometry factors I (for pitting, corresponds to ZE along ISO10300) and J (for bending, corresponds to YF*YS along ISO10300) are calculated along similar philosophies for both methods, however, the formulas used show considerable differences. Especially the effect of an addendum shift on the rating is very different for the two methods. E.g. for a given ratio of 1.5, it is recommended to have a positive profile shift on the pinion to achieve more favourable sliding conditions. Along ISO10300, if the addendum shift is chosen sensibly, comparable stresses for both pinion and wheel result. However, for AGMA2003, the root stresses are comparable (root stress in pinion compared to root stress in wheel) for a profile shift close to zero and change rapidly (reducing the stress level on the pinion) even for a small profile shift. This explains the differences in the root stresses for pinion and wheel in the table 1.3-1.

1.2 Implementation in KISSsoft

For the release 09-2007, the bevel gear rating along AGMA2003 has been implemented in KISSsoft. Furthermore, the following rating methods are available:

- ISO10300
- DIN3991
- KN3028/3030 (Klingelnberg standards)
- VDI2545 (for plastic gears)
- Static rating

Rating of Gleason geometry bevel gears may be done using a conversion tool, converting Gleason geometry data to ISO geometry data, allowing for a subsequent rating along DIN or ISO standard.

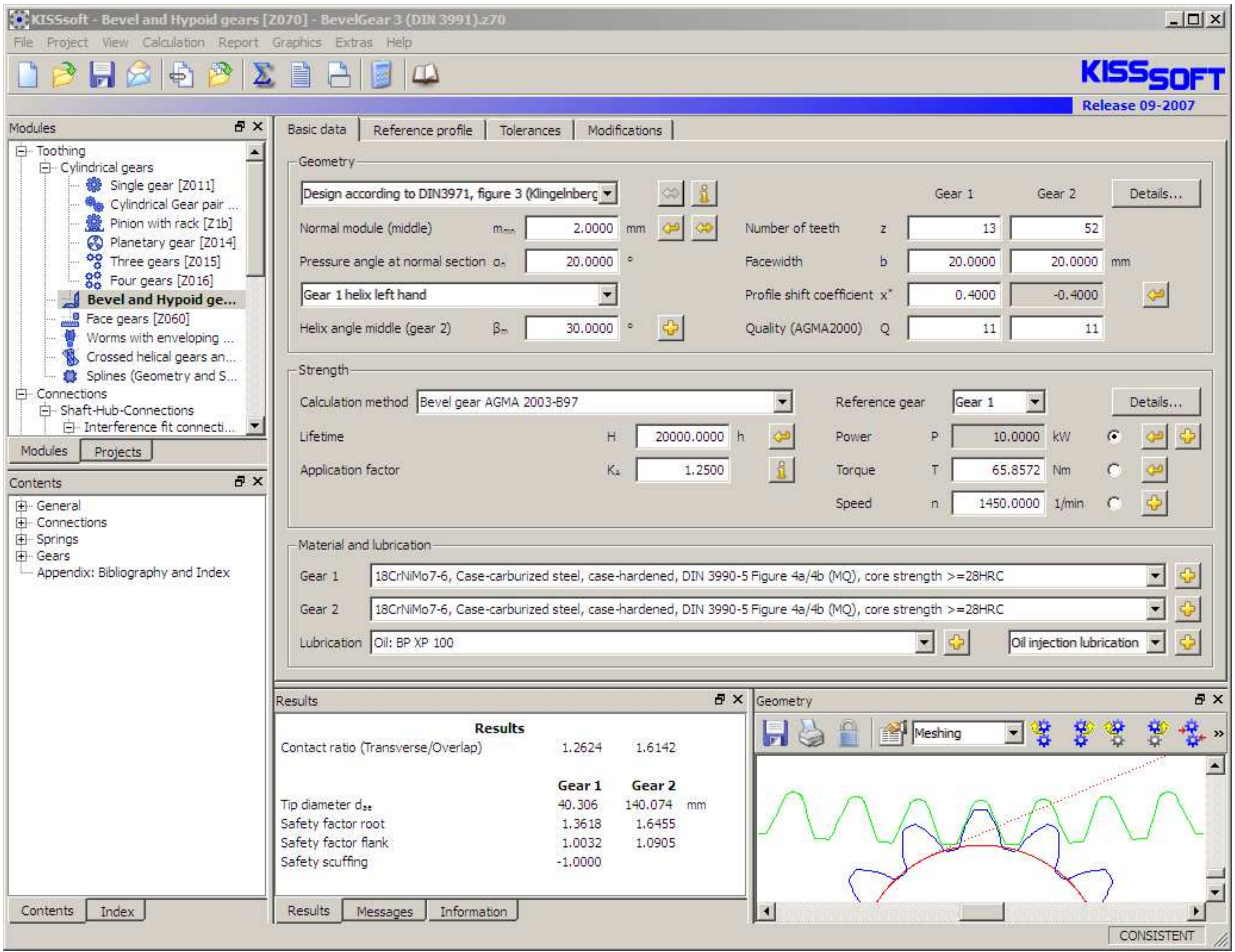


Figure 1.2-1Bevel gear calculation in KISSsoft 09-07

1.3 Calculation example

Bevel gears have been compared using both AGMA2003 and ISO10300 rating method. The ratio used is z1/z2=15/49, profile shift on the pinion x1=0.37, torque was set such that SF>=1.40 and SH>=1.00 along ISO10300.

The table shows a comparison of results for different bevel gear sizes, using small, medium and large module. The differences in the safety factors calculated is considerable. It can also be seen that the differences are smaller for larger gears, as expected based on the behaviour of the size factors as described above.

Example mmn b mm mm	Method	Torque T2 Nm	Load factors pitting KHβ* Zxc (*1) KHβ* KHα/0.85 (*2)	Load factors bending KHβ (*1) KFβ* KFα/0.85 (*2)	σH N/mm²	SH	σF N/mm²	SF
1.0 10.	AGMA	20	1.25*1.5=1.87	1.25	957.	1.53/1.65	114./195.	3.51/2.09
	ISO	20	1.88*1.41/.85=3.12	1.81*1.41/.85=3.00	1236.	1.00/1.04	504./499.	1.44/1.50
6.0 60.	AGMA	6960	1.27*1.5=1.91	1.27	1510	0.97/1.04	184./311.	2.18/1.31
	ISO	6960	1.88*1.00/.85=2.21	1.63*1.00/.85=1.92	1339.	1.00/1.04	515./511.	1.40/1.45
20.0 200.	AGMA	211400	1.47*1.5=2.21	1.47	1769.	0.83/0.89	236./397.	1.70/1.03
	ISO	211400	1.88*1.00/.85=2.21	1.63*1.00/.85=1.92	1241.	1.16/1.20	442./439.	1.40/1.45

Table 1.3-1 Comparison of resulting safety factors for bevel gears of different sizes

Note: *1: AGMA2003, *2: ISO10300 (0.85 as face width is reduced by 15% if ISO10300 is applied)

The profile shift x1 has been selected such that a balances specific sliding condition is achieved. The difference in root stress between pinion and gear for the different gear sizes are very small if ISO10300 is used, however, using AGMA2003, the differences are considerable (in the range of 50%).

While the rating methods for cylindrical (spur or helical) gears (ISO6336 and AGMA2001) also result in different safety factors (especially for bending), they more or less agree in the trend (e.g. for different moduls). It could have been expected that this agreement in trend is also visible for the bevel gear calculation. However, the above shows that AGMA2003 and ISO10300 yield results that can not be compared. Therefore, in the light of international standardization, action to harmonize the standards is required. For the gear designer, it is important to know that if bevel gears have originally been designed along AGMA2003 standard, they may not achieve required safety factors if they are rated along ISO10300.

2 Verification calculations

2.1 Example in AGMA2003-B97 standard (Annex E)

This section compares computational results of
Pac – Allowable transmitted power for pitting resistance
Pat - Allowable transmitted power for bending resistance.
The calculation were carried out with KISSsoft and compared to the values given in AGMA2003:B97, Annex E.

Summary of the results:

```
Transmittable power                    [Pac/SHmin^2]     71.62 (71.70)       81.03 (80.56)
Rel. error                                                   -0.11%              0.58%

Transmittable power                      [Pat/SFmin]     61.79 (62.0)       63.49 (63.2)
Rel. error                                                   -0.34%              0.45%
```

Maximum deviation: 0.58%: The difference is caused by the rounding of KL and CL factors to only 2 digits in the AGMA example.The results coincide very well!

Important notes:
The exact input geometry for calculation of the I, J factors is not known, therefore the I, J factors are set to the values given in the example for the check of computation of I and J factors.

File
Name : AGMA2003B97AnnexE
Description: KISSsoft Datensatz
Changed by : mh on: 29.08.2007 at: 11:47:04

BEVEL-GEAR-CALCULATION (BEVEL-GEAR-PAIR)

Drawing or article number:
Gear 1: 0.000.0
Gear 2: 0.000.0

Calculation-method Bevel gear AGMA 2003-B97
Cone form: different tip and foot cone (according to figure 2, DIN 3971)

Production process

grinded/hard toothed
Spiral toothing

		GEAR 1	GEAR 2
Nominal power (kW)	[P]	29.82	
Speed (1/min)	[n]	1750.0	628.2
Rotation direction, wheel 1, viewed on cone tip:		left	
Torque (Nm)	[T]	162.7	453.2
Gear driving (+) / driven (-)		+	-
Application factor	[KA]	1.00	
Service life in hours	[H]	9523.81	

1. TOOTH GEOMETRY AND MATERIAL

		GEAR 1	GEAR 2
Centre distance (mm)	[a]	0.000	
Axis angle (°)	[Sigma]	90.00	
Mean normal module (mn) (mm)	[mn]	3.2133	
Normal Diametral Pitch (1/in)	[Pnd]	7.90460	
Pressure angle at normal section (°)	[alfn]	20.000	
Mean helix angle (°)	[beta]	35.0000	
Helix		Left	Right
Number of teeth	[z]	14	39
Facewidth (mm)	[b]	25.40	25.40
Facewidth for calcul. (mm)	[be]	25.40	25.40
Internal diameter gearbody (mm)	[di]	0.00	0.00

Material
Gear 1: (Own input) ASTM A536 Ductile, Class120-90-02(AGMA), Case-carburized steel, case-hardened
AGMA 2001, AGMA 2101: Quenched + tempered
Gear 2: (Own input) ASTM A536 Ductile, Class120-90-02(AGMA), Case-carburized steel, case-hardened
AGMA 2001, AGMA 2101: Quenched + tempered

		GEAR 1	GEAR 2
Surface hardness		HB 269	HB 269
Yield point (N/mm²)	[sigs]	420.00	420.00
		(lb/in²), (N/mm²)	(lb/in²), (N/mm²)
Allowable bending stress number	[sat]	30000, 206.84	30000, 206.84
Allowable contact stress number	[sac]	200000,1378.95	200000,1378.95
Yield point (N/mm²)	[Rp]	420.00	420.00
Youngs modulus (N/mm²)	[E]	206843	206843
Poisson's ratio	[ny]	0.300	0.300
Average roughness, Ra, tooth flank (µm)	[RAH]	0.60	0.60
Mean roughness tooth flank (µm)	[RZH]	4.80	4.80
Mean roughness tooth root (µm)	[RZF]	20.00	20.00

Reference Profile

		GEAR 1	GEAR 2
Dedendum reference profile (module)	[hfP*]	1.250	1.250
Tooth root radius Refer. profile (module)			

	[rofP*]	0.380	0.380
Addendum Reference profile (module)	[haP*]	1.000	1.000
Protuberance height (module)	[hk*]	0.000	0.000
Protuberance angle (°)	[alfPro]	0.000	0.000
Buckling root flank height (module)	[hko*]	0.000	0.000
Buckling root flank angle (°)	[alfnk]	0.000	0.000

Type of profile modification:		No	
Tip relief (µm)	[Ca]	8.40	8.40

Type of lubrication		oil injection lubrication
Type of oil		Oil: BP XP 100
Lubricant base		Mineral-oil base
Kinem. viscosity oil at 40 °C (mm²/s)	[nu40]	96.00
Kinem. viscosity oil at 100 °C (mm²/s)	[nu100]	11.10
FZG-Test A/8.3/90 step	[FZGtestA]	12
Specific density at 15 °C (kg/dm³)	[roOil]	0.901
Oil temperature (°C)	[theOil]	70.000

		------- GEAR 1	--------	GEAR 2 -------
Overall transmission ratio	[itot]		-2.786	
Gear ratio	[u]		2.786	
Mean transverse module (mn) (mm)	[mtm]		3.923	
Pressure angle at Pitch circle (°)	[alft]		23.957	
Base helix angle (°)	[betab]		32.615	
Sum of the Addendum modification	[Summexi]		0.0000	
Addendum modification coefficient	[x]	0.3000		-0.3000
Tooth thickness variation factor	[xs]	0.0300		-0.0300
Mean reference diameter (mm)	[dm]	54.918		152.987
Medium tip diameter (mm)	[dam]	62.782		154.507
Mean root diameter (mm)	[dfm]	49.172		149.621
Angle of cone (grd)	[delta]	19.747		70.253
Length of reference cone outside (mm)	[Re]		93.973	
Length of reference cone middle (mm)	[Rm]		81.273	
Length of reference cone inside (mm)	[Ri]		68.573	
Tip chamfer/ tip rounding (mm)	[Fased]	0.000		0.000

AGMA2003, Annex C:

Length of path of contact (mm)	[gan]	16.082
Transverse contact ratio	[eps.a]	1.203
Overlap ratio	[eps.b]	1.454
Total contact ratio	[eps.0]	1.887

2. FACTORS OF GENERAL INFLUENCE

Effective facewidth (mm)	[F,b]		25.40	
Nennumfangskraft am Wälzkreis (N)	[Ftw]		5925.1	
Nominal circum. force at pitch circle (N)	[Ft]		5925.1	
Axial force (N)	[Fa]		0.0	
Radial force (N)	[Fr]		0.0	
Normal force (N)	[Fnorm]		0.0	
Umfangsgeschwindigkeit bei dm (m/sec)	[vm]		5.03	
Umfangsgeschwindigkeit bei de (m/sec)	[ve]		5.82	
Load ditribution modifier	[Kmb]		1.100	
Load distribution factor	[Km,KHb]		1.104	
Transmission accuracy grade number	[Qv]		11	
Dynamic factor	[Kv]		1.081	
Number of load cycles (in mio.)	[NL]	1000.000		358.974

3. TOOTH ROOT STRENGTH

		------- GEAR 1	--------	GEAR 2 -------
Size factor	[KS]	0.5248		0.5248
		(in) , (mm)		(in) , (mm)
Bending lever arm (mm)	[hN]	0.119, 3.01		0.102, 2.60
Tooth thickness at critical section	[2*sN]	0.279, 7.10		0.279, 7.08
Radius at curvature of fillet curve	[rfm]	0.051, 1.30		0.050, 1.26
Load angle (°)	[alfh]	21.26		19.12
Tooth form factor Y	[Y]	0.726		0.840
Stress correction factor	[Kf]	2.942		3.044
facing head tip diameter (mm)	[rc0]		114.000	
Tooth lengthwise correction factor	[Kx,Ybet]		1.000	
Bending strength geometry factor J	[J]	0.222		0.224

Values for I,J are introduced as given in the example. *No* computational results due to a lack of geometry data.

		(lb/in²), (N/mm²)	(lb/in²), (N/mm²)
Bending stress number	[st]	18201, 125.49	18039, 124.37

Stress cycle factor (for general applications)	[KL,YNT]	0.938	0.955
		(lb/in^2), (N/mm^2)	(lb/in^2), (N/mm^2)
Allowable bending stress number	[sat]	30000, 206.84	30000, 206.84
Temperature factor	[KT]	1.00	1.00
Reliability factor	[KR,YZ]	1.00	
Reverse loading factor	[-]	1.000	1.000
Effective allow. b.s.n.	[sateff]	28127, 193.93	28644, 197.49
Bending strength power rating (hp) (Calculated with SFmin = 1.0)	[Pat]	61.79(46.07 kW)	63.49(47.35 kW)
Safety factor (foot)	[sateff/st]	1.55	1.59
Required safety factor	[SFmin]	1.00	1.00
Transmittable power	[Pat/SFmin]	61.79 (62.0)	63.49 (63.2)

AGMA2003, Annex C(M):

```
hfe1 =    3.53 mm hfe2 =    5.76 mm rhoao1=   1.22 mm rhoao2=   1.22 mm
s1   =    5.87 mm s2   =    3.98 mm thef1=    2.15 °  thef2=    3.51 °
Y1   =    0.73  Yf1 =    2.94  YK1 =     0.25  epsNJ=   1.00  Yi  =    1.06
rmyo1=   30.12 mm rmpt1=   29.17 mm b1' =   21.33 mm b1  =   25.40 mm
Y2   =    0.84  Yf2 =    3.04  YK2 =     0.28  epsNJ=   1.00  Yi  =    1.06
rmyo2=  232.57 mm rmpt2=  226.40 mm b2' =   20.43 mm b2  =   25.40 mm
```

4. SAFETY AGAINST PITTING (TOOTH FLANK)

		------- GEAR 1 --------	GEAR 2 -------
		(lb^.5/in), (N^.5/mm)	
Elastic coefficient	[Cp,ZE]	2290.0, 190.20	
Size factor	[Cs,Zx]	0.562	0.562
Crowning factor	[Cxx,Zxx]	1.500	
Geometry factor I	[I]	0.109	

Values for I,J are introduced as given in the example. *No* computational results due to a lack of geometry data.

		(lb/in^2), (N/mm^2)	
Contact stress number	[sc,sigH]	149452,1030.43	
Stress cycle factor (for general applications)	[CL,ZNT]	1.000	1.064
Hardness ratio factor	[CH,ZW]	1.00	1.00
Temperature factor	[KT]	1.00	1.00
Reliability factor	[CR,ZZ]	1.00	
		(lb/in^2), (N/mm^2)	(lb/in^2), (N/mm^2)
Allowable contact stress number	[sac]	200000,1378.95	200000,1378.95
Effective allow. c.s.n. (lb/in^2)	[saceff]	200025,1379.12	212750,1466.86
Pitting resistance power rating (hp) (Calculated with SHmin = 1.0)	[Pac]	71.62(53.41 kW)	81.03(60.42 kW)
Safety factor (flanc)	[saceff/sc]	1.34	1.42
Required safety factor	[SHmin]	1.00	1.00
Transmittable power	[Pac/SHmin^2]	71.62 (71.70)	81.03 (80.56)

AGMA2003, Annex C(M):

```
Re    =   93.97 mm hae1 =    4.96 mm hae2 =    2.73 mm de1  =   63.50 mm de2  =  176.89 mm
del1 =   19.75 °  del2 =   70.25 °  dela1=   23.25 °  dela2=   72.40 °
p2    =   13.37 mm gan1 =    9.66 mm gan2 =    6.42 mm gc   =   16.08 mm
rhoy0=   14.56 mm mmt  =    3.92 mm met  =    4.54 mm
Zi    =    1.06 mm epsNI=    0.98
```

SERVICE FACTORS:

Service factor for tooth root	[KSF]	1.55	1.59
Service factor for pitting	[CSF]	1.79	2.03
Service factor for gear set	[SF]	1.55	

6. MEASURES FOR TOOTH THICKNESS

		------- GEAR 1 --------	GEAR 2 -------
Tooth thickness tolerance DIN 3967		Own Input	Own Input
Tooth thickness allowance (normal section) (mm)	[As.e/i]	-0.054 / -0.084	-0.130 / -0.190

The following data apply on the middle of the tooth width:

Tooth thickness (chordal) in pitch diameter (mm)	['smn]	5.930	4.152
(mm)	['smn.e/i]	5.873 / 5.842	4.014 / 3.950
Reference chordal height (mm)	[ha]	4.326	2.258

Circumferential backlash (mm)	[jt]	0.356 / 0.239
Normal backlash (mm)	[jn]	0.274 / 0.184

7. TOLERANCES

		------- GEAR 1 --------	GEAR 2 --
Following AGMA 2000-A88:			
Accuracy grade	[Q-AGMA2000]	11	11
Following AGMA 2015-1-1A01:			
Accuracy grade	[Q-AGMA2015]	A6	A6

8. CONE GEOMETRY

Helix angle outside (°)	[betae]		40.0000	
Helix angle in middle (°)	[betam]		35.0000	
Helix angle in inside (°)	[betai]		30.0000	
Normal module outside (mm)	[mne]		3.4746	
Transverse module outside (mm)	[mte]		4.5357	
Normal module inside (mm)	[mni]		2.8663	
Transverse module inside (mm)	[mti]		3.3098	
Dimensions (mm):	[dae]	72.828		178.735
(mm)	[dam]	62.782		154.507
(mm)	[dai]	52.735		130.278
(mm)	[de]	63.500		176.893
(mm)	[dm]	54.918		152.987
(mm)	[di]	46.337		129.080
(mm)	[dfe]	56.856		173.002
(mm)	[dfm]	49.172		149.621
(mm)	[dfi]	41.488		126.241
Addendum (mm)	[hae]	4.956		2.726
(mm)	[ham]	4.177		2.249
(mm)	[hai]	3.399		1.772
Dedendum (mm)	[hfe]	3.530		5.759
(mm)	[hfm]	3.053		4.981
(mm)	[hfi]	2.576		4.202
Distances in axial direction of the cone tip (mm)				
	[ye]	88.447		31.750
(mm)	[yae]	86.772		29.184
(mm)	[yai]	63.392		21.500
Angle (°):	[dela]	23.2537		72.4042
	[del]	19.7468		70.2531
	[delf]	17.5958		66.7463

Hinweis: Diese Angaben sind nur Richtwerte, für genaue Angaben ist die Vorgabe des Kopf- und Fusskegelwinkels notwendig!

9. ADDITIONAL DATA

Medium coef. of friction (acc. Niemann)	[mum]	0.066
Wear sliding coef. by Niemann	[zetw]	0.569
Power loss from gear load (kW)	[PVZ]	0.263
(Meshing efficiency (%)	[etaz]	99.119)

End report lines: 304

Annex E
(informative)
Bevel gear sample calculations

[The foreword, footnotes, and annexes, if any, are provided for informational purposes only and should not be construed as a part of ANSI/AGMA 2003-B97, *Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zerol Bevel and Spiral Bevel Gear Teeth*.]

The example in table E.1 is included to assist users in the rating of a hypothetical gear set.The clause references specify where that information is presented. These calculations are in conventional U.S. units.

Table E.1 - Calculation example

Item		Selection or calculation: Pinion	Both	Gear
General design considerations (given):				
Type			Spiral bevel	
Ratio			2.786 : 1	
Material	Table 3		Steel Grade I	
Accuracy requirement			AGMA Class Q11	
Minimum life required in cycles		10^9		3.59×10^8
Mounting		Overhung		Straddle
Load considerations				
Torque		T_P = 1440 in lb		T_G = 4011 in lb
Speed		n_p = 1750 rpm		628 rpm
Number of teeth		n = 14		N = 39
Diameter		d = 2.5 in		D = 6.964 in
Face width			F = 1.00 in	
Diametral pitch			P_d = 5.600 in^{-1}	
Spiral angle			ψ = 35°	
Pressure angle			ϕ = 20°	
Shaft angle			Σ = 90°	
Cutter radius			r_c = 4.5 in	
Mean cone distance			A_m = 3.200 in	
Dynamic factor:	Clause 10			
$K_v = \left[\frac{A}{A+\sqrt{v_t}}\right]^{-B}$	Eq. 13			
$B = 0.25\,(12 - Q_v)^{0.667}$	Eq. 15		0.25	
$A = 50 + 56\,(1.0 - B)$	Eq. 14		92.0	
$v_t = .262\, d n_P$	Eq. 16		1145	
K_v Dynamic factor			1.081	
Contact stress formula:				
$s_c = C_P\sqrt{\frac{2T_P}{Fd^2I}K_o K_v K_m C_s C_{xc}}$	Eq. 1			
C_P	Clause 20		2290	
T_P	Given	1440		
K_o	Clause 7		1.0	
K_v	Clause 10		1.081	
F	Given		1.0	
d	Given	2.5		

(continued)

Table E.1 *(continued)*

Item	Selection or calculation		
	Pinion	Both	Gear
K_{mb} .... Figure 4		1.10	
$K_m = K_{mb} + 0.0036\,F^2$ .... Eq 20		1.1036	
$C_s = 0.125F + 0.4375$ Eq 18		0.5625	
C_{xc} .... Clause 13		1.5	
I .... Annex D		0.109	
s_c Calculated contact stress number, lb/in²		149 384	
Permissible contact stress number $s_{wc} = \dfrac{s_{ac}\,C_L\,C_H}{S_H K_T\,C_R}$ Eq. 2			
s_{ac} .... Table 3		200 000	
C_L .... Clause 16	1.0		1.06
C_H .... Clause 17		1.0	
s_H .... Clause 8		1.0	
K_T .... Clause 18		1.0	
C_R .... Clause 19		1.0	
s_{wc} Permissible contact stress number, lb/in²	200 000		212 000
Pitting resistance power formula $P_{ac} = \dfrac{n_P F}{126\,000}\,\dfrac{I}{K_v K_m K_o C_s C_{xc}}\left(\dfrac{s_{ac} d C_L C_H}{S_H C_p K_T C_R}\right)^2$ Eq. 4			
n_P, n_G	1750		628
F .... Given		1.0	
I .... Annex D		0.109	
K_v .... Clause 10		1.081	
K_m .... Clause 12		1.1036	
K_o .... Clause 7		1.0	
C_s .... Clause 11		0.5625	
C_{xc} .... Clause 13		1.5	
s_{ac} .... Table 4		200 000	
d, D	2.5		6.964
C_L .... Clause 16	1.0		1.06
C_H .... Clause 17		1.0	
s_H .... Clause 8		1.0	
C_p .... Clause 20		2290	
K_T .... Clause 18		1.0	
C_R .... Clause 19		1.0	
P_{ac} Allowable transmitted power for pitting resistance, hp	71.70		80.56
Bending stress formula $s_t = \dfrac{2T_P}{F\,d}\,\dfrac{P_d K_o K_v}{1}\,\dfrac{K_s K_m}{K_x J}$ Eq. 5			
T_P, T_G .... Given	1440		4011
F .... Given		1.0	
d, D .... Given	2.5		6.965
P_d .... Given		5.6	
K_o .... Clause 7		1.0	
K_v .... Clause 10		1.081	

(continued)

AMERICAN NATIONAL STANDARD   ANSI/AGMA 2003-B97

Table E.1 *(concluded)*

Item	Selection or calculation		
	Pinion	Both	Gear
K_m ... Clause 12		1.1036	
$K_s = 0.4867 + \frac{0.2133}{P_d}$ ... Eq. 19		0.5248	
$K_x = 0.211\left(\frac{r_c}{A_m}\right)^q + 0.789$ ... Eq. 21			
$q = \frac{0.279}{\log_{10}(\sin\psi)}$ ... Eq. 23		−1.156	
$K_x = 0.211\left(\frac{4.5}{3.200}\right)^{-1.156} + 0.789 < 1$			
$\therefore K_x = 1$			
K_x .... Clause 14		1.0	
J .... Annex D	0.222		0.224
s_t Calculated bending stress number, lb/in²	18 194		18 027
Permissible bending stress number			
$s_{wt} = \frac{s_{at} K_L}{S_F K_T K_R}$ ... Eq. 6			
s_{at} .... Table 5		30 000	
K_L .... Clause 16	0.94		0.95
S_F .... Clause 8		1.0	
K_T .... Clause 18		1.0	
K_R .... Clause 19		1.0	
s_{wt} Permissible bending stress number, lb/in²	28 200		28 500
Bending strength power formula			
$P_{at} = \frac{n_p F}{126\,000} \frac{J K_x}{K_s K_m K_o K_v} \frac{s_{at} d}{P_d} \frac{K_L}{K_T K_R S_F}$ ... Eq. 8			
nP, nG .... Given	1750		628
F .... Given		1.0	
J .... Annex D	0.222		0.224
K_x .... Clause 14		1.0	
K_m .... Clause 12		1.1036	
K_o .... Clause 7		1.0	
K_v .... Clause 10		1.081	
s_{at} .... Table 6		30 000	
d, D .... Given	2.5		6.964
P_d .... Given		5.6	
K_L .... Clause 16	0.94		0.95
K_T .... Clause 18		1.0	
K_R .... Clause 19		1.0	
S_F .... Clause 8		1.0	
K_s .... Clause 11		0.5248	
P_{at} Allowable transmitted power for bending strength, hp	62.0		63.2

NOTE:
Since the allowable transmitted power is lower for bending stress than for contact stress, use 62.0 hp as the limiting horsepower.

75

2.2 Comparison to proprietary code

A comparison has been performed in collaboration with a KISSsoft customer, comparing KISSsoft software to their own code. To protect our customer interest, only selected data is listed below:

This section compares results of the calculaction of I and Jp,Jg factors following Annex C.

This check is necessary and important, because the example in AGMA2003, Annex E does not provide all the input data for such a check.

The overall results (transmittable power, ratings) can not be compared between KISSsoft and the customers programm, because for that part of the calculation the customer input data is not clearly defined and furthermore we suspect, that the calculation in the customer programm was performed with a manually introduced J factor (0.3) and not with the later documented exact factor.

Example 1:

```
Tooth form factor Y                  [Y]               0.923 (0.928)        0.879 (0.880)
```
Cause of deviation: Customer program iteration acc. to 2003-A86, KISSsoft iteration acc.to 2003-B97

```
Bending strength geometry factor J   [J]          0.241 (0.295)                0.222 (0.236)
```
Cause of deviation: mix-up of radians and degrees in Customer program computation (see eqns. (C.98) – (C.100))

```
Geometry factor I                    [I]                              0.0901 (0.09079)
```

Example 2:

```
Tooth form factor Y                  [Y]               0.923 (0.928)        0.879 (0.880)
```
Cause of deviation: Customer program iteration acc. to 2003-A86, KISSsoft iteration acc.to 2003-B97

```
Bending strength geometry factor J   [J]          0.241 (0.295)                0.222 (0.236)
```
Cause of deviation: mix-up of radians and degrees in Customer program computation (see eqns. (C.98) – (C.100))

```
Geometry factor I                    [I]                              0.1193 (0.11962)
```

The results coincide very well!

KISSsoft report, Example 1
(X_s = -0.022, no backlash)

```
—————————————————— KISSsoft mit HIRNware - Release 05-2007
KISSsoft-Hirnware beta version for testing only

———————————————————————————————————— File
Name        :
Changed by : uk          on: 28.08.2007          at: 15:35:47
```

BEVEL-GEAR-CALCULATION (BEVEL-GEAR-PAIR)

```
Drawing or article number:
Gear 1:                          0.000.0
Gear 2:                          0.000.0

Calculation-method   Bevel gear AGMA 2003-B97
Cone form: different tip and foot cone (according to figure 2, DIN 3971)
 Production process
                   lapped
                   Spiral toothing
                                                        ------- GEAR 1 -------- GEAR 2 -------

Nominal power (hp)                             [P]                     662.50
Speed (1/min)                                  [n]            1750.0             1139.5
Rotation direction, wheel 1, viewed on cone tip:    left
Torque (ft*lb)                                 [T]            1988.3             3053.5
Gear driving (+) / driven (-)                            +                    -
Application factor                             [KA]                      1.00
Service life in hours                          [H]                   12500.00
```

1. TOOTH GEOMETRY AND MATERIAL

```
                                                        ------- GEAR 1 -------- GEAR 2 -------
Centre distance (in)                           [a]                       0.000
Axis angle (°)                                 [Sigma]                   90.00
```

Mean normal module (mn) (in)	[mn]	0.2330	
Pressure angle at normal section (°)	[alfn]	20.000	
Mean helix angle (°)	[beta]	27.5000	
Helix		Left	Right
Number of teeth	[z]	28	43
Facewidth (in)	[b]	2.75	2.75
Facewidth for calcul. (in)	[be]	2.75	2.75
Internal diameter gearbody (in)	[di]	0.00	0.00

Material

Gear 1: (Own input) Tester, Through hardened steel, unalloyed, through hardened
AGMA 2001, AGMA 2101: Quenched + tempered

Gear 2: (Own input) Tester, Through hardened steel, unalloyed, through hardened
AGMA 2001, AGMA 2101: Quenched + tempered

		GEAR 1	GEAR 2
Surface hardness		HB 269	HB 269
Yield point (lbf/in²)	[sigs]	60916.11	60916.11
		(lb/in²), (N/mm²)	(lb/in²), (N/mm²)
Allowable bending stress number	[sat]	35000, 241.32	35000, 241.32
Allowable contact stress number	[sac]	225000,1551.32	225000,1551.32
Yield point (lbf/in²)	[Rp]	60916.11	60916.11
Youngs modulus (lbf/in²)	[E]	30000125	30000125
Poisson's ratio	[ny]	0.300	0.300
Average roughness, Ra, tooth flank (mil)	[RAH]	0.02	0.02
Mean roughness tooth flank (mil)	[RZH]	0.19	0.19
Mean roughness tooth root (mil)	[RZF]	0.79	0.79

Input for gear 1: Bezugsprofil Zahnrad

Reference Profile

1.25 / 0.38 / 1.0 ISO 53.2 Profil A

Addendum factor	[haP*]	0.994
Dedendum coefficient	[hfP*]	1.255
Tip radius factor	[rhoaP*]	0.000
Root radius factor	[rhofP*]	0.489
Addendum form factor	[hFaP*]	0.000
Protuberanzhöhenfaktor	[hprP*]	0.000
Protuberanzwinkel	[alfprP]	0.000
Ramp angle	[alfKP]	0.000
		not topping

Input for gear 2: Bezugsprofil Zahnrad

Reference Profile

1.25 / 0.38 / 1.0 ISO 53.2 Profil A

Addendum factor	[haP*]	0.994
Dedendum coefficient	[hfP*]	1.255
Tip radius factor	[rhoaP*]	0.000
Root radius factor	[rhofP*]	0.245
Addendum form factor	[hFaP*]	0.000
Protuberanzhöhenfaktor	[hprP*]	0.000
Protuberanzwinkel	[alfprP]	0.000
Ramp angle	[alfKP]	0.000
		not topping

Zusammenfassung Bezugsprofil der Zahnräder:

Dedendum reference profile (module)	[hfP*]	1.255	1.255
Tooth root radius Refer. profile (module)	[rofP*]	0.489	0.245
Addendum Reference profile (module)	[haP*]	0.994	0.994
Protuberance height (module)	[hk*]	0.000	0.000
Protuberance angle (°)	[alfPro]	0.000	0.000
Buckling root flank height (module)	[hko*]	0.000	0.000
Buckling root flank angle (°)	[alfnk]	0.000	0.000

Type of profile modification:		No	
Tip relief (mil)	[Ca]	0.80	0.80

Type of lubrication	oil bath lubrication	
Type of oil	Oil: ISO-VG 220	
Lubricant base	Mineral-oil base	
Kinem. viscosity oil at 40 °C (cSt)	[nu40]	2.20
Kinem. viscosity oil at 100 °C (cSt)	[nu100]	0.18
FZG-Test A/8.3/90 step	[FZGtestA]	12
Specific density at 15 °C (lb/ft³)	[roOil]	55.874
Oil temperature (°F)	[theOil]	158.000

		GEAR 1 / GEAR 2
Overall transmission ratio	[itot]	-1.536

Gear ratio	[u]		1.536	
Mean transverse module (mn) (in)	[mtm]		0.263	
Pressure angle at Pitch circle (°)	[alft]		22.310	
Base helix angle (°)	[betab]		25.715	
Sum of the Addendum modification	[Summexi]		0.0000	
Addendum modification coefficient	[x]	0.3363		-0.3363
Tooth thickness variation factor	[xs]	-0.0220		0.0220
Mean reference diameter (in)	[dm]	7.356		11.296
Medium tip diameter (in)	[dam]	7.875		11.464
Mean root diameter (in)	[dfm]	6.997		10.892
Angle of cone (grd)	[delta]	33.071		56.929
Length of reference cone outside (in)	[Re]		8.115	
Length of reference cone middle (in)	[Rm]		6.740	
Length of reference cone inside (in)	[Ri]		5.365	
Tip chamfer/ tip rounding (in)	[Fased]	0.000		0.000

AGMA2003, Annex C:

Length of path of contact (in)	[gan]	1.205
Transverse contact ratio	[eps.a]	1.422
Overlap ratio	[eps.b]	1.780
Total contact ratio	[eps.0]	2.278

2. FACTORS OF GENERAL INFLUENCE

Effective facewidth (in)	[F,b]		2.75	
Nominal transverse load at pitch circle (lbf)	[Ftw]		6487.3	
Nominal circum. force at pitch circle (lbf)	[Ft]		6487.3	
Axial force (lbf)	[Fa]		0.0	
Radial force (lbf)	[Fr]		0.0	
Normal force (lbf)	[Fnorm]		0.0	
Umfangsgeschwindigkeit bei dm (m/sec)	[vm]		17.12	
Umfangsgeschwindigkeit bei de (m/sec)	[ve]		20.61	
Load distribution modifier	[Kmb]		1.100	
Load distribution factor	[Km,KHb]		1.127	
Transmission accuracy number introduced:				
Transmission accuracy grade number	[Qv]		10	
Dynamic factor	[Kv]		1.252	
Number of load cycles (in mio.)	[NL]	1312.500		854.651

3. TOOTH ROOT STRENGTH

		------- GEAR 1	--------	GEAR 2 -------
Size factor	[KS]	0.5542		0.5542
		(in) , (mm)		(in) , (mm)
Bending lever arm (in)	[hN]	0.007, 0.19		0.008, 0.20
Tooth thickness at critical section	[2*sN]	0.523,13.29		0.538,13.68
Radius at curvature of fillet curve	[rfm]	0.116, 2.94		0.064, 1.64
Load angle (°)	[alfh]	20.37		18.25
Tooth form factor Y	[Y]	0.923 (0.928)		0.879 (0.880)

Cause of deviation: Customer program iteration acc. to 2003-A86, KISSsoft iteration acc.to 2003-B97

Stress correction factor	[Kf]	3.017		3.105
facing head tip diameter (in)	[rc0]		3.937	
Tooth lengthwise correction factor	[Kx,Ybet]		1.119	
Bending strength geometry factor J	[J]	0.241 (0.295)		0.222 (0.236)

Cause of deviation: mix-up of radians and degrees in Customer program computation (see eqns. (C.98) – (C.100))

		(lb/in²), (N/mm²)		(lb/in²), (N/mm²)
Bending stress number	[st]	17974, 123.93		19541, 134.73
Stress cycle factor (for general applications)	[KL,YNT]	0.933		0.940
		(lb/in²), (N/mm²)		(lb/in²), (N/mm²)
Allowable bending stress number	[sat]	35000, 241.32		35000, 241.32
Temperature factor	[KT]	1.00		1.00
Reliability factor	[KR,YZ]		1.00	
Reverse loading factor	[-]	1.000		1.000
Effective allow. b.s.n.	[sateff]	32656, 225.15		32906, 226.88
Bending strength power rating (hp) (Calculated with SFmin = 1.0)	[Pat]	1203.64(897.55 kW)		1115.61(831.91 kW)
Safety factor (foot)	[sateff/st]	1.82		1.68
Required safety factor	[SFmin]	1.00		1.00
Transmittable power	[Pat/SFmin]	1203.64(897.55 kW)		1115.61(831.91 kW)

AGMA2003, Annex C(M):
hfe1 = 0.258 in hfe2 = 0.446 in rhoao1= 0.114 in rhoao2= 0.057 in
s1 = 0.413 in s2 = 0.319 in thef1= 1.82 ° thef2= 3.13 °
Y1 = 0.92 Yf1 = 3.02 YK1 = 0.31 epsNJ= 0.84 Yi = 1.00

```
rmyo1=   4.470 in rmpt1=   4.389 in b1' =   2.158 in b1  =   2.750 in
Y2  =     0.88  Yf2 =    3.10  YK2 =     0.28  epsNJ=   0.84  Yi  =    1.00
rmyo2=  10.373 in rmpt2=  10.351 in b2' =   2.182 in b2  =   2.750 in
```

4. SAFETY AGAINST PITTING (TOOTH FLANK)

```
                                                     ------- GEAR 1 -------- GEAR 2 -------
                                                              (lb^.5/in), (N^.5/mm)
Elastic coefficient                      [Cp,ZE]                  2290.0,  190.20
Size factor                              [Cs,Zx]               0.781                0.781
Crowning factor                          [Cxx,Zxx]                       1.500
Geometry factor I                        [I]                             0.0901 (0.09079)
                                                                 (lb/in²), (N/mm²)
Contact stress number                    [sc,sigH]                 145913,1006.04
Stress cycle factor                      [CL,ZNT]              0.984                1.010
 (for general applications)
Hardness ratio factor                    [CH,ZW]               1.00                 1.00
Temperature factor                       [KT]                  1.00                 1.00
Reliability factor                       [CR,ZZ]                         1.00
                                                        (lb/in²), (N/mm²)   (lb/in²), (N/mm²)
Allowable contact stress number          [sac]            225000,1551.32      225000,1551.32
Effective allow. c.s.n. (lb/in²)         [saceff]         221374,1526.32      227166,1566.25
Pitting resistance power rating (hp)     [Pac]         1524.94(1137.14 kW)    1605.78(1197.42 kW)
 (Calculated with SHmin = 1.0)
Safety factor (flanc)                    [saceff/sc]           1.52                 1.56
Required safety factor                   [SHmin]               1.00                 1.00
Transmittable power                   [Pac/SHmin^2]    1524.94(1137.14 kW)    1605.78(1197.42 kW)

AGMA2003, Annex C(M):
Re    =   8.115 in hae1 =   0.385 in hae2 =   0.197 in de1  =   8.856 in de2  =  13.601 in
del1  =   33.07 °  del2 =   56.93 °  dela1=   36.21 °  dela2=   58.75 °
p2    =   0.847 in gan1 =   0.775 in gan2 =   0.430 in gc   =   1.205 in
rhoy0=   1.376 in mmt  =   0.263 in met  =   0.316 in
Zi    =   0.039 in epsNI=    0.84


SERVICE FACTORS:
Service factor for tooth root            [KSF]                 1.82                 1.68
Service factor for pitting               [CSF]                 2.30                 2.42
Service factor for gear set              [SF]                            1.68
```

6. MEASURES FOR TOOTH THICKNESS

```
                                                     ------- GEAR 1 -------- GEAR 2 -------
Tooth thickness tolerance DIN 3967                            Own Input        Own Input
Tooth thickness allowance (normal section) (in)
                                              [As.e/i]    0.000 / 0.000    0.000 / 0.000

The following data apply on the middle of the tooth width:
Tooth thickness (chordal) in pitch diameter (in)
                                              ['smn]           0.413                0.319
                               (in)           ['smn.e/i]  0.413 / 0.413     0.319 / 0.319
Reference chordal height (in)                 [ha]             0.315                0.155

Circumferential backlash (in)                 [jt]        -0.000 / -0.000
Normal backlash (in)                          [jn]        -0.000 / -0.000
```

7. TOLERANCES

```
                                                        ------- GEAR 1 -------- GEAR 2 --
Following AGMA 2000-A88:
Accuracy grade                           [Q-AGMA2000]           10                   10

Following AGMA 2015-1-1A01:
Accuracy grade                           [Q-AGMA2015]           A7                   A7
```

8. CONE GEOMETRY

```
Helix angle outside (°)                       [betae]                   31.0626
Helix angle in middle (°)                     [betam]                   27.5000
Helix angle in inside (°)                     [betai]                   23.9374
Normal module outside (in)                    [mne]                      0.2709
Transverse module outside (in)                [mte]                      0.3163
Normal module inside (in)                     [mni]                      0.1911
Transverse module inside (in)                 [mti]                      0.2091
Dimensions (in) :                              [dae]            9.502                13.816
```

(in)	[dam]	7.875	11.464
(in)	[dai]	6.249	9.112
(in)	[de]	8.856	13.601
(in)	[dm]	7.356	11.296
(in)	[di]	5.855	8.992
(in)	[dfe]	8.424	13.114
(in)	[dfm]	6.997	10.892
(in)	[dfi]	5.570	8.669
Addendum (in)	[hae]	0.385	0.197
(in)	[ham]	0.310	0.153
(in)	[hai]	0.235	0.110
Dedendum (in)	[hfe]	0.258	0.446
(in)	[hfm]	0.214	0.371
(in)	[hfi]	0.170	0.295
Distances in axial direction of the cone tip (in)			
	[ye]	6.800	4.428
	(in) [yae]	6.590	4.263
	(in) [yai]	4.368	2.836
Angle (°):	[dela]	36.2054	58.7486
	[del]	33.0707	56.9293
	[delf]	31.2514	53.7946

9. ADDITIONAL DATA

Medium coef. of friction (acc. Niemann)	[mum]	0.034
Wear sliding coef. by Niemann	[zetw]	0.539
Power loss from gear load (hp)	[PVZ]	2.013
(Meshing efficiency (%)	[etaz]	99.696)

End report lines: 303

	Pinion		Gear						
Module		0							
Ratio		1.536							
Number of Teeth	28		43						
HP Rating	####	@	1750	rpm					
Tool Edge Radius	0.114		0.057						
Pitch Diameter	8.855		13.599	inches					
Pitch Angle	33.071		56.929						
Complement: to Pitch Angle	56.929		33.071						
J Factor	0.300		0.300						
Outer Cone Distance		8.114		inches					
Mean Cone Distance		6.739		inches					
Tooth Face Width		2.750		inches					
Face Angle (Standard)	36.205		58.743						
Root Angle (Standard)	31.257		53.795						
Outer Addendum	0.386		0.199	inches					
Outer Dedendum	0.257		0.444	inches					
Pitch Cone Apex to Crown	6.589		4.261	inches					
Mean Diametral Pitch		3.807							
Mean Pitch Diameter	7.355		11.294	inches					
Addendum Angle	3.135		1.814						
Outside Diameter	9.502		13.816						
Outer Whole Depth		0.643							
2 x O.W.D. x SIN * Pitch Angle Complement	0.702		1.078	Backing Length (Crown to Back Face)					
Distance:Crown to Face Cone Apex	6.490		4.193						
	0.211		0.167						
	0.211		0.167						
Pitch Cone Apex to Pitch Line Breakout on Backface	6.799		4.428						
Distance:Crown to Pitch Line Breakout on Backface	0.211		0.167						
Distance:Pitch Cone Apex to Face Cone Apex	0.098		0.068						
Face vertical difference	1.624		2.351						
Small end OD	6.254		9.114						
Apex to Small end point	4.370		2.834						
Apex to Mean Pitch Diameter	5.647		3.677	inches					
Apex to Back Face (approx)	7.353		5.401	inches					
Crown to Back Face	0.764		1.140	inches					0.0938
Back Face to Mean Pitch Diameter	1.706		1.724	inches				0.4375	0.125
Mean Whole depth	0.524			inches				0.5625	0.1875
small end whole depth (approx)	0.405			inches				0.875	0.25
small end root diameter (approx)	5.574			inches				1.25	0.3125
bore	1.750			inches				1.375	0.375
Keyway "T" dimension	1.922			inches				1.75	0.5
Keyway width	0.375			inches				2.25	0.625
clearance keyway to root (small end)	1.723			inches				2.75	0.75
length thru bore approx	2.983			inches				3.25	0.875
clearance/small end whole depth	4.251							3.75	1
								4.5	1.25

Ratings are per AGMA 2003-B97

INPUT

		Pinion	Pair	Gear
Type of Analysis: m - Minor's Rule, x-other	ACode		x	
Bevel Gear Tooth Taper Type Code s - Standard Taper d - Duplex Taper t - Tilted Taper u - Uniform Depth	TCode		s	
Bevel Pinion Speed RPM	np		1750	
Diametral Pitch	Pd		3.162	
Spiral Angle	Ψ		27.5	
Pressure Angle	Φ		20	
Shaft Angle	Σ		90	
Number of Teeth	n, N	28		43
Tooth Face Width	F		2.75000	
Quality Number	Qv		10	
Is this "Very Accurate Gearing"? (1=yes, 2=no) If yes Kv will be set = 1.0			2	
Life in Hours			12500	
AGMA Allowable Bending Stress	Sat	35000		35000
AGMA Allowable Contact Stress	Sac	225000		225000
Operating Temperature (deg F)	Tt		200	
Young's Modulus	E	30000000		30000000
Mounting Factor Code: 0: neither straddle mounted, 1: one member straddle mounted 2: both members straddle mounted			1	
Poisson's Ratio	v	0.300		0.300
Overload Factor	Ko		1.000	
Surface Condition Factor	Cf		1.000	
Bending Reliability Factor	Kr		1.000	
Durability Reliability Factor	Cr		1.000	
Do you want to manually input J Factors? (1=yes,2=no) If yes values in D41 & F41 will be used, else D63 & F63 values are used.			1.000	
Manually Input J Factors (otherwise run macro "Jiterate". Use button at top of this page)	J	0.300		0.300
Hardness Ratio Factor	CH		1.000	
Tooth Crown Code? (crowned=1, no crown=2)			1.000	
Contact Safety Factor	SH		1.000	
Tool Edge Radius (This input is required if macro Jiterate is to be run)	rTP, rTG	0.114		0.057
Cutter Radius	rC		9.500	