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GEARCALC Tutorial 002: LUBE925

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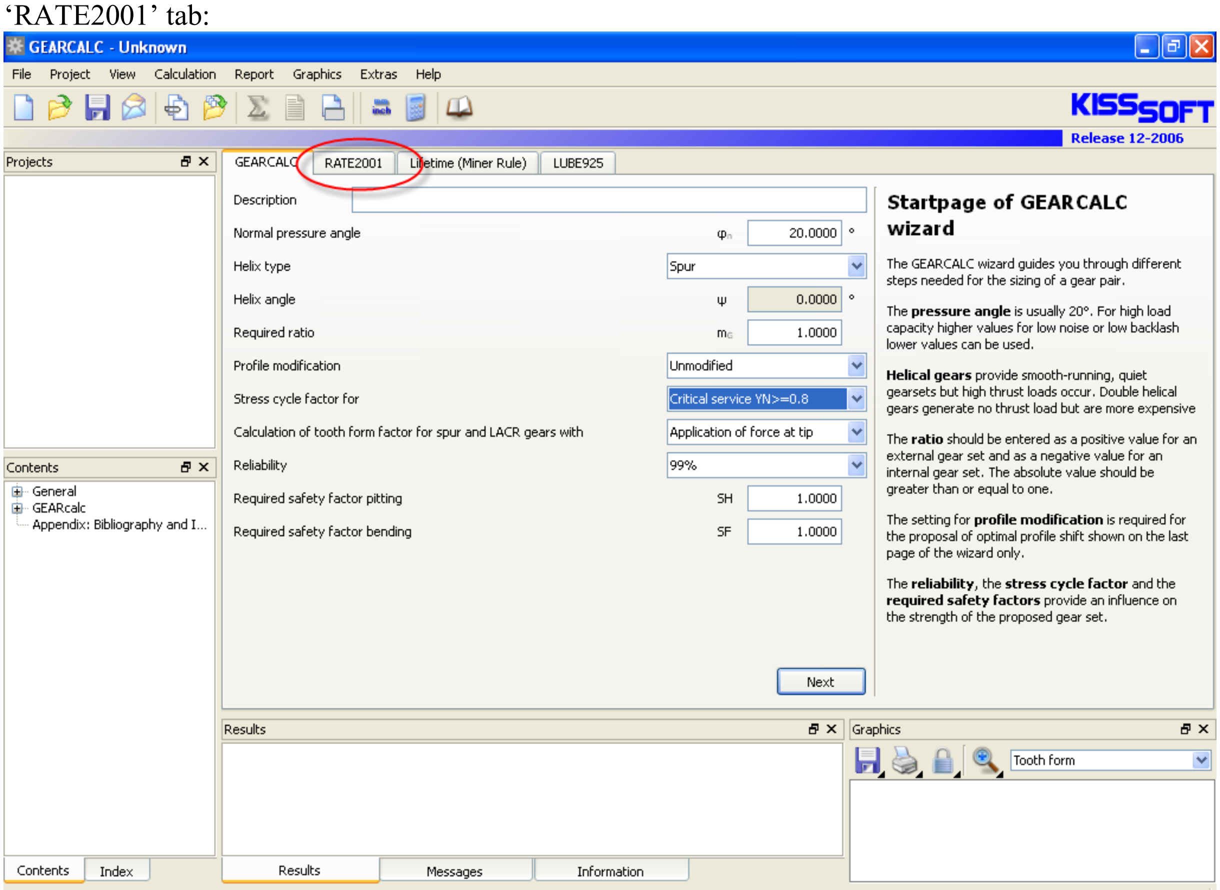
Starting Scoring Calculation

Start the program as described in GEARCALC Tutorial1 – AGMA2001.The calculation of scoring is carried out on LUBE925 tab, but first the main design and operating data must be defined and entered. Click on the 'RATE2001' tab:



Enter Data

Task description – Low Speed Sun/Planet Gear Set

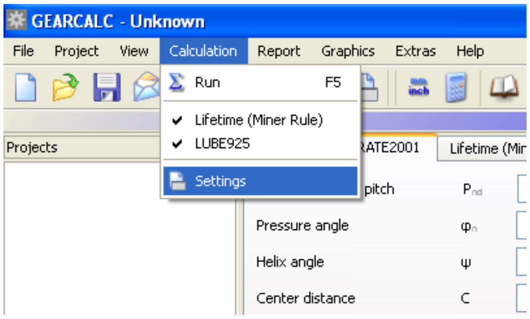
The task will be to rate a gear pair using the scoring calculation. We will consider a hypothetical gear set which in no way can be considered a valid design guide.

The example is a planetary speed increaser for a wind turbine generator. Under rated load conditions the wind turbine rotor delivers 75,000 lb-in torque at 90rpm to the low speed planet carrier of the unit.

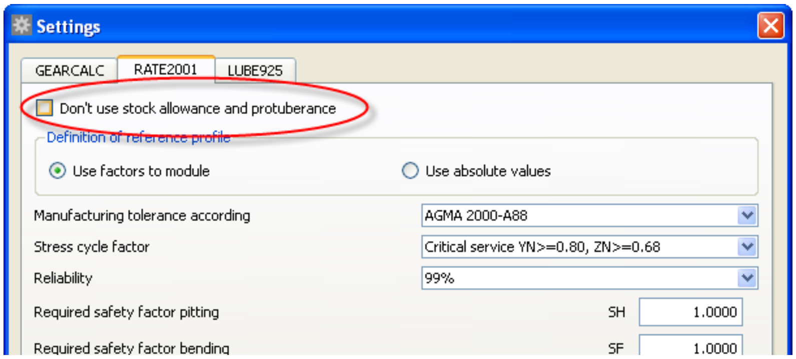
Z_S = 21 (no. teeth in sun gear)
Z_P = 26 (no. teeth in planet gear)
Z_G = 72 (no. teeth in internal gear)
W_C = 90 rpm (carrier speed)
T_C = 75000 lb-in (carrier torque)
Q = 11 (AGMA quality)
Contacts = 3 (no. planets)

Activate Stock Allowance

As the gears are pre-hobbed and ground the stock allowance must be activated. Open the settings dialog, and click on the RATE2001 tab under Calculation->Settings.



Click on the 'Don't use stock allowance and protuberance' check-box to remove the tick:



Enter Data For RATE2001

The sun is to be considered to be the pinion as it has fewer teeth than the planet gear. The geometric data is defined in this list:

P_{nd} = 6.35
ϕ_C = 20°
ψ_S = 0°
C = 3.7795 in

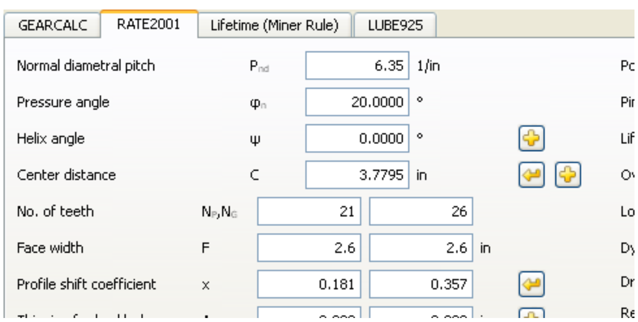
Pinion : N_P = Z_P = 21
Gear : N_G = Z_G = 26

F1 = 2.6 in
F2 = 2.6 in

The values for x_1 and x_2 can be calculated from the standard:

x_1 = 0.181
x_2 = 0.357

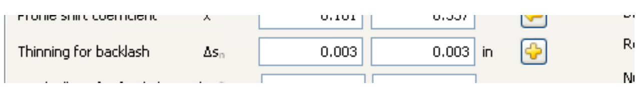
This data is to be entered directly in the cells as shown:



Tooth Thinning For Backlash

Both pinion and gear teeth are thinned 0.003 in to obtain 0.006 in backlash.:

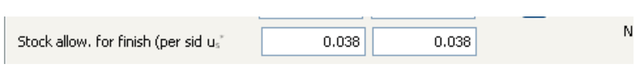
$\Delta s_{n1} = \Delta s_{n2}$ = 0.003 in



Stock Allowance per side For Finishing

The pinion and gear teeth are hobbed leaving 0.006 in of stock per side to be removed by grinding. In terms of P_{nd} = 1.0:

$u_{s1} = u_{s2}$ = 0.006 * P_{nd} = 0.038



Tool Geometry

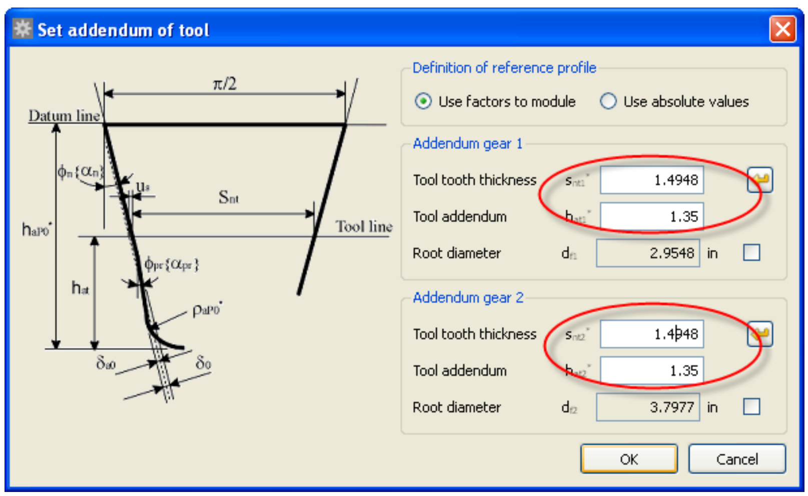
Tool Addendum

The pinion and gear are cut with the same pre-grind protuberance hob. The hob tooth thickness is thinner than $\pi/2$ to provide stock allowance for grinding.
The plus button beside the 'Tool Addendum' field can be used to define the addendum form.

In the dialog, the definition of profile should be set to 'Use factors to module' (in terms of P_{nd} = 1.0):

s_{nt}^{*} = $\pi/2 - 2u_s$ = 1.4948
h_{at}^{*} = 1.35

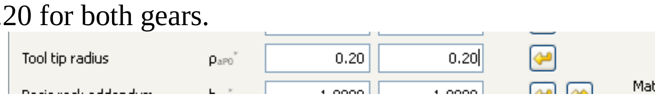
Click on the 'Root Diameter' cell after each value entry to ensure the correct value is recalculated.



Click once on the 'Root Diameter', d_f, cell to calculate the appropriate root diameter values for each gear. Press OK to return to the main dialog. The value of h_{aP0}^{*} = 1.3777 has been determined for both gears.

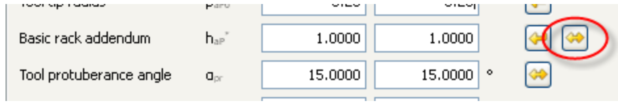
Tip Radius

Enter the tip radius ρ_{aP0}^{*} = 0.20 for both gears.

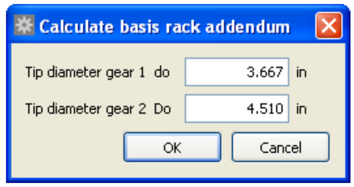


Basic Rack Addendum

Define the tip diameters by pressing the converting button beside the 'Basic Rack Addendum' field.



The tip diameter values d_0 = 3.667in and D_0 = 4.510in can be entered in the cells provided. Press OK to return to the main dialog.



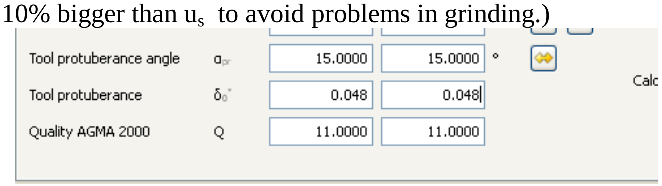
The values of h_{aP} will change to 0.9617, and 0.9622 for gear 1 and 2 respectively.

Tool Protuberance

Enter the following values in the cells provided to define the tool protuberance:

α_{pr} = 15.0° (for both gears)
δ_{0*} = 0.048 (for both gears)

(**NOTE**: δ_{0*} should be at least 10% bigger than u_s to avoid problems in grinding.)



These cells are directly above the AGMA quality value cells (which has been earlier defined as 11):

De-Rating Factors

Load Data for Sun/Planet Meshing

m_{G0} = (72/21) +1 = 4.42857

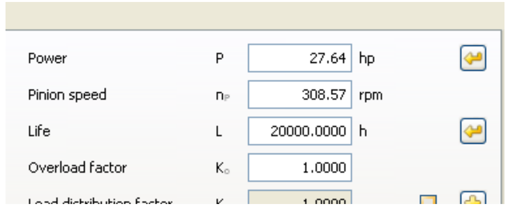
W_S = 90 * m_{G0} = 398.57 rpm
W_{SR} = W_S - 90 = 308.57 rpm
W_{PR} = 90 * (72/26) = 249.23 rpm

T_S = (75000/ m_{G0}) = 16935 lb-in

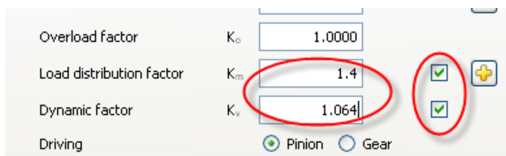
The sun gear is considered as the pinion as it has fewer teeth than the planet. The pinion speed and power are:

n_p = W_{SR} = 308.57 rpm

P = 27.64 hp

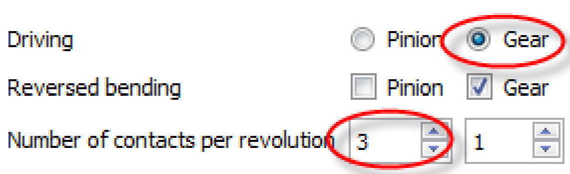


The specific carrier torque was obtained from measurements of the peak torque on similar gear units, hence the overload factor is assigned a value of unity (K_o = 1.0). The gear unit has a ‘floating’ sun to allow the three planets to share the load equally, but some misalignment if the axes is expected. Estimates of the misalignment and observations of the contact patterns on similar units indicates that the load distribution factor is about K_m = 1.4. Low dynamic loads are expected with the accurate gearing and low speeds so the dynamic factor is assigned a value of K_V = 1.064. This data must also be entered on the RATE2001 tab interface. Click the check box beside the fields to edit the K_m or K_V values.



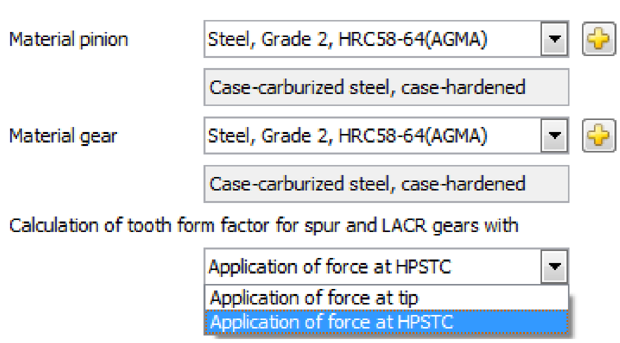
Reversed bending and Number of Contacts

In a planetary configuration the tooth of the planet experiences reversed bending while the tooth on the sun is pulsating. The sun has 3 contact per rotation (representing the contact with the three planets). Change Driving member to gear. Since the planetary gear unit is a speed increaser, the planet (gear) drives the sun (pinion).



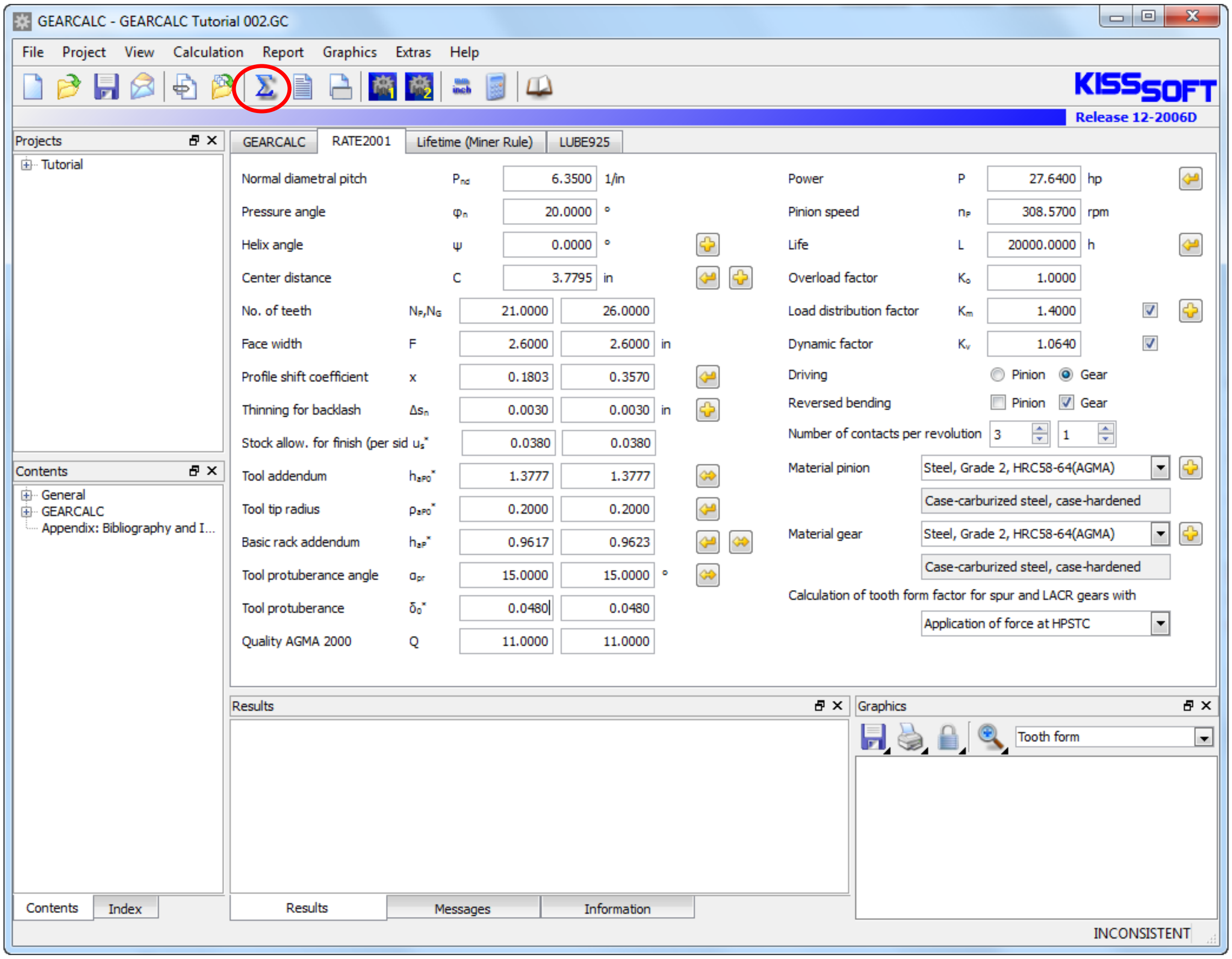
Materials

The material used for pinion and gear is AGMA HRC58-64 Grade 2 case carburised, case hardened steel. Experience has shown that the surface roughness of gear profile of this type is 30micro-in rms “as-ground”. In similar applications the surface roughness has reduced to 20micro-in rms after running in. Change Application of force at tip to HPSTC.

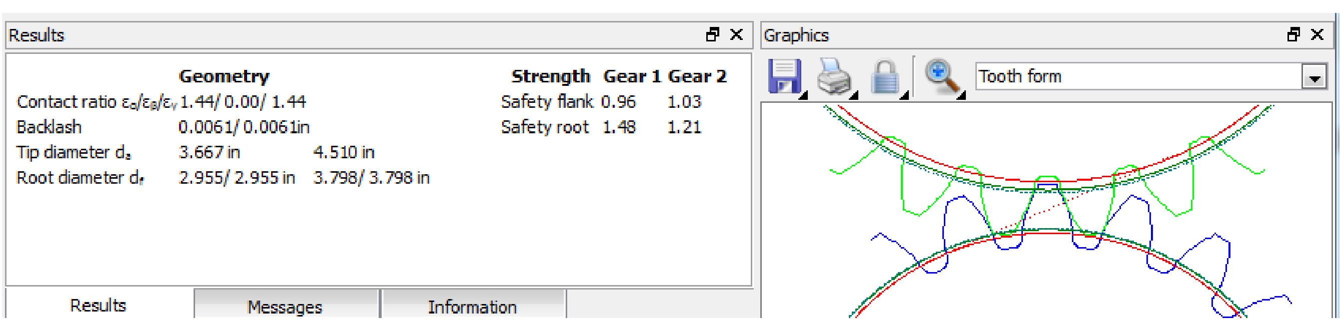


Run Calculation after RATE2001 Data Entry

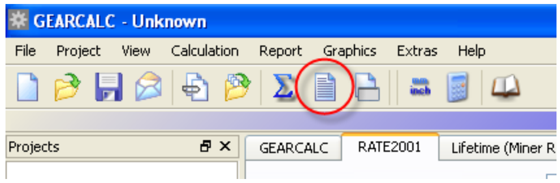
After data entry the page should look as follows:



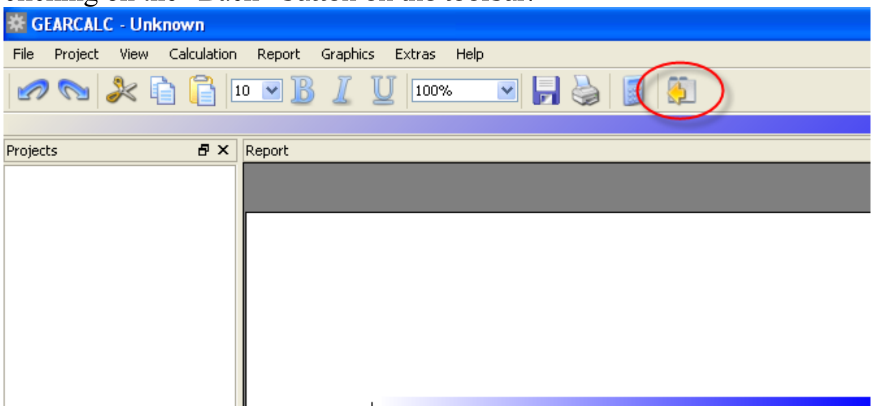
Run the RATE2001 calculation to check the data entry by clicking the calculate button: Σ. On doing this the tooth mesh and safety factors based on the input will be shown in the 'Graphics' and 'Output' windows respectively.



A text report is generated by pressing the 'Report' button in the toolbar above the interface:

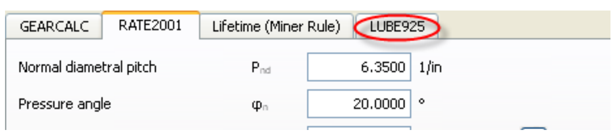


A text report document for this analysis can be found in Annex I. You can return to the RATE2001 page by clicking on the “Back”-button on the toolbar:



Enter Data For LUBE925

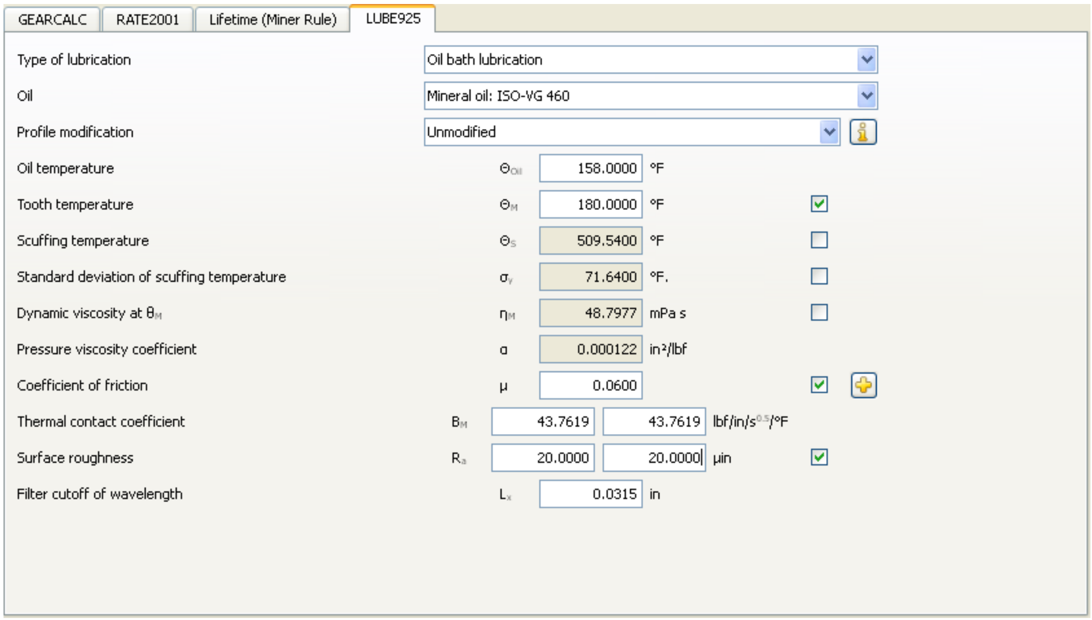
Change to the scoring calculation by clicking the LUBE925 tab:



Lubricant Data

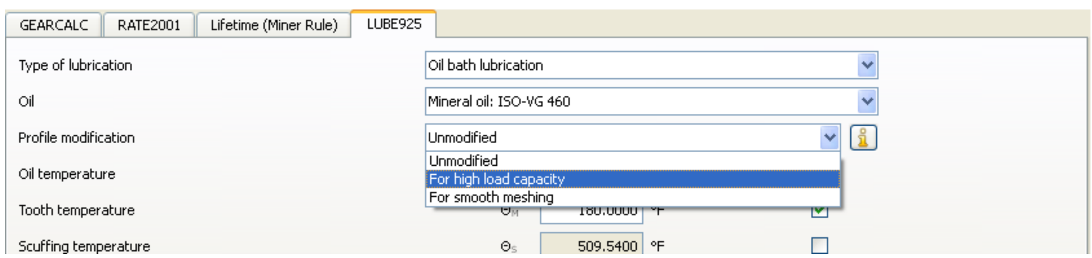
The lubrication type to be used is an oil bath with ISO-VG 460 gear oil (not containing additives for high pressure) and be set using the drop down list options. The bulk (tooth) temperature of the gear teeth is estimated to be 180°F. The pressure viscosity coefficient of such an oil at 180°F is 1.22 x 10^{-4} in^2/Lb.

Ticking the check-box at the side of the entry fields of these temperatures permits entry of the tooth temperature value in the cell.



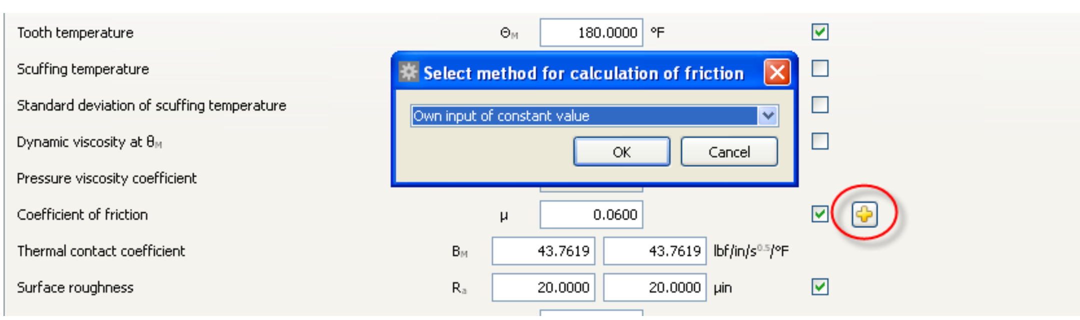
Profile modification

Change profile modification from unmodified to for high load capacity. Select the option "For high load Capacity" from the drop down menu:

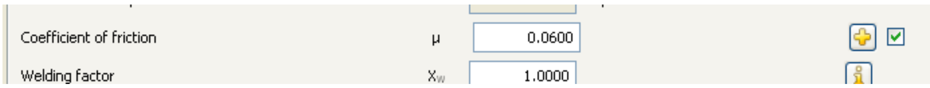


Coefficient of friction

Press the plus button at the side of the field as circled in red below. Select 'Own input of constant value' from drop down menu and press OK to return to main dialog. The check box will now be activated to allow the entry of a value in the cell.



Enter the coefficient of friction as 0.06.



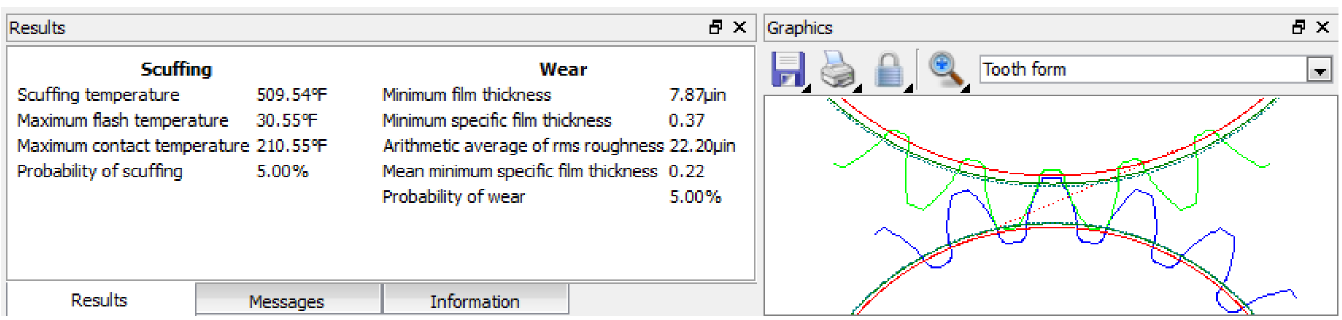
Surface Roughness

Tick the check-box at the side of the input fields:

Set the surface roughness to 20μin for both gears as defined by the material choice before.

Scoring Analysis and Results

Run the LUBE925 calculation to check the data entry by clicking the calculate button. The results and the geometry of the gear pair are generated in the 'Output' and 'Graphics' windows respectively under the interface:



The report can be printed for copy, storage or distribution. The results of the calculation are contained in Annex II.

Annex – Results

Annex I – Results of RATE2001 calculation

GEARCALC - Release 12-2006

GEARCALC evaluation version

File

Name : GEARCALC Tutorial 002
Changed by : ho on: 10/13/11 at: 6:24 pm

RESULTS FOR RESISTANCE CALCULATION FOLLOWING AGMA 2001-D04 STANDARD

INPUT DATA SUMMARY

GEAR GEOMETRY DATA		**Pinion**	**Gear**
Tooth number	NP,NG =	21	26
Net face width	F1,F2 =	2.6000	2.6000
Outside diameter	do,Do =	3.6668	4.5100
Normal diametral pitch (1/in)	Pnd =	6.3500	
Normal pressure angle	PHI(n) =	20.0000	
Standard helix angle	PSI(s) =	0.0000	
Operating center distance	C =	3.7795	
Centre distance tolerance	C.e/i =	0.0000 / 0.0000	
Gear geometry data for Pnd = 1.0			
Profile shift coefficient	X1,X2 =	0.18027	0.35700
Thinning for backlash	del.sn1, del.sn2 =	0.01905	0.01905
Stock allow. per side for finishing	Us1,Us2 =	0.03800	0.03800
Tool geometry data for Pnd = 1.0			
Tool normal tooth thickness	tce1,tce2 =	1.5708	1.5708
Tool addendum (Precutting)	hao1,hao2 =	1.3777	1.3777
Tool addendum (Finish)	hao1,hao2 =	1.2733	1.2733
Tool tip radius	rTe1,rTe2 =	0.2000	0.2000
Tool protuberance	DELTA(o1),DELTA(o2) =	0.0480	0.0480
Tool protuberance	ANGLE(1),ANGLE(2) =	15.0000	15.0000

MATERIALS/HEAT-TREATMENT DATA

Material (Pinion) = Steel, Grade 2, HRC58-64(AGMA)
AGMA 2001-C95; AGMA 2101-C95
Material (Gear) = Steel, Grade 2, HRC58-64(AGMA)
AGMA 2001-C95; AGMA 2101-C95

		Pinion	Gear
Material type	=	Case-carburized stee	Case-carburized stee
Heat-treatment	=	case-hardened	case-hardened

LOAD DATA		**Pinion**	**Gear**
Transmitted power (HP)	P =	27.6400	
Pinion speed (rpm)	n(P) =	308.5700	
Required life (HRS)	L =	20000	
Reliability	R =	99 %	
Driving:	=	GEAR	
Number of contacts per revolution	=	3	1
Reversed bending (0=No; 1=Yes)	=	0	1
Spur gear loading type	=	HPSTC	
Stress cycle factors, Curve chosen, Figs. 17 & 18	=	Lower	(for critical applications)

DERATING FACTORS

Overload (or application) factor	Ko =	1.0000	
Size factor	Ks =	1.0000	
Surface condition factor	Cf =	1.0000	
Rim thickness factor	KB =	1.0000	1.0000
Load distribution factor introduced:	Km =	1.4000	
Dynamic factor introduced:	Kv =	1.0640	

GEOMETRY SUMMARY-1

		Pinion	**Gear**
Generating pitch dia	ds,Ds =	3.3071	4.0945
Operating pitch dia	d,D =	3.3774	4.1816
Base dia	db,Db =	3.1076	3.8476
Mean dia of pinion	dm =	3.3579	
Root diameter (manufactured)	dR,DR =	2.9546/2.9546	3.7977/3.7977
Limit (SAP) (manufactured)	dc,Dc =	3.1664/3.1664	3.9790/3.9790
Top of fillet (manufactured)	de,De =	3.1278/3.1278	3.9272/3.9272

PRESSURE ANGLES

Standard transverse	PHI(s) =	20.0000
Operating transverse	PHI(t) =	23.0560
Standard normal	PHI(c) =	20.0000
Operating normal	PHI(n) =	23.0560

HELIX ANGLES

Standard	PSI(s) =	0.0000
Operating	PSI =	0.0000
Base	PSI(b) =	0.0000

PITCHES

Normal circular	pn =	0.4947
Transverse base	pb =	0.4649
Normal base	pN =	0.4649
Axial	px =	------

DISTANCES ALONG LINE OF ACTION

Start of active profile (SAP)	C1 =	0.3037
Low single tooth contact (LPSTC)	C2 =	0.5082
Pitch point	C3 =	0.6614
High single tooth contact (HPSTC)	C4 =	0.7686
End of active profile (EAP)	C5 =	0.9731
Distance between interference points	C6 =	1.4802
Active length of line of action	Z =	0.6694
Pinion addendum portion of Z	Za =	0.3118
Pinion dedendum portion of Z	Zb =	0.3577
Dist. from pitch point to stress calc	Zc =	0.0573

LENGTH OF CONTACT LINE

Minimum	Lmin =	2.6000
Maximum	Lmax =	5.2000
Average	Lavg =	3.9000

RATIOS

Contact length	mL =	2.0000
Transverse (profile) contact	mp =	1.4399
Axial (face) contact	mF =	0.0000
Total contact	mt =	1.4399
Gear ratio	mG =	1.2381
Load sharing (mN = F/Lmin)	mN =	1.0000

TRANSVERSE RADII OF CURVATURE

At operating pitch point of pinion	RP =	0.6614
At operating pitch point of gear	RG =	0.8188
At point of stress calc of pinion	R1 =	0.5082
At point of stress calc of gear	R2 =	0.9720

TOOTH DEPTHS

Operating addendum	a1,a2 =	0.1447/ 0.1447	0.1642/ 0.1642
Operating dedendum	b1,b2 =	0.2114/ 0.2114	0.1920/ 0.1920
Operating clearance	c1,c2 =	0.0473/ 0.0473	0.0472/ 0.0472
Whole depth	ht1,ht2 =	0.3561/ 0.3561	0.3562/ 0.3562
Working depth	hK =	0.3088/ 0.3088	0.3090/ 0.3090

TRANSVERSE CIRCULAR TOOTH THICKNESSES (manufactured)

Topland	to1,to2 =	0.1037/0.1037	0.0988/0.0988
Operating	tr1,tr2 =	0.2426/0.2426	0.2566/0.2566
Generating	tg1,tg2 =	0.2650/0.2650	0.2853/0.2853
Base	tb1,tb2 =	0.2954/0.2954	0.3254/0.3254

NORMAL CIRCULAR TOOTH THICKNESSES (manufactured)

Topland	tno1,tno2 =	0.1037/0.1037	0.0988/0.0988
Operating	tnr1,tnr2 =	0.2426/0.2426	0.2566/0.2566
Generating	tng1,tng2 =	0.2650/0.2650	0.2853/0.2853
Base	tnb1,tnb2 =	0.2954/0.2954	0.3254/0.3254

LEAD	L1,L2 =	0.0000	0.0000

OPERATING CIRCULAR BACKLASH (manufactured)

Transverse (only through Center dist. tol.)	=	0.0000/ 0.0000
Transverse (total)	B =	0.0061/ 0.0061
Normal (total)	Bn =	0.0058/ 0.0058

PROFILE SHIFT COEFFICIENTS FOR MANUFACTURING

Theoretical, no backlash	x1,x2 =	0.1803	0.3570
Prefabrication	xg1,xg2 =	0.2585/ 0.2585	0.4352/ 0.4352
Finishing	xg1,xg2 =	0.1541/ 0.1541	0.3308/ 0.3308

NOTE: All dims in inches, all angles in degrees.
All geometry data, which are not declared as 'manufacturing',
are for the theoretical (no backlash) tooth meshing situation.

GEOMETRY SUMMARY-2

PITTING RESISTANCE GEOMETRY FACTOR DATA

Helical overlap factor	C(PSI) =	1.0000
Minimum length of contact	Lmin =	2.6000
Pitting resistance geometry factor	I =	0.0909

BENDING STRENGTH GEOMETRY FACTOR DATA

		Pinion	**Gear**
Load angle	PHI(L) =	22.896	24.102
Height of Lewis parabola	h =	1.1948	1.2190
Tooth thickness at critical section	t =	1.9505	2.1145
Radius at curvature of fillet curve	ro =	0.2742	0.2403
Loaded at PSTC (Load sharing)			
(h, t, ro for Pnd = 1.0)			
Diameter of the critical point F	DFpoint =	3.0200	3.8513
Helical factor	Ch =	1.0000	
Helix angle factor	K(PSI) =	1.0000	
Stress correction factor	Kf =	1.8534	1.9555
Tooth form factor	Y =	0.5989	0.7077
Bending strength geometry factor	J =	0.3231	0.3619

LOAD / MATERIAL SUMMARY

Pitch line velocity	(FPM)	vt =	272.8
Transmitted tangential load	(LB.)	Wt =	3414.1
Torque transmitted by pinion	(LB.IN.)	T(1) =	5645.4
Torque transmitted by gear	(LB.IN.)	T(2) =	6989.6
Contact load factor for pitting resist.		K =	688.0
Unit load factor for bending strength		U(L) =	8161.9

MATERIALS/HEAT TREATMENT DATA

Modulus of elasticity (lb/in²)	EP,EG =	30000000	30000000
Poisson's ratio	mu(P),mu(G) =	0.3000	0.3000
Surface hardness		HRC 60	HRC 60
Allowable contact stress	sac(P), sac(G) =	225000	225000
Allowable bending stress	sat(P), sat(G) =	65000	45500
Yield point (lb/in²)	sigs =	119221	119221

DERATING FACTOR SUMMARY

Overload (or application) factor	Ko =	1.0000	
Size factor	Ks =	1.0000	
Surface condition factor	Cf =	1.0000	
Rim thickness factor	KB =	1.0000	1.0000
Load distribution factor introduced			
Load distribution factor	Km =	1.4000	
Dynamic factor introduced			
Dynamic factor	Kv =	1.0640	
Combined derating factor pitting	Ko*Kv*Km*Ks*Cf =	1.4896	
Combined derating factor bending	Ko*Kv*Km*Ks*KB =	1.4896	

STRENGTH SUMMARY

		Pinion	**Gear**
Stress cycle factor (Contact)	Z(N) =	0.7681*a*	0.8267*a*
Surface condition factor	C(f) =	1.0000	1.0000
Hardness ratio factor	C(H) =	1.0000	1.0000
Temperature factor	K(T) =	1.0000	1.0000
Reliability factor	K(R) =	1.0000	
Allow. contact stress No. (lb/in²)	sac =	172830	186008
Stress cycle factor (Root)	Y(N) =	0.8589*a*	0.8961*a*
Reverse loading factor	=	1.0000	0.7000
Allow. bending stress No. (lb/in²)	sat =	55828	40771

a NOTE: Based on life (HRS) L = 20000
Curve chosen, Figs. 17 & 18 = Lower (for critical applications)

STRESS SUMMARY

Elastic coefficient	(lb^.5/in)	Cp =	2290.0
Contact stress No.	(lb/in²)	sc =	180876.8
Pinion bending stress No.	(lb/in²)	st1 =	37627.1
Gear bending stress No.	(lb/in²)	st2 =	33593.0

NOTE: Materials with HB > 400: Yield strength is not checked.

RESULTING SAFETY FACTORS

Safety factor (Bending)	Sat/st =	1.48	1.21
Safety factor (Contact)	Sac/sc =	0.96	1.03

SERVICE FACTORS

Service factor for bending	KSF =	1.48	1.21
Service factor for contact	CSF =	0.91	1.06
Service factor for gear set	SF =	0.91	

POWER RATING CALCULATION

(Calculation of the transmittable power)

			Pinion	**Gear** *a*
Allow. transmitted power for pitting	(HP)	Pac =	25.24	29.23
Allow. transmitted power for bending	(HP)	Pat =	41.01	33.55
Allowable transmitted power	(HP)	P =	25.24	

Life factor for pitting resistance	Z(N) =	0.768 *b*	0.827 *b*
Life factor for bending resistance	Y(N) =	0.859 *b*	0.896 *b*
Durability (Pitting) life (HRS)	L(C) =	20000.0	20000.0
Durability (Pitting) life (CYCS/10^6)	N(C) =	1110.9	299.1
Bending fatigue life (HRS)	L(T) =	20000.0	20000.0
Bending fatigue life (CYCS/10^6)	N(T) =	1110.9	299.1

a NOTE: Based on allowable stresses at life (HRS) L = 20000
b NOTE: Pitting and Bending Life calculated for critical applications
(Lower portion in fig. 17 and 18)

MANUFACTURING DATA

Tooth thickness dimensions

		Pinion	Gear
Tooth thickness measurements before final treatment (precutting data)			
Stock allowance for finishing (per side)	us =	0.0060	0.0060
Normal circular tooth thickness	sn =	0.2770/ 0.2770	0.2973/ 0.2973
Span measurement	Wk =	1.2364/ 1.2364	1.7314/ 1.7314
Number of teeth spanned	k =	3.0000	4.0000
Diameter of span contact point	dWk =	3.3446	4.2192
Measurement over 1 ball	MrK =	1.8996/ 1.8996	2.3546/ 2.3546
Measurement over 2 balls	MdK =	3.7893/ 3.7893	4.7324/ 4.7324 *c*
Ball or roll diameter	DM =	0.2880	0.3200
Diameter of ball/roll contact point	dMM =	3.3867	4.2649
Normal chordal thickness	'sn =	0.2767/ 0.2767	0.2970/ 0.2970 *a*
Normal chordal height	ha =	0.1853	0.2128
Tooth thickness measurements after final treatment			
Thinning for backlash	As =	0.0030/ 0.0030	0.0030/ 0.0030
Normal circular tooth thickness	sn =	0.2650/ 0.2650	0.2853/ 0.2853
Span measurement	Wk =	1.2252/ 1.2252	1.7201/ 1.7201
Number of teeth spanned	k =	3.0000	4.0000
Diameter of span contact point	dWk =	3.3404	4.2146
Measurement over 1 ball	MrK =	1.8873/ 1.8873	2.3546/ 2.3546
Measurement over 2 balls	MdK =	3.7649/ 3.7649	4.7092/ 4.7092 *c*
Ball or roll diameter	DM =	0.2880	0.3200
Diameter of ball/roll contact point	dMM =	3.3659	4.2445
Normal chordal thickness	'sn =	0.2647/ 0.2647	0.2851/ 0.2851 *a*
Normal chordal height	ha =	0.1853	0.2128

a NOTE: Tooth thickness measured at generating pitch diameter
c NOTE: When measuring over 2 balls, the two balls must be in the same transverse plane.
NOTE: All dims in inches.

Tolerances

Following AGMA 2000-A88:

Accuracy grade (Quality)	Q-AGMA2000 =	11	11
Pitch Variation Allowable	VpA =	3.0	3.1
Runout Radial Tolerance	VrT =	11.4	12.2
Profile Tolerance	VphiT =	4.3	4.3
Tooth Alignment Tolerance	VpsiT =	5.1	5.1
Composite Tolerance, Tooth-to-Tooth	VqT =	6.3	5.9
Composite Tolerance, Total	VcqT =	17.3	18.1

NOTE: All dims in 1/10000 in.

End report lines: 336

MANUFACTURING DATA

Tooth thickness dimensions

		Pinion	Gear
Tooth thickness measurements before final treatment (precutting data)			
Stock allowance for finishing (per side)	us =	0.0060	0.0060
Normal circular tooth thickness	sn =	0.2770/ 0.2770	0.2973/ 0.2973
Span measurement	Wk =	1.2364/ 1.2364	1.7314/ 1.7314
Number of teeth spanned	k =	3.0000	4.0000
Diameter of span contact point	dWk =	3.3446	4.2192
Measurement over 1 ball	MrK =	1.8996/ 1.8996	2.3546/ 2.3546
Measurement over 2 balls	MdK =	3.7893/ 3.7893	4.7324/ 4.7324 *c*
Ball or roll diameter	DM =	0.2880	0.3200
Diameter of ball/roll contact point	dMM =	3.3867	4.2649
Normal chordal thickness	'sn =	0.2767/ 0.2767	0.2970/ 0.2970 *a*
Normal chordal height	ha =	0.1853	0.2128
Tooth thickness measurements after final treatment			
Thinning for backlash	As =	0.0030/ 0.0030	0.0030/ 0.0030
Normal circular tooth thickness	sn =	0.2650/ 0.2650	0.2853/ 0.2853
Span measurement	Wk =	1.2252/ 1.2252	1.7201/ 1.7201
Number of teeth spanned	k =	3.0000	4.0000
Diameter of span contact point	dWk =	3.3404	4.2146
Measurement over 1 ball	MrK =	1.8873/ 1.8873	2.3546/ 2.3546
Measurement over 2 balls	MdK =	3.7649/ 3.7649	4.7092/ 4.7092 *c*
Ball or roll diameter	DM =	0.2880	0.3200
Diameter of ball/roll contact point	dMM =	3.3659	4.2445
Normal chordal thickness	'sn =	0.2647/ 0.2647	0.2851/ 0.2851 *a*
Normal chordal height	ha =	0.1853	0.2128

a NOTE: Tooth thickness measured at generating pitch diameter
c NOTE: When measuring over 2 balls, the two balls must be in the same transverse plane.
NOTE: All dims in inches.

Tolerances

Following AGMA 2000-A88:

		Pinion	Gear
Accuracy grade (Quality)	Q-AGMA2000 =	11	11
Pitch Variation Allowable	VpA =	3.0	3.1
Runout Radial Tolerance	VrT =	11.4	12.2
Profile Tolerance	VphiT =	4.3	4.3
Tooth Alignment Tolerance	VpsiT =	5.1	5.1
Composite Tolerance, Tooth-to-Tooth	VqT =	6.3	5.9
Composite Tolerance, Total	VcqT =	17.3	18.1

NOTE: All dims in 1/10000 in.

End report lines: 336

Annex II – Results of LUBE925 calculation

——————————————— GEARCALC - Release 12-2006
GEARCALC evaluation version

——————————————— File
Name : GEARCALC Tutorial 002
Changed by : ho on: 10/14/11 at: 8:29 am

Effect of Lubrication on Gear Surface Distress (AGMA925-A03)
Risk of scuffing / Risk of wear

General and Geometry input data
>> See AGMA2001 Report

Profile correction
Profile correction: for high load capacity gearboxes

Material input data

Average surface roughness at Lx, pinion	[Ra1x]	20.0000	µin
Average surface roughness at Lx, gear	[Ra2x]	20.0000	µin
Filter cutoff of wavelength x	[Lx]	0.0315	in
Mean coefficient of friction	[mym]	0.060000	
Method for approximate mean coef. friction	:	INPUT	
Welding factor	[Xw]	1.000	

Input temperature data

Tooth temperature	[ThetaM]	180.000	°F
Calculation of thetaM	:	INPUT	
Thermal contact coefficient, pinion	[BM1]	43.762	lbf/in/s^.5/°F
Thermal contact coefficient, gear	[BM2]	43.762	lbf/in/s^.5/°F
Oil inlet or sump temperature	[Thetaoil]	158.000	°F
Parameter for calculating tooth temperature	[ksump]	1.000	
Number of calculation points	[nNop]	25.000	

Lubrication data

Lubrication with oil		Mineral oil: ISO-VG 460	
Kinematic viscosity at 40 deg C	[Nu40]	460.000	cSt
Kinematic viscosity at 100 deg C	[Nu100]	31.001	cSt
Kinematic viscosity at gear tooth temperature	[NuM]	57.028	cSt
Dynamic viscosity at 40 deg C	[Eta40]	412.082	cP
Dynamic viscosity at 100 deg C	[Eta100]	26.341	cP
Oil factor k	[k_coef]	0.010471	
Oil factor s	[s_coef]	0.134800	
Dynamic viscosity at gear tooth temperature	[EtaM]	48.8	cP
Pressure-viscosity coefficient	[Alpha]	0.000122	in2/lbf

Gear tooth velocity and loads

Rotational (angular) velocity, pinion	[Omega1]	32.313	rad/s
Rotational (angular) velocity, gear	[Omega2]	26.099	rad/s
Operating pitch line velocity	[vt]	272.839	ft/min
Nominal tangential load	[Ftnom]	3343.036	lbf
Combined derating factor	[KD]	1.490	
Actual tangential load	[Ft]	4979.786	lbf
Normal operating load	[Fwn]	5412.091	lbf
Normal unit load	[wn]	2081.600	lbf/in

Material property and tooth surface finish

Reduced modulus of elasticity	[Er]	32967047.471	lbf/in2
Average of pinion and gear average roughness	[Ravgx]	20.00000	µin
Surface roughness constant	[CRavgx]	1.81672	
Composite surface roughness at filter cutoff	[Sigmax]	28.28427	µin

Risk of scuffing

Calculation of scuffing temperature thetaS	:	With formula (94)
Scuffing temperature	[thetaS]	509.54 °F
Tooth temperature	[ThetaM]	180.00 °F
Maximum flash temperature	[thetaflmax]	30.47 °F
Maximum contact temperature	[thetaBmax]	210.47 °F
Probability of scuffing	[Pscuff]	5.00 % or lower

(y=210.47 °F, muy=509.54 °F, Sigmay=71.64 °F, x=((y-muy)/Sigmay)=-4.17)
Risk of scuffing (AGMA 925, Table 5): LOW

Risk of wear

Minimum film thickness (at xsi=15.312°)	[hmin]	7.86948 µin
Minimum specific film thickness (at xsi=18.740°)	[LambdaMin]	0.41025
Average surface (rms) roughness, pinion	[Rq1x]	22.2000 µin
Average surface (rms) roughness, gear	[Rq2x]	22.2000 µin
Arithmetic average of rms roughness	[Rqxavg]	22.2000 µin
Operating pitch line velocity	[vt]	272.839 ft/min
Mean minimum specific film thickness	[MuLambdaMin]	0.21595

MuLambdaMin: Value for LambdaMinAdj with 50% wear risk (AGMA 925, Table 7)
Probability of wear: y=0.4102 , muy=0.2160 , Sigmay=0.1126 , x=((y-muy)/Sigmay)=1.7252
Probability of wear [Pwear] 5.00 % or lower

Profile radii of curvature

Index	xsi(rad)	d1(in)	rho1(in)	rho2(in)	rhon1(in)	rhon2(in)	rhon(in)	Index
A	0.19545	3.16645	0.30369	1.17648	0.30369	1.17648	0.24138	A
B	0.32707	3.26964	0.50821	0.97196	0.50821	0.97196	0.33372	B
C	0.42563	3.37743	0.66135	0.81882	0.66135	0.81882	0.36585	C
D	0.49465	3.46705	0.76860	0.71157	0.76860	0.71157	0.36949	D
E	0.62627	3.66677	0.97311	0.50706	0.97311	0.50706	0.33336	E
1	0.19545	3.16645	0.30369	1.17648	0.30369	1.17648	0.24138	1
2	0.21340	3.17762	0.33159	1.14858	0.33159	1.14858	0.25730	2
3	0.23135	3.18973	0.35948	1.12069	0.35948	1.12069	0.27217	3
4	0.24930	3.20276	0.38737	1.09280	0.38737	1.09280	0.28599	4
5	0.26725	3.21671	0.41526	1.06491	0.41526	1.06491	0.29876	5
6	0.28520	3.23156	0.44315	1.03701	0.44315	1.03701	0.31048	6
7	0.30315	3.24731	0.47105	1.00912	0.47105	1.00912	0.32114	7
8	0.32110	3.26393	0.49894	0.98123	0.49894	0.98123	0.33076	8
9	0.33906	3.28141	0.52683	0.95334	0.52683	0.95334	0.33932	9
10	0.35701	3.29975	0.55472	0.92545	0.55472	0.92545	0.34683	10
11	0.37496	3.31892	0.58262	0.89755	0.58262	0.89755	0.35329	11
12	0.39291	3.33891	0.61051	0.86966	0.61051	0.86966	0.35870	12
13	0.41086	3.35971	0.63840	0.84177	0.63840	0.84177	0.36306	13
14	0.42881	3.38131	0.66629	0.81388	0.66629	0.81388	0.36636	14
15	0.44676	3.40368	0.69419	0.78598	0.69419	0.78598	0.36862	15
16	0.46471	3.42681	0.72208	0.75809	0.72208	0.75809	0.36982	16
17	0.48266	3.45069	0.74997	0.73020	0.74997	0.73020	0.36998	17
18	0.50061	3.47530	0.77786	0.70231	0.77786	0.70231	0.36908	18
19	0.51856	3.50063	0.80575	0.67441	0.80575	0.67441	0.36713	19
20	0.53651	3.52666	0.83365	0.64652	0.83365	0.64652	0.36413	20
21	0.55446	3.55337	0.86154	0.61863	0.86154	0.61863	0.36008	21
22	0.57241	3.58075	0.88943	0.59074	0.88943	0.59074	0.35497	22
23	0.59037	3.60879	0.91732	0.56285	0.91732	0.56285	0.34882	23
24	0.60832	3.63747	0.94522	0.53495	0.94522	0.53495	0.34161	24
25	0.62627	3.66677	0.97311	0.50706	0.97311	0.50706	0.33336	25

Velocities

Index	xsi(rad)	d1(in)	vr1(in/s)	vr2(in/s)	vs(in/s)	ve(in/s)	vss1	vss2	Index
A	0.1955	3.16645	9.813	30.705	-20.892	40.519	-2.1289	0.6804	A
B	0.3271	3.26964	16.422	25.368	-8.946	41.789	-0.5447	0.3526	B
C	0.4256	3.37743	21.371	21.371	0.000	42.741	0.0000	0.0000	C
D	0.4946	3.46705	24.836	18.572	6.264	43.407	0.2522	-0.3373	D
E	0.6263	3.66677	31.444	13.234	18.210	44.678	0.5791	-1.3760	E
1	0.1955	3.16645	9.813	30.705	-20.892	40.519	-2.1289	0.6804	1

2	0.2134	3.17762	10.715	29.977	-19.263	40.692	-1.7978	0.6426	2
3	0.2314	3.18973	11.616	29.249	-17.633	40.865	-1.5180	0.6029	3
4	0.2493	3.20276	12.517	28.521	-16.004	41.038	-1.2786	0.5611	4
5	0.2672	3.21671	13.419	27.793	-14.375	41.212	-1.0713	0.5172	5
6	0.2852	3.23156	14.320	27.065	-12.745	41.385	-0.8901	0.4709	6
7	0.3031	3.24731	15.221	26.337	-11.116	41.558	-0.7303	0.4221	7
8	0.3211	3.26393	16.122	25.609	-9.487	41.732	-0.5884	0.3705	8
9	0.3391	3.28141	17.024	24.881	-7.858	41.905	-0.4616	0.3158	9
10	0.3570	3.29975	17.925	24.153	-6.228	42.078	-0.3475	0.2579	10
11	0.3750	3.31892	18.826	23.425	-4.599	42.252	-0.2443	0.1963	11
12	0.3929	3.33891	19.728	22.698	-2.970	42.425	-0.1505	0.1308	12
13	0.4109	3.35971	20.629	21.970	-1.341	42.598	-0.0650	0.0610	13
14	0.4288	3.38131	21.530	21.242	0.289	42.772	0.0134	-0.0136	14
15	0.4468	3.40368	22.431	20.514	1.918	42.945	0.0855	-0.0935	15
16	0.4647	3.42681	23.333	19.786	3.547	43.118	0.1520	-0.1793	16
17	0.4827	3.45069	24.234	19.058	5.176	43.292	0.2136	-0.2716	17
18	0.5006	3.47530	25.135	18.330	6.806	43.465	0.2708	-0.3713	18
19	0.5186	3.50063	26.037	17.602	8.435	43.638	0.3240	-0.4792	19
20	0.5365	3.52666	26.938	16.874	10.064	43.812	0.3736	-0.5964	20
21	0.5545	3.55337	27.839	16.146	11.693	43.985	0.4200	-0.7242	21
22	0.5724	3.58075	28.741	15.418	13.323	44.158	0.4636	-0.8641	22
23	0.5904	3.60879	29.642	14.690	14.952	44.332	0.5044	-1.0178	23
24	0.6083	3.63747	30.543	13.962	16.581	44.505	0.5429	-1.1876	24
25	0.6263	3.66677	31.444	13.234	18.210	44.678	0.5791	-1.3760	25

Specific film thickness

Material parameter [G] 4019.605

Index	xsi(rad)	d1(in)	U	W	Hc	hc(µin)	bH(in)	Lambda2bH	Index
A	0.1955	3.16645	1.8018e-011	3.7369e-005	3.4140e-005	8.24072	0.00235	0.75347	A
B	0.3271	3.26964	1.3442e-011	1.8921e-004	2.3714e-005	7.91380	0.00733	0.41025	B
C	0.4256	3.37743	1.2540e-011	1.7259e-004	2.2814e-005	8.34649	0.00767	0.42285	C
D	0.4946	3.46705	1.2610e-011	1.7089e-004	2.2924e-005	8.47037	0.00771	0.42806	D
E	0.6263	3.66677	1.4387e-011	0.0000e+000	0.0000e+000	0.00000	0.00000	0.00000	E
1	0.1955	3.16645	1.8018e-011	3.7369e-005	3.4140e-005	8.24072	0.00235	0.75347	1
2	0.2134	3.17762	1.6976e-011	6.3743e-005	3.1060e-005	7.99191	0.00328	0.61930	2
3	0.2314	3.18973	1.6117e-011	8.7380e-005	2.9036e-005	7.90297	0.00406	0.55030	3
4	0.2493	3.20276	1.5403e-011	1.0897e-004	2.7529e-005	7.87296	0.00476	0.50608	4
5	0.2672	3.21671	1.4807e-011	1.2902e-004	2.6340e-005	7.86948	0.00542	0.47447	5
6	0.2852	3.23156	1.4308e-011	1.4792e-004	2.5376e-005	7.87851	0.00603	0.45030	6
7	0.3031	3.24731	1.3891e-011	1.6599e-004	2.4578e-005	7.89291	0.00660	0.43097	7
8	0.3211	3.26393	1.3543e-011	1.8349e-004	2.3911e-005	7.90870	0.00715	0.41499	8
9	0.3391	3.28141	1.3257e-011	1.8608e-004	2.3527e-005	7.98321	0.00739	0.41213	9
10	0.3570	3.29975	1.3023e-011	1.8205e-004	2.3291e-005	8.07818	0.00747	0.41475	10
11	0.3750	3.31892	1.2838e-011	1.7872e-004	2.3105e-005	8.16265	0.00754	0.41716	11
12	0.3929	3.33891	1.2696e-011	1.7603e-004	2.2963e-005	8.23690	0.00759	0.41936	12
13	0.4109	3.35971	1.2595e-011	1.7392e-004	2.2864e-005	8.30110	0.00764	0.42135	13
14	0.4288	3.38131	1.2532e-011	1.7235e-004	2.2806e-005	8.35539	0.00768	0.42315	14
15	0.4468	3.40368	1.2506e-011	1.7129e-004	2.2787e-005	8.39985	0.00770	0.42475	15
16	0.4647	3.42681	1.2515e-011	1.7073e-004	2.2807e-005	8.43450	0.00771	0.42615	16
17	0.4827	3.45069	1.2560e-011	1.7066e-004	2.2864e-005	8.45931	0.00771	0.42736	17
18	0.5006	3.47530	1.2641e-011	1.3999e-004	2.3426e-005	8.64586	0.00697	0.45952	18
19	0.5186	3.50063	1.2759e-011	1.2063e-004	2.3930e-005	8.78521	0.00643	0.48592	19
20	0.5365	3.52666	1.2915e-011	1.0136e-004	2.4555e-005	8.94123	0.00585	0.51867	20
21	0.5545	3.55337	1.3112e-011	8.1997e-005	2.5345e-005	9.12596	0.00520	0.56133	21
22	0.5724	3.58075	1.3353e-011	6.2382e-005	2.6376e-005	9.36288	0.00447	0.62106	22
23	0.5904	3.60879	1.3642e-011	4.2321e-005	2.7828e-005	9.70686	0.00362	0.71568	23
24	0.6083	3.63747	1.3984e-011	2.1607e-005	3.0276e-005	10.34271	0.00253	0.91159	24
25	0.6263	3.66677	1.4387e-011	0.0000e+000	0.0000e+000	0.00000	0.00000	0.00000	25

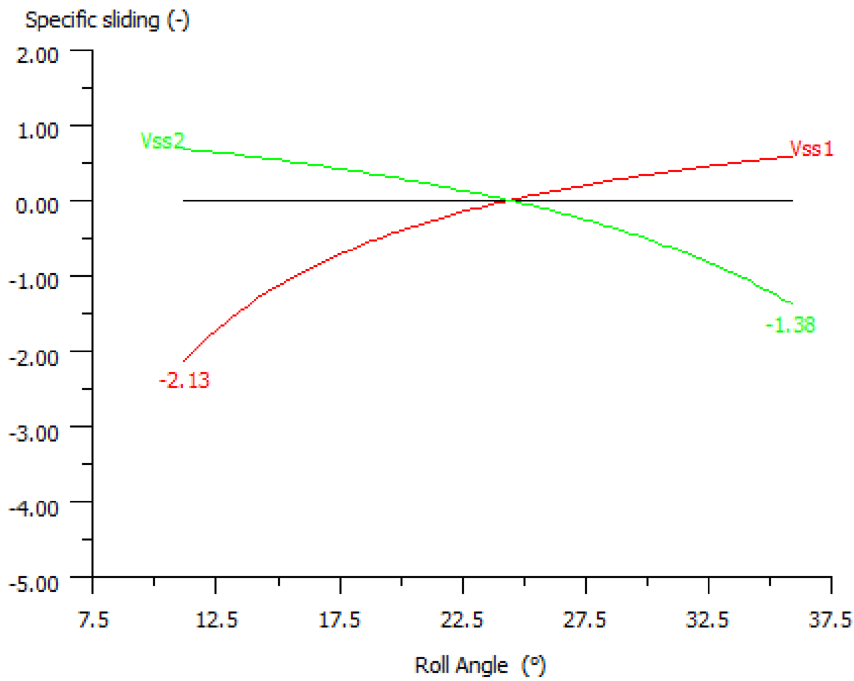
Flash temperatur

Index	xsi(rad)	d1(in)	mum	XGamma	bH(in)	vr1(in/s)	vr2(in/s)	Thetafl(°F)	Index
A	0.1955	3.16645	0.06000	0.14286	0.00235	9.81336	30.70515	16.18821	A
B	0.3271	3.26964	0.06000	1.00000	0.00733	16.42182	25.36754	26.25367	B
C	0.4256	3.37743	0.06000	1.00000	0.00767	21.37052	21.37052	0.00000	C
D	0.4946	3.46705	0.06000	1.00000	0.00771	24.83593	18.57153	17.52894	D
E	0.6263	3.66677	0.06000	0.00000	0.00000	31.44439	13.23393	0.00000	E
1	0.1955	3.16645	0.06000	0.14286	0.00235	9.81336	30.70515	16.18821	1

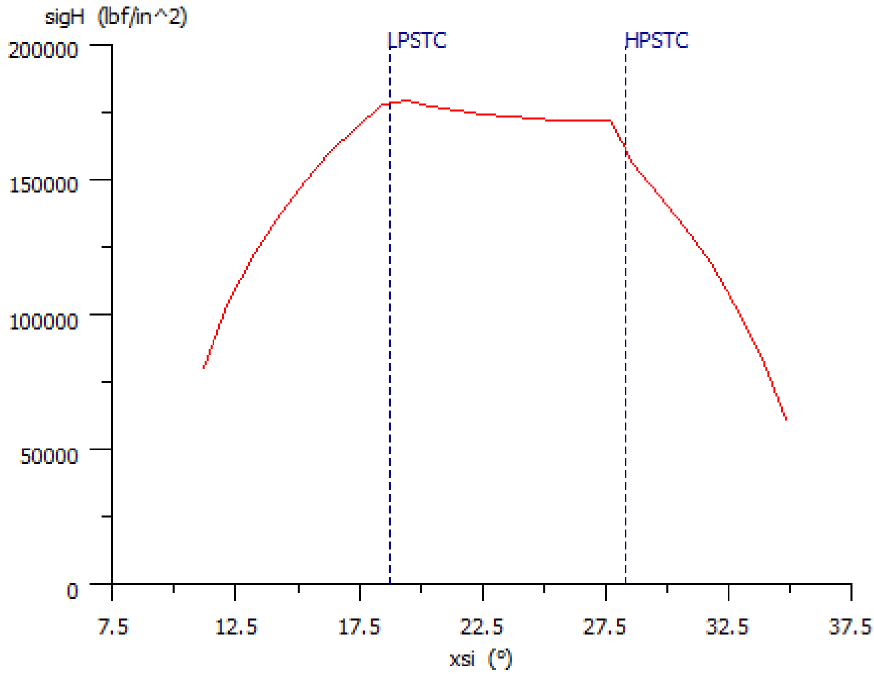
2	0.2134	3.17762	0.06000	0.25976	0.00328	10.71465	29.97718	22.80511	2
3	0.2314	3.18973	0.06000	0.37666	0.00406	11.61595	29.24921	26.99127	3
4	0.2493	3.20276	0.06000	0.49356	0.00476	12.51724	28.52125	29.42667	4
5	0.2672	3.21671	0.06000	0.61046	0.00542	13.41853	27.79328	30.46850	5
6	0.2852	3.23156	0.06000	0.72736	0.00603	14.31982	27.06531	30.33913	6
7	0.3031	3.24731	0.06000	0.84426	0.00660	15.22112	26.33734	29.18941	7
8	0.3211	3.26393	0.06000	0.96117	0.00715	16.12241	25.60938	27.12674	8
9	0.3391	3.28141	0.06000	1.00000	0.00739	17.02370	24.88141	22.90157	9
10	0.3570	3.29975	0.06000	1.00000	0.00747	17.92500	24.15344	17.98624	10
11	0.3750	3.31892	0.06000	1.00000	0.00754	18.82629	23.42547	13.17626	11
12	0.3929	3.33891	0.06000	1.00000	0.00759	19.72758	22.69751	8.45159	12
13	0.4109	3.35971	0.06000	1.00000	0.00764	20.62888	21.96954	3.79405	13
14	0.4288	3.38131	0.06000	1.00000	0.00768	21.53017	21.24157	0.81313	14
15	0.4468	3.40368	0.06000	1.00000	0.00770	22.43146	20.51360	5.38573	15
16	0.4647	3.42681	0.06000	1.00000	0.00771	23.33275	19.78564	9.93882	16
17	0.4827	3.45069	0.06000	1.00000	0.00771	24.23405	19.05767	14.48708	17
18	0.5006	3.47530	0.06000	0.81831	0.00697	25.13534	18.32970	16.38592	18
19	0.5186	3.50063	0.06000	0.70141	0.00643	26.03663	17.60173	18.10908	19
20	0.5365	3.52666	0.06000	0.58451	0.00585	26.93793	16.87377	18.88444	20
21	0.5545	3.55337	0.06000	0.46760	0.00520	27.83922	16.14580	18.61927	21
22	0.5724	3.58075	0.06000	0.35070	0.00447	28.74051	15.41783	17.17042	22
23	0.5904	3.60879	0.06000	0.23380	0.00362	29.64181	14.68986	14.29566	23
24	0.6083	3.63747	0.06000	0.11690	0.00253	30.54310	13.96190	9.49015	24
25	0.6263	3.66677	0.06000	0.00000	0.00000	31.44439	13.23393	0.00000	25

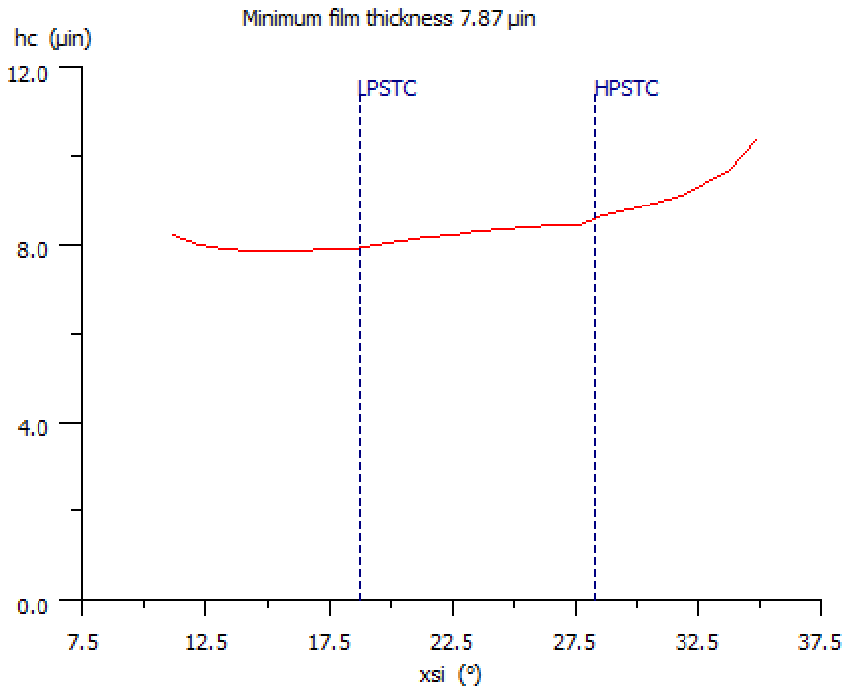
Hertzian stress

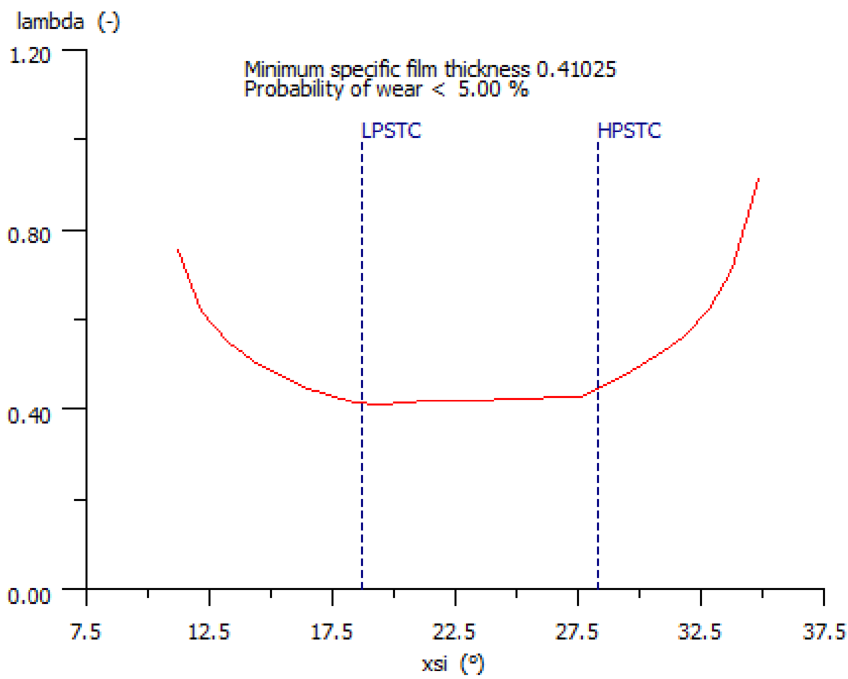
Index	xsi(rad)	d1(mm)	XGamma	bH(in)	sigH(lbf/in2)	Index
A	0.1955	3.16645	0.143	0.002	80397.67	A
B	0.3271	3.26964	1.000	0.007	180907.70	B
C	0.4256	3.37743	1.000	0.008	172779.36	C
D	0.4946	3.46705	1.000	0.008	171926.51	D
E	0.6263	3.66677	0.000	0.000	0.00	E
1	0.1955	3.16645	0.143	0.002	80397.67	1
2	0.2134	3.17762	0.260	0.003	105004.33	2
3	0.2314	3.18973	0.377	0.004	122941.07	3
4	0.2493	3.20276	0.494	0.005	137289.93	4
5	0.2672	3.21671	0.610	0.005	149387.34	5
6	0.2852	3.23156	0.727	0.006	159958.44	6
7	0.3031	3.24731	0.844	0.007	169448.16	7
8	0.3211	3.26393	0.961	0.007	178152.32	8
9	0.3391	3.28141	1.000	0.007	179408.26	9
10	0.3570	3.29975	1.000	0.007	177454.85	10
11	0.3750	3.31892	1.000	0.008	175824.90	11
12	0.3929	3.33891	1.000	0.008	174494.17	12
13	0.4109	3.35971	1.000	0.008	173443.76	13
14	0.4288	3.38131	1.000	0.008	172659.27	14
15	0.4468	3.40368	1.000	0.008	172130.23	15
16	0.4647	3.42681	1.000	0.008	171849.75	16
17	0.4827	3.45069	1.000	0.008	171814.20	17
18	0.5006	3.47530	0.818	0.007	155612.79	18
19	0.5186	3.50063	0.701	0.006	144451.42	19
20	0.5365	3.52666	0.585	0.006	132407.70	20
21	0.5545	3.55337	0.468	0.005	119093.50	21
22	0.5724	3.58075	0.351	0.004	103876.68	22
23	0.5904	3.60879	0.234	0.004	85559.87	23
24	0.6083	3.63747	0.117	0.003	61134.67	24
25	0.6263	3.66677	0.000	0.000	0.00	25

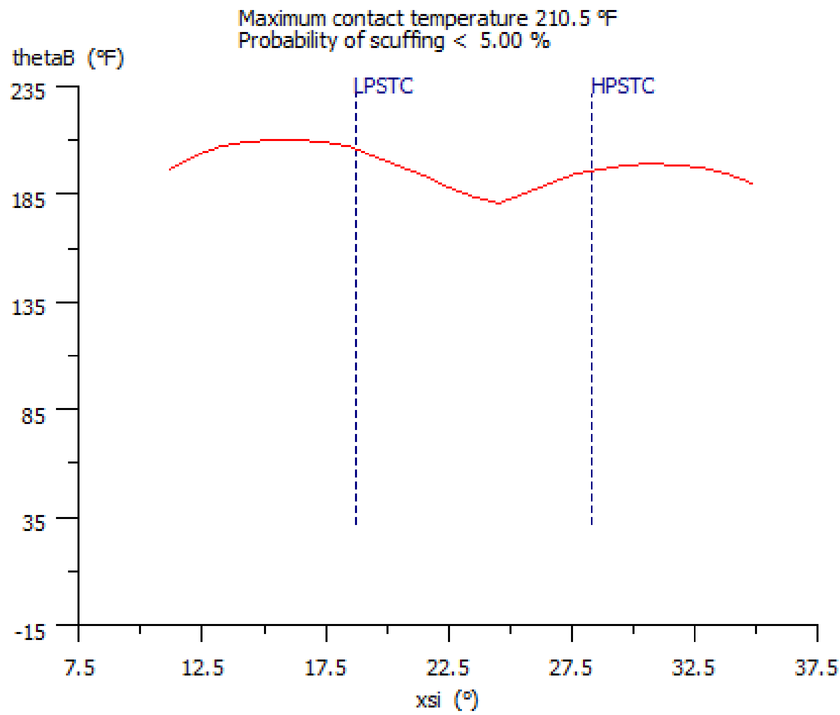


Maximum Hertzian Stress = 180907.7 lb/in^2




Minimum film thickness 7.87 µin
hc (µin)
12.0
8.0
4.0
0.0
LPSTC
HPSTC
7.5
12.5
17.5
22.5
27.5
32.5
37.5
xsi (°)


lambda (-)
1.20
0.80
0.40
0.00
Minimum specific film thickness 0.41025
Probability of wear < 5.00 %
LPSTC
HPSTC
7.5
12.5
17.5
22.5
27.5
32.5
37.5
xsi (°)



End report   lines: 281