[2] involute Σ iii(bevel gear design system)

English version

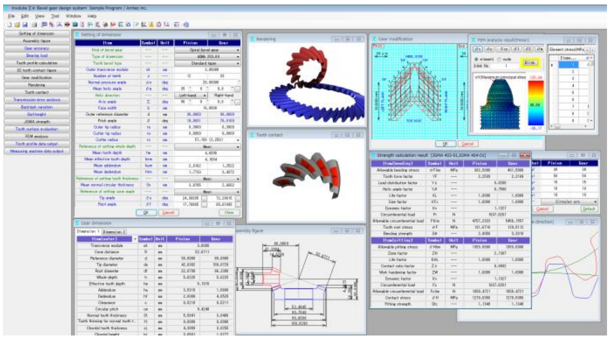


Fig.2.1 involute Σ iii(bevel gear design system)

2. 1 Abstract

involute Σ i (bevel gear) has functions such as bevel gear dimensions, strength (steel, resin), assembly chart, axial load, tooth surface modification, transmission error, tooth surface evaluation, FEM analysis, tooth profile data and measurement data, so it helps the users to design efficiently and accurately. Fig.2.1 shows the entire screen.

2.2 Software structure

Table 2.1 shows the structure of involute Σ iii(bevel gear). ○ in the table is the basic function of the software and ◎is the optional function.

Table 2.1 Software structure

No.	Item	Page	Structure
1	Dimension	2.4	○
2	Accuracy	2.5	○
3	Bearing load	2.22	○
4	Drawing	2.6	○
5	Meshing drawing	2.8	○
6	Tooth shape rendering	2.9	○
7	Backlash changes	2.12	○
8	Ball height	2.13	○
9	Strength calculation (steel) JGMA403-01, 404-01	2.19	○
10	Strength calculation(resin)	2.21	○
11	Strength calculation(Steel) AGMA2003-B97	2.20	◎
12	Gear modification (Involute, lead) & contact pattern	2.10 2.11	◎
13	Transmission error analysis	2.15	◎
14	Surface evaluation	2.23	◎
15	FEM tooth shape stress analysis	2.24	◎
16	Tooth data output（straight gear）	2.14	◎
17	Tooth data output（Spiral + Zerol）	2.14	◎
18	Tooth data output（Osaka seimitsu）	2.16	◎
19	measured data output（Carl Zeiss）	2.16	◎

2.3 Dimension setup（Property）

Types of bevel gears and dimension classification are shown below. Fig.2.2 shows an example gear setting screen.

(1) Bevel gear type

Straight bevel gear, spiral bevel gear, zerol

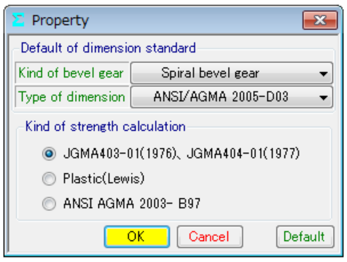
(2) Dimension classification

(2.1) Straight bevel
- standard
- Parallel summon
- ANSI/AGMA 2005-D03
- AGMA 208.03（minimum # of teeth is 7）
- Gleason automotive application

(2.2) Spiral bevel
- ANSI/AGMA 2005-D03
- AGMA 209.04
- Gleason (1960）
- Gleason （less than 11 teeth）

(2.3) Zerol bevel gear
- ANSI/AGMA 2005-D03
- AGMA 202.03

(3) Tooth inclination corresponds to standard taper, parallel tooth, duplex taper, TRL (AGMA) .



Property

Default of dimension standard

Kind of bevel gear: Spiral bevel gear

Type of dimension: ANSI/AGMA 2005-D03

Kind of strength calculation

● JGMA403-01(1976)、JGMA404-01(1977)

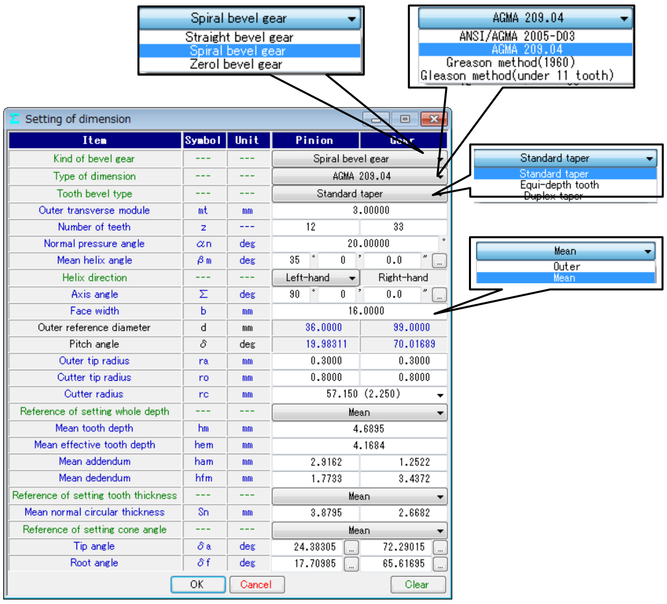
○ Plastic(Lewis)

○ ANSI AGMA 2003- B97

Fig.2.2 Property

2.4 Dimension

Standard value can be automatically entered by inputting module and number of teeth. The shaft angle is standard 90° and the input range corresponds to Σ = 60°~160° and the crown gear (pitch cone angle less than 90° max).



Setting of dimension

Item	Symbol	Unit	Pinion	Gear
Kind of bevel gear	---	---	Spiral bevel gear	
Type of dimension	---	---	AGMA 209.04	
Tooth bevel type	---	---	Standard taper	
Outer transverse module	mt	mm	3.00000	
Number of teeth	z	---	12	33
Normal pressure angle	αn	deg	20.00000 °	
Mean helix angle	βm	deg	35 ° 0 ′ 0.0 ″	
Helix direction	---	---	Left-hand	Right-hand
Axis angle	Σ	deg	90 ° 0 ′ 0.0 ″	
Face width	b	mm	16.0000	
Outer reference diameter	d	mm	36.0000	99.0000
Pitch angle	δ	deg	19.98311	70.01689
Outer tip radius	ra	mm	0.3000	0.3000
Cutter tip radius	ro	mm	0.8000	0.8000
Cutter radius	rc	mm	57.150 (2.250)	
Reference of setting whole depth	---	---	Mean	
Mean tooth depth	hm	mm	4.6895	
Mean effective tooth depth	hem	mm	4.1684	
Mean addendum	ham	mm	2.9162	1.2522
Mean dedendum	hfm	mm	1.7733	3.4372
Reference of setting tooth thickness	---	---	Mean	
Mean normal circular thickness	Sn	mm	3.8795	2.6682
Reference of setting cone angle	---	---	Mean	
Tip angle	δa	deg	24.38305	72.29015
Root angle	δf	deg	17.70985	65.61695

Fig.2.3 Dimension input screen

As shown in Fig.2.3, by setting module, number of teeth, and shaft angle, the standard value is displayed based on standard dimension. Also, input operation has the following functions.

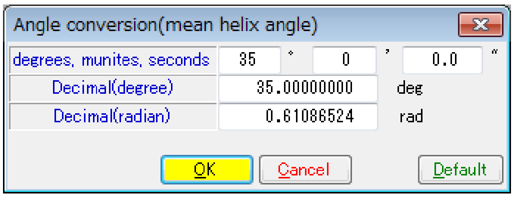
(1) In the property, gear type is selected, but it can be changed

by gear dimension as shown in Fig.2.3.

(2) Setting criteria for tooth depth, tooth thickness and cone angle are based on outer end or central standard.

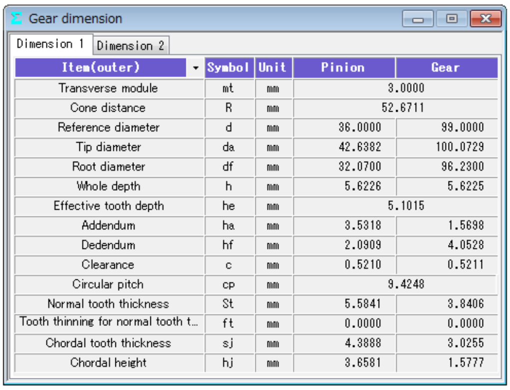
(3) Tooth tip and toot conical angle can be switched between hexa decimal and decimal as shown in Fig.2.4.

(4) Fig.2.5 shows the numerical value of the outer end, but middle part, inner end part value can be also displayed. Fig.2.6 Result-2 shows the contact ratio and etc.


Angle conversion(mean helix angle)

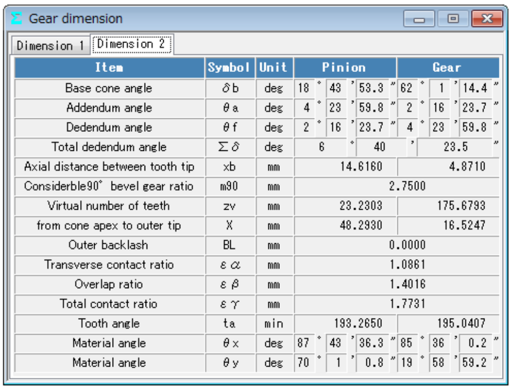
degrees, munites, seconds	35 °	0 ′	0.0 ″
Decimal(degree)	35.00000000	deg	
Decimal(radian)	0.61086524	rad	

Fig.2.4 Angle change


Gear dimension

Item(outer)	Symbol	Unit	Pinion	Gear
Transverse module	mt	mm	3.0000	
Cone distance	R	mm	52.6711	
Reference diameter	d	mm	36.0000	99.0000
Tip diameter	da	mm	42.6382	100.0729
Root diameter	df	mm	32.0700	96.2300
Whole depth	h	mm	5.6226	5.6225
Effective tooth depth	he	mm	5.1015	
Addendum	ha	mm	3.5318	1.5698
Dedendum	hf	mm	2.0909	4.0528
Clearance	c	mm	0.5210	0.5211
Circular pitch	cp	mm	9.4248	
Normal tooth thickness	St	mm	5.5841	3.8406
Tooth thinning for normal tooth t…	ft	mm	0.0000	0.0000
Chordal tooth thickness	sj	mm	4.3888	3.0255
Chordal height	hj	mm	3.6581	1.5777

Fig.2.5 Dimension result-1

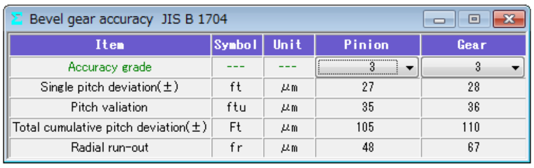

Gear dimension

Item	Symbol	Unit	Pinion	Gear
Base cone angle	δb	deg	18° 43′ 53.3″	62° 1′ 14.4″
Addendum angle	θa	deg	4° 23′ 59.8″	2° 16′ 23.7″
Dedendum angle	θf	deg	2° 16′ 23.7″	4° 23′ 59.8″
Total dedendum angle	Σδ	deg	6° 40′ 23.5″	
Axial distance between tooth tip	xb	mm	14.6160	4.8710
Considerble90° bevel gear ratio	m90	mm	2.7500	
Virtual number of teeth	zv	mm	23.2303	175.6793
from cone apex to outer tip	X	mm	48.2930	16.5247
Outer backlash	BL	mm	0.0000	
Transverse contact ratio	εα	mm	1.0861	
Overlap ratio	εβ	mm	1.4016	
Total contact ratio	εγ	mm	1.7731	
Tooth angle	ta	min	193.2650	195.0407
Material angle	θx	deg	87° 43′ 36.3″	85° 36′ 0.2″
Material angle	θy	deg	70° 1′ 0.8″	19° 58′ 59.2″

Fig.2.6 Dimension result-2

2.5 Accuracy

Fig.2.7 shows accuracy of bevel gear (JIS B 1704:1978).


Bevel gear accuracy JIS B 1704

Item	Symbol	Unit	Pinion	Gear
Accuracy grade	---	---	3	3
Single pitch deviation(±)	ft	μm	27	28
Pitch valiation	ftu	μm	35	36
Total cumulative pitch deviation(±)	Ft	μm	105	110
Radial run-out	fr	μm	48	67

Fig.2.7 Bevel gear accuracy（JIS B 1704）

2.6 Assembly drawing

As shown in Fig.2.8 to 2.11, users can set assembly distance and boss diameter to plot. As drawing feature, there are enlargement, distance measurement, etc. In Fig.2.8, when chamfering is set, a shape with a chamfered edge will be created at the small end (Fig.2.9). Fig.2.10 shows an example of a pair of shaft angles of 60° and Fig.2.11 shows an assembled view of an axis angle of 160°.

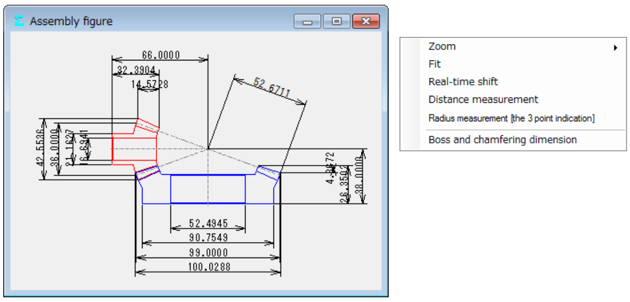
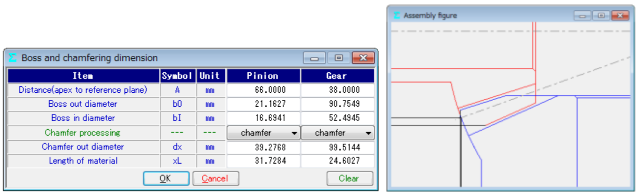


Fig.2.8 Assembly 1


Boss and chamfering dimension

Item	Symbol	Unit	Pinion	Gear
Distance(apex to reference plane)	A	mm	66.0000	38.0000
Boss out diameter	b0	mm	21.1627	90.7549
Boss in diameter	bI	mm	16.6941	52.4945
Chamfer processing	---	---	chamfer	chamfer
Chamfer out diameter	dx	mm	39.2768	99.5144
Length of material	xL	mm	31.7284	24.6027

Fig.2.9 Boss & chamfer dimension setup and drawing

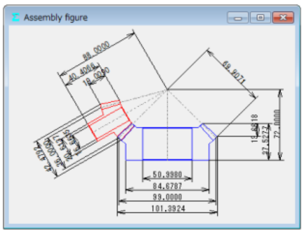


Fig.2.10 Shaft angle Σ=60°

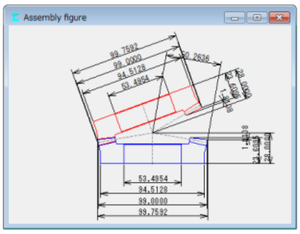


Fig.2.11 Shaft angle Σ=160°

2.7 Bevel gear tooth shape

The tooth profile generated by involute Σ iii (bevel gear design) is the spherical involute as shown in Fig.2.12, and the root is the spherical trochoid curve. Therefore, even gears with few teeth such as differential bevel gears show correct meshing.

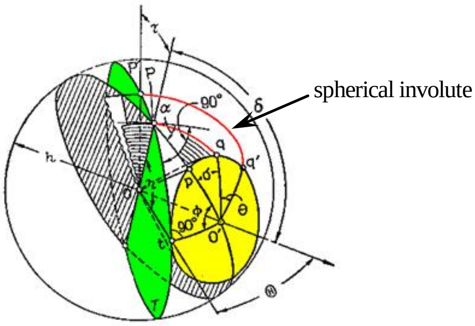
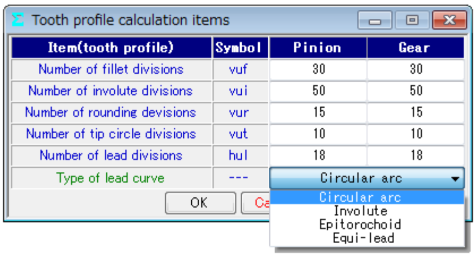


Fig.2.12 spherical involute

The tooth profile calculation condition is shown in Fig.2.13. Also, spiral bevel gear's lead (Fig.2.14) can select "circular arc", involute, "epitorochoid", "epui-lead"(Fig.2.15) ", or " Equal lead ".


Tooth profile calculation items

Item(tooth profile)	Symbol	Pinion	Gear
Number of fillet divisions	vuf	30	30
Number of involute divisions	vui	50	50
Number of rounding devisions	vur	15	15
Number of tip circle divisions	vut	10	10
Number of lead divisions	hul	18	18
Type of lead curve	---	Circular arc	

Fig.2.13 Tooth shape calculation dimension

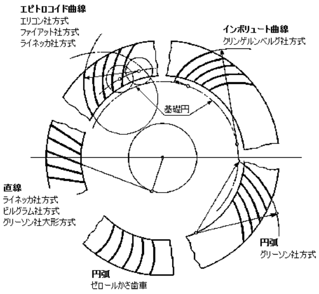


Fig.2.14 Lead curve

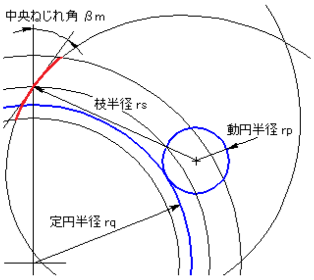
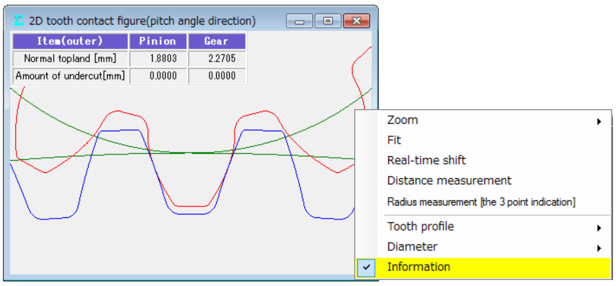


Fig.2.15 Epitorochoid curve

2.8 Meshing drawing

There are features such as enlargement, distance measurementfor the front tooth form, and the outer end, the center, and the inner end part are displayed.

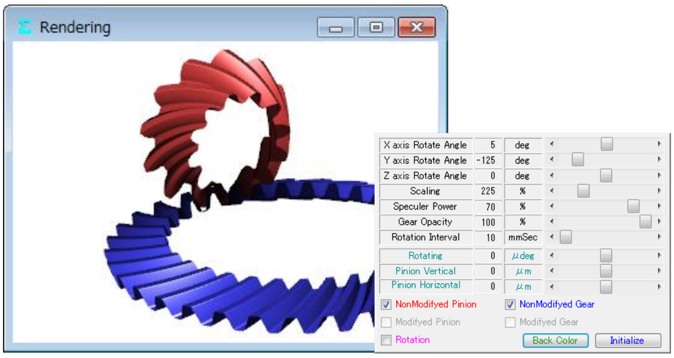

2D tooth contact figure(pitch angle direction)

Item(outer)	Pinion	Gear
Normal topland [mm]	1.8803	2.2705
Amount of undercut[mm]	0.0000	0.0000

Fig.2.16 Tooth shape（outer end）, pitch conical angle direction

2.9 Tooth shape rendering

Tooth profile rendering is shown in Fig.2.17. The display angle and size of the gear can be changed on control form. In addition, to confirm tooth contact, angle conversion is shown in Fig.2.18. As pinion can be moved in "horizontal" or "vertical", meshing contact line with errors can be easily understood.


Rendering

X axis Rotate Angle	5	deg
Y axis Rotate Angle	-125	deg
Z axis Rotate Angle	0	deg
Scaling	225	%
Speculer Power	70	%
Gear Opacity	100	%
Rotation Interval	10	mmSec
Rotating	0	μdeg
Pinion Vertical	0	μm
Pinion Horizontal	0	μm

☑ NonModifyed Pinion ☑ NonModifyed Gear
☐ Modifyed Pinion ☐ Modifyed Gear
☐ Rotation

Fig.2.17 Tooth rendering-1 & Control form

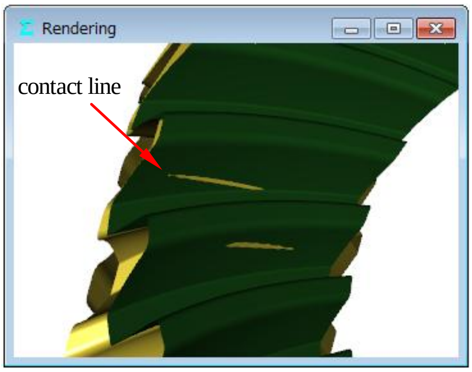

Rendering

Fig.2.18 Tooth rendering-2 (modified tooth example)

2.10 Involute/lead modification （optional）

In case of involute, lead modification, modification can be given as shown in Fig.2.19 ~ 2.23. In Fig.2.21, users can enter a number of designated points to be modified (maximum = 50), or users can also enter it as an arc pattern as shown in Fig.2.22.

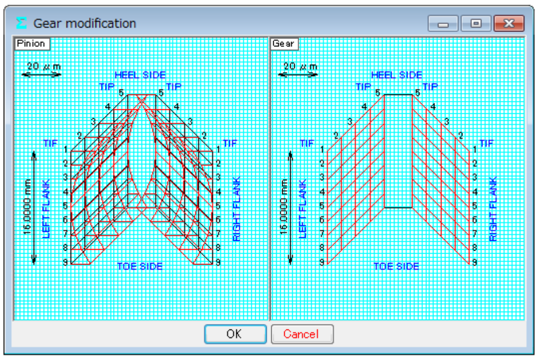
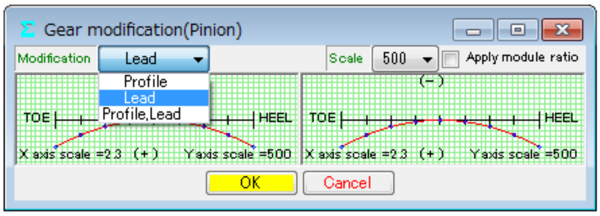
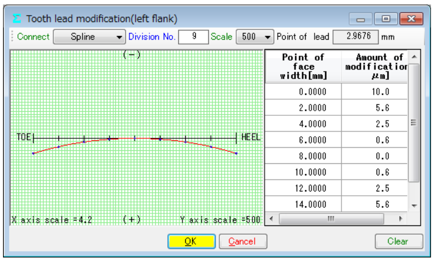

Gear modification

Fig.2.19 Involute / Lead modification topo graph


Gear modification(Pinion)

Modification: Lead
Scale: 500
☐ Apply module ratio

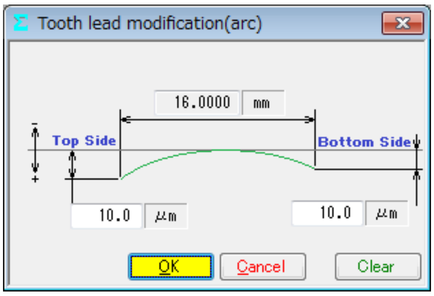
Fig.2.20 Lead modification example


Tooth lead modification(left flank)

Connect: Spline
Division No.: 9
Scale: 500
Point of lead: 2.9676 mm

Point of face width[mm]	Amount of modification[μm]
0.0000	10.0
2.0000	5.6
4.0000	2.5
6.0000	0.6
8.0000	0.0
10.0000	0.6
12.0000	2.5
14.0000	5.6

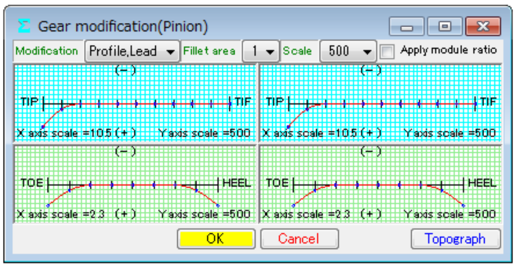
Fig.2.21 Lead modification input-1


Tooth lead modification(arc)

16.0000 mm
Top Side: 10.0 μm
Bottom Side: 10.0 μm

Fig.2.22 Arc pattern input

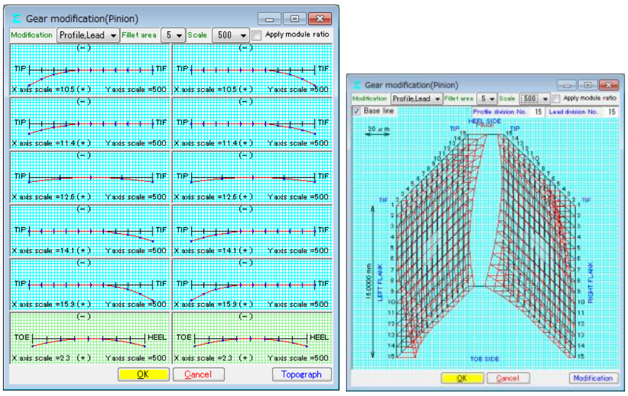
One line of modification for involute and lead is shown as a example in Fig.2.23.


Gear modification(Pinion)

Modification: Profile,Lead
Fillet area: 1
Scale: 500
☐ Apply module ratio

Fig.2.23 Involute/Lead input

Fig.2.24 shows an example of modification and topo graph when tooth profile cross sectional division is set to 5 and lead is 1. In the topo graph, it is possible to set the number of divisions of the tooth profile and the lead up to 50 each.



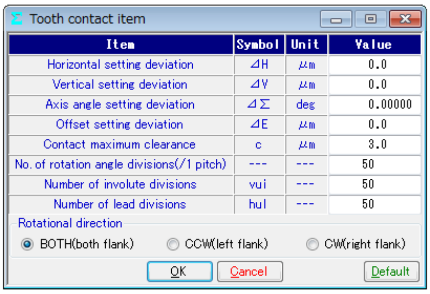
Modification: Profile,Lead   Fillet area: 5   Scale: 500   ☐ Apply module ratio

☑ Base line   Profile division No. 15   Lead division No. 15

Fig.2.24 Involute/Lead (bias) modification & topo graph example

2.11 Contact pattern（optional）

It displays contact pattern (including non-modified tooth profile) of gears with involute/lead modification. In the setup menu in Fig. 2.25, it is possible to set the mounting error and maximum contact clearance (paint thickness). For example, the modification given in Fig.2.19 can be shown in terms of contact pattern in Fig.2.26.

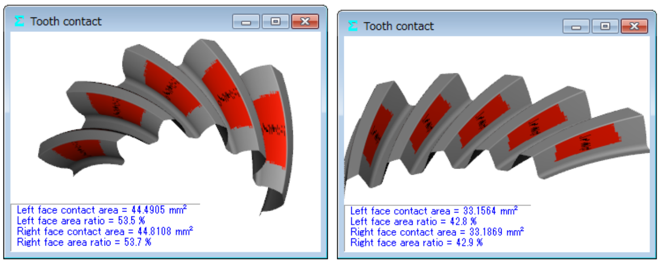


Item	Symbol	Unit	Value
Horizontal setting deviation	ΔH	μm	0.0
Vertical setting deviation	ΔV	μm	0.0
Axis angle setting deviation	ΔΣ	deg	0.00000
Offset setting deviation	ΔE	μm	0.0
Contact maximum clearance	c	μm	3.0
No. of rotation angle divisions(/1 pitch)	---	---	50
Number of involute divisions	vui	---	50
Number of lead divisions	hul	---	50

Rotational direction

● BOTH(both flank)　○ CCW(left flank)　○ CW(right flank)

Fig.2.25 Contact pattern setup



Left face contact area = 44.4905 mm²
Left face area ratio = 53.5 %
Right face contact area = 44.8108 mm²
Right face area ratio = 53.7 %

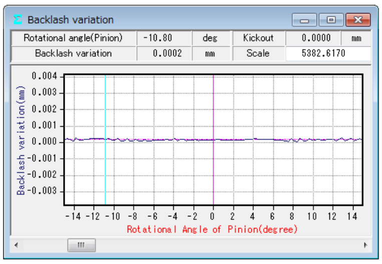
Left face contact area = 33.1564 mm²
Left face area ratio = 42.8 %
Right face contact area = 33.1869 mm²
Right face area ratio = 42.9 %

(a)Pinion (b)Gear

Fig.2.26 Contact pattern

2.12 Backlash change

Fig.2.27 shows the change in the backlash of the gear with the tooth involute/lead modification in Fig.2.24. From Fig.2.27, the kick-out of this gear is observed as 0.2 μm.

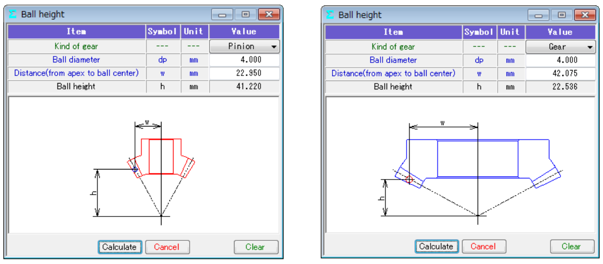


Rotational angle(Pinion)	-10.80	deg	Kickout	0.0000	mm
Backlash variation	0.0002	mm	Scale	5382.6170	

Fig.2.27 Backlash change

2.13 Ball height

In order to control tooth thickness, a ball is placed near tooth width center, and then ball height (only straight bevel) is calculated. It is suitable for tooth thickness control during manufacturing. An example of the ball height of bevel gear is shown in Fig.2.28.



Item	Symbol	Unit	Value
Kind of gear	---	---	Pinion
Ball diameter	dp	mm	4.000
Distance(from apex to ball center)	w	mm	22.950
Ball height	h	mm	41.220

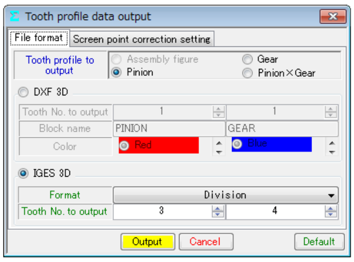
Item	Symbol	Unit	Value
Kind of gear	---	---	Gear
Ball diameter	dp	mm	4.000
Distance(from apex to ball center)	w	mm	42.075
Ball height	h	mm	22.536

(a)Pinion (b)Gear

Fig.2.28 Ball height

2.14 Tooth profile data output（optional）

Tooth profile with involute/lead modification can be output as CAD data. By setting tooth profile file condition in Fig.2.29, 3D-IGES file can be output as shown in Fig.2.31 (3D-DXF can also be output). Also, meshing tooth shaped 3D-IGES and 2D-DXF file can be output as shown in Fig.2.30. In Fig.2.30, a number of tooth profile divisions can be changed as well.



Tooth profile to output: ○ Assembly figure　● Pinion　○ Gear　○ Pinion×Gear

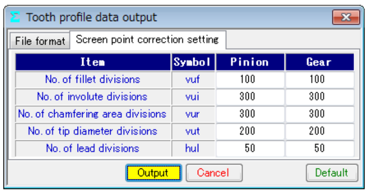
○ DXF 3D

Tooth No. to output	1	1
Block name	PINION	GEAR
Color	Red	Blue

● IGES 3D

Format	Division	
Tooth No. to output	3	4

Fig.2.29 Tooth profile setup



Item	Symbol	Pinion	Gear
No. of fillet divisions	vuf	100	100
No. of involute divisions	vui	300	300
No. of chamfering area divisions	vur	300	300
No. of tip diameter divisions	vut	200	200
No. of lead divisions	hul	50	50

Fig.2.30 Tooth shape profile setup（division number）

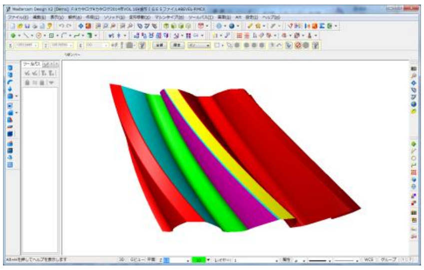


Fig.2.31 CAD example（Pinion ; separated type）

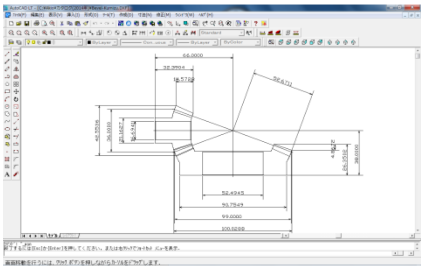
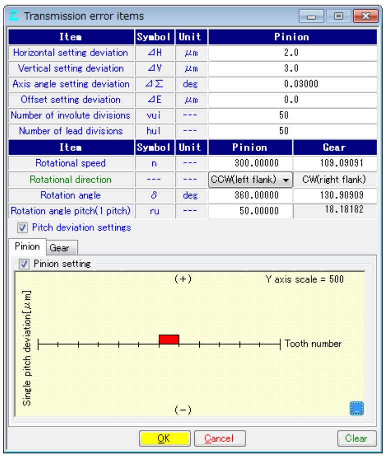


Fig.2.32 CAD example（assembly）

2.15 Transmission error analysis（optional）

Below is an example of analysis of rotational transmission error (TE) at no load by using the tooth form from Fig.2.19. The mounting error is given as shown in Fig.2.33 and 5 µm is given as Pinion's pitch error (only tooth number 6).


Transmission error items

Item	Symbol	Unit	Pinion
Horizontal setting deviation	⊿H	μm	2.0
Vertical setting deviation	⊿V	μm	3.0
Axis angle setting deviation	⊿Σ	deg	0.03000
Offset setting deviation	⊿E	μm	0.0
Number of involute divisions	vui	---	50
Number of lead divisions	hul	---	50

Item	Symbol	Unit	Pinion	Gear
Rotational speed	n	---	300.00000	109.09091
Rotational direction	---	---	CCW(left flank)	CW(right flank)
Rotation angle	δ	deg	360.00000	130.90909
Rotation angle pitch(1 pitch)	ru	---	50.00000	18.18182

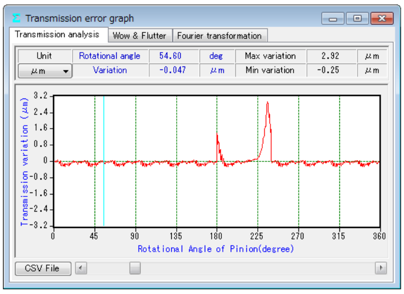
☑ Pitch deviation settings

☑ Pinion setting

Fig.2.33 TE setup

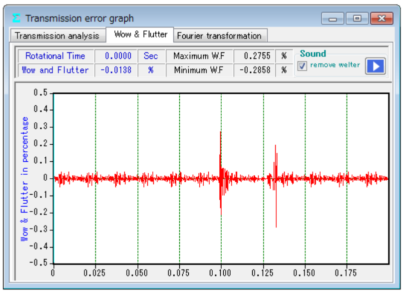
Calculation results of TE, wow flutter, Fourier analysis are shown in Fig.2.34 ~ 2.36. In the wow flutter of Fig.2.35, this graph waveform can be checked as sound (Sound on the upper right of the graph ▶).

As shown in Fig.2.37 and Fig.2.38, pitch error can be input with maximum value or tooth error individually.


Transmission error graph

Unit	Rotational angle	54.60	deg	Max variation	2.92	μm
μm	Variation	-0.047	μm	Min variation	-0.25	μm

Fig.2.34 TE result

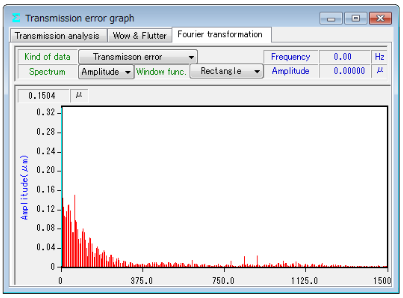

Transmission error graph

Rotational Time	0.0000	Sec	Maximum W.F	0.2755	%
Wow and Flutter	-0.0138	%	Minimum W.F	-0.2858	%

Sound

☑ remove welter

Fig.2.35 wow flutter


Transmission error graph

Kind of data: Transmisson error

Spectrum: Amplitude

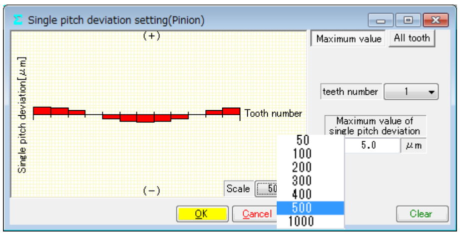
Window func.: Rectangle

Frequency: 0.00 Hz

Amplitude: 0.00000 μ

0.1504 μ

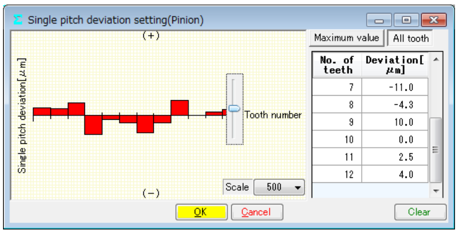
Fig.2.36 Fourier analysis


Single pitch deviation setting(Pinion)

teeth number: 1

Maximum value of single pitch deviation: 5.0 μm

Fig.2.37 Pitch error setup example（Max value）


Single pitch deviation setting(Pinion)

No. of teeth	Deviation[μm]
7	-11.0
8	-4.3
9	10.0
10	0.0
11	2.5
12	4.0

Scale: 500

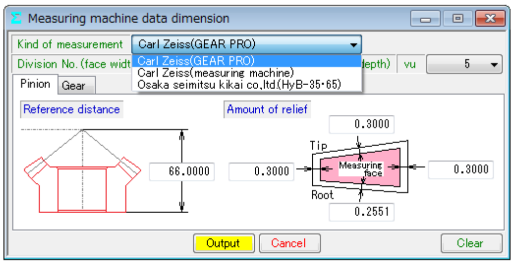
Fig.2.38 Pitch error setup example（each tooth）

2.16 Tooth shape measured data output（optional）

There are two kinds of measurement data output function; Carl Zeiss 3D measuring machine and Osaka precision machine measuring machine.

(1) Outline of measurement data output for 3D measuring machine (Carl Zeiss)

Fig.2.39 shows the measurement data setting screen. By setting the tooth shape division number, tooth surface measurement clearance amount and measurement reference distance, this feature outputs the measurement point coordinates and normal vector to the file.


Measuring machine data dimension

Kind of measurement: Carl Zeiss(GEAR PRO)

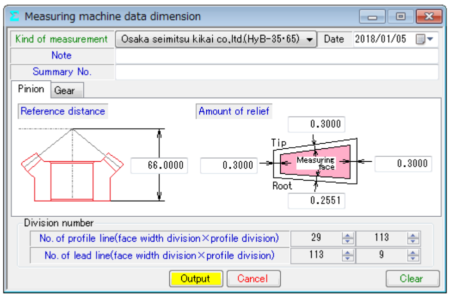
Carl Zeiss(GEAR PRO)
Carl Zeiss(measuring machine)
Osaka seimitsu kikai co,ltd.(HyB-35･65)

Division No. (face widt … depth) vu: 5

Fig.2.39 Measured data setup (Carl Zeiss)

(2) Outline of measurement data output of Osaka Precision Machine measuring machine.

By setting measurement data from Fig.2.40, measurement nominal data can be output to a file. "The measuring machine (HyB-35 · 65) can measure precisely because tooth surface is measured with "line" instead of "point". By measuring up to the edge of the tooth with a line rather than a lattice point like a 3D measuring machine, delicate shape errors can be captured for noise and vibration (Reference: Osaka Precision Machinery Co., Ltd. Catalog).


Measuring machine data dimension

Kind of measurement: Osaka seimitsu kikai co,ltd.(HyB-35･65)

Date: 2018/01/05

Note:

Summary No.:

Division number

No. of profile line(face width division×profile division)	29	113
No. of lead line(face width division×profile division)	113	9

Fig.2.40 Measured data setup（Osaka Seimitsu）

2.17 Measurement example 1

Tooth profile data and measurement vector for bevel gear is exported from involuteΣiii (bevel gear design) to bevel gear measurement software (*GearPro-Bevel* [1)]) of Carl Zeiss's 3D measuring machine) as shown in Fig.2.41 ~ 2.43.

* 1): "GearPro is a product of Carl Zeiss IMT GmbH, Germany"

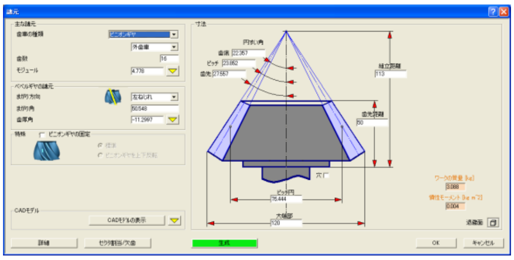


Fig.2.41 Bevel gear dimension（Carl Zeiss）

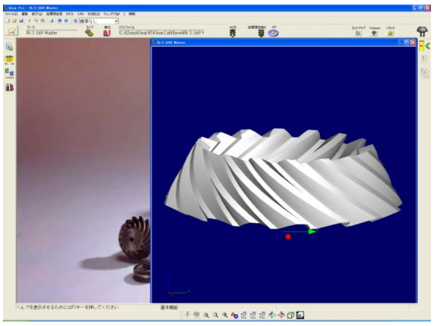
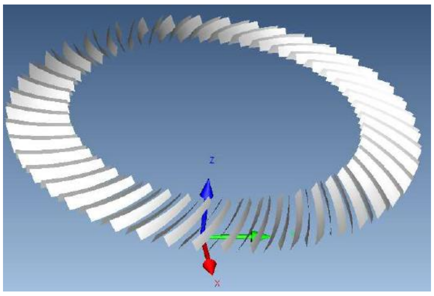


Fig.2.42 bevel gear measurement screen（Carl Zeiss）



$m6, z_1=11, z_2=45, \alpha=20°, \Sigma=90°$

Fig.2.43 Measurement point & vector data（Carl Zeiss）

2.18 Measurement example 2

Fig.2.44 shows a measurement example from Osaka precision machine measuring machine (HyB-35 · 65) by using tooth profile data and bevel vector on bevel gear measurement from involuteΣiii (bevel gear design).

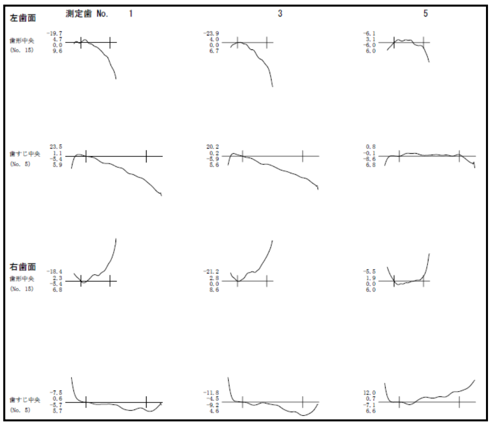
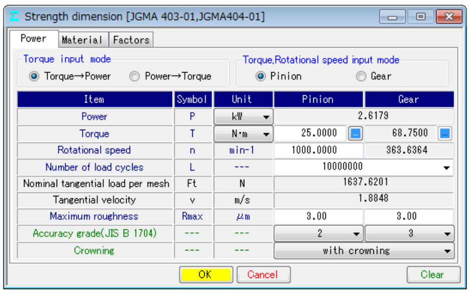


Fig.2.44 Straight bevel involute/lead measurement example

2.19 Gear strength calculation（JGMA）

It is calculate based on JGMA 403-01:1976 (bending), 404-01:1977 (contact pressure).

(1) Power setting: Torque setting (MN · m, kN · m, N · m, N · cm, N · mm, kgf · m, kgf · cm, gf · cm) and rotational speed, presence / absence of crowning settings are shown in Fig.2.45.



Strength dimension [JGMA 403-01,JGMA404-01]

Power | Material | Factors

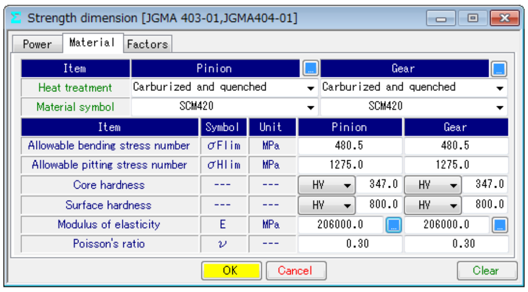
Torque input mode: ● Torque→Power ○ Power→Torque

Torque,Rotational speed input mode: ● Pinion ○ Gear

Item	Symbol	Unit	Pinion	Gear
Power	P	kW	2.6179	
Torque	T	N·m	25.0000	68.7500
Rotational speed	n	min-1	1000.0000	363.6364
Number of load cycles	L	---	10000000	
Nominal tangential load per mesh	Ft	N	1637.6201	
Tangential velocity	v	m/s	1.8848	
Maximum roughness	Rmax	μm	3.00	3.00
Accuracy grade(JIS B 1704)	---	---	2	3
Crowning	---	---	with crowning	

Fig.2.45 Power setup

(2) Material setting: Allowable stress of materials can be set in Fig.2.46. For material selection, allowable stress value can be determined based on the hardness reference information from Fig.2.47. In addition, material symbols, allowable stress values (σ_{Flim}, σ_{Hlim}) and hardness can be entered arbitrarily.



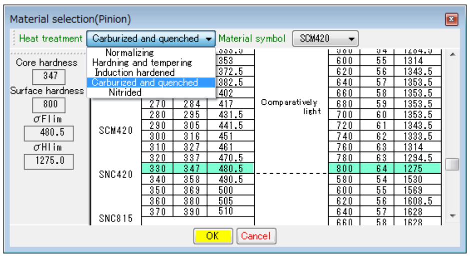
Strength dimension [JGMA 403-01,JGMA404-01]

Power | Material | Factors

Item	Pinion	Gear
Heat treatment	Carburized and quenched	Carburized and quenched
Material symbol	SCM420	SCM420

Item	Symbol	Unit	Pinion		Gear	
Allowable bending stress number	σFlim	MPa	480.5		480.5	
Allowable pitting stress number	σHlim	MPa	1275.0		1275.0	
Core hardness	---	---	HV	347.0	HV	347.0
Surface hardness	---	---	HV	800.0	HV	800.0
Modulus of elasticity	E	MPa	206000.0		206000.0	
Poisson's ratio	ν	---	0.30		0.30	

Fig.2.46 Material setting



Material selection(Pinion)

Heat treatment: Carburized and quenched　Material symbol: SCM420

Normalizing
Hardning and tempering
Induction hardened
Carburized and quenched
Nitrided

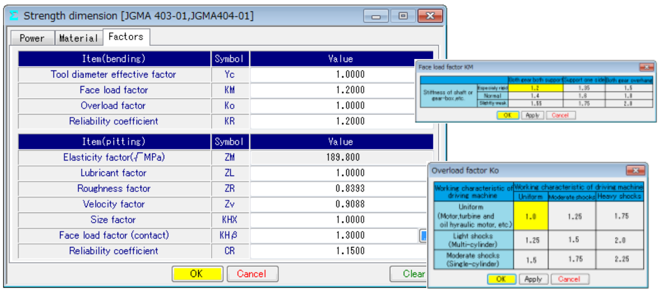
Core hardness: 347
Surface hardness: 800
σFlim: 480.5
σHlim: 1275.0

			353
			372.5
			382.5
			402
	270	284	417
	280	295	431.5
	290	305	441.5
SCM420	300	316	451
	310	327	461
	320	337	470.5
	330	347	480.5
SNC420	340	358	490.5
	350	369	500
	360	380	505
	370	390	510
SNC815			

	600	55	1314
	620	56	1343.5
	640	57	1353.5
	660	58	1353.5
Comparatively light	680	59	1353.5
	700	60	1353.5
	720	61	1343.5
	740	62	1333.5
	760	63	1314
	780	63	1294.5
	800	64	1275
	580	54	1530
	600	55	1569
	620	56	1608.5
	640	57	1628
	660	58	1628

Fig.2.47 Material selection

(3) Coefficient setting: Fig.2.48 shows the coefficient setting screen for Strength calculation. Coefficients can be either selected from the support forms, or directly typed in specific numbers. Fig.2.49 shows strength calculation result.



Strength dimension [JGMA 403-01,JGMA404-01]

Power | Material | Factors

Item(bending)	Symbol	Value
Tool diameter effective factor	Yc	1.0000
Face load factor	KM	1.2000
Overload factor	Ko	1.0000
Reliability coefficient	KR	1.2000

Item(pitting)	Symbol	Value
Elasticity factor(√MPa)	ZM	189.800
Lubricant factor	ZL	1.0000
Roughness factor	ZR	0.8393
Velocity factor	Zv	0.9088
Size factor	KHX	1.0000
Face load factor (contact)	KHβ	1.3000
Reliability coefficient	CR	1.1500

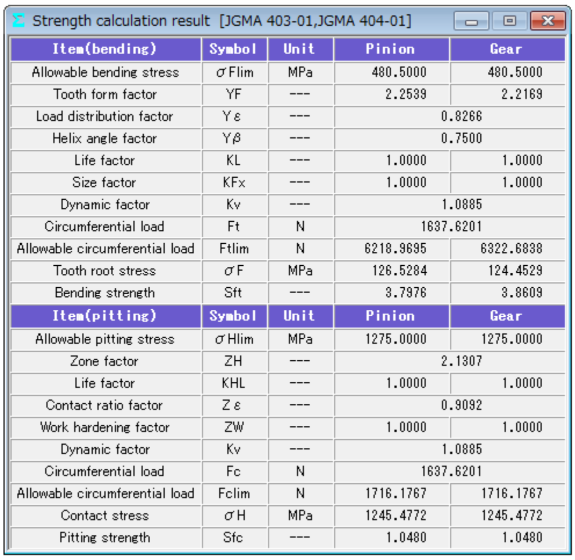
Face load factor KM

		Both gear both support	Support one side	Both gear overhang
Stiffness of shaft or gear-box,etc.	Especially rigid	1.2	1.35	1.5
	Normal	1.4	1.6	1.8
	Slightly weak	1.55	1.75	2.0

Overload factor Ko

Working characteristic of driving machine	Working characteristic of driving machine		
	Uniform	Moderate shocks	Heavy shocks
Uniform (Motor,turbine and oil hyraulic motor, etc)	1.0	1.25	1.75
Light shocks (Multi-cylinder)	1.25	1.5	2.0
Moderate shocks (Single-cylinder)	1.5	1.75	2.25

Fig.2.48 Strength calculation coefficient

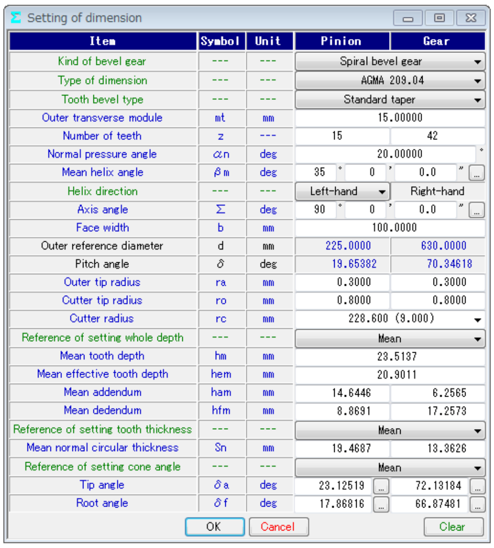


Item(bending)	Symbol	Unit	Pinion	Gear
Allowable bending stress	σFlim	MPa	480.5000	480.5000
Tooth form factor	YF	---	2.2539	2.2169
Load distribution factor	Yε	---	0.8266	
Helix angle factor	Yβ	---	0.7500	
Life factor	KL	---	1.0000	1.0000
Size factor	KFx	---	1.0000	1.0000
Dynamic factor	Kv	---	1.0885	
Circumferential load	Ft	N	1637.6201	
Allowable circumferential load	Ftlim	N	6218.9695	6322.6838
Tooth root stress	σF	MPa	126.5284	124.4529
Bending strength	Sft	---	3.7976	3.8609
Item(pitting)	**Symbol**	**Unit**	**Pinion**	**Gear**
Allowable pitting stress	σHlim	MPa	1275.0000	1275.0000
Zone factor	ZH	---	2.1307	
Life factor	KHL	---	1.0000	1.0000
Contact ratio factor	Zε	---	0.9092	
Work hardening factor	ZW	---	1.0000	1.0000
Dynamic factor	Kv	---	1.0885	
Circumferential load	Fc	N	1637.6201	
Allowable circumferential load	Fclim	N	1716.1767	1716.1767
Contact stress	σH	MPa	1245.4772	1245.4772
Pitting strength	Sfc	---	1.0480	1.0480

Fig.2.49　Strength calculation result

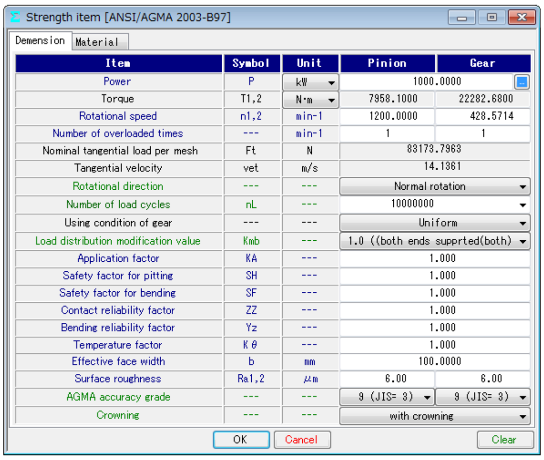
2.20 Gear strength calculation（AGMA）（optional）

It is calculated based on AGMA 2003-B97:1997, by selecting strength calculation "AGMA 2003-B 97" in the property of Fig.2.2. Here, an example of Strength calculation for the gear from Fig.2.51 is shown in Fig.2.52 to 2.56.



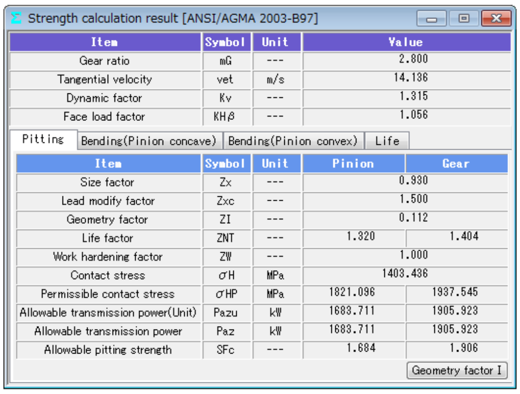
Item	Symbol	Unit	Pinion	Gear
Kind of bevel gear	---	---	Spiral bevel gear	
Type of dimension	---	---	AGMA 209.04	
Tooth bevel type	---	---	Standard taper	
Outer transverse module	mt	mm	15.00000	
Number of teeth	z	---	15	42
Normal pressure angle	αn	deg	20.00000 °	
Mean helix angle	βm	deg	35 ° 0 ′ 0.0 ″	
Helix direction	---	---	Left-hand	Right-hand
Axis angle	Σ	deg	90 ° 0 ′ 0.0 ″	
Face width	b	mm	100.0000	
Outer reference diameter	d	mm	225.0000	630.0000
Pitch angle	δ	deg	19.65382	70.34618
Outer tip radius	ra	mm	0.3000	0.3000
Cutter tip radius	ro	mm	0.8000	0.8000
Cutter radius	rc	mm	228.600 (9.000)	
Reference of setting whole depth	---	---	Mean	
Mean tooth depth	hm	mm	23.5137	
Mean effective tooth depth	hem	mm	20.9011	
Mean addendum	ham	mm	14.6446	6.2565
Mean dedendum	hfm	mm	8.8691	17.2573
Reference of setting tooth thickness	---	---	Mean	
Mean normal circular thickness	Sn	mm	19.4687	13.3626
Reference of setting cone angle	---	---	Mean	
Tip angle	δa	deg	23.12519	72.13184
Root angle	δf	deg	17.86816	66.87481

Fig.2.50　Dimension



Item	Symbol	Unit	Pinion	Gear
Power	P	kW	1000.0000	
Torque	T1,2	N·m	7958.1000	22282.6800
Rotational speed	n1,2	min-1	1200.0000	428.5714
Number of overloaded times	---	min-1	1	1
Nominal tangential load per mesh	Ft	N	83173.7963	
Tangential velocity	vet	m/s	14.1361	
Rotational direction	---	---	Normal rotation	
Number of load cycles	nL	---	10000000	
Using condition of gear	---	---	Uniform	
Load distribution modification value	Kmb	---	1.0 ((both ends supprted(both)	
Application factor	KA	---	1.000	
Safety factor for pitting	SH	---	1.000	
Safety factor for bending	SF	---	1.000	
Contact reliability factor	ZZ	---	1.000	
Bending reliability factor	Yz	---	1.000	
Temperature factor	Kθ	---	1.000	
Effective face width	b	mm	100.0000	
Surface roughness	Ra1,2	μm	6.00	6.00
AGMA accuracy grade	---	---	9 (JIS= 3)	9 (JIS= 3)
Crowning	---	---	with crowning	

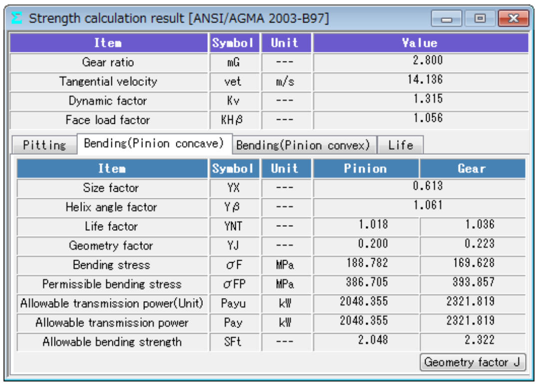
Fig.2.51　Strength dimension



Item	Symbol	Unit	Value
Gear ratio	mG	---	2.800
Tangential velocity	vet	m/s	14.136
Dynamic factor	Kv	---	1.315
Face load factor	KHβ	---	1.056

Item	Symbol	Unit	Pinion	Gear
Size factor	Zx	---	0.930	
Lead modify factor	Zxc	---	1.500	
Geometry factor	ZI	---	0.112	
Life factor	ZNT	---	1.320	1.404
Work hardening factor	ZW	---	1.000	
Contact stress	σH	MPa	1403.436	
Permissible contact stress	σHP	MPa	1821.096	1937.545
Allowable transmission power(Unit)	Pazu	kW	1683.711	1905.923
Allowable transmission power	Paz	kW	1683.711	1905.923
Allowable pitting strength	SFc	---	1.684	1.906

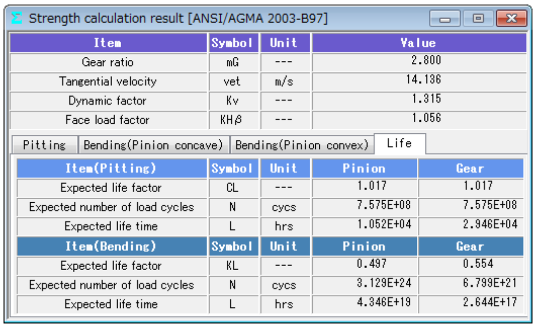
Fig.2.52　Strength calculation result（stress）



Item	Symbol	Unit	Value
Gear ratio	mG	---	2.800
Tangential velocity	vet	m/s	14.136
Dynamic factor	Kv	---	1.315
Face load factor	KHβ	---	1.056

Item	Symbol	Unit	Pinion	Gear
Size factor	YX	---	0.613	
Helix angle factor	Yβ	---	1.061	
Life factor	YNT	---	1.018	1.036
Geometry factor	YJ	---	0.200	0.223
Bending stress	σF	MPa	188.782	169.628
Permissible bending stress	σFP	MPa	386.705	393.857
Allowable transmission power(Unit)	Payu	kW	2048.355	2321.819
Allowable transmission power	Pay	kW	2048.355	2321.819
Allowable bending strength	SFt	---	2.048	2.322

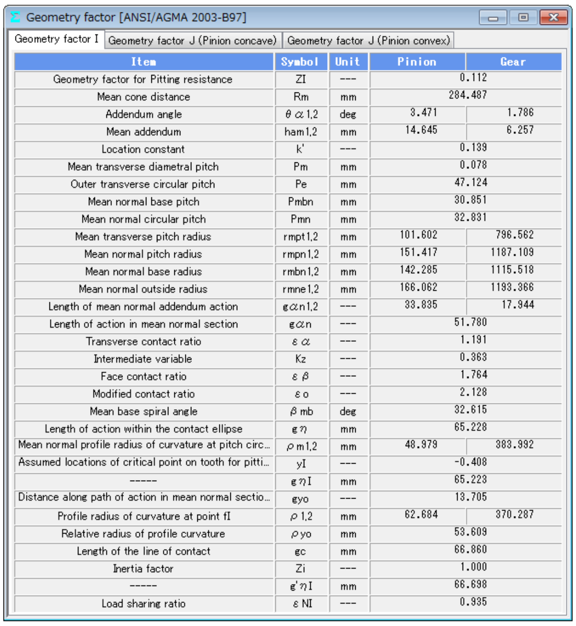
Fig.2.53　Strength calculation result（bending：Pinion 凹）



Item	Symbol	Unit	Value
Gear ratio	mG	---	2.800
Tangential velocity	vet	m/s	14.136
Dynamic factor	Kv	---	1.315
Face load factor	KHβ	---	1.056

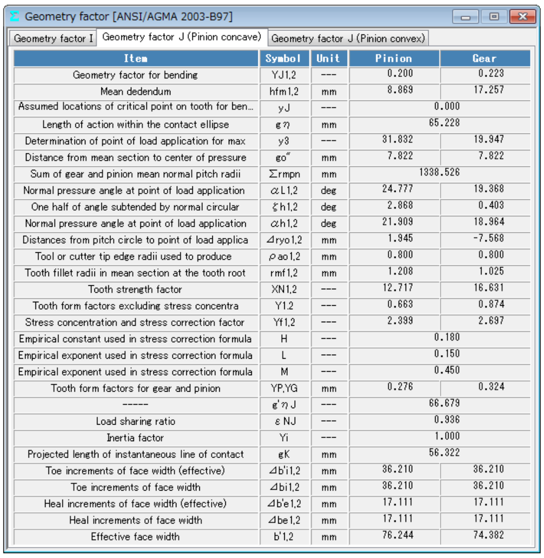
Item(Pitting)	Symbol	Unit	Pinion	Gear
Expected life factor	CL	---	1.017	1.017
Expected number of load cycles	N	cycs	7.575E+08	7.575E+08
Expected life time	L	hrs	1.052E+04	2.946E+04
Item(Bending)	**Symbol**	**Unit**	**Pinion**	**Gear**
Expected life factor	KL	---	0.497	0.554
Expected number of load cycles	N	cycs	3.129E+24	6.799E+21
Expected life time	L	hrs	4.346E+19	2.644E+17

Fig.2.54　Life calculation result



Item	Symbol	Unit	Pinion	Gear
Geometry factor for Pitting resistance	ZI	---	0.112	
Mean cone distance	Rm	mm	284.487	
Addendum angle	θα1,2	deg	3.471	1.786
Mean addendum	ham1,2	mm	14.645	6.257
Location constant	k'	---	0.139	
Mean transverse diametral pitch	Pm	mm	0.078	
Outer transverse circular pitch	Pe	mm	47.124	
Mean normal base pitch	Pmbn	mm	30.851	
Mean normal circular pitch	Pmn	mm	32.831	
Mean transverse pitch radius	rmpt1,2	mm	101.602	796.562
Mean normal pitch radius	rmpn1,2	mm	151.417	1187.109
Mean normal base radius	rmbn1,2	mm	142.285	1115.518
Mean normal outside radius	rmne1,2	mm	166.062	1193.366
Length of mean normal addendum action	gαn1,2	---	33.835	17.944
Length of action in mean normal section	gαn	---	51.780	
Transverse contact ratio	εα	---	1.191	
Intermediate variable	Kz	---	0.363	
Face contact ratio	εβ	---	1.764	
Modified contact ratio	εo	---	2.128	
Mean base spiral angle	βmb	deg	32.615	
Length of action within the contact ellipse	gη	mm	65.228	
Mean normal profile radius of curvature at pitch circ…	ρm1,2	mm	48.979	383.992
Assumed locations of critical point on tooth for pitti…	yI	---	-0.408	
-----	gηI	mm	65.223	
Distance along path of action in mean normal sectio…	gyo	---	13.705	
Profile radius of curvature at point fI	ρ1,2	mm	62.684	370.287
Relative radius of profile curvature	ρyo	mm	53.609	
Length of the line of contact	gc	mm	66.860	
Inertia factor	Zi	---	1.000	
-----	g'ηI	mm	66.698	
Load sharing ratio	εNI	---	0.935	

Fig.2.55　Geometry factor（I）

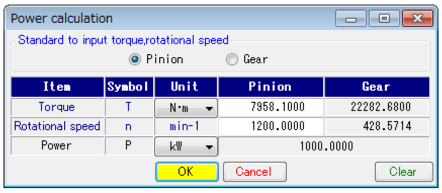


Geometry factor [ANSI/AGMA 2003-B97]

Item	Symbol	Unit	Pinion	Gear
Geometry factor for bending	YJ1,2	---	0.200	0.223
Mean dedendum	hfm1,2	mm	8.869	17.257
Assumed locations of critical point on tooth for ben…	yJ	---	0.000	
Length of action within the contact ellipse	gη	mm	65.228	
Determination of point of load application for max	y3	---	31.832	19.947
Distance from mean section to center of pressure	go″	mm	7.822	7.822
Sum of gear and pinion mean normal pitch radii	Σrmpn	mm	1338.526	
Normal pressure angle at point of load application	αL1,2	deg	24.777	19.368
One half of angle subtended by normal circular	ξh1,2	deg	2.868	0.403
Normal pressure angle at point of load application	αh1,2	deg	21.909	18.964
Distances from pitch circle to point of load applica	⊿ryo1,2	mm	1.945	-7.568
Tool or cutter tip edge radii used to produce	ρao1,2	mm	0.800	0.800
Tooth fillet radii in mean section at the tooth root	rmf1,2	mm	1.208	1.025
Tooth strength factor	XN1,2	---	12.717	16.631
Tooth form factors excluding stress concentra	Y1,2	---	0.663	0.874
Stress concentration and stress correction factor	Yf1,2	---	2.399	2.697
Empirical constant used in stress correction formula	H	---	0.180	
Empirical exponent used in stress correction formula	L	---	0.150	
Empirical exponent used in stress correction formula	M	---	0.450	
Tooth form factors for gear and pinion	YP,YG	mm	0.276	0.324
-----	g′ηJ	---	66.679	
Load sharing ratio	εNJ	---	0.936	
Inertia factor	Yi	---	1.000	
Projected length of instantaneous line of contact	gK	mm	56.322	
Toe increments of face width (effective)	⊿b′i1,2	mm	36.210	36.210
Toe increments of face width	⊿bi1,2	mm	36.210	36.210
Heal increments of face width (effective)	⊿b′e1,2	mm	17.111	17.111
Heal increments of face width	⊿be1,2	mm	17.111	17.111
Effective face width	b′1,2	mm	76.244	74.382

Fig.2.56　Geometry factor（J：Pinion 凹）

Fig.2.57 shows a support function screen that calculates the relationship between power and torque.



Power calculation

Standard to input torque,rotational speed

● Pinion　○ Gear

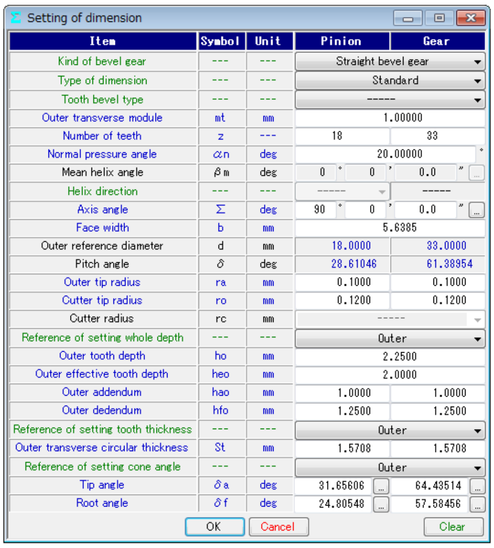
Item	Symbol	Unit	Pinion	Gear
Torque	T	N·m	7958.1000	22282.6800
Rotational speed	n	min-1	1200.0000	428.5714
Power	P	kW	1000.0000	

Fig.2.57　Support function

2.21 Gear strength calculation（resin gear）

The bending strength of the resin gear is calculated by Lewis equation, and the tooth surface strength is calculated by Hertz's equation by selecting "Resin" in the property of Fig.2.2. Here, an example of Strength calculation for the straight bevel gear from Fig.2.58 is used as shown in Fig.2.59 and Fig.2.60.

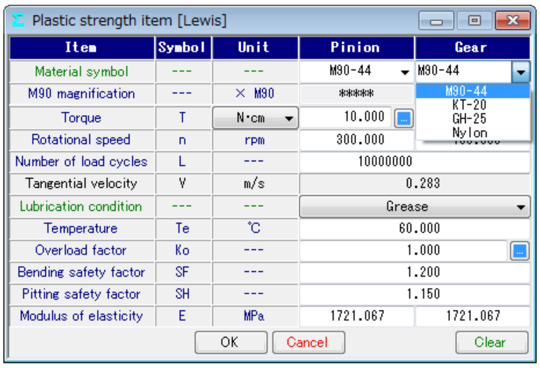
The allowable stress value of resin material is experimental value by considering temperature and life. The applicable materials are M90, KT20, GH25, nylon. Other materials can be calculated by M90 ratio coefficient (ratio to common physical property value).



Setting of dimension

Item	Symbol	Unit	Pinion	Gear
Kind of bevel gear	---	---	Straight bevel gear	
Type of dimension	---	---	Standard	
Tooth bevel type	---	---	-----	
Outer transverse module	mt	mm	1.00000	
Number of teeth	z	---	18	33
Normal pressure angle	αn	deg	20.00000 °	
Mean helix angle	βm	deg	0 ° 0 ′ 0.0 ″	
Helix direction	---	---	-----	-----
Axis angle	Σ	deg	90 ° 0 ′ 0.0 ″	
Face width	b	mm	5.6385	
Outer reference diameter	d	mm	18.0000	33.0000
Pitch angle	δ	deg	28.61046	61.38954
Outer tip radius	ra	mm	0.1000	0.1000
Cutter tip radius	ro	mm	0.1200	0.1200
Cutter radius	rc	mm	-----	
Reference of setting whole depth	---	---	Outer	
Outer tooth depth	ho	mm	2.2500	
Outer effective tooth depth	heo	mm	2.0000	
Outer addendum	hao	mm	1.0000	1.0000
Outer dedendum	hfo	mm	1.2500	1.2500
Reference of setting tooth thickness	---	---	Outer	
Outer transverse circular thickness	St	mm	1.5708	1.5708
Reference of setting cone angle	---	---	Outer	
Tip angle	δa	deg	31.65606	64.43514
Root angle	δf	deg	24.80548	57.58456

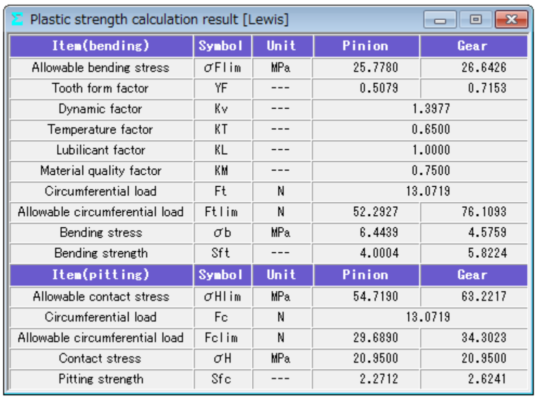
Fig.2.58　Dimension



Plastic strength item [Lewis]

Item	Symbol	Unit	Pinion	Gear
Material symbol	---	---	M90-44	M90-44
M90 magnification	---	× M90	*****	
Torque	T	N·cm	10.000	
Rotational speed	n	rpm	300.000	
Number of load cycles	L	---	10000000	
Tangential velocity	V	m/s	0.283	
Lubrication condition	---	---	Grease	
Temperature	Te	℃	60.000	
Overload factor	Ko	---	1.000	
Bending safety factor	SF	---	1.200	
Pitting safety factor	SH	---	1.150	
Modulus of elasticity	E	MPa	1721.067	1721.067

Fig.2.59　Strength dimension（resin gear）



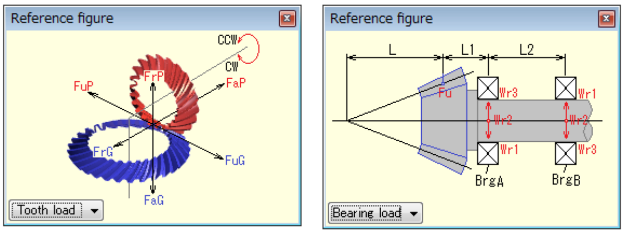
Plastic strength calculation result [Lewis]

Item(bending)	Symbol	Unit	Pinion	Gear
Allowable bending stress	σFlim	MPa	25.7780	26.6426
Tooth form factor	YF	---	0.5079	0.7153
Dynamic factor	Kv	---	1.3977	
Temperature factor	KT	---	0.6500	
Lubilicant factor	KL	---	1.0000	
Material quality factor	KM	---	0.7500	
Circumferential load	Ft	N	13.0719	
Allowable circumferential load	Ftlim	N	52.2927	76.1093
Bending stress	σb	MPa	6.4439	4.5759
Bending strength	Sft	---	4.0004	5.8224
Item(pitting)	**Symbol**	**Unit**	**Pinion**	**Gear**
Allowable contact stress	σHlim	MPa	54.7190	63.2217
Circumferential load	Fc	N	13.0719	
Allowable circumferential load	Fclim	N	29.6890	34.3023
Contact stress	σH	MPa	20.9500	20.9500
Pitting strength	Sfc	---	2.2712	2.6241

Fig.2.60　Strength result（resin gear）

2.22　Bearing load

Load acting on teeth and bearings are calculated. Fig.2.61 shows a reference diagram of the load direction acting on the teeth and the bearing position. In Fig.2.62, bearing load is indicated by inputting torque and bearing distance.



(a) Direction of load acting on teeth　　(b)Bearing position

Fig.2.61　Example picture

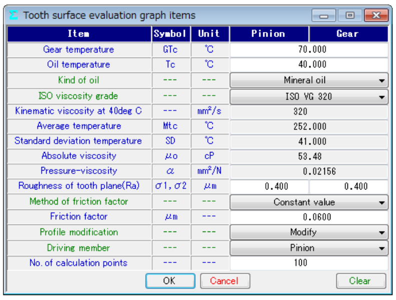
Bearing load

Item	Symbol	Unit	Pinion	Gear
Rotational direction	---	---	CCW	CW
Torque	T	N·m	25.000	68.750
Bearing support method	---	---	Overhang	
Cone apex ～ center of face width	L	mm	41.982	15.266
Bearing span1	L1	mm	30.0000	30.0000
Bearing span2	L2	mm	30.0000	30.0000
Load to tooth			☐ Display reference figure	
Shaft thrust load	Fa	N	1326.301	291.960
Transverse load factor	Fu	N	1637.620	1637.620
Radial load	Fr	N	291.960	1326.301
Radial load to bearing A				
Radial load(total)	Wr	N	3276.504	3970.252
Radial load by Fa	Wr1	N	583.920	2652.603
Radial load by Fu	Wr2	N	3275.240	3275.240
Radial load by Fr	Wr3	N	674.913	408.566
Radial load to bearing B				
Radial load(total)	Wr	N	1681.800	1877.242
Radial load by Fa	Wr1	N	291.960	1326.301
Radial load by Fu	Wr2	N	1637.620	1637.620
Radial load by Fr	Wr3	N	674.913	408.566

Fig.2.62　Bearing load

2.23 Gear surface evaluation （optional）

After strength calculation, by inputting presence / absence of tooth profile modification, type of drive gear, number of calculation points in the tooth surface evaluation graph setting screen in Fig.2.63, slip ratio graph (Fig.2.64) and Hertz stress graph (Fig.2.65) will be displayed.


Tooth surface evaluation graph items

Item	Symbol	Unit	Pinion	Gear
Gear temperature	GTc	℃	70.000	
Oil temperature	Tc	℃	40.000	
Kind of oil	---	---	Mineral oil	
ISO viscosity grade	---	---	ISO VG 320	
Kinematic viscosity at 40deg C	---	mm²/s	320	
Average temperature	Mtc	℃	252.000	
Standard deviation temperature	SD	℃	41.000	
Absolute viscosity	μo	cP	53.48	
Pressure-viscosity	α	mm²/N	0.02156	
Roughness of tooth plane(Ra)	σ1, σ2	μm	0.400	0.400
Method of friction factor	---	---	Constant value	
Friction factor	μm	---	0.0600	
Profile modification	---	---	Modify	
Driving member	---	---	Pinion	
No. of calculation points	---	---	100	

Fig.2.63　Surface evaluation graph

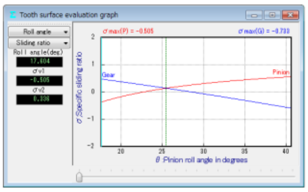


Fig.2.64　Slip ratio graph

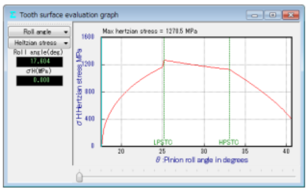
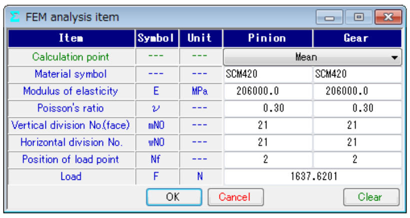


Fig.2.65　Hertz stress graph

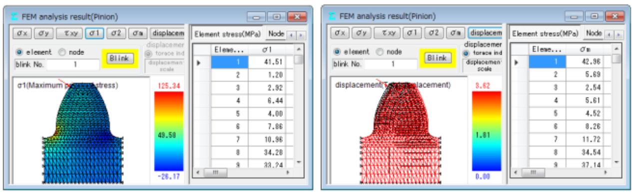
2.24 FEM tooth shape stress analysis（optional）

Five types of stress (σ_x ,σ_y, shear stress τ , principal stress σ_1 ,σ_2) can be calculated by inputting the longitudinal modulus of elasticity, Poisson's ratio, number of divisions, load position and load in the setting screen of FEM analysis as shown in Fig.2.66. Since the actual stress acting on the teeth can be evaluated together with the gear strength calculation, the reliability of the gear strength can be enhanced. Maximum principal stress σ_1 and displacement diagram are shown in Fig. 2.67.


FEM analysis item

Item	Symbol	Unit	Pinion	Gear
Calculation point	---	---	Mean	
Material symbol	---	---	SCM420	SCM420
Modulus of elasticity	E	MPa	206000.0	206000.0
Poisson's ratio	ν	---	0.30	0.30
Vertical division No.(face)	mNO	---	21	21
Horizontal division No.	wNO	---	21	21
Position of load point	Nf	---	2	2
Load	F	N	1637.6201	

Fig.2.66　FEM analysis setup


FEM analysis result(Pinion)

Eleme...	σ1
1	41.51
2	1.20
3	2.92
4	6.44
5	4.00
6	7.86
7	10.96
8	34.28
9	33.24

FEM analysis result(Pinion)

Eleme...	σa
1	42.96
2	5.69
3	2.54
4	5.61
5	4.52
6	8.26
7	11.72
8	34.54
9	37.14

(a) Pinion,　σ_1　　　(b)　Pinion,　displacement

Fig.2.67　FEM analysis result

2.25 Gear drawing example

A tooth profile of spiral bevel gear outputting tooth lead at equal lead is shown in Fig.2.68, while an example of axis angle with 160 ° is shown in Fig.2.68. Even gears with a small number of teeth like differential bevel gear, it shows correct tooth contact because they are spherical involute tooth profiles.

An example of machining with a ball end mill using a tooth profile data is shown in Fig.2.71. Also, a photograph of a photo-fabrication model is shown in Fig.2.72.

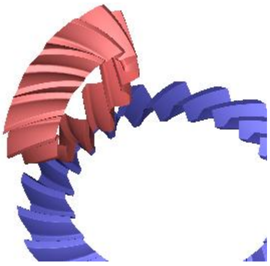

m2, z_1=12, z_2=23, β=35°, Σ =90°

Fig.2.68　Equi-lead spiral

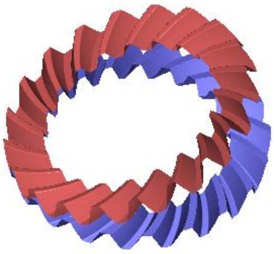

m2, z_1= z_2=20, β=35°, Σ =160°

Fig.2.69　Shaft angle 160° spiral

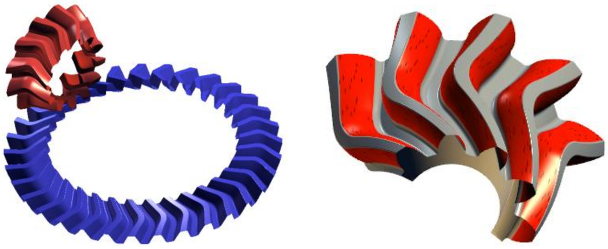

Fig.2.71　Gear manufacturing


m1,z28, α20°, β35°

Fig.2.72　Photo-fabrication model

2.26 Special bevel gear

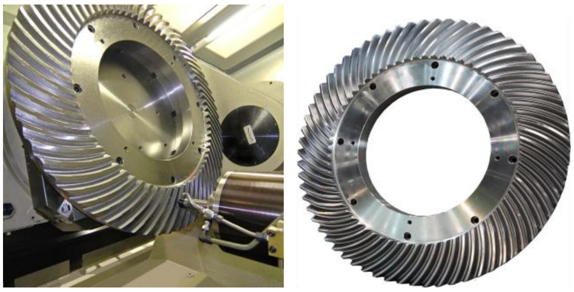
Although it is not a standard function of software, it is also possible to generate a tooth profile of a double spiral bevel gear as shown in Fig.2.73. Please contact us for this tooth form.


(a)Rendering　　　(b)　Contact pattern


(c)　Processing example　　　(d)　Made by 3D printer

Fig.2.73　Double spiral bevel gear

2.27 Process example of bevel Gear by machining center

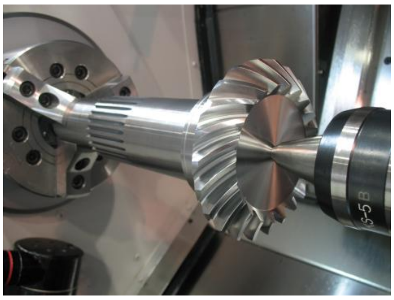

m15, z65, α20°, β=35°, d=975.0

(Provided by Mitsui Seiki Kogyo Co., Ltd.)

HU80A-5X（JIMTOF2008）

Fig.2.74　Spiral bevel gear manufacturing example

D500（m5, z30, α20°, β=0°, d=150）
(Provided by Makino Mill Inc.)
Fig.2.75 Straight bevel gear processing example



m6, z22, α20°, β=35°, d=132
Intelligent multi-task machine：MULTUS B300C
（Provided by Okuma Co., Ltd.)
Fig.2.76 Spiral bevel gear manufacturing example

YBMVi40（m5, z20, α20°, β=35°, d=100.0）
(Provided by Yasuda Kogyo Co., Ltd.)
Fig.2.77 Spiral bevel gear manufacturing example

HERMLE C-50U（m10, z47, α20°, β=35°, d=470）
(Provided by Aichi Sangyo Co., Ltd.)
Fig.2.78 Spiral bevel gear manufacturing example

NMV3000 DCG（m4, z40, α20°, β=35°, d=160）
(Provided by DMG Mori Seiki Co., Ltd.)
Fig.2.79 Spiral bevel gear manufacturing example

(GMT-630, provided by Otori Kiko Co., Ltd.)
Fig.2.80 Example of blisk processing