[3] involute Σ iii (worm gear design system)

English version

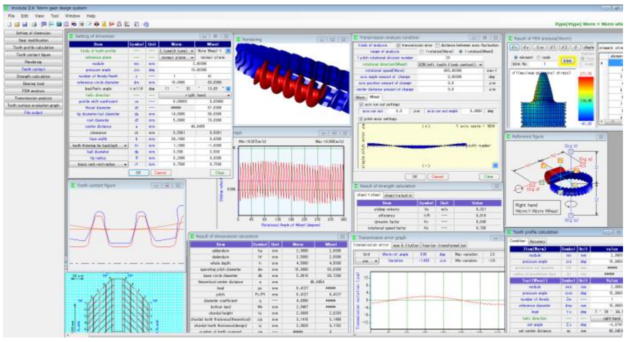


Fig.3.1 involute Σ iii (worm gear)

3.1 Abstract

This software is a newly developed software that combined both involuteΣ (worm gear) and involuteΣ (worm and helical gear). In addition, some optional functions are incorporated into the basic software, and various new functions are also added.

3.2 Software structure

Table 3.1 shows software configuration. ○ in the table is included in the basic software and ◎ is optional.

In involute Σ iii (worm gear), the worm's mating gear is a worm wheel, but it can be helical gear. In case of helical gear, please see 3.16 or later.

When ordering, please select necessary software from the price list.

Table 3.1 Software structure

No.	Item	Page		Structure
		WG	WH	
1	Basic rack	3.3	3.16	○
2	Dimension	3.4	3.17	○
3	Gear modification	3.5	3.18	◎
4	Tooth profile calculation	3.6	3.19	○
5	Meshing drawing	3.7	3.20	○
6	Tooth profile rendering	3.8	3.21	○
7	Contact pattern	3.9	3.22	◎
8	Strength calculation(metal-to-metal)	3.10	------	○
9	Strength calculation(metal-to-resin)	3.10	3.23	○
10	Bearing load	3.11	3.24	○
11	FEM tooth stress analysis	3.12	3.25	◎
12	Transmission error analysis	3.13	3.26	◎
13	Center distance change analysis	3.13	3.26	◎
14	Tooth surface evaluation	3.14	3.27	◎
15	Tooth profile export	3.15	3.28	○
16	Design data management	3.29		○

WG : worm gear, WH : worm and helical gear

3.3 Basic rack (property)

Basic rack of worm gear is shown in Fig.3.2. Reference plane can be selected for a right angle of axial plane or shaft plane. In addition, as shown in Fig.3.2, actual dimensions of the basic rack can be displayed, and then, lead angle can be determined from base circle diameter of the worm, or alternatively, base circle diameter can be determined from lead angle.

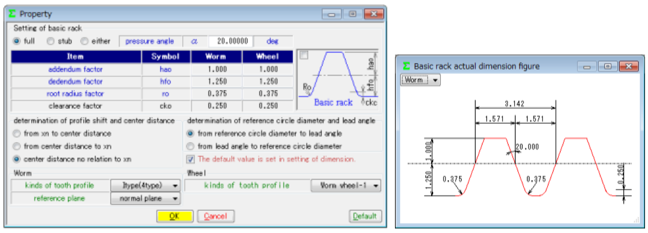


Fig.3.2 Basic rack（worm gear）

3.4 Dimension

Input screen for worm gear dimension is shown in Fig.3.3. As shown in Fig.3.4 (a), worm tooth profile includes five types such as A, N, K, I and C-type in the standard software. However, since C-type is not applicable to strength calculation standard, it is limited to generating dimensions and tooth form only. In addition, input range is 0.001 to 50 for module, 5 to 30 ° for pressure angle, and 1 to 15 for number of threads. The method of tooth thickness modification can be set by tooth thinning amount or transverse profile shift coefficient as shown in Fig. 3.4 (c). In this example, decreased tooth thickness of worm and increased tooth thickness of worm wheel are shown.

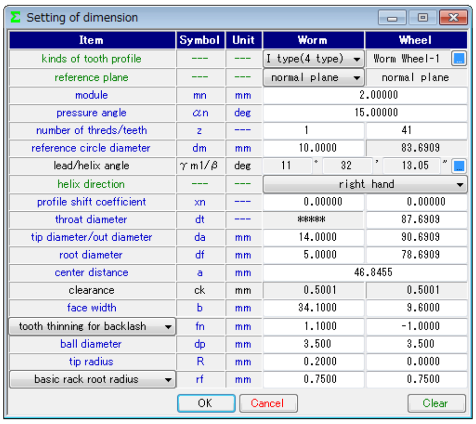
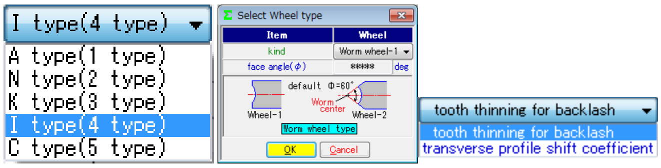


Fig.3.3 Dimension input



(a)Tooth type (b) Wheel type (c)Thinning amount

Fig.3.4 Support form

3.5 Gear modification（optional）

Worm tooth shape modification can be set as shown in Fig.3.5. As shown in Fig.3.6, worm is given with tooth shape modification of 3 μm at tooth tip and root.

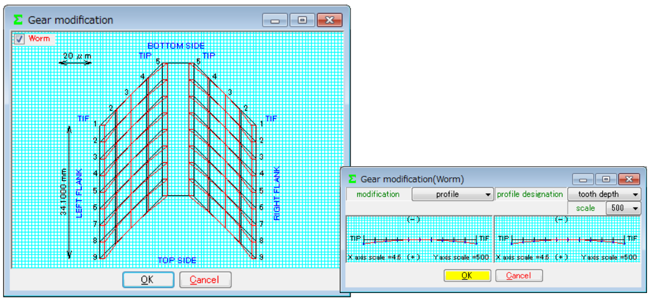


Fig.3.5 Worm tooth modification 1

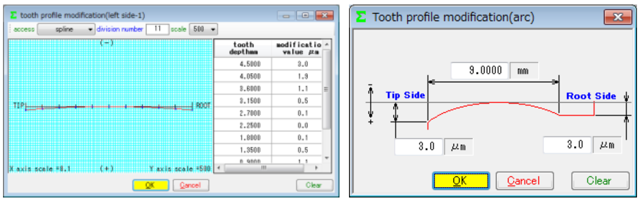
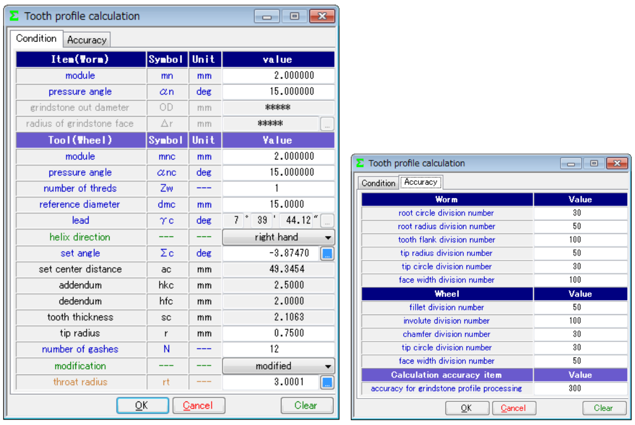


Fig.3.6 Worm tooth modification 2

3.6 Tooth profile calculation

Tooth profile calculation condition can be set for wheel processing tool (hob) dimension as shown in Fig.3.7 (a). The number of divisions can be set for displaying tooth profile as shown in Fig.3.7 (b). When applying tooth profile modification to wheel hob, it can be set as shown in Fig.3.8.



Item(Worm)	Symbol	Unit	value
module	mn	mm	2.000000
pressure angle	αn	deg	15.000000
grindstone out dameter	OD	mm	*****
radius of grindstone face	Δr	mm	*****
Tool(Wheel)	**Symbol**	**Unit**	**Value**
module	mnc	mm	2.000000
pressure angle	αnc	deg	15.000000
number of threds	Zw	---	1
reference diameter	dmc	mm	15.0000
lead	γc	deg	7° 39' 44.12"
helix direction	---	---	right hand
set angle	Σc	deg	-3.87470
set center distance	ac	mm	49.3454
addendum	hkc	mm	2.5000
dedendum	hfc	mm	2.0000
tooth thickness	sc	mm	2.1063
tip radius	r	mm	0.7500
number of gashes	N	---	12
modification	---	---	modified
throat radius	rt	---	3.0001

Worm	Value
root circle division number	30
root radius division number	50
tooth flank division number	100
tip radius division number	50
tip circle division number	30
face width division number	100
Wheel	**Value**
fillet division number	50
involute division number	100
chamfer division number	30
tip circle division number	30
face width division number	50
Calculation accuracy item	**Value**
accuracy for grindstone profile processing	300

(a) Condition setting (b) Accuracy setting

Fig.3.7 Tooth profile calculation setup

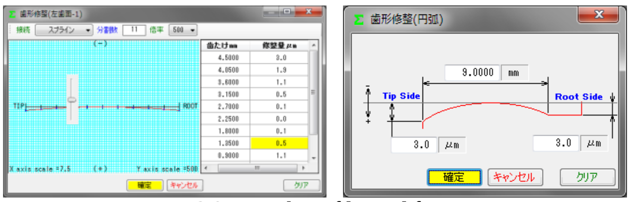
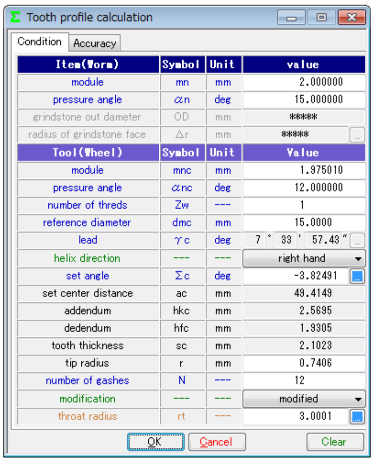


Fig.3.8 Tooth profile modification

It is possible to set wheel processing hob as shifted hob (e.g. α = 12 °) as shown in Fig.3.9 (m_n=1.975 is determined by setting as α = 12 °). This method is adopted as a contact pattern adjustment method. Fig.3.10 shows contact patterns when processing with standard hob and shifted hob, but it shows that the contact pattern of shifted hob is close to the center of the tooth. Please see 3.9 for contact patterns.



Item(Worm)	Symbol	Unit	value
module	mn	mm	2.000000
pressure angle	αn	deg	15.000000
grindstone out dameter	OD	mm	*****
radius of grindstone face	Δr	mm	*****
Tool(Wheel)	**Symbol**	**Unit**	**Value**
module	mnc	mm	1.975010
pressure angle	αnc	deg	12.000000
number of threds	Zw	---	1
reference diameter	dmc	mm	15.0000
lead	γc	deg	7° 33' 57.43"
helix direction	---	---	right hand
set angle	Σc	deg	-3.82491
set center distance	ac	mm	49.4149
addendum	hkc	mm	2.5695
dedendum	hfc	mm	1.9305
tooth thickness	sc	mm	2.1023
tip radius	r	mm	0.7406
number of gashes	N	---	12
modification	---	---	modified
throat radius	rt	---	3.0001

Fig.3.9 Shifted hob setting

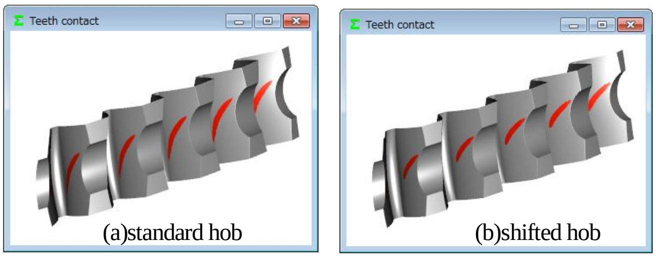
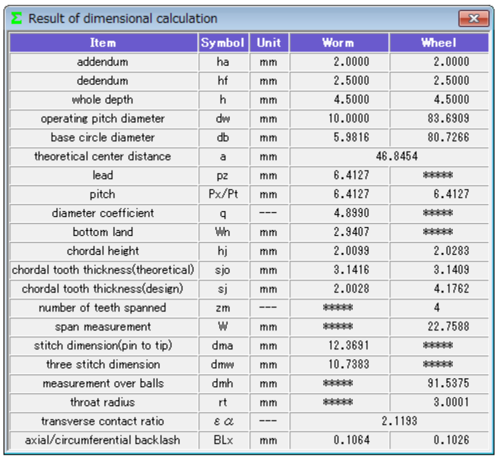


Fig.3.10 Contact pattern（No tooth modification）

After tooth profile calculation, dimension result is displayed in Fig. 3.11. The three-needle dimension and backlash of worm are calculated based on the actual tooth form considering tooth profile modification.



Item	Symbol	Unit	Worm	Wheel
addendum	ha	mm	2.0000	2.0000
dedendum	hf	mm	2.5000	2.5000
whole depth	h	mm	4.5000	4.5000
operating pitch diameter	dw	mm	10.0000	83.6909
base circle diameter	db	mm	5.9816	80.7266
theoretical center distance	a	mm	46.8454	
lead	pz	mm	6.4127	*****
pitch	Px/Pt	mm	6.4127	6.4127
diameter coefficient	q	---	4.8990	*****
bottom land	Wn	mm	2.9407	*****
chordal height	hj	mm	2.0099	2.0283
chordal tooth thickness(theoretical)	sjo	mm	3.1416	3.1409
chordal tooth thickness(design)	sj	mm	2.0028	4.1762
number of teeth spanned	zm	---	*****	4
span measurement	W	mm	*****	22.7588
stitch dimension(pin to tip)	dma	mm	12.3691	*****
three stitch dimension	dmw	mm	10.7383	*****
measurement over balls	dmh	mm	*****	91.5375
throat radius	rt	mm	*****	3.0001
transverse contact ratio	εα	---	2.1193	
axial/circumferential backlash	BLx	mm	0.1064	0.1026

Fig.3.11 Dimension result

3.7 Meshing drawing

After tooth profile calculation, tooth profile can be displayed as shown in Fig.3.12. There are enlargement, distance measurement, R-measurement, and rotation functions for tooth form as shown in Fig. 3.13.

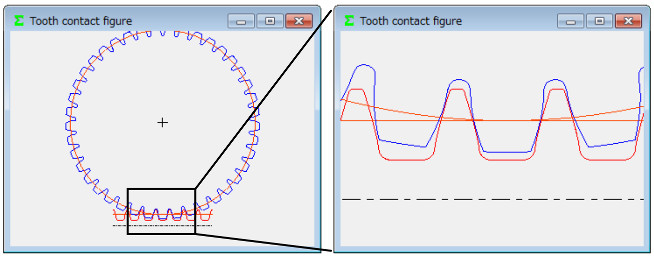


Fig.3.12 Meshing drawing

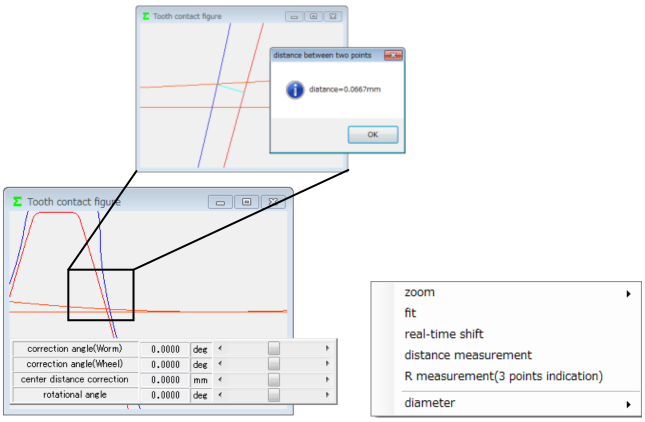


Fig.3.13 Tooth meshing & Support form

3.8 Tooth profile rendering

After tooth profile calculation, tooth profile rendering can be displayed as shown in Fig. 3.14. In Fig 3.13, the tooth surfaces are not in contact with each other, but this does not come into contact at the pitch circle area because the tooth surface is in contact with the root and the side surface area of the wheel as shown in Fig. 3.15. The support form in Fig 3.15 has an observation angle, gear position change, enlargement function, and automatic rotation function.

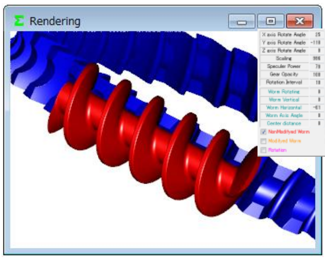


Fig 3.14 Rendering

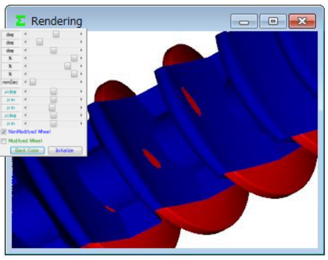


Fig 3.15 Tooth contact

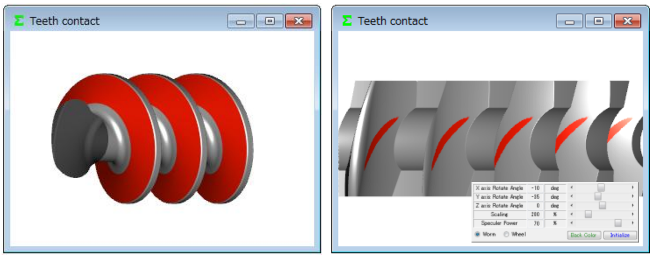
3.9 Contact pattern（optional）

In contact pattern setting shown in Fig. 3.16, shaft mounting tolerance and max. contact clearance (paint thickness) can be defined. In this example, the contact pattern is shown in Fig. 3.17 when max. contact clearance is c=3 μm. Contact pattern changes can be studied by considering tooth profile of worm, tooth profile modification, mounting tolerance, and machined wheel with shifted hob.

In addition, tooth profile can be enlarged and observation angle can be changed by support form at the bottom right of Fig 3.17 (b). Fig 3.18 shows that the contact pattern significantly changes when the lead angle is $\gamma = 5.74°$.

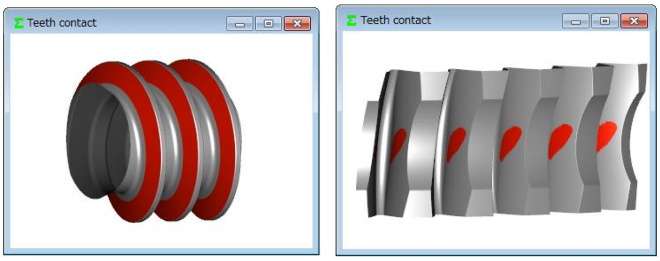
項　目	記号	単位	数　値
軸位置変化量	⊿V	μm	0.0
軸角変化量	⊿Σ	deg	0.00000
中心距離変化量	⊿a	μm	0.0
接触最大クリアランス	c	μm	3.0
1ピッチ回転分割数	---	---	20

Fig 3.16 Contact pattern setting



(a) Worm (b) Wheel

Fig 3.17 Contact pattern1（m_n=2,α=15°, γ=11.54°, I-type）



(a) Worm (b) Wheel

Fig 3.18 Contact pattern 2（m_n=2,α=15°, γ=5.74°, I-type）

3.10 Strength calculation

3.10.1 metal-to-metal

Strength dimension is shown in Fig 3.19, and strength calculation result is shown in Fig 3.20. Strength calculation is calculated based on JGMA405-01:1978. Also, kW and W for power, MN · m, kN · m, N · m, N · cm for torque can be selected. In addition, tooth surface strength allowable stress coefficient (Sclim) can be arbitrarily defined. Although various coefficients are displayed as standard value, they can be changed arbitrarily. Even if the gears are not applicable to the standards, they can be entered arbitrarily at the judgment of the designer.

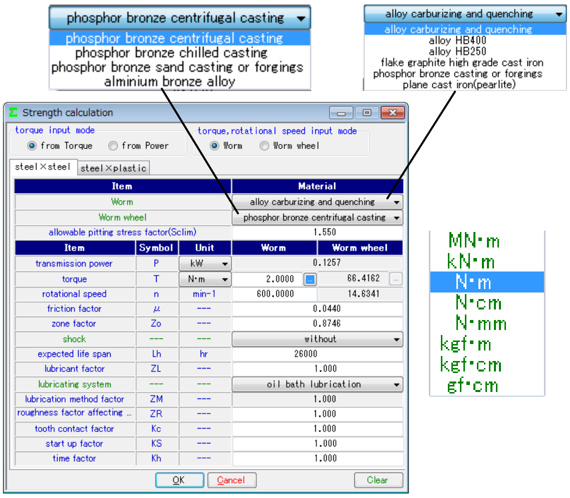
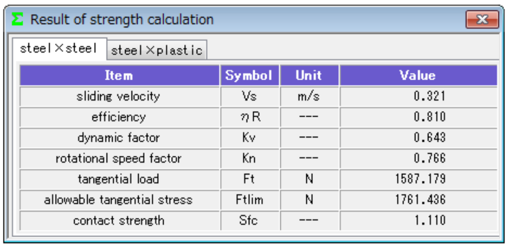


Fig 3.19 Strength dimension（metal-to-metal）



Item	Symbol	Unit	Value
sliding velocity	Vs	m/s	0.321
efficiency	ηR	---	0.810
dynamic factor	Kv	---	0.643
rotational speed factor	Kn	---	0.766
tangential load	Ft	N	1587.179
allowable tangential stress	Ftlim	N	1761.436
contact strength	Sfc	---	1.110

Fig 3.20 Strength result

3.10.2 Metal-to-resin

When worm is metal and wheel is resin, strength dimension is shown in Fig 3.21. Strength calculation result is shown in Fig 3.22. Strength calculation is based on Lewis's equation and the tooth surface strength is calculated based on Hertz stress.

M90-44 is the standard resin material, but other materials (KT-20, GH - 25, MC nylon) can be selected. For other materials, it is possible to cope with M90 ratio coefficient (ratio with common physical property value).

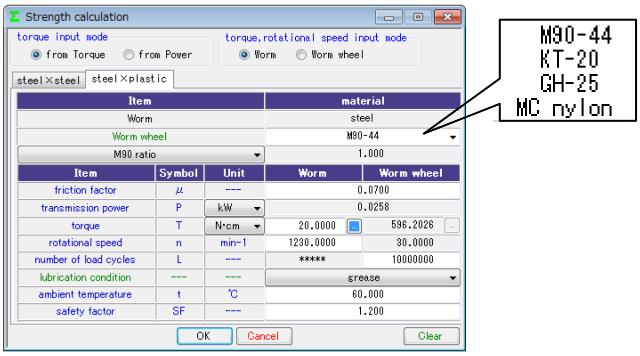


Fig 3.21 Strength dimension（metal-to-resin）

Item	Symbol	Unit	Value
tangential velocity	V	m/s	0.131
efficiency	ηR	---	0.727
tangential load	Ft	N	142.477
effective face width	bw	mm	9.600
Bending(Worm wheel)			
material factor	KM	---	1.000
tooth profile factor	YF	---	0.903
dynamic factor	Kv	---	1.399
temperature factor	KT	---	0.650
lubrication factor	KL	---	1.000
allowable bending stress	σblim	MPa	10.843
max allowable bending stress	σlim	MPa	9.860
allowable tangential load	Fa	N	308.039
bending strength	Sfb	---	2.162
Shearing(Worm wheel)			
arc tooth thickness	So	mm	4.573
crooss-sectional area	A	mm²	102.526
allowable shearing stress	σslim	MPa	5.975
allowable tangential load	Fs	N	510.471
shearing strength	Sfs	---	3.583

Fig 3.22　Strength result（metal-to-resin）

3.11　Bearing load

Bearing load calculation result is shown in Fig 3.23.

Item	symbol	Unit	Worm	Wheel
torque of Worm	T	N·m	2.0000	66.4162
friction factor	μ	---	0.044	
bearing span	w1,h1	mm	50.0000	50.0000
bearing span	w2,h2	mm	50.0000	50.0000
rotational direction of worm	---	---	foward rotation	

<load acting on Worm, Wheel>

Item	Symbol	Unit	Worm	Wheel
circumference load	Ft	N	400.000	1587.178
axial load	Fa	N	1587.178	400.000
radius load	Fr	N	438.126	438.126

<load acting on Worm side bearing>

Item	Symbol	Unit	Brg a1	Brg a2
thrust load	Faa	N	1587.178	
radial load(comp.) of Ft	Fra1	N	200.000	200.000
radial load(comp.) of Fr	Fra2	N	219.063	219.063
radial load(comp.) of Fa	Fra3	N	-79.359	79.359
radial load(res.)	Fra	N	243.962	359.243

<load acting on Wheel side bearing>

Item	Symbol	Unit	Brg b1	Brg b2
thrust load	Fab	N	400.000	
radial load(comp.) of Fr	Frb1	N	219.063	219.063
radial load(comp.) of Ft	Frb2	N	793.589	793.589
radial load(comp.) of Fa	Frb3	N	-167.382	167.382
radial load(res.)	Frb	N	795.270	882.680

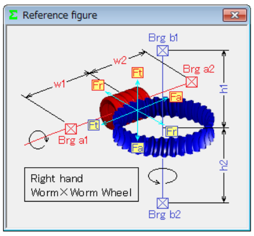


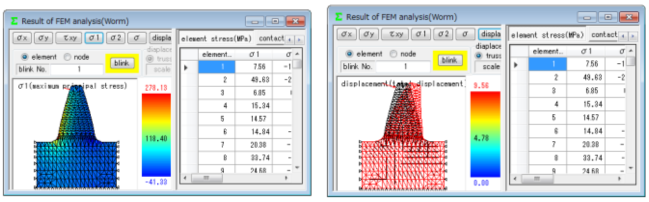
Fig 3.23　Bearing load

3.12　2D-FEM TOOTH STRESS ANALYSIS（optional）

In FEM setting screen in Fig. 3.24, modulus of longitudinal elasticity, Poisson's ratio, number of divisions and the load (in the example, the value obtained by dividing the circumferential force by ε) can be set. Fig.3.25 and Fig.3.26 show the analysis results of worm and wheel. The maximum value node and element can be displayed in flashing display.

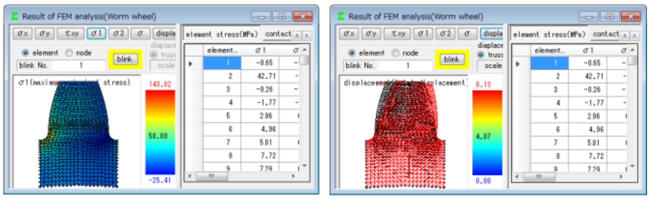
Item	Symbol	Unit	Worm	Wheel
material unit(Worm)			alloy carburizing and quenching	
material unit(Wheel)			phosphor bronze centrifugal casting	
modulus of elasticity	E	MPa	205800.0	80000.0
Poisson's ratio	ν	---	0.30	0.30
No. of partitions(depth)	mNo	---	21	21
No. of partitions(width)	wNo	---	21	21
position of the load point	Nf	---	2	2
load	F	N	750.0000	

Fig 3.24　FEM analysis setup



(a)Max main stress （σ_1）　　(b)Displacement

Fig 3.25　Worm



(a)Max main stress （σ_1）　　(b)Displacement

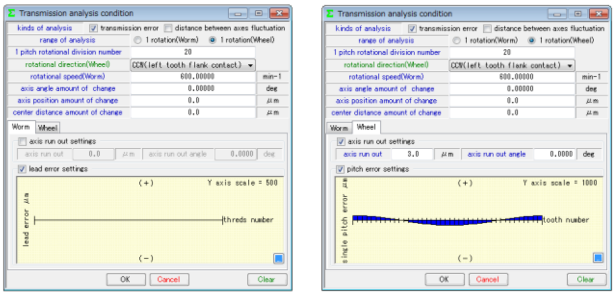
Fig 3.26　Wheel

3.13　Transmission error analysis（optional）

3.13.1　Transmission error analysis（optional）

Transmission error (TE) analysis is shown in Fig 3.27. Transmission error analysis due to single flank engagement and center distance change analysis due to double flank engagement can be performed. Worm with 1 rotation and wheel with 1 rotation can be selected. In the example, analysis is performed when wheel is 1 rotation at worm rotation speed 600min^{-1} while there is no shaft axis mounting error.

Pitch error can be set (maximum value setting or at each tooth) as shown in Fig. 3.28. Transmission error analysis results are shown in Fig. 3.29, wow flutter (rotation irregularity) is shown in Fig. 3.30, and Fourier analysis result is shown in Fig 3.31 There is also a function to convert wow flutter to "sound", and analysis result can be exported to CSV file.



(a)Worm（Lead error）　　(b)Wheel（Pitch error）

Fig 3.27　Pitch error setting

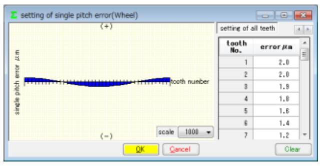


Fig 3.28　Pitch error(Wheel)

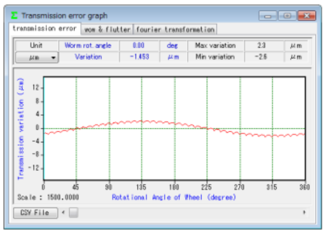


Fig 3.29　TE results

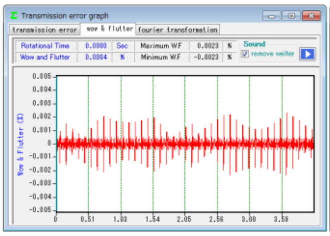


Fig 3.30　Wow flutter

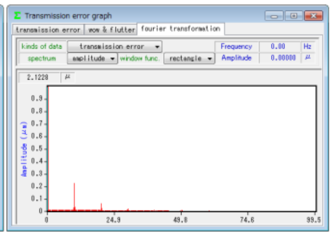
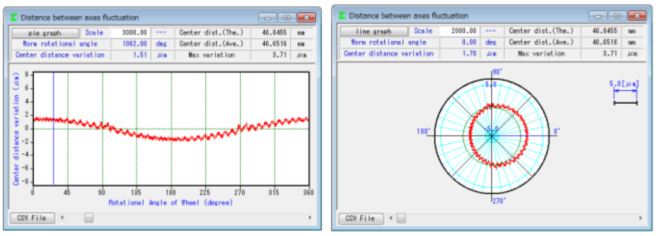


Fig 3.31　Fourier analysis

3.13.2　Center distance change analysis（optional）

Many worm gears are used as single-tooth flank contact, but depending on the device, double tooth flank may happen. Center distance change analysis analyzes fluctuation of the center distance in consideration of pitch error and mounting error settings in Fig 3.27. The analysis result is shown in Fig 3.22. In addition, analysis results can be exported to CSV file.



(a)Graph1　　　(b)Graph2

Fig 3.32　Center distance change analysis

3.14　Tooth surface evaluation（optional）

Tooth surface evaluation has slip velocity graph (Fig 3.33) and Hertz stress graph (Fig 3.34). The slip velocity is calculated from the tooth contact position, and Hertz stress is calculated from the tooth profile at the tooth contact position (tooth deformation is not taken into consideration). Both are valid after strength calculation and transmission error analysis.

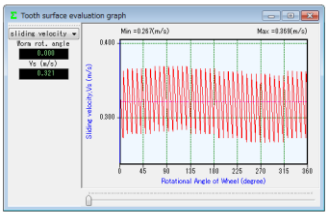


Fig 3.33　Slip velocity graph

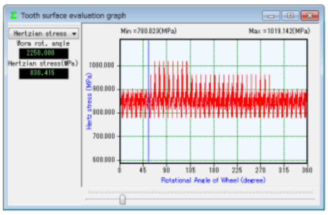
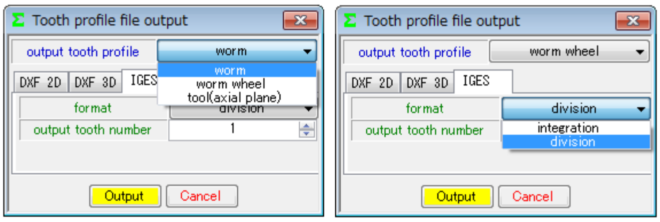


Fig 3.34　Hertz stress

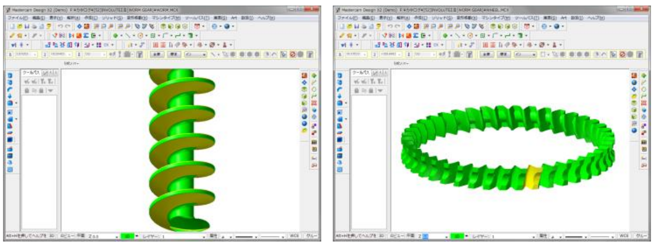
3.15　Tooth profile export

Tooth profile file is generated in worm, wheel and tooth form of the tool (hob) as shown in Fig 3.35 (output of arbitrary number of teeth is possible). There are three types of files such as DXF - 2D, DXF - 3D, and IGES - 3D. An example of CAD drawing is shown in Fig 3.36.



(a)　Output tooth profile　　(b)3D-IGES example

Fig 3.35　Tooth profile export



(a)Worm　　　(b)Wheel（all teeth output example）

Fig 3.36　CAD example

◆ Worm and helical gear◆

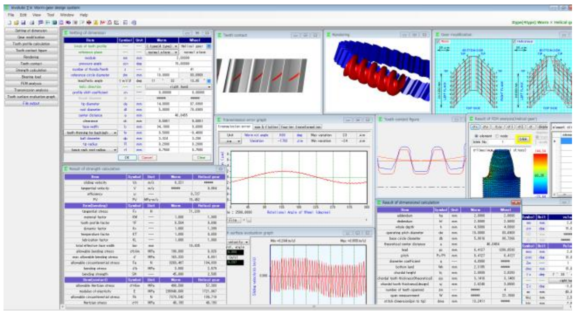


Fig 3.37　Example when worm's mating gear is a helical gear

3.16　Basic rack

Basic rack of worm gear is shown in Fig 3.38. The reference plane can be selected as a right angle to teeth, or an axial plane.

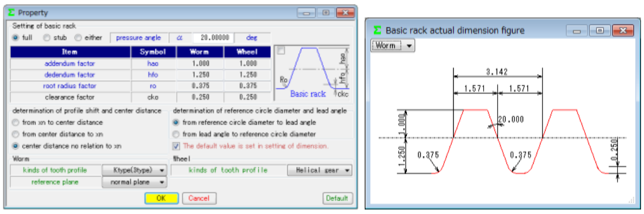


Fig 3.38　Basic rack（Worm & helical gear）

3.17　Dimension

Fig 3.39 shows input screen for worm & helical gear dimension. As shown in Fig. 3.40 (a), worm's tooth form is included in the standard software in five types such as A, N, K, I and C types. However, since C type is not applicable to the strength calculation standard, it is limited to generating dimensions and tooth shapes only. In addition, input range is 0.001 to 50 for module, 5 to 30 ° for pressure angle, and 1 to 15 for number of threads. The method of adjusting tooth thickness can be set by tooth thinning amount or transverse shift coefficient as shown in Fig 3.40 (c). In this example, decreased tooth thickness in worm and increased tooth thickness in helical gear are shown.

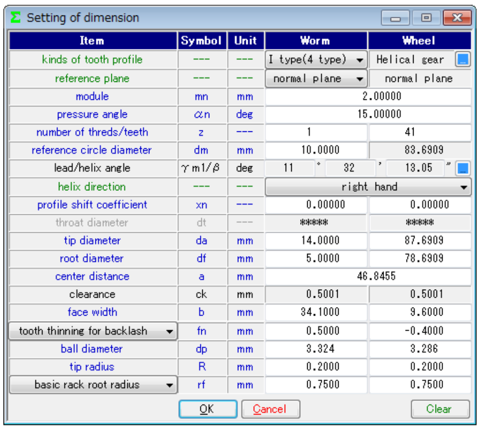
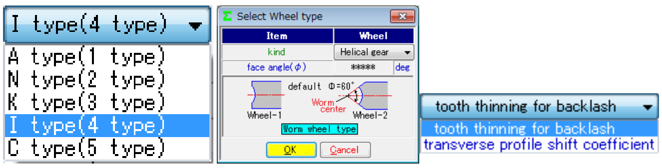


Fig 3.39　Dimension input



(a)Tooth profile type　(b) Helical gear　(c) Tooth thinning amount

Fig 3.40　Support form

3.18 Gear modification（optional）

As shown in Fig 3.41, tooth profile modification can be given to worm, and tooth surface modification can be given to helical gear. Fig 3.42 and Fig 3.43 show an example of worm's tooth profile setting and helical gear tooth surface modification.

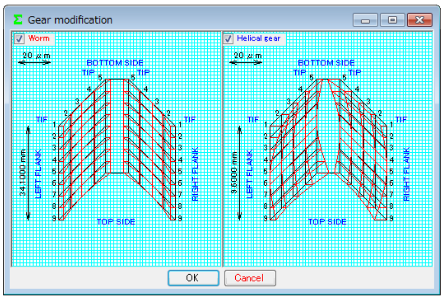


Fig 3.41 Tooth profile modification（Worm & helical gear）

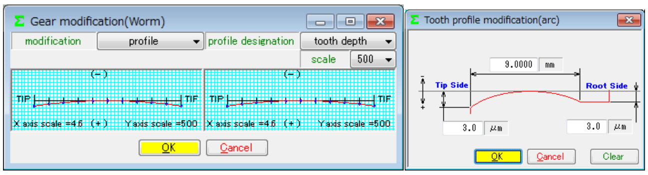


Fig 3.42 Worm tooth modification

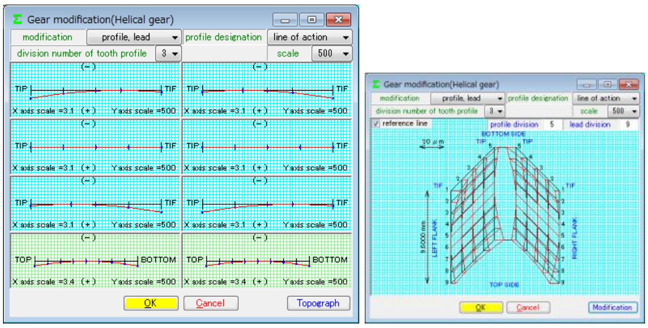
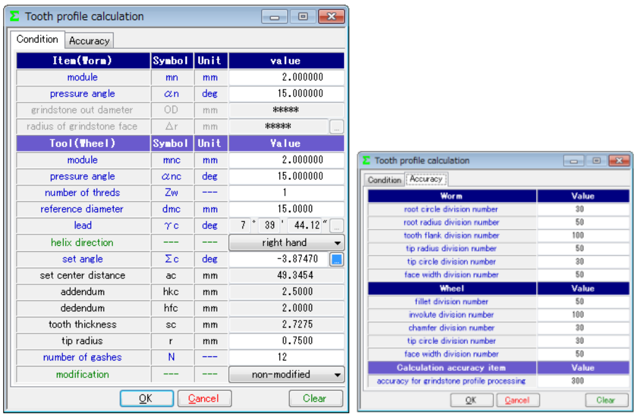


Fig 3.43 Helical gear involute/lead modification & topo graph

3.19 Tooth profile calculation

Tooth profile calculation conditions can be set in helical gear processing tool (hob) as shown in Fig 3.44 (a). A number of divisions for displaying tooth profile can be set in Fig 3.44 (b). After tooth profile calculation, dimension result is displayed in Fig 3.45. Three-needle dimension and backlash of worm are calculated based on actual tooth shape considering tooth profile modification. Helical gear is generated based on tooth shape of the tool from Fig 3.44.



Tooth profile calculation

Condition | Accuracy

Item(Worm)	Symbol	Unit	value
module	mn	mm	2.000000
pressure angle	αn	deg	15.000000
grindstone out dameter	OD	mm	*****
radius of grindstone face	Δr	mm	*****
Tool(Wheel)	**Symbol**	**Unit**	**Value**
module	mnc	mm	2.000000
pressure angle	αnc	deg	15.000000
number of threds	Zw	---	1
reference diameter	dmc	mm	15.0000
lead	γc	deg	7 ° 39 ' 44.12 "
helix direction	---	---	right hand
set angle	Σc	deg	-3.87470
set center distance	ac	mm	49.3454
addendum	hkc	mm	2.5000
dedendum	hfc	mm	2.0000
tooth thickness	sc	mm	2.7275
tip radius	r	mm	0.7500
number of gashes	N	---	12
modification	---	---	non-modified

OK Cancel Clear

(a)Condition setting

Tooth profile calculation

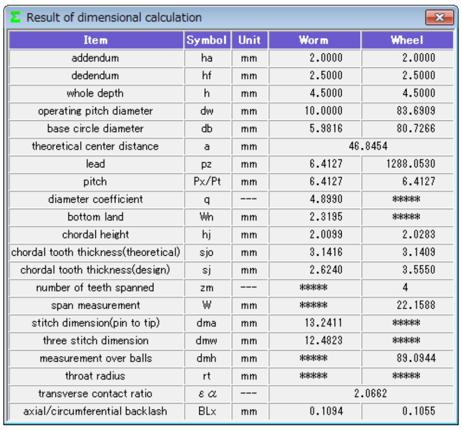
Condition | Accuracy

Worm	Value
root circle division number	30
root radius division number	50
tooth flank division number	100
tip radius division number	50
tip circle division number	30
face width division number	50
Wheel	**Value**
fillet division number	50
involute division number	100
chamfer division number	30
tip circle division number	30
face width division number	50
Calculation accuracy item	**Value**
accuracy for grindstone profile processing	300

OK Cancel Clear

(b)Accuracy setting

Fig 3.44 Tooth profile calculation setting



Result of dimensional calculation

Item	Symbol	Unit	Worm	Wheel
addendum	ha	mm	2.0000	2.0000
dedendum	hf	mm	2.5000	2.5000
whole depth	h	mm	4.5000	4.5000
operating pitch diameter	dw	mm	10.0000	83.6909
base circle diameter	db	mm	5.9816	80.7266
theoretical center distance	a	mm	46.8454	
lead	pz	mm	6.4127	1288.0530
pitch	Px/Pt	mm	6.4127	6.4127
diameter coefficient	q	---	4.8990	*****
bottom land	Wn	mm	2.3195	*****
chordal height	hj	mm	2.0099	2.0283
chordal tooth thickness(theoretical)	sjo	mm	3.1416	3.1409
chordal tooth thickness(design)	sj	mm	2.6240	3.5550
number of teeth spanned	zm	---	*****	4
span measurement	W	mm	*****	22.1588
stitch dimension(pin to tip)	dma	mm	13.2411	*****
three stitch dimension	dmw	mm	12.4823	*****
measurement over balls	dmh	mm	*****	89.0944
throat radius	rt	mm	*****	*****
transverse contact ratio	εα	---	2.0662	
axial/circumferential backlash	BLx	mm	0.1094	0.1055

Fig 3.45 Dimension result

3.20 Meshing drawing

After tooth profile calculation, tooth shape can be displayed as shown in Fig 3.46, and there are some functions such as enlargement plotting, distance measurement, R measurement, and rotation function are available as shown in Fig 3.47.

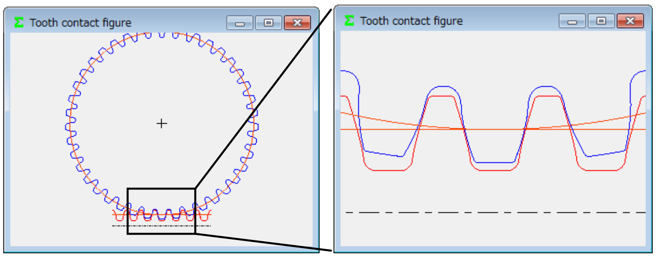


Fig 3.46 Meshing drawing

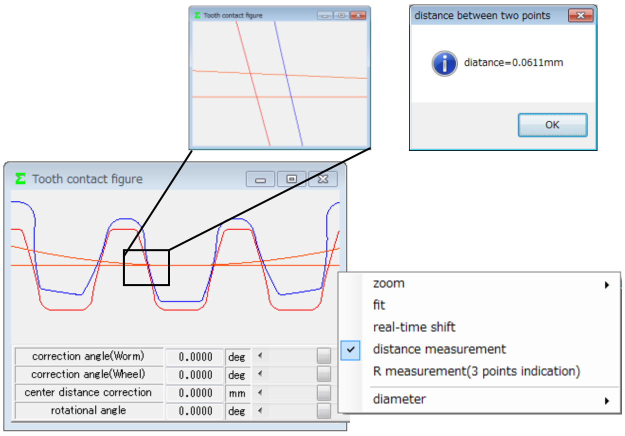


Fig 3.47 Tooth meshing & support form

3.21 Tooth profile rendering

After tooth profile calculation, tooth profile rendering can be displayed as shown in Fig 3.48. Support form in Fig 3.49 has observation angle, gear position change, enlargement function, automatic rotation function etc.

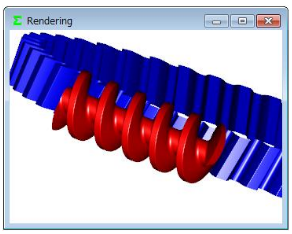


Fig 3.48 Rendering

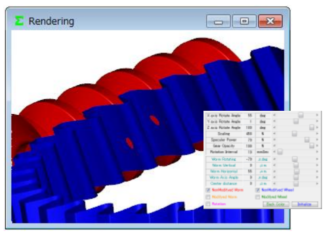


Fig 3.49 Tooth contact

3.22 Contact pattern（optional）

For contact pattern setting in Fig. 3.50, axis mounting error and max contact clearance (paint thickness) can be defined. In this example, Fig. 3.51 shows the contact pattern when max contact clearance is c=3μm. Contact pattern changes can be studied when worm type, tooth profile modification, and shaft mounting error are given.

In addition, support form allows users to enlarge tooth profile and change observation angle at the lower right of support form as shown in Fig 3.51 (b).

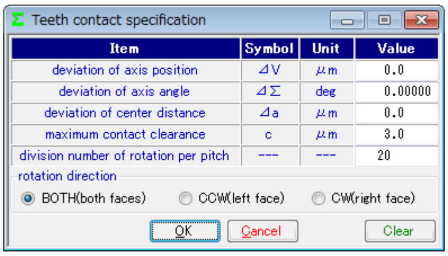
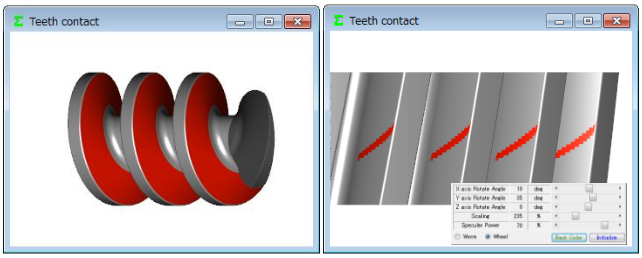


Fig 3.50　Contact pattern setting



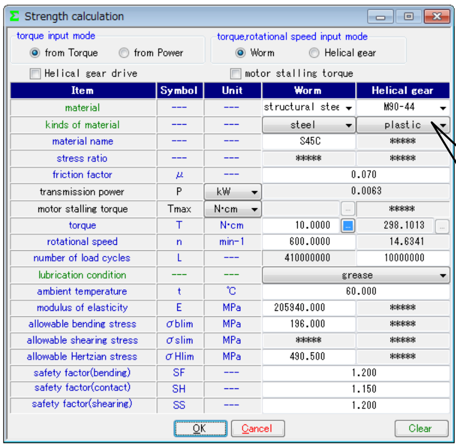
(a) Worm　　(b) Wheel

Fig 3.51　Contact pattern

3.23 Strength calculation

Strength dimension is shown in Fig. 3.52, and strength calculation result is shown in Fig 3.53. Bending strength is based on Lewis equation and tooth surface strength is calculated based on Hertz stress. kW and W for power, MN · m, kN · m, N · m, N · cm for torque can be selected.

For material setting, any materials can be selected from Fig 3.52a for both worm and helical gear. Although standard value is displayed for friction coefficient and various coefficients, it can be changed arbitrarily.



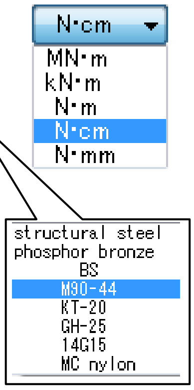
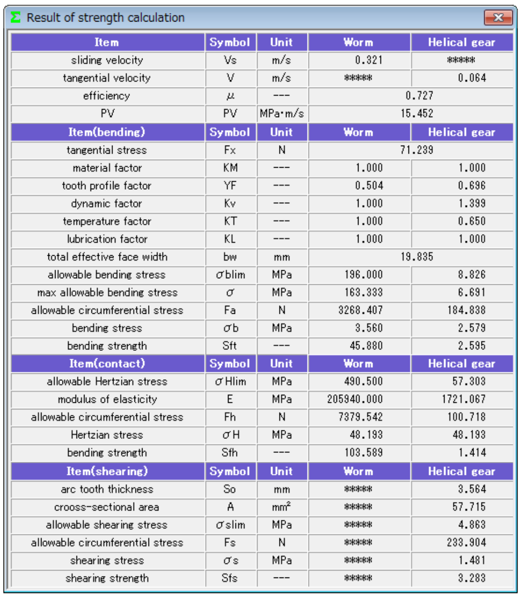


Fig 3.52a Material

Fig 3.52　Strength dimension



Result of strength calculation

Item	Symbol	Unit	Worm	Helical gear
sliding velocity	Vs	m/s	0.321	*****
tangential velocity	V	m/s	*****	0.064
efficiency	μ	---	0.727	
PV	PV	MPa·m/s	15.452	
Item(bending)	**Symbol**	**Unit**	**Worm**	**Helical gear**
tangential stress	Fx	N	71.239	
material factor	KM	---	1.000	1.000
tooth profile factor	YF	---	0.504	0.696
dynamic factor	Kv	---	1.000	1.399
temperature factor	KT	---	1.000	0.650
lubrication factor	KL	---	1.000	1.000
total effective face width	bw	mm	19.835	
allowable bending stress	σblim	MPa	196.000	8.826
max allowable bending stress	σ	MPa	163.333	6.691
allowable circumferential stress	Fa	N	3268.407	184.838
bending stress	σb	MPa	3.560	2.579
bending strength	Sft	---	45.880	2.595
Item(contact)	**Symbol**	**Unit**	**Worm**	**Helical gear**
allowable Hertzian stress	σHlim	MPa	490.500	57.303
modulus of elasticity	E	MPa	205940.000	1721.067
allowable circumferential stress	Fh	N	7379.542	100.718
Hertzian stress	σH	MPa	48.193	48.193
bending strength	Sfh	---	103.589	1.414
Item(shearing)	**Symbol**	**Unit**	**Worm**	**Helical gear**
arc tooth thickness	So	mm	*****	3.564
crooss-sectional area	A	mm²	*****	57.715
allowable shearing stress	σslim	MPa	*****	4.863
allowable circumferential stress	Fs	N	*****	233.904
shearing stress	σs	MPa	*****	1.481
shearing strength	Sfs	---	*****	3.283

Fig 3.53　Strength result

3.24 Bearing load

Bearing load calculation result is shown in Fig 3.54.

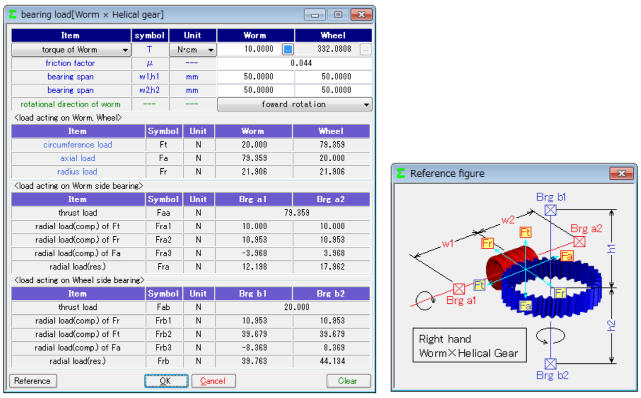


Fig 3.54　Bearing load

3.25 2D-FEM Tooth stress analysis（optional）

For FEM setting screen in Fig. 3.55, modulus of longitudinal elasticity, Poisson's ratio, number of divisions and load (in the example, circumscribing force divided by ε) can be defined. Fig 3.56 and Fig. 3.57 show analysis results of worm and helical gear. Maximum value node and element can be displayed in flashing display.

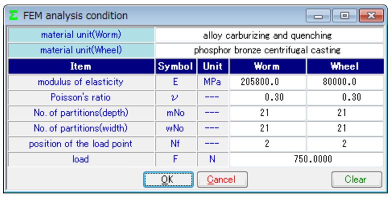
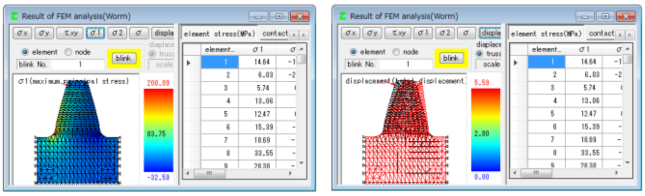
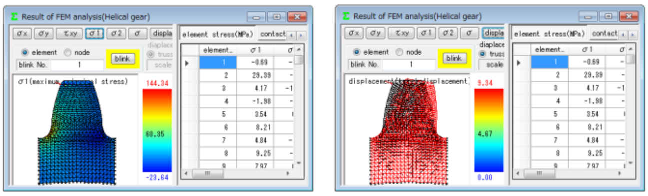


Fig 3.55　FEM analysis setting



(a)Max main stress　(σ_1)　　(b)Displacement

Fig 3.56　Worm



(a)Max main stress （σ_1） (b)Displacement

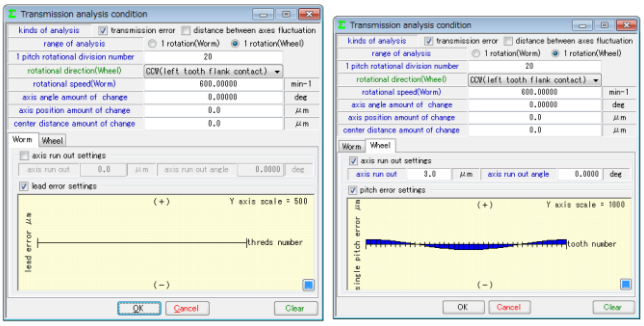
Fig 3.57 Helical gear

3.26 Transmission error（optional）

3.26.1 Transmission error analysis (TE)

As shown in the upper part of Fig. 3.58, transmission error analysis can be performed for analysis due to single tooth flank engagement and center distance change analysis due to double tooth flank engagement. Also, users can select between worm at 1 rotation and helical gear at 1 rotation. In the example, helical gear at 1 rotation at worm rotation speed 600min^{-1} is analyzed assuming that there is no shaft mounting error.

Pitch error can be set (maximum value setting, or setting for each tooth) as shown in Fig 3.58. Transmission error analysis results are shown in Fig. 3.60, and wow flutter (rotation irregularity) is shown in Fig 3.61, and Fourier analysis result is shown in Fig 3.62. There is also a function to convert wow flutter to "sound", and the analysis result can be exported to CSV file.



(a)Worm （lead error） (b)Gear （Pitch error）

Fig 3.58 Pitch error setting

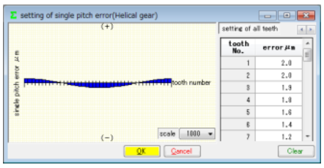


Fig 3.59 Pitch error(gear)

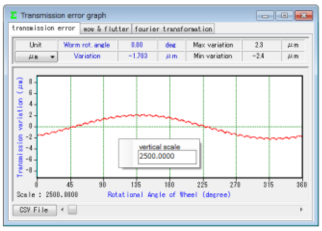


Fig 3.60 TE results

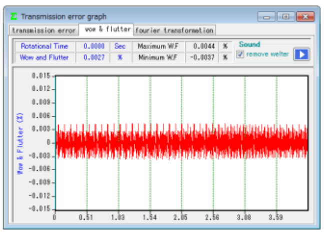


Fig 3.61 Wow flutter

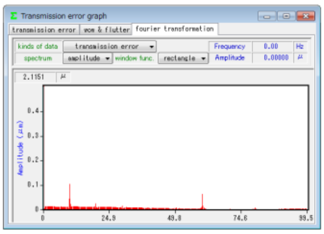
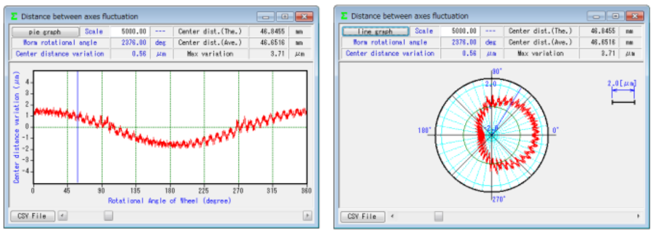


Fig 3.62 Fourier analysis

3.26.2 Center distance change analysis

Many worm gears are used as single flank contact, but depending on the device, double flank contact may be used. For center distance change analysis in Figure 3.63, it analyzes variation of center distance in consideration of pitch error from Fig 3.58. In addition, analysis results can be exported to CSV file.



(a)Graph1 (b)Graph2

Fig 3.63 Center distance change analysis

3.27 Tooth surface evaluation（optional）

In tooth surface evaluation, there are slip velocity graph (Fig. 3.64) and Hertz stress graph (Fig 3.65). Slip velocity is calculated for the velocity at the tooth contact position, while Hertz stress is calculated from the tooth profile at the tooth contact position (the tooth deformation is not taken into account). Both are valid after strength calculation and transmission error analysis.

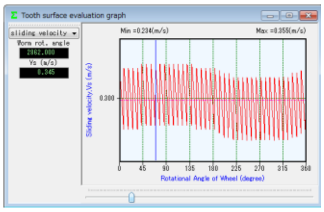


Fig 3.64 Slip velocity Graph

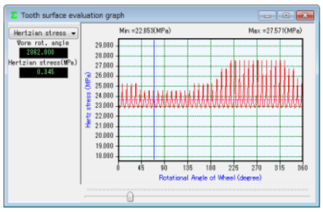
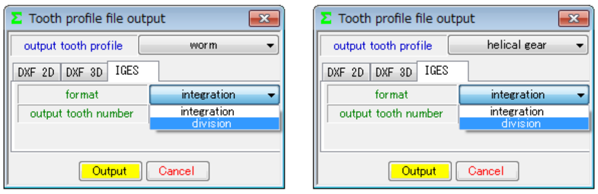


Fig 3.65 Hertz stress

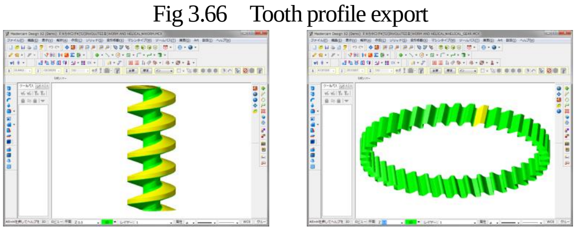
3.28 Tooth profile export

Tooth shape file is generated for worm, helical gear and tool (hob) of tooth profile (output of arbitrary number of teeth is possible) as shown in Fig 3.66. There are three types of files such as DXF - 2D, DXF - 3D, and IGES - 3D. An example of CAD drawing is shown in Fig. 3.67.



(a)Output tooth profile (b)3D-IGES example

Fig 3.66 Tooth profile export



(a)Worm (b) Gear （All teeth output example）

Fig 3.67 CAD drawing example

3.29 Design data management

The database is compatible with Microsoft Access Database, Microsoft SQL Server and ORACLE MySQL Server. In addition, it is also possible to read design data created by old software such as involute Σ (Worm Gear) and involute Σ (Worm and Helical Gear). The setting screen of the database is shown in Fig 3.68.

* Microsoft SQL Server and ORACLE MySQL Server must be installed

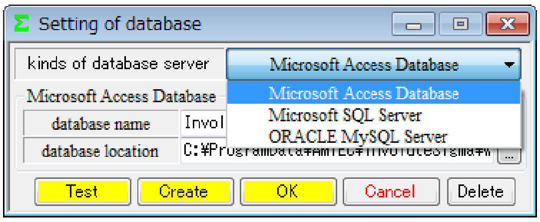


Fig 3.68 Database setting

3.30 HELP feature

If there are any questions how to use it during the operation, [F1] key can be pressed on the active screen to display explanation as shown in Fig 3.69.

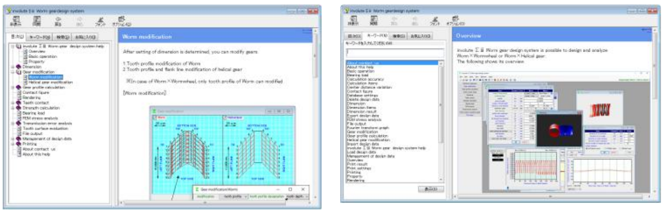


Fig 3.69 HELP feature example

3.31 worm gear types

Types of worm gear are shown in Fig 3.70 to 3.76. The numerical value in [ ] indicates the software number.

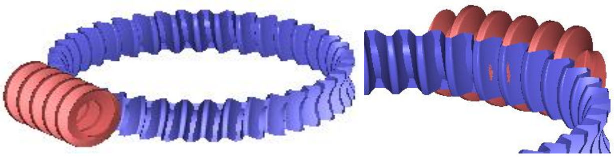


Fig 3.70 [3]Cylindrical worm gear

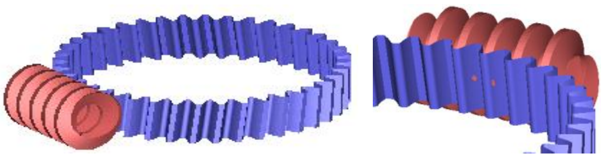


Fig 3.71 [3]Worm×helical gear

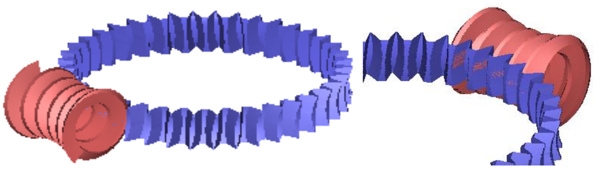


Fig 3.72 [36] Hindley worm gear

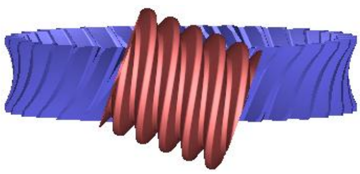


Fig 3.73 [28]Tilted worm gear

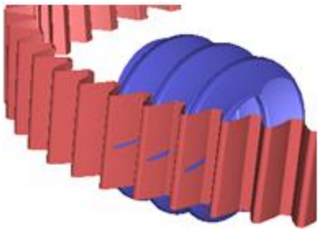


Fig 3.74 [39]Internal teeth worm

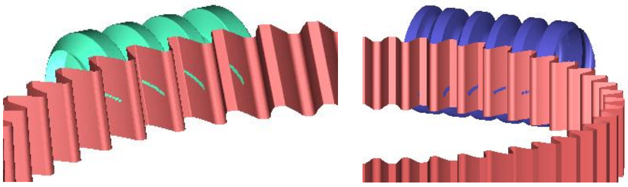
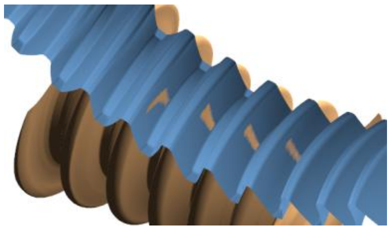


Fig 3.75 [37]LCCW Worm×helical gear



Drum shape worm meshing with hob cut wheel

Fig 3.76 [44]SS-Worm gear（drum shape worm gear）

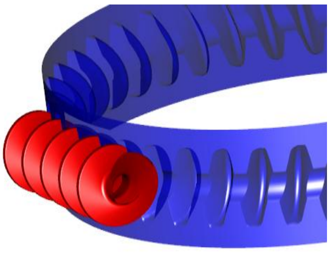


Fig 3.77 [3]Cylindrical worm gear（Wheel wide tooth example）