[32] Sin curved tooth profile gear design system

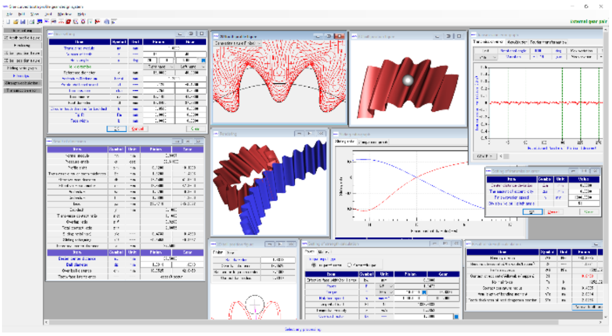


Fig. 32.1 Sin curved tooth profile gear design system

32.1 Abstract

Gears that use a sine-tooth profile as a reference rack “Sine-gear” have a smaller sliding ratio than involute gears, so their power loss is smaller. Therefore, it can be considered that the amount of frictional heat generation at the time of engagement decreases and the temperature rise of the teeth can be suppressed. From this, it can be expected that the decrease in allowable bending stress of plastic material with temperature rise also decreases and the load capacity of plastic gears also increases.

In addition, the meshing of the sinusoidal gear has a smaller relative curvature at the meshing point and a larger tooth thickness at the dangerous cross section than involute gear. Therefore, it is expected that this will bring about a decrease in the contact stress on the tooth surface and the bending stress on the base, which will be advantageous for increasing the load capacity.

32.2 Gear type and tooth profile

(1) Gear type: External gear pair, internal gear pair

(2) Tooth profile: Sine-tooth profile (Basic rack)

32.3 Basic rack

The "Sine-Gear" reference rack is shown in Figure 32.2, and the gear pair selection and reference rack gear setting are shown in Figure 32.3. "Sine-Gear" is easy to HOB and form grinding.

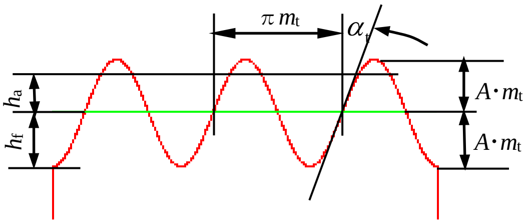
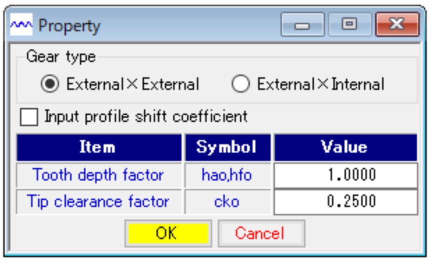


Fig. 32.2 Basic rack



Gear type

● External×External ○ External×Internal

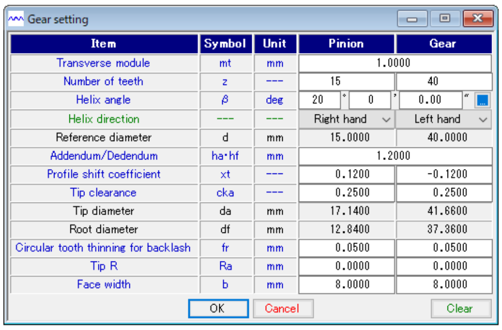
☐ Input profile shift coefficient

Item	Symbol	Value
Tooth depth factor	hao,hfo	1.0000
Tip clearance factor	cko	0.2500

Fig. 32.3 Selection of gear pair and Basic rack

32.4 Gear specification

Figure 32.4 shows the input screen of gear specifications. In addition, the sum of the tooth shift coefficients of the Sine-gear must always be zero.

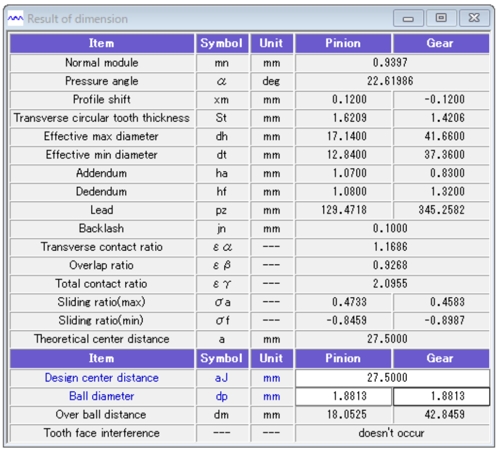


Item	Symbol	Unit	Pinion	Gear
Transverse module	mt	mm	1.0000	
Number of teeth	z	---	15	40
Helix angle	β	deg	20 ° 0 ' 0.00 "	
Helix direction	---	---	Right hand	Left hand
Reference diameter	d	mm	15.0000	40.0000
Addendum/Dedendum	ha･hf	mm	1.2000	
Profile shift coefficient	xt	---	0.1200	-0.1200
Tip clearance	cka	---	0.2500	0.2500
Tip diameter	da	mm	17.1400	41.6600
Root diameter	df	mm	12.8400	37.3600
Circular tooth thinning for backlash	fr	mm	0.0500	0.0500
Tip R	Ra	mm	0.0000	0.0000
Face width	b	mm	8.0000	8.0000

Fig. 32.4 Gear specification

32.5 Gear dimensions

Calculation results of gear dimensions, contact ratio, and sliding ratio are shown in Fig. 32.5. Non-involute gears like "Sine-gear" mesh correctly only at the theoretical center distance, but with this software you can intentionally change the center distance to check the tooth meshing.



Item	Symbol	Unit	Pinion	Gear
Normal module	mn	mm	0.9397	
Pressure angle	α	deg	22.61986	
Profile shift	xm	mm	0.1200	-0.1200
Transverse circular tooth thickness	St	mm	1.6209	1.4206
Effective max diameter	dh	mm	17.1400	41.6600
Effective min diameter	dt	mm	12.8400	37.3600
Addendum	ha	mm	1.0700	0.8300
Dedendum	hf	mm	1.0800	1.3200
Lead	pz	mm	129.4718	345.2582
Backlash	jn	mm	0.1000	
Transverse contact ratio	εα	---	1.1686	
Overlap ratio	εβ	---	0.9268	
Total contact ratio	εγ	---	2.0955	
Sliding ratio(max)	σa	---	0.4733	0.4583
Sliding ratio(min)	σf	---	-0.8459	-0.8987
Theoretical center distance	a	mm	27.5000	
Item	**Symbol**	**Unit**	**Pinion**	**Gear**
Design center distance	aJ	mm	27.5000	
Ball diameter	dp	mm	1.8813	1.8813
Over ball distance	dm	mm	18.0525	42.8459
Tooth face interference	---	---	doesn't occur	

Fig. 32.5 Gear dimensions

32.6 Tooth profile

The mesh of "Sine-gear" is shown in Fig. 32.6. In the case of involute gears, the contact line is a straight line, but the working line of "Sine-gear" is an S-shaped line. Therefore, the meshing range is from the meshing start point "p" to the meshing end point "q".

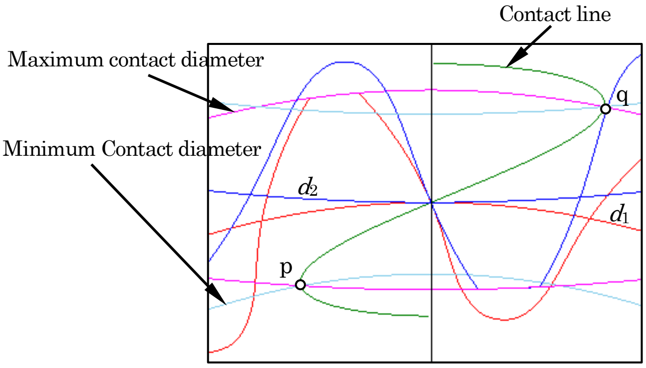
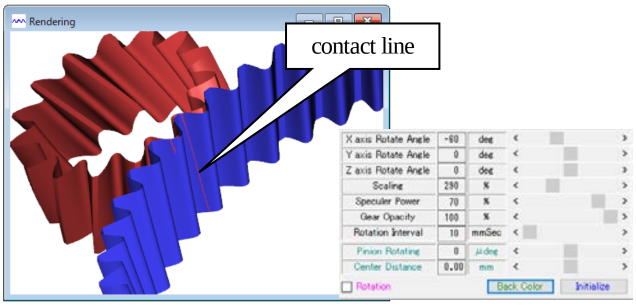


Fig. 32.6 Tooth profile and contact line

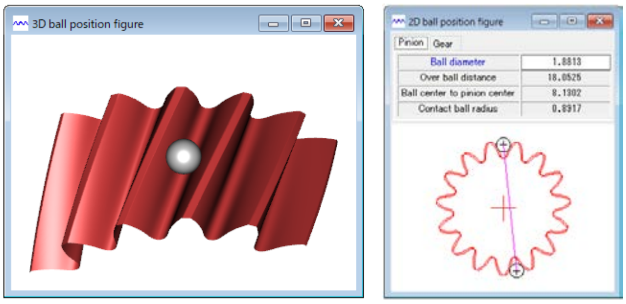
In the case of involute gears, the meshing ratio increases as the number of teeth on the other gear increases, but the meshing ratio of "Sine-gear" does not increase significantly. A contact line (not straight line) can be seen at the center of the tooth surface in the tooth profile rendering in Figure 32.7. The tooth thickness of this gear can be measured with the over ball size as shown in Fig. 32.8.



X axis Rotate Angle	-60	deg
Y axis Rotate Angle	0	deg
Z axis Rotate Angle	0	deg
Scaling	290	%
Speculer Power	70	%
Gear Opacity	100	%
Rotation Interval	10	mmSec
Pinion Rotating	0	μdeg
Center Distance	0.00	mm

☐ Rotation

Fig. 32.7 Teeth rendering



Ball diameter	1.8813
Over ball distance	18.0525
Ball center to pinion center	8.1302
Contact ball radius	0.8917

(a) Measurement (3D) (b) Measurement (2D)

Fig. 32.8 Over-ball measurement (example of pinion)

32.7 Sliding ratio

Fig. 32.9 shows the sliding ratio of "Sine-gear", and Fig. 32.10 shows the sliding ratio of the involute gear superimposed on the sliding ratio of "Sine-gear". However, the specifications of involute gear are the same as "Sine-gear".

The graph in Fig. 32.10 shows that the sliding area of "Sine-gear (pinion)" is 1 / 3.5 smaller than that of involute, and that of "Sine-gear (gear)" is 1 / 1.90.

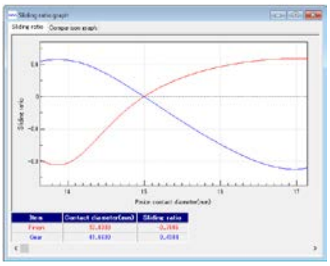


Fig. 32.9 Sliding ratio of "Sine-gear" Fig. 32.10

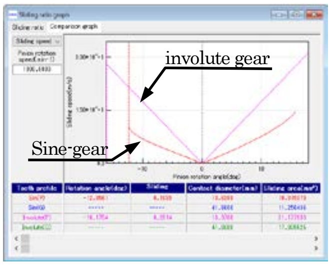


Fig. 3.10Sliding speed of involute gear and "Sine-gear"

Table 32.1 Maximum sliding ratio and sliding area

	Maximum sliding ratio	Sliding area (mm^2)
Sine-gear (P)	-0.791	10.3
Sine-gear (G)	0.438	11.3
involute gear (P)	-2.89	21.2
involute gear (G)	0.743	17.9

32.8 Change in contact ratio

When changing the number of gear teeth to 18, 25, 30, 50, 100 by fixing the number of teeth of the pinion to 18 with the involute gear and "Sine-gear" both set to m_n=1, β=0° As a result, involute gears have an increase in contact ratio as the number of gear teeth increases, but "Sine-gear" hardly changes.

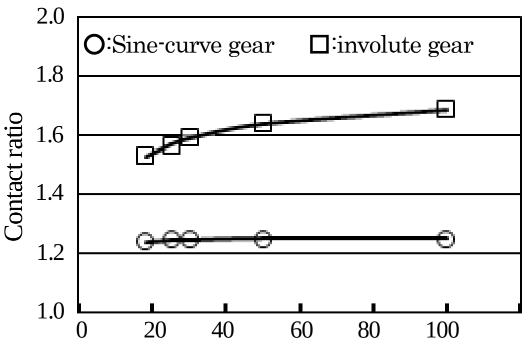


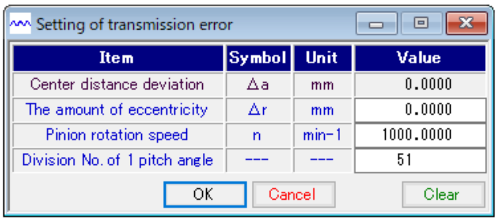
Fig. 32.11 Change in contact ratio

Table 32.2 Combination of teeth numbers and contact ratio

z_1	z_2	a	$\varepsilon_{\alpha(\mathrm{Involute})}$	$\varepsilon_{\alpha(\mathrm{Sine})}$
18	18	18.000	1.5298	1.2422
18	25	21.500	1.5707	1.2473
18	30	24.000	1.5916	1.2487
18	50	34.000	1.6422	1.2498
18	100	59.000	1.6911	1.2498

32.9 Transmission error

The transmission error analysis setup is shown in Fig. 32.12 and the transmission error analysis and the analysis result of wow and flutter are shown in Fig. 32.13 and Fig. 32.14.



Item	Symbol	Unit	Value
Center distance deviation	Δa	mm	0.0000
The amount of eccentricity	Δr	mm	0.0000
Pinion rotation speed	n	min-1	1000.0000
Division No. of 1 pitch angle	---	---	51

Fig. 32.12 Transmission error setting

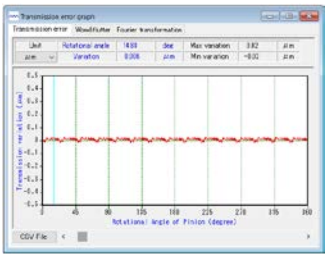
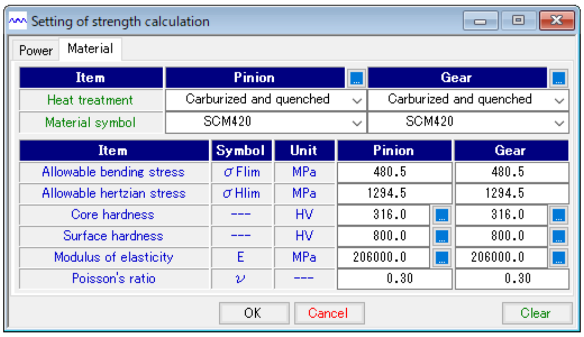


Fig. 32.13 TE=0.04μm

Fig. 2.14 W&F=0.0319%

32.10 Gear strength calculation

Set the torque and material in Figure 32.15 to calculate the bending strength and pitting strength of the gear.

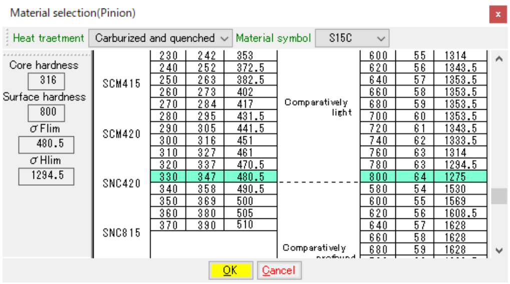


Item	Pinion	Gear
Heat treatment	Carburized and quenched	Carburized and quenched
Material symbol	SCM420	SCM420

Item	Symbol	Unit	Pinion	Gear
Allowable bending stress	σFlim	MPa	480.5	480.5
Allowable hertzian stress	σHlim	MPa	1294.5	1294.5
Core hardness	---	HV	316.0	316.0
Surface hardness	---	HV	800.0	800.0
Modulus of elasticity	E	MPa	206000.0	206000.0
Poisson's ratio	ν	---	0.30	0.30

Fig. 32.15　Gear strength calculation specifications

Fig. 32.16 shows the material selection screen set in Fig. 32.15. You can select the materials σ_{Flim} and σ_{Hlim} from the material, heat treatment, and hardness. You can also enter arbitrary σ_{Flim} and σ_{Hlim} in Figure 32.15. The strength of the gear is displayed as the ratio of the allowable stress of the material to the generated stress as shown in Fig. 32.17.

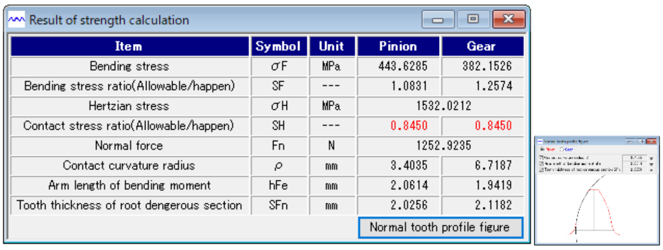


Heat traetment: Carburized and quenched
Material symbol: S15C

Core hardness: 316
Surface hardness: 800
σFlim: 480.5
σHlim: 1294.5

	230	242	353		600	55	1314
	240	252	372.5		620	56	1343.5
SCM415	250	263	382.5		640	57	1353.5
	260	273	402		660	58	1353.5
	270	284	417	Comparatively light	680	59	1353.5
	280	295	431.5		700	60	1353.5
SCM420	290	305	441.5		720	61	1343.5
	300	316	451		740	62	1333.5
	310	327	461		760	63	1314
	320	337	470.5		780	63	1294.5
	330	347	480.5		800	64	1275
SNC420	340	358	490.5		580	54	1530
	350	369	500		600	55	1569
	360	380	505		620	56	1608.5
	370	390	510		640	57	1628
SNC815					660	58	1628
				Comparatively	680	59	1628

Fig. 32.16　Material selection

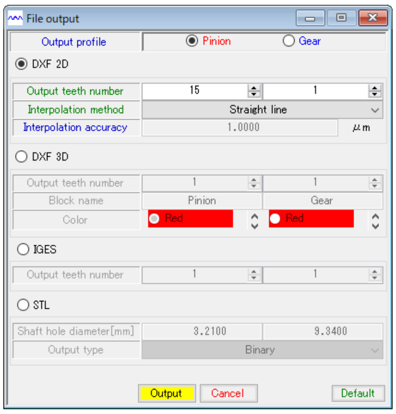


Item	Symbol	Unit	Pinion	Gear
Bending stress	σF	MPa	443.6285	382.1526
Bending stress ratio(Allowable/happen)	SF	---	1.0831	1.2574
Hertzian stress	σH	MPa	1532.0212	
Contact stress ratio(Allowable/happen)	SH	---	0.8450	0.8450
Normal force	Fn	N	1252.9235	
Contact curvature radius	ρ	mm	3.4035	6.7187
Arm length of bending moment	hFe	mm	2.0614	1.9419
Tooth thickness of root dengerous section	SFn	mm	2.0256	2.1182

Fig. 32.17　Gear strength calculation result

32.11　Tooth profile output

The generated tooth profile can be output as a CAD file using the tooth profile output function shown in Figure 34.18. An example of CAD drawing is shown in Figure 34.19.



Output profile: ● Pinion ○ Gear

● DXF 2D

Output teeth number	15	1
Interpolation method	Straight line	
Interpolation accuracy	1.0000 μm	

○ DXF 3D

Output teeth number	1	1
Block name	Pinion	Gear
Color	Red	Red

○ IGES

Output teeth number	1	1

○ STL

Shaft hole diameter[mm]	3.2100	9.3400
Output type	Binary	

Fig. 32.18　Tooth profile output

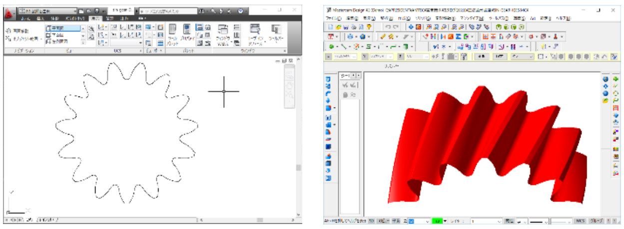
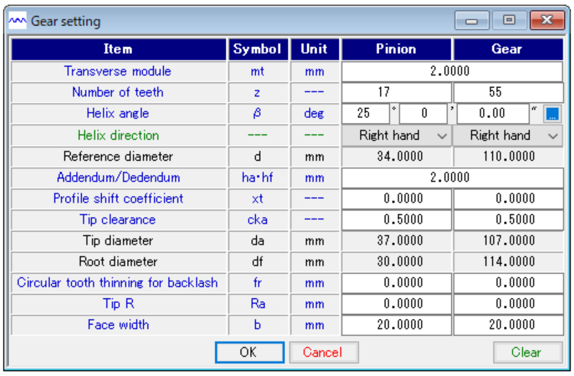

(a) 2D-DXF　　(b) 3D-IGES

Fig. 32.19　CAD drawing example (pinion)

32.12　Internal gear pair (optional)

Figures 32.20 to 32.24 show examples of calculation of internal gear pairs.



Item	Symbol	Unit	Pinion	Gear
Transverse module	mt	mm	2.0000	
Number of teeth	z	---	17	55
Helix angle	β	deg	25° 0' 0.00"	
Helix direction	---	---	Right hand	Right hand
Reference diameter	d	mm	34.0000	110.0000
Addendum/Dedendum	ha･hf	mm	2.0000	
Profile shift coefficient	xt	---	0.0000	0.0000
Tip clearance	cka	---	0.5000	0.5000
Tip diameter	da	mm	37.0000	107.0000
Root diameter	df	mm	30.0000	114.0000
Circular tooth thinning for backlash	fr	mm	0.0000	0.0000
Tip R	Ra	mm	0.0000	0.0000
Face width	b	mm	20.0000	20.0000

Fig. 32.20　Gear specifications (internal gear)

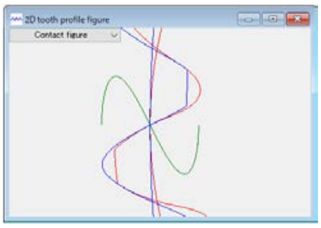


Fig. 32.21　Tooth profile

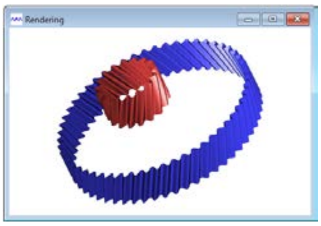


Fig. 32.22　Teeth rendering

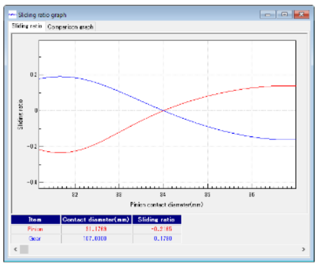


Fig. 32.23　Sliding ratio of "Sine-gear"　Fig. 32.10

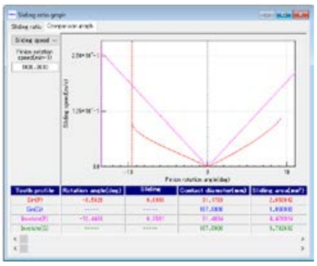


Fig. 32.24 Sliding speed of involute gear and "Sine-gear"

32.13　Postscript

The contact ratio of "Sine-gear" is smaller than that of involute gear, but the sliding ratio is smaller than that of involute gear, so it can be expected to reduce heat generation and improve efficiency. The efficiency of the plastic gear (m=1, z_1=z_2=48) experiment is improved compared to the involute gear of the same specifications. See Appendix **[E]** for details.