[47] Strain wave gearing design system

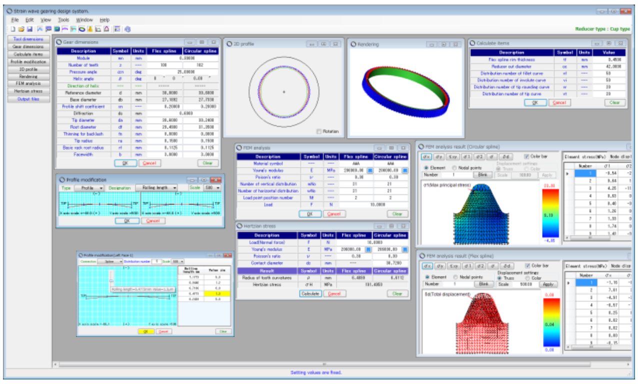


Fig.47.1 Strain wave gearing design system

47.1 Overview

Strain wave gearing design system is a software that generates wave gear tooth profile, based on basic rack or tool (hob). Meshing of the generated tooth profile and rendering can be displayed, and also 2D-DXF file output can be generated. Overall display is shown in Table 47.1.

47.2 Software configuration

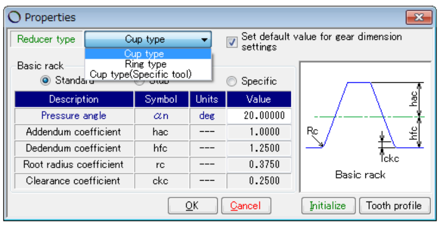
Strain wave gearing design system configuration is shown in Table 47.1.

Table 47.1 Software Configuration

No.	Item	Figure	
1	Basic rack		47.3
	Tool（HOB）	-----	47.12
	Type of Ring		-----
2	Tool dimension	-----	47.12
3	Gear dimension	47.4	47.12.2
4	Tooth profile	47.5	47.12.3
5	Tooth modification	47.6	-----
6	2DTooth profile	47.7	47.12.3
7	Tooth rendering	47.8	47.12.3
8	FEM-Analysis	47.9	47.12.4
9	Hertzian stress	47.10	47.12.4
10	Output (Tooth profile)	47.11	47.12.5
11	Design-data management	47.13	

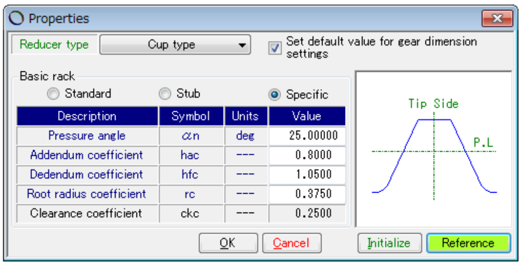
47.3 Basic Rack（Property）

Basic rack (cup type) is shown in Figure 47.2. As basic rack can be chosen between full depth tooth, low tooth and special tooth, Initialize is used to set up special tooth with α=25°, h_{ac}=0.8, h_{fc}=1.05, r_c=0.375. After basic rack is specified, actual basic rack can be displayed as shown by Figure 47.3, by clicking Tooth profile (Hob-based tooth profile is shown in Figure 47.12)



Description	Symbol	Units	Value
Pressure angle	αn	deg	20.00000
Addendum coefficient	hac	---	1.0000
Dedendum coefficient	hfc	---	1.2500
Root radius coefficient	rc	---	0.3750
Clearance coefficient	ckc	---	0.2500

Fig.47.2 Basic rack（Cup type）



Description	Symbol	Units	Value
Pressure angle	αn	deg	25.00000
Addendum coefficient	hac	---	0.8000
Dedendum coefficient	hfc	---	1.0500
Root radius coefficient	rc	---	0.3750
Clearance coefficient	ckc	---	0.2500

Fig.47.3 Property and basic rack（Cup type）

47.4 Dimension

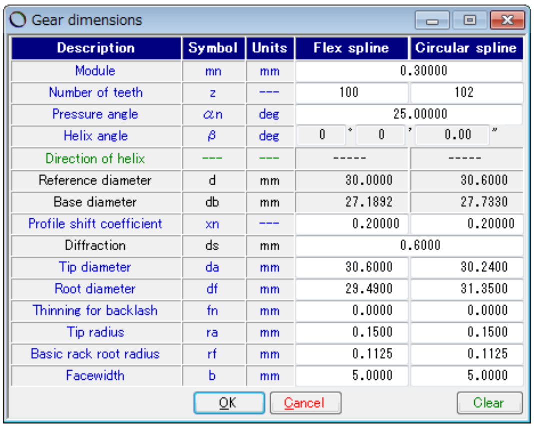
Dimension display is shown in Figure 47.4 by using the example with m_n=0.3, z_{FS}=100 , z_{CS}=102 . Although the addendum modification coefficient is shown as x_n=0.2, it can be set to any value. Also, tip R can be defined all the way to the addendum pointed limit. In basic rack root R, the value specified in Figure 47.2 is taken as the standard value, but it can be defined all the way to the established limit of basic rack profile. The input range is shown below.

Module : $0 < m_n < 10$

Number of teeth : $10 < z_{FS} \leqq 1000$, $z_{FS}+2 < z_{CS} \leqq 1000$

Profile shift : $-2 < x_n < +3$

Face width : $0 < b < 1000$

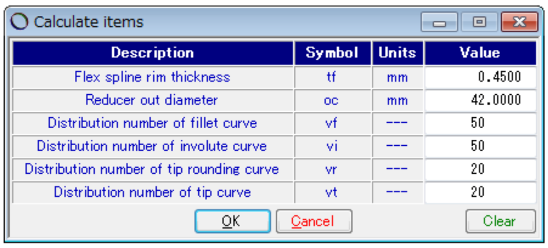


Description	Symbol	Units	Flex spline	Circular spline
Module	mn	mm	0.30000	
Number of teeth	z	---	100	102
Pressure angle	αn	deg	25.00000	
Helix angle	β	deg	0 ° 0 ' 0.00 "	
Direction of helix	---	---	-----	-----
Reference diameter	d	mm	30.0000	30.6000
Base diameter	db	mm	27.1892	27.7330
Profile shift coefficient	xn	---	0.20000	0.20000
Diffraction	ds	mm	0.6000	
Tip diameter	da	mm	30.6000	30.2400
Root diameter	df	mm	29.4900	31.3500
Thinning for backlash	fn	mm	0.0000	0.0000
Tip radius	ra	mm	0.1500	0.1500
Basic rack root radius	rf	mm	0.1125	0.1125
Facewidth	b	mm	5.0000	5.0000

Fig.47.4 Gear dimensions

47.5 Tooth profile calculation

The tooth profile calculation setup display is shown in Figure 47.5. Flex spline thickness, device outer diameter and number of divisions for tooth profile calculation set-up can be specified. After setting the values, click OK to proceed to tooth profile calculation.



Description	Symbol	Units	Value
Flex spline rim thickness	tf	mm	0.4500
Reducer out diameter	oc	mm	42.0000
Distribution number of fillet curve	vf	---	50
Distribution number of involute curve	vi	---	50
Distribution number of tip rounding curve	vr	---	20
Distribution number of tip curve	vt	---	20

Fig.47.5 Tooth Profile Set-up

47.6 Tooth profile modification

Generated flex spline tooth profile can be modified as shown in Figure 47.6. Tooth profile can be specified either by line of action or diameter, while the magnification of the tooth profile modification can be selected from 50, 100, 200, 300, 400, 500, 1000.

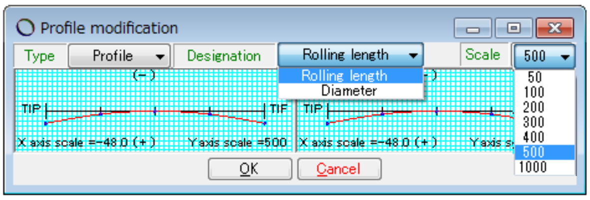


Fig.47.6 Tooth Profile Modification

The tooth profile modification can be applied by track-bar (shown at the center of Figure 47.7) and table-entry on the right hand side of the screen. In Figure 47.7, tooth profile is shown with 9 divisions, but it can be specified up to 50 divisions. Also, connection of the tooth profile can be spline (as shown by this example) or straight line connection. Moreover, numerical value can be entered into the template figure as shown in Figure 47.8.

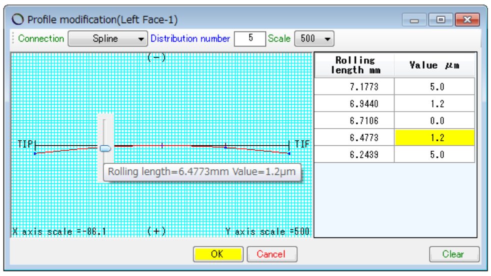


Fig.47.7 Profile modification setup

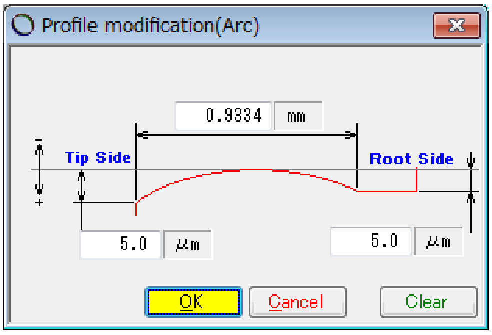


Fig.47.8 Profile modification setup (Template)

47.7 Tooth Profile Figure (2D)

Generated tooth profile can be displayed as shown in Figure 47.9. Enlarged sections [A] to [D] are shown in Figure 47.10. Also, distance can be measured as shown in Figure 47.11. Moreover, rotation-related tooth profile meshing can be checked by rotation Rotation in right hand corner of Figure 47.9.

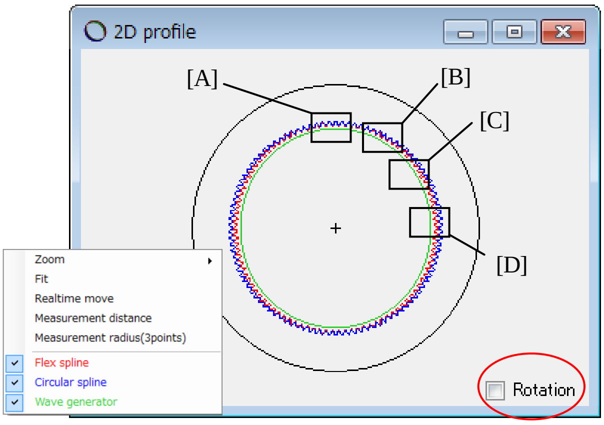
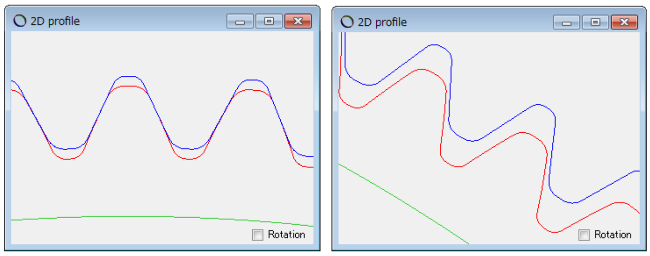
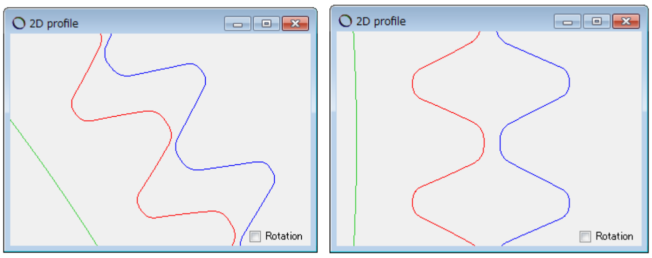


Fig.47.9 Tooth Profile & Supplemental Feature



(a) Section[A] (b) Section [B]



(c) Section [C] (d) Section [D]

Fig.47.10 Enlarged figure at each section

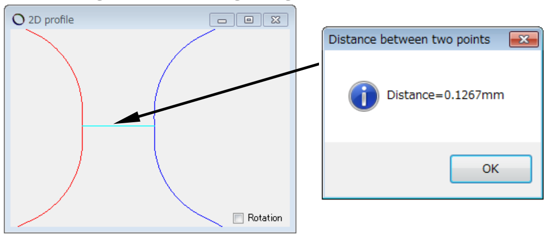


Fig.47.11 Distance measurement

47.8 Rendering

Tooth profile can be displayed as shown in Figure 47.12. This rendering can be enlarged, reduced and rotated by using Rotation .

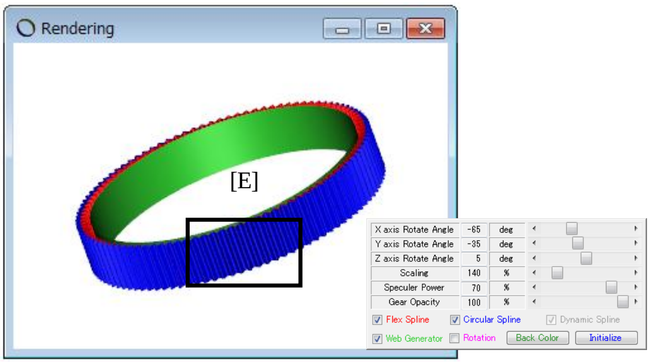


Fig.47.12 Rendering and supplemental form

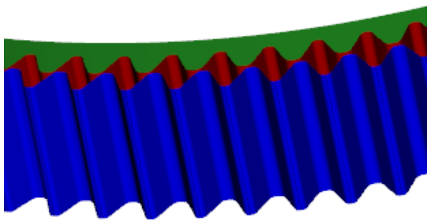


Fig.47.13 Rendering enlargement[E]

47.9 FEM Analysis (2D)

When load is applied to teeth, root stress in the teeth can be calculated. FEM analysis setup display is shown in Figure 47.14, but in FEM analysis, material is symbols only, as it is based on longitudinal elastic modulus and Poisson's ratio. Vertical division number and horizontal division number can be specified arbitrarily. The position of the load (2 in the example: the second node from the tooth tip), less than 2 in the vertical division number can be specified. For the load applied in this case, please set the value per designer's intension.

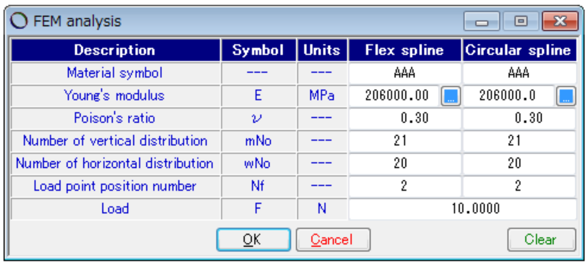


Fig.47.14 FEM analysis setup

FEM analysis results are shown in Figure 47.15 to 47.20. The analysis items are σx σy τxy σ1 σ2 σ δd , and flex spline max main stress is found to be σ_{1max}=24.0MPa as shown in Figure 47.15. Also, displacement figure is shown in Figure 47.17 while stress summary (selective results only) is shown in Figure 47.18.

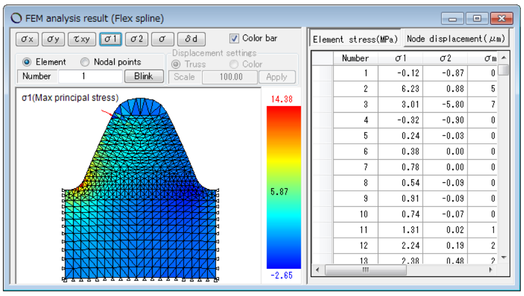


Fig.47.15 Flex Spline, σ_{1max}=14.4MPa

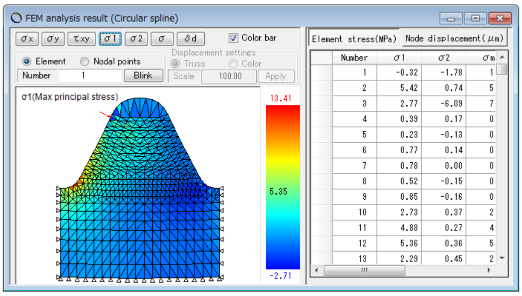


Fig.47.16 Circular spline, σ_{1max}=13.4MPa

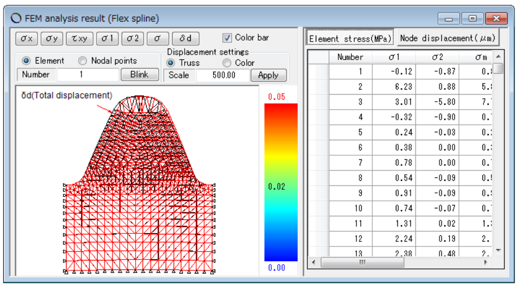
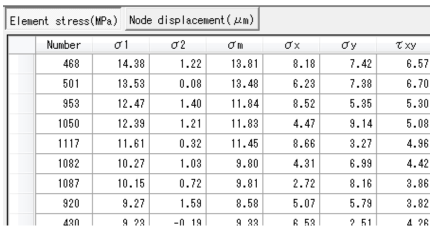


Fig.47.17 Flex Spline displacement, δmax=0.08μm



Element stress(MPa) Node displacement(μm)

Number	σ1	σ2	σm	σx	σy	τxy
468	14.38	1.22	13.81	8.18	7.42	6.57
501	13.53	0.08	13.48	6.23	7.38	6.70
953	12.47	1.40	11.84	8.52	5.35	5.30
1050	12.39	1.21	11.83	4.47	9.14	5.08
1117	11.61	0.32	11.45	8.66	3.27	4.96
1082	10.27	1.03	9.80	4.31	6.99	4.42
1087	10.15	0.72	9.81	2.72	8.16	3.86
920	9.27	1.59	8.58	5.07	5.79	3.82
430	9.23	-0.19	9.33	6.53	2.51	4.26

Fig. 47.18 Stress Summary (selective results)

47.10 Tooth contact stress

The calculation of Hertzian stress acting on tooth surface is shown in Figure 47.19. The purpose of this feature is to compare the Hertzian stress due to tooth profile differences, so the load acting on one tooth should be designer's intended value.

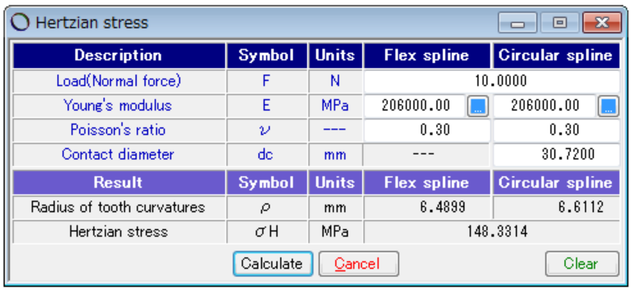


Fig.47.19 Hertzian Stress

47.11 Tooth profile output

The resulting F/S (perfect circle), F/S (ellipse) and C/S tooth profile output can be generated. F/S tooth profile output display is shown in Figure 47.20 while CAD drawing sample is shown in Figure 47.21.

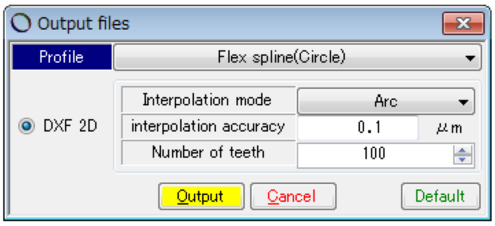
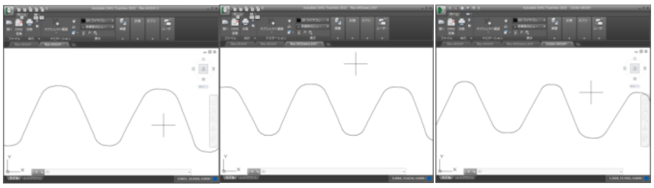


Fig.47.20 F/S Tooth profile output setup



(a) F/S(perfect circle) F/S(Ellipse) (c) C/S

Fig.47.21 CAD Drawing sample

47.12 Tooth profile made by hob

47.12.1 Hob dimensions

When hob blade profile is known, the hob profile can be defined by selecting cup Cup type(Specific tool) in reducer type property in Figure 47.32.

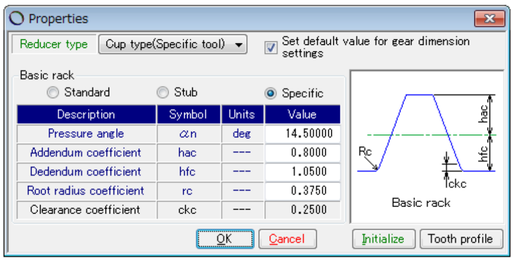


Fig.47.32 Property, Cup type (Special tool)

Hob dimension input sample is shown in Figure 47.33. In this sample, pitch=0.9425 is used to achieve module 0.3, but any value can be specified. After input entry, true hob profile can be displayed by clicking profile Tooth profile . The hob profile is based on gear front surface.

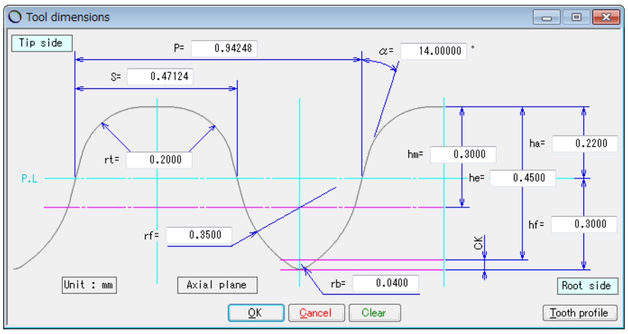


Fig.47.33 Hob dimensions

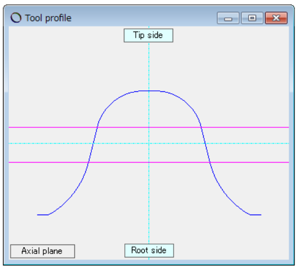
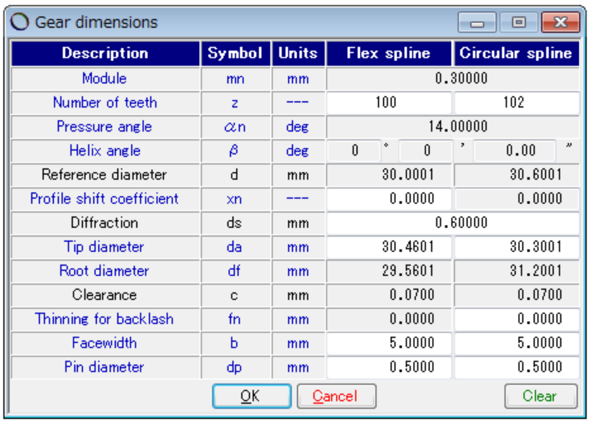


Fig.47.34 Hob profile

47.12.2 Gear Dimensions

In Figure 47.4, module was entered, but module, pressure angle and root diameter cannot be entered in Figure 47.35 because pitch is already entered in Figure 47.33 (background is grayed out).



Gear dimensions

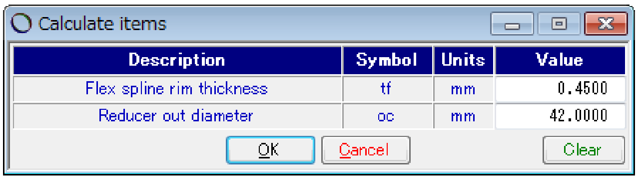
Description	Symbol	Units	Flex spline	Circular spline
Module	mn	mm	0.30000	
Number of teeth	z	---	100	102
Pressure angle	αn	deg	14.00000	
Helix angle	β	deg	0 ° 0 ' 0.00 "	
Reference diameter	d	mm	30.0001	30.6001
Profile shift coefficient	xn	---	0.0000	0.0000
Diffraction	ds	mm	0.60000	
Tip diameter	da	mm	30.4601	30.3001
Root diameter	df	mm	29.5601	31.2001
Clearance	c	mm	0.0700	0.0700
Thinning for backlash	fn	mm	0.0000	0.0000
Facewidth	b	mm	5.0000	5.0000
Pin diameter	dp	mm	0.5000	0.5000

OK Cancel Clear

Fig. 47.35 Gear dimensions

47.12.3 Tooth profile

After gear dimensions are specified, tooth profile calculation is performed based on rim thickness and outer diameter as shown in Figure 47.36.



Calculate items

Description	Symbol	Units	Value
Flex spline rim thickness	tf	mm	0.4500
Reducer out diameter	oc	mm	42.0000

OK Cancel Clear

Fig.47.36 Rim thickness and outer diameter

After tooth profile calculation is completed, transverse tooth profile can be displayed as shown in Figure 47.37. However, tooth profile modification cannot be performed when it is based on hob. Since C/S tooth profile is generated to mesh with F/S tooth profile, both gears are contacting without any gaps as shown in the enlarged view of [E] in Figure 47.37. Also, there is 22μm of gap between tooth tips in [F], and there is 2.6μm of gap between teeth in [G]. The clearance is 0.07mm as shown in Figure 47.40, and F/S tip area is found to be arc-shape of 0.359mm as calculated in Figure 47.41. When gear is specified as over-pin, tooth profile and pin are contacting as shown in Figure 47.42, and F/S contact diameter is found to be d_c=33.01mm.

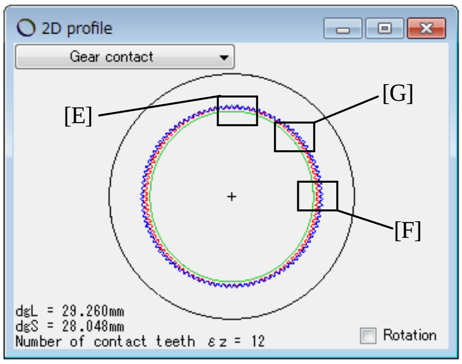
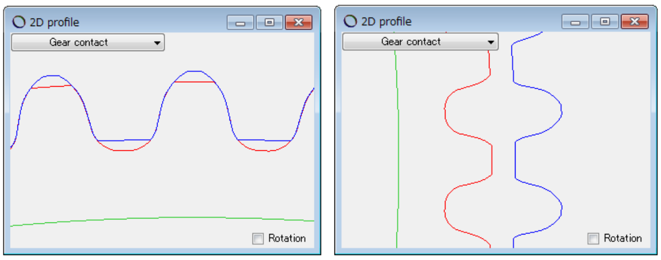


Fig.47.37 Tooth profile



(a) [E] section (b) [F] section

Fig. 47.38 Enlarged tooth profile

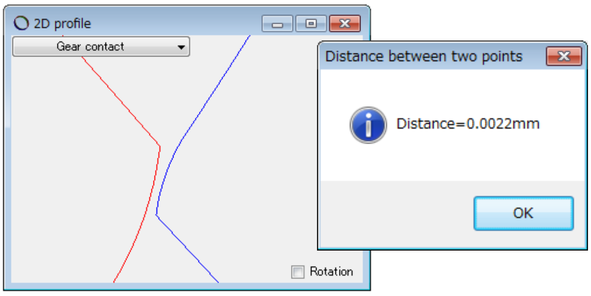


Fig.47.39 Enlarged tooth profile [G] section, distance measurement

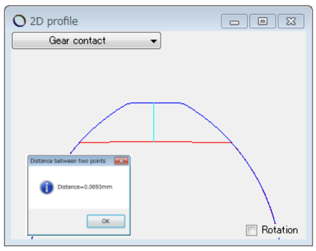


Fig.47.40 Distance measurement

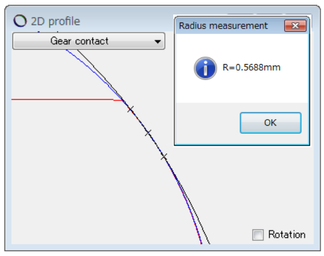
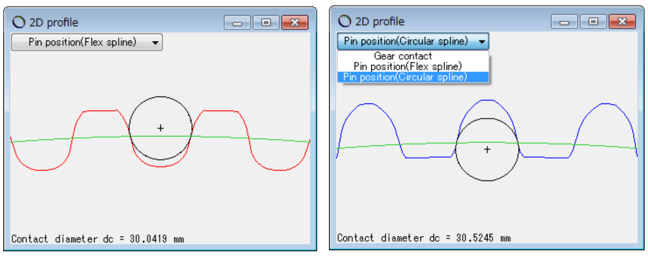


Fig.47.41 Arc measurement



(a) F/S & Pin (b) C/S & Pin

Fig.47.42 Pin positions

After tooth profile is generated, tooth profile rendering can be displayed as shown in Figure 47.43. This figure can be rotated just like 2D tooth profile, while changing observation angle in the supplemental form.

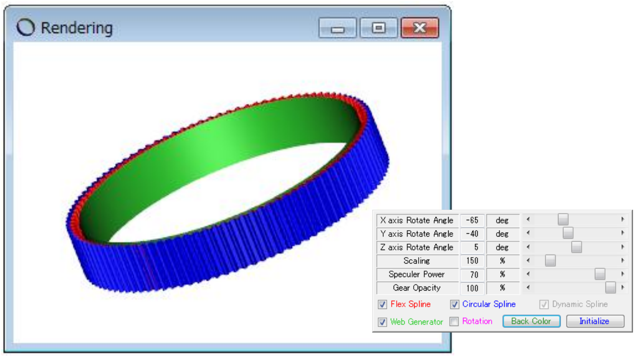
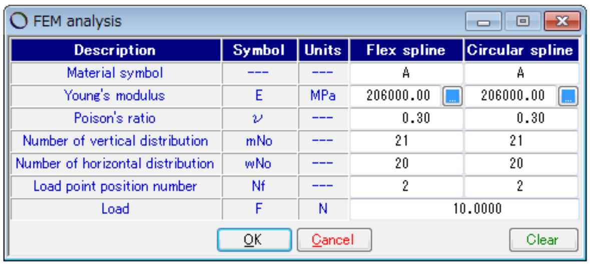


Fig.47.43 Rendering & supplemental form

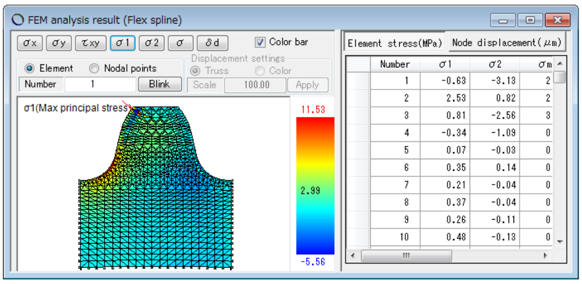
47.12.4 FEM analysis & Hertzian stress

Analysis results are shown in Fig.47.44 to Fig. 47.47.



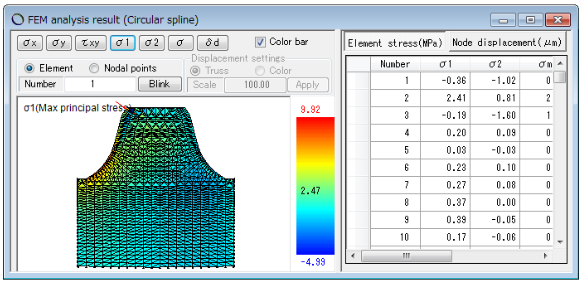
Description	Symbol	Units	Flex spline	Circular spline
Material symbol	---	---	A	A
Young's modulus	E	MPa	206000.00	206000.00
Poison's ratio	ν	---	0.30	0.30
Number of vertical distribution	mNo	---	21	21
Number of horizontal distribution	wNo	---	20	20
Load point position number	Nf	---	2	2
Load	F	N	10.0000	

Fig.47.44 FEM analysis setup



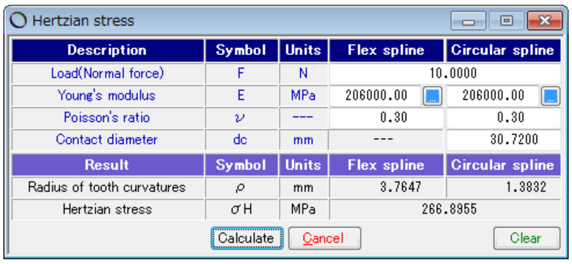
Number	σ1	σ2	σm
1	-0.63	-3.13	2
2	2.53	0.82	2
3	0.81	-2.56	3
4	-0.34	-1.09	0
5	0.07	-0.03	0
6	0.35	0.14	0
7	0.21	-0.04	0
8	0.37	-0.04	0
9	0.26	-0.11	0
10	0.48	-0.13	0

Fig.47.45 Flex spline, σ_{1max}=11.5MPa



Number	σ1	σ2	σm
1	-0.36	-1.02	0
2	2.41	0.81	2
3	-0.19	-1.60	1
4	0.20	0.09	0
5	0.03	-0.03	0
6	0.23	0.10	0
7	0.27	0.08	0
8	0.37	0.00	0
9	0.39	-0.05	0
10	0.17	-0.06	0

Fig.47.46 Circular spline, σ_{1max}=472MPa

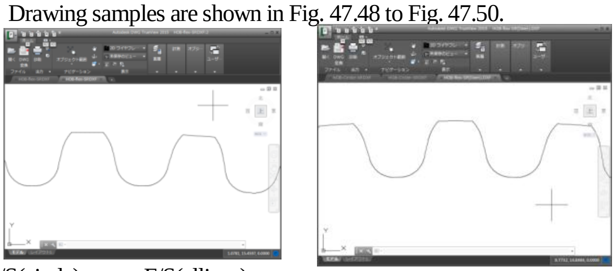


Description	Symbol	Units	Flex spline	Circular spline
Load(Normal force)	F	N	10.0000	
Young's modulus	E	MPa	206000.00	206000.00
Poisson's ratio	ν	---	0.30	0.30
Contact diameter	dc	mm	---	30.7200
Result	**Symbol**	**Units**	**Flex spline**	**Circular spline**
Radius of tooth curvatures	ρ	mm	3.7647	1.3832
Hertzian stress	σH	MPa	266.8955	

Fig.47.47 Hertzian stress

47.12.5 CAD drawing sample

Drawing samples are shown in Fig. 47.48 to Fig. 47.50.



F/S(circle) F/S(ellipse)

Fig.47.48 CAD drawing sample,

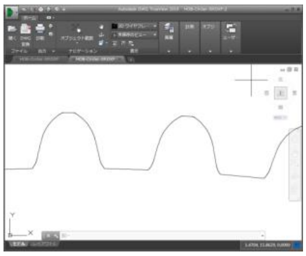


Fig.47.50 CAD drawing sample, C/S

47.13 Design data management

Design data can be managed as shown in Figure 47.51, while it can be also imported and exported as shown in Figure 47.52.

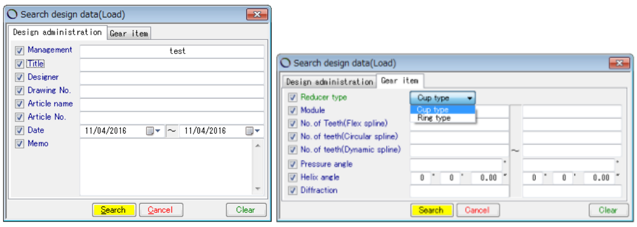


Fig.47.51 Design data management

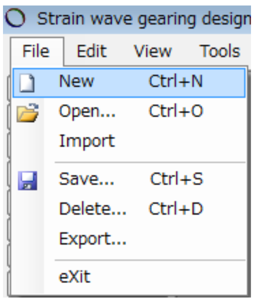


Fig.47.52 File management

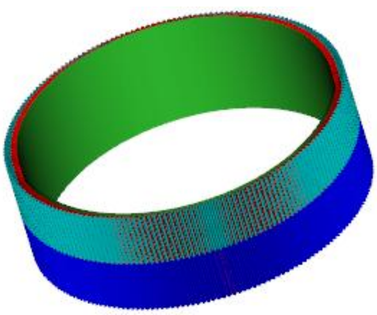


Fig.47.53 Ring type, m=0.15, z_1=z_3=200, z_2=204

◆日本語版カタログは別途お申しつけください.