[22] CT-FEM ASM (Stress analysis of asymmetry gears)

English version

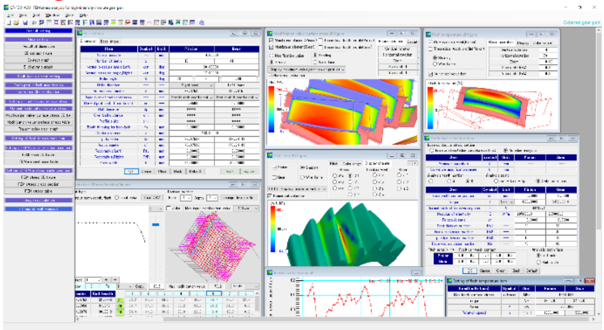


Fig.22.1　CT-FEM ASM

22.1　Abstract

Asymmetric gears can increase tooth loading capacity without changing gear size or material. Compared to standard pressure angle, Hertz stress decreases, friction coefficient and sliding ratio are small. Therefore, the flash temperature is low. For details, please refer to [Appendix H].

CT-FEM ASM is FEM stress analysis software for asymmetric tooth gear. Like CT-FEM Opera iii, it can calculate flash temperature, friction coefficient, oil film thickness, occurrence probability and lifetime of scuffing and wear, and addition of tooth edge contact analysis and optimal tooth surface modification function. Fig.22.1 shows the whole screen.

22.2　Software structure

The structure of **CT-FEM ASM** is shown in Table 22.1. ○ in the table is included in the basic software, and ◎ is optional. Applicable gear: involute spur and helical gear (external gear, internal gear)

Table 22.1　software structure

Item	Structure
〈1〉 Basic rack (asymmetry tooth profile)	○
〈2〉 Gear dimension	○
〈3〉 Meshing drawing	○
〈4〉 Tooth modification	○
〈5〉 Tooth surface stress distribution (3D)	○
〈6〉 Tooth surface evaluation (1) friction coefficient, oil film thickness, calorific potential, Power loss, PV, PVT	○
〈7〉 Scuffing probability of occurrence (1)	○
〈8〉 Wear probability of occurrence (1)	○
〈9〉 Life time (1)	○
〈10〉 Power loss (1)	○
〈11〉3D-FEM	○
〈12〉 Edge contact analysis	◎
〈13〉 Transmission analysis, Fourier analyses, CSV	◎
〈14〉 Internal gear	◎
〈15〉 Best tooth surface modification	◎

(1) Doesn't support a plastic gear

22.3　Property (Basic rack)

A setting screen is shown to Fig.22.3.

・Gear combination　: external × external,　external × internal
・Basic rack　　　　: standard,　low,　special
・tooth tip circle decision　: normal,　equal clearance

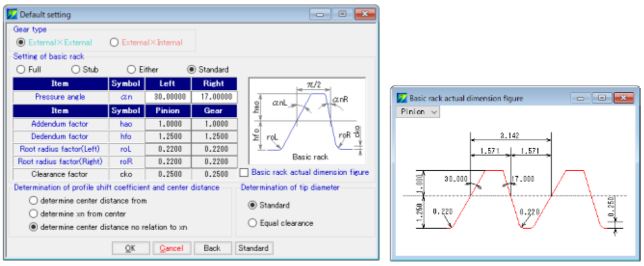


Fig.22.2　property (basic rack)

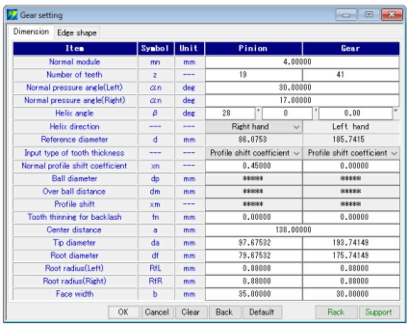
22.4　Gear dimensions

Gear dimension calculates parts dimensions, contact ratio, sliding ratio, tooth thickness and so on. The gear with undercut determines the contact rate based on the TIF (True Involute Form) diameter. If tooth tip is rounded, R and C is considered in contact ratio.

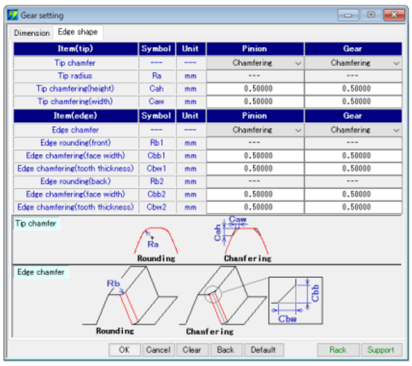
(1) center distance and shift coefficient have the following 3 relationships.
<1> shift coefficient is given to pinion and gear to determine center distance.
<2> based on center distance, shift factor of each gear is determined.
<3> center distance is set, regardless of shift coefficient.

(2) shift coefficient is set per following 4 types;
<1> directly enter shift coefficient
<2> based on split tooth thickness, shift coefficient is set
<3> based on over ball dimension, shift coefficient is set
<4> addendum modification, shift coefficient is set

For inputting dislocation coefficients, in addition to the direct input method of dislocation coefficients, the dislocation coefficients can also be inversely calculated based on the tooth thickness. Since it is not possible to measure the "tangential tooth thickness" of the asymmetric tooth gear, it is not included in the setting method of the dislocation coefficient. Fig.22.3 shows the specification setting screen, and Fig.22.4 to 22.6 shows the dimensional results. Fig.22.7 shows the over ball measurement position map of the asymmetric tooth gear.



(a) gear dimension



(b) chamfering

Fig.22.3　gear specification

Item	Symbol	Unit	Pinion	Gear
Transverse module	mt	mm	4.5303	
Transverse pressure angle	αt	deg	33.1803(L) / 19.0990(R)	
Base helix angle	βb	deg	23.9898(L) / 26.6768(R)	
Base diameter	db	mm	72.0410(L) / 81.3373(R)	155.4569(L) / 175.5173(R)
Tooth depth	h	mm	9.0000	9.0000
Cutting profile shift coefficient	xnc	---	0.4500	0.0000
Min involute diameter(TIF)	dt	mm	80.9964(L) / 82.2786(R)	177.1713(L) / 178.7837(R)
Max involute diameter	dh	mm	96.6753(L) / 96.6753(R)	192.7415(L) / 192.7415(R)
Normal circular tooth thickness	sn	mm	7.8727	6.2832
Transverse circular tooth thickness	st	mm	8.9164	7.1161
Over ball diameter	dp	mm	7.7738	6.9972
Over ball distance(Reference)	dm	mm	101.0832	195.6964
Over ball distance(Design)	dm'	mm	101.0832	195.6964

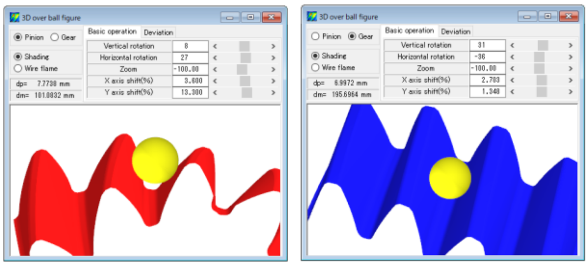
Fig.22.4 dimension result-1

Item	Symbol	Unit	Pinion	Gear
Transverse contact module	αwt	deg	34.4857(L) / 21.4664(R)	
Contact helix angle	βw	deg	28.3643	
Contact pitch diameter	dw	mm	87.4000	188.6000
Teeth number ratio	zh	---	2.1579	0.4634
Effective face width	bw	mm	30.0000	
Clearance	ck	mm	1.2916	1.2916
Transverse contact ratio	εα	---	0.9292(L) / 1.1485(R)	
Overlap contact ratio	εβ	---	1.1208(L) / 1.1208(R)	
Total contact ratio	εγ	---	2.0500(L) / 2.2693(R)	
Sliding ratio	σ1	---	-0.2474(L) / -0.7278(R)	0.1983(L) / 0.4212(R)
Sliding ratio	σ2	---	0.3401(L) / 0.5676(R)	-0.5154(L) / -1.3129(R)
Transverse backlash	Jt	mm	0.3010(L) / 0.3398(R)	
Backlash angle	Jθ	deg	0.4788	0.2219
Contact diameter(max)	dja	mm	96.6753(L) / 96.6753(R)	192.7415(L) / 192.7415(R)
Contact diameter(min)	djf	mm	83.5572(L) / 84.0954(R)	180.5396(L) / 182.1619(R)

Fig.22.5 dimension result-2

Item	Symbol	Unit	Pinion	Gear
Max contact stress(membrane element stress)	σh	MPa	1700.05	
Element number	---	---	55698	45337
Node number	---	---	93335	76184
Max bending stress(σ1)	σ1	MPa	498.55	566.29
Max bending element No.	---	---	36023	29400

Fig.22.6 dimension result-3



(a) pinion (b) gear

Fig.22.7 over ball diameter

25.5 Tooth profile

Meshing drawing is shown in Fig.22.8. As shown in support form, zoom, distance measurement, R-measurement, diameter, involute modification, line of action, display and rotation function are available.

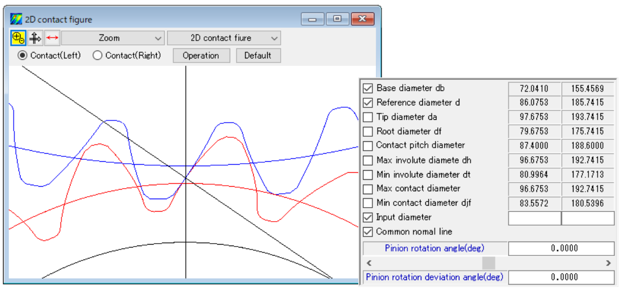
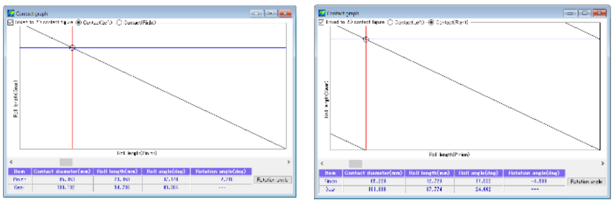


Fig.22.8 meshing drawing & support form

22.6 Contact line and sliding ratio graph

The contact line graph is shown in Fig.22.9. This graph shows the relation of the meshing well because the line of action length of the gear is shown in the vertical axis with the line of action length of the pinion shown in the transverse. In the Fig.22.9, when the contact diameter of the pinion is 85.853 mm, the contact diameter of the gear is 190.192 mm. Also, the line of action length of this pinion is 23.350 mm and the gear is 54.786 mm.

Moreover, the meshing of the tooth can be grasped because are connected with contact profile (Fig.22.8). The rotation angle computation (Fig.22.10) is the auxiliary calculation function to compute relation between the contact diameter, the line of action length and the roll angle and then the rotation angle. And, the sliding ratio graph is shown in Fig.22.11.

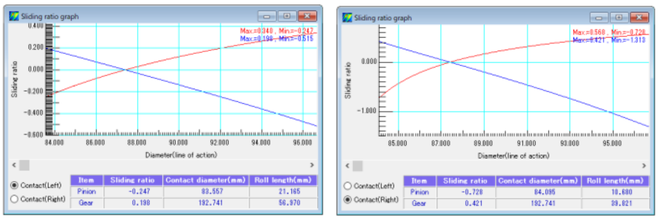


(a) left flank (b) right flank

Fig.22.9 contact line

Item	Symbol	Unit	Pinion	Gear
Contact diameter	d'	mm	87.4000	188.6000
Roll length	L	mm	24.7430	53.3927
Roll angle	φ	deg	39.3572	39.3572
Rotation angle	θ	deg	0.0000	*****

Fig.22.10 rotation angle (left flank)



(a) left flank (b) right flank

Fig.22.11 sliding ratio

22.7 Tooth surface element setting

The tooth surface element setting is shown in Fig.22.12. It sets a torque, and Young's modulus, Poisson's ratio and then the tooth profile distribution number and a pitch error with this screen. The plastic gear can be analyzed by setting Young's modulus and Poisson's ratio. The analysis tooth profile can choose 1 tooth, 3 teeth, 5 teeth. It chooses 5 teeth when total contact ratio is big.

Edge contact analysis setting: Edge analysis(edge curvature setting) / No edge analysis (selected)

Item	Symbol	Unit	Pinion	Gear
Minimum curvature	ρ	mm	---	---
Curvature modification range	h	mm	---	---

Analysis teeth number: 1 / 3 / 5 (selected); Analysis point: root + face + tip / Only tooth face (selected)

Item	Symbol	Unit	Pinion	Gear
Face width center position	bm	mm	0.0000	0.0000
Torque	T	N·m	1600.0000	3452.6316
Normal forth at transverse plane	F	N	44419.2	
Modulus of elasticity	E	MPa	205800.0	205800.0
Poisson's ratio	ν	---	0.3000	0.3000
Root division number	Nh1	---	20	20
Involute division number	Nh2	---	40	40
Tip, edge division number	Nh3	---	10	10
Face width division number	Nb	---	40	40

Pitch error(μm) Positive : weak contact

Pinion	0.0	0.0	0.0	0.0	0.0
Gear	0.0	0.0	0.0	0.0	0.0

Analysis tooth face: Left side (selected) / Right side

OK Cancel Clear Back Default

Fig.22.12 tooth surface element setting (left flank)

22.8 The profile and lead modification setting

There are a profile and lead modification and three kinds (Type1-3) of the fixed form respectively. In this example, it gives the pinion a profile modification (Fig.22.13, 22.14) but a gear isn't modification. Incidentally, in this example, the gear is not modification.

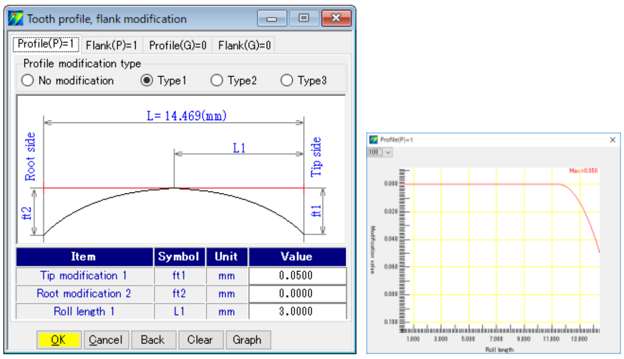


Fig.22.13 tooth modification and graph (×100)

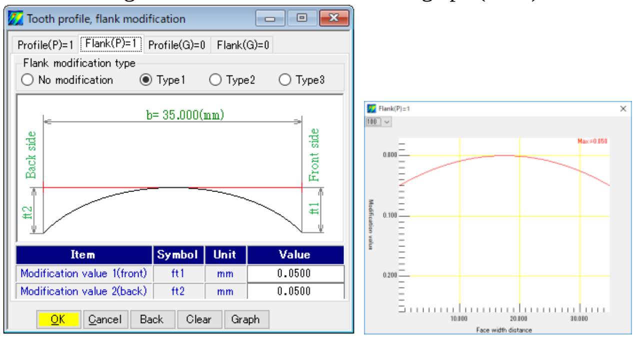
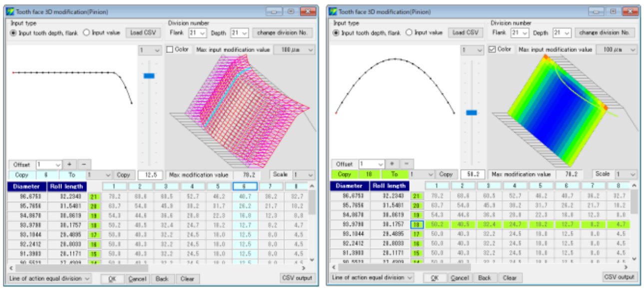


Fig22.14 lead modification and graph (×100)

22.9 Tooth modification (3D) setting

Like Fig.22.15, the tooth surface modification (3D) can type in directly. Also, the profile modification which was set at Fig.22.13 and Fig.22.14 can be taken over, too. As for Fig.22.15, it is displaying the modification which was set at Fig.22.13 and Fig.22.14 by 3D-profile (gear is a theory tooth profile.). This tooth profile can be output by the [CSV] file. Also, this screen can read the inspection data (csv).

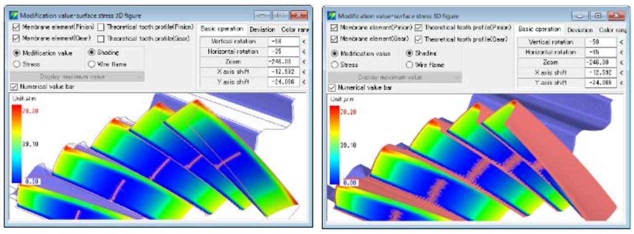


(a) profile modification (b) color palette distribution

Fig.22.15 profile modification (Ex. pinion)

22.10 Profile modification & tooth surface stress (3D)

The tooth profile which was set with the Fig.22.15 can be confirmed with 3D figure. The gear can be turned by the support form and it is possible to make it magnify a gear figure. Moreover, the contact pattern by the tooth when giving an error can be confirmed. Fig.22.16(a) is a modified tooth profile and (b) is the adjusted figure which piled a theory tooth profile on it. Also, a tooth surface element mesh model is shown to Fig.22.17.



(a) tooth modification (b) tooth modification + profile

Fig.22.16 tooth surface element

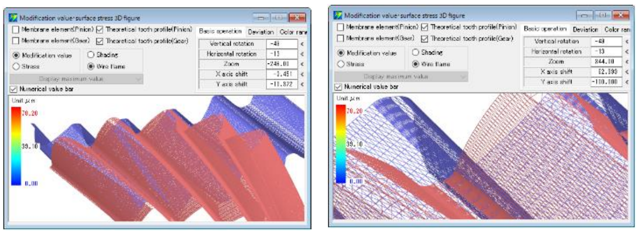


Fig.22.17 tooth surface element model (mesh / Fig22.12)

22.11 Tooth surface stress analysis condition setting

The gear specification and torque and then, it analyzes the tooth surface stress when giving a tooth surface modification. There are two 1 angle pitch and maximum contact angle kinds of setting of an analysis angle range (Free angle can be set). It sets start angle θ_S=-28.578° and end angle θ_e=36.102° like Fig.22.18 as the computation and divide that contact angle into 60. Then calculate by giving discrepancy error φ_1=0.01° and parallelism error φ_2=-0.001°. This axis angle error is the error angle when the bearing or the gear box is distorted by the load, which causes a change in the tooth contact and a change in the stress distribution.

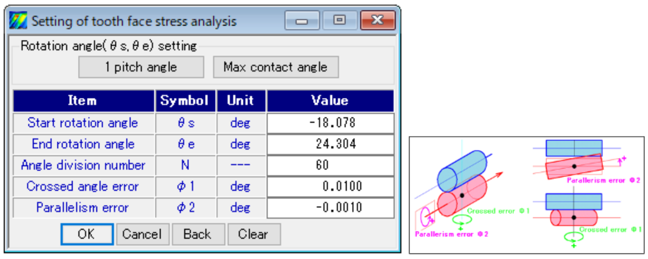
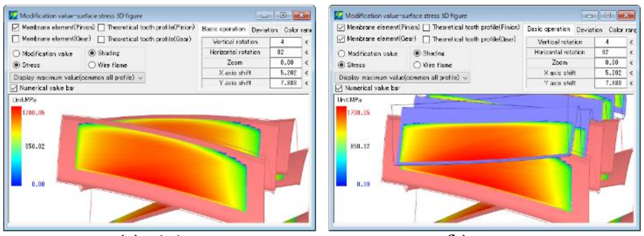


Fig.22.18 tooth surface analysis setting screen, ϕ_1 and ϕ_2

22.12 Tooth surface stress analysis result (3D diagram)

The results of the tooth surface stress analysis are shown in Fig.22.19. In addition, the stress distribution with narrowed stress range is shown in Fig.22.20. In this way, by narrowly displaying the stress range, the range where large stress is generated is well understood. Also, as shown in Figure 22.21, the rotation angle of the pinion with the maximum stress (σ_{Hmax}=1700 MPa) is θ_p=-3.711° and the minimum stress (σ_{Hmin}=1498 MPa) is θ_p=7.064 °.



(a) pinion (b) gear

Fig.22.19 tooth surface stress (σ_{Hmax}=1700MPa)

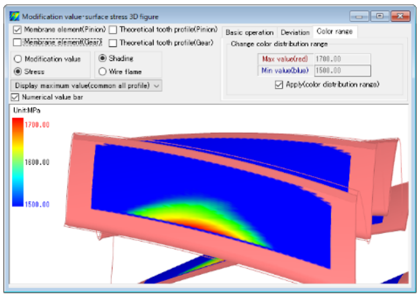
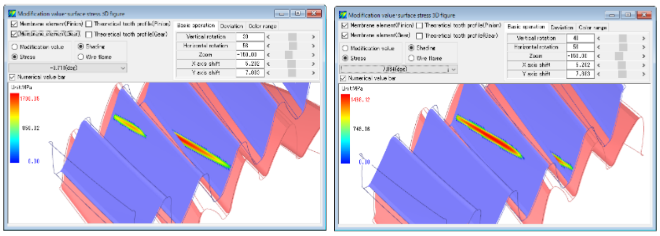


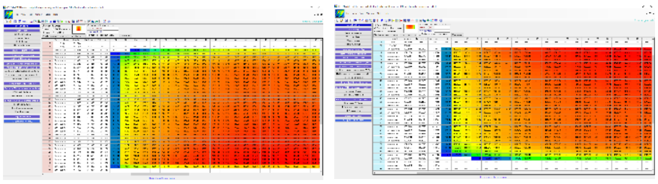
Fig.22.20　tooth surface stress（area: σ_H=1.5～1.7GPa）



(a) σ_{Hmax}=1700MPa(θ_p=-3.711°)　(b) σ_{Hmin}=1498MPa(θ_p=7.064°)

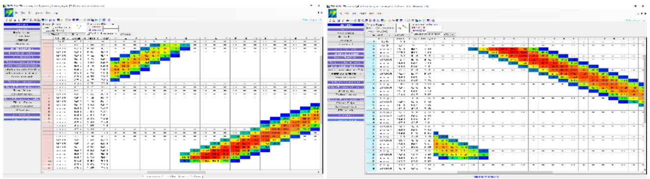
Fig.22.21　tooth surface stress (max. and min.)

The stress distribution (cell display) of the entire tooth surface is shown in Fig.22.22. In the case of example, we display the stress in the area of 98 in the tooth width direction (including the tooth width chamfer) and 70 in the tooth direction (including the tooth tip chamfer) so the stress value at the tooth surface position is understood. In addition, the stress value displayed here can be output as a CSV file. Stress at each rotation angle can display stress distribution corresponding to pinion rotation angle continuously as shown in Fig. 22.23, so it is possible to grasp stress change and contact position.



(a) pinion　(b) gear

Fig.22.22　tooth surface stress, cell（σ_{Hmax}=1700MPa）

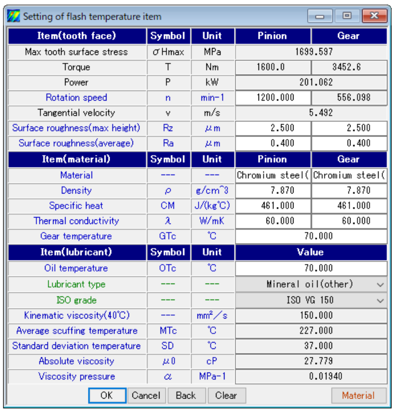


(a) pinion　(b) gear

Fig.22.23　tooth surface stress on θ_p=-3.711°（σ_{Hmax}=1700MPa）

22.13　Flash temperature, friction coefficient, oil film thickness etc.

Fig.22.24 shows the setting screen for flash temperature calculation. Here, material (thermal conductivity) is selected in addition to the rotation speed and tooth surface roughness (Fig. 22.25). Mineral oils and synthetic oils can be selected for the type of lubricant, but in case of nonstandard, kinematic viscosity and average temperature of oil can be arbitrarily set. Calculation results of flash temperature, coefficient of friction, oil film thickness are shown in Fig.22.26 to 22.33. The probability of occurrence of scuffing and probability of wear are shown in Fig.22.34.



Setting of flash temperature item

Item(tooth face)	Symbol	Unit	Pinion	Gear
Max tooth surface stress	σHmax	MPa	1699.597	
Torque	T	Nm	1600.0	3452.6
Power	P	kW	201.062	
Rotation speed	n	min-1	1200.000	556.098
Tangential velocity	v	m/s	5.492	
Surface roughness(max height)	Rz	μm	2.500	2.500
Surface roughness(average)	Ra	μm	0.400	0.400
Item(material)	**Symbol**	**Unit**	**Pinion**	**Gear**
Material	---	---	Chromium steel(	Chromium steel(
Density	ρ	g/cm^3	7.870	7.870
Specific heat	CM	J/(kg℃)	461.000	461.000
Thermal conductivity	λ	W/mK	60.000	60.000
Gear temperature	GTc	℃	70.000	
Item(lubricant)	**Symbol**	**Unit**	**Value**	
Oil temperature	OTc	℃	70.000	
Lubricant type	---	---	Mineral oil(other)	
ISO grade	---	---	ISO VG 150	
Kinematic viscosity(40℃)	---	mm²/s	150.000	
Average scuffing temperature	MTc	℃	227.000	
Standard deviation temperature	SD	℃	37.000	
Absolute viscosity	μ0	cP	27.779	
Viscosity pressure	α	MPa-1	0.01940	

OK　Cancel　Back　Clear　Material

Fig.22.24　flash temperature setting

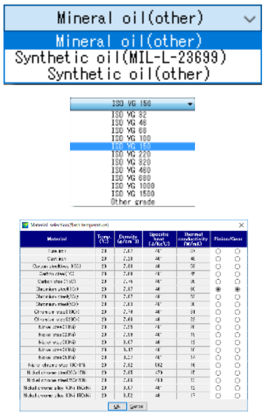
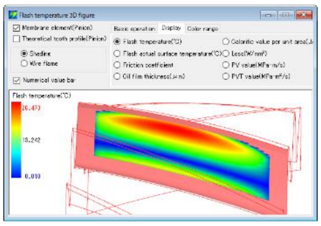
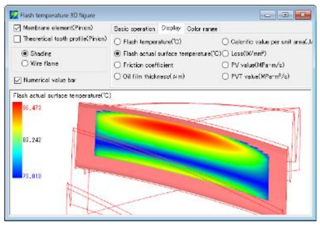


Fig.22.25　material and oil



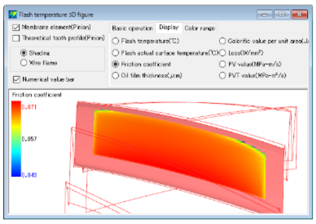
T_{fl}=26.5(℃)

Fig.22.26　flash temperature



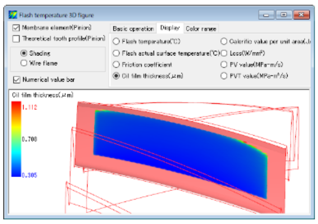
T_{flB}=96.5(℃)

Fig.22.27　gear temperature



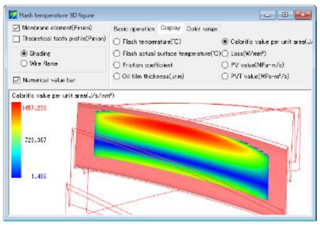
μ_{max}=0.071

Fig.22.28　friction coefficient



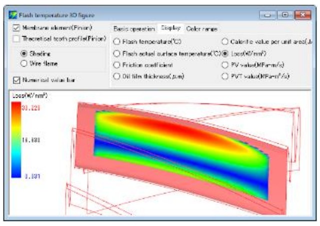
λ_{min}=0.305(μm)

Fig.22.29　oil film thickness



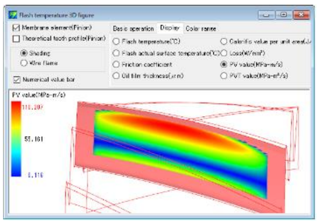
J_{max}=1457(J/s/mm^2)

Fig.22.30　calorific value



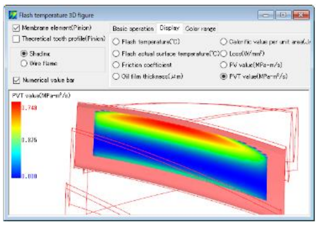
W_{max}=33.2(W)

Fig.22.31　power loss



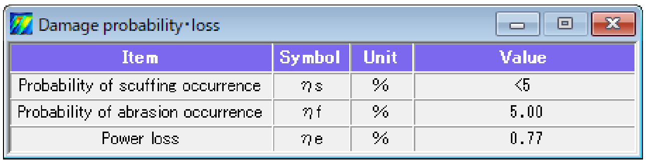
PV_{max}=110.2(MPa-m/s)

Fig.22.32　PV value



PVT_{max}=0.749(MPa-m^2/s)

Fig.22.33　PVT value



Damage probability･loss

Item	Symbol	Unit	Value
Probability of scuffing occurrence	ηs	%	<5
Probability of abrasion occurrence	ηf	%	5.00
Power loss	ηe	%	0.77

Fig.22.34　damage probability

22.14 Edge analysis (option)

In paragraphs 22.11 to 22.14, we analyzed the involute tooth surface, but here we show the result of the end analysis of the tooth tip and side part (Fig.22.35, end set at R = 1.0 mm).

As a result of analysis, as shown in Fig.22.36, large stress σ_{Hmax}=4423 MPa is generated in pinion tooth and gear tooth tip. In the analysis of the involute tooth surface, the flash temperature is 26.5 ° C at the tooth tip as shown in Fig.22.26. However, in the edge analysis, it can be seen that as shown in Fig.22.37, the pinion tooth rose greatly to 105 ° C.

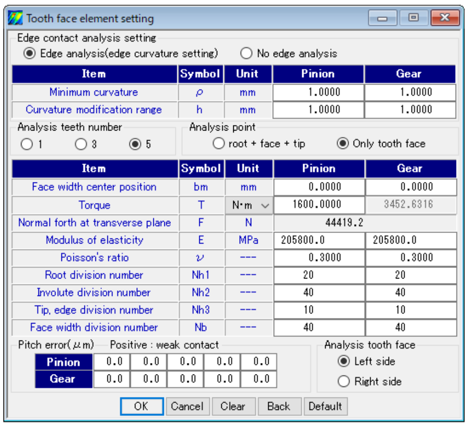
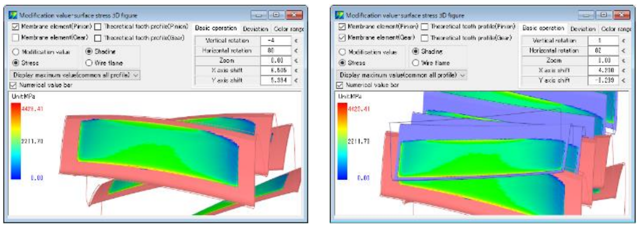
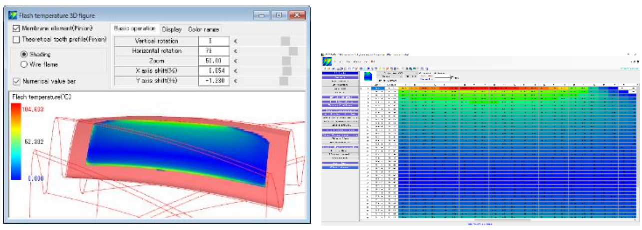


Fig.22.35 tooth surface element setting (edge analysis)



(a) pinion (b) gear

Fig.22.36 tooth surface stress (edge analysis, σ_{Hmax}=4423MPa)



(a) tooth profile (b) cell

Fig.22.37 flash temperature, T_{fl}=105(℃)

22.15 FEM analysis

In the analysis condition of Fig.22.12, to make FEM analysis, create a mesh model in Fig.22.38. Here we create a mesh with the standard model, but there are two ways of setting, one is to determine the tooth profile with accuracy and the other is to determine the tooth profile by the number of divisions.

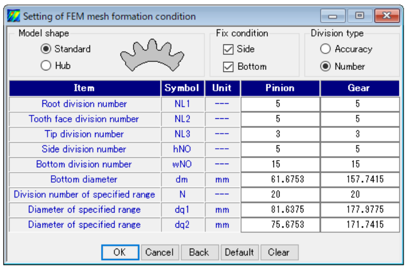
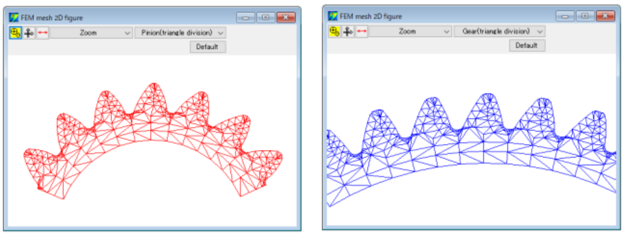


Fig.22.38 mesh model setting

The meshed teeth can be confirmed with the 2D mesh model as shown in Fig.22.39 or the 3D mesh model in Fig.22.40. Also, 3D-FEM mesh elements can display coordinates and nodes as shown in Fig.22.41.



(a) pinion (b) gear

Fig.22.39 2D-mesh model

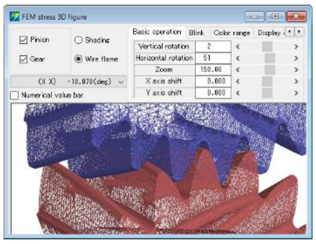


Fig.22.40 3D-mesh model

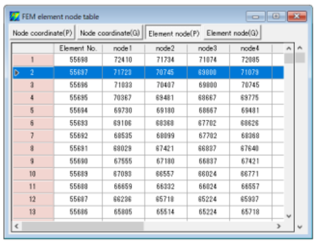


Fig.22.41 element nod table

The mesh model can be generated as a rim / hub model as shown in Fig.22.42, so it is effective for gears with low elastic modulus like plastic gears.

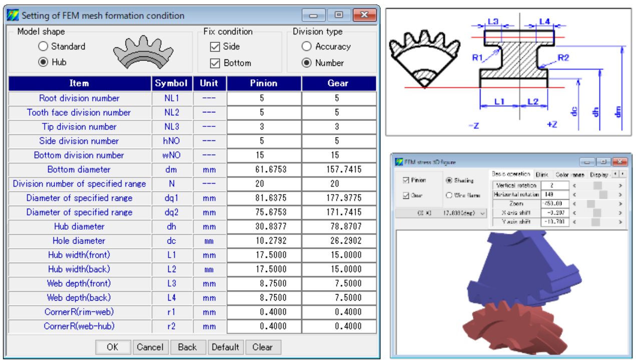


Fig.22.42 rim / hub model

Next, an example of FEM analysis using the mesh model set in Fig.22.38 is explained below. Since the angle (-28.578 ° to 36.102 °) set in the tooth surface analysis setting in Fig.22.18 is divided into 60, the angle of θ_P = 14.247 ° (Fig.22.21) with the largest tooth surface stress is selected and subjected to FEM analysis. If you want to know the change in the bending stress within the meshing angle, check the ☐ in Fig. 22.43 to calculate 60 pairs of bending stress. Since the number of analyzes is large, it is effective to select only the required meshing angle and calculate. The items to be analyzed are the stress, displacement and strain shown in Fig.22.45. FEM analysis results are shown in Fig.22.45 ~ 22.48.

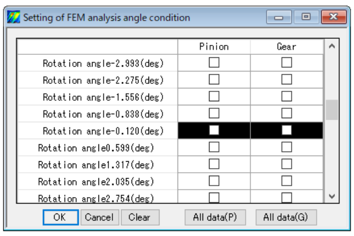
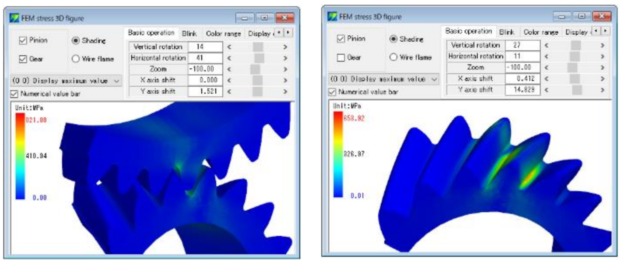


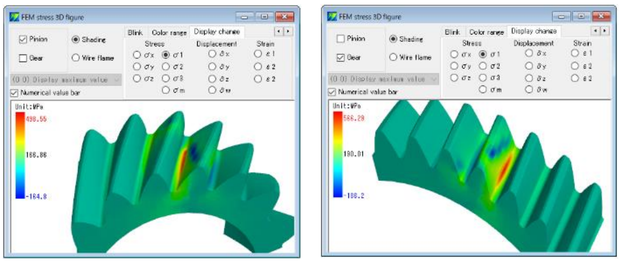
Fig.22.43 FEM analysis choice

Fig.22.44 kind of the analysis



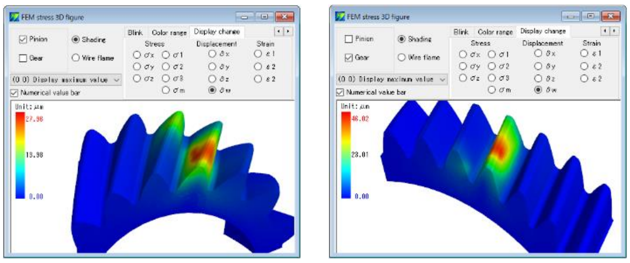
(a) one pair gear (b) pinion, σ_{mmax}=654MPa

Fig.22.45 σ_m (Mises stress), θ_p=-0.120°



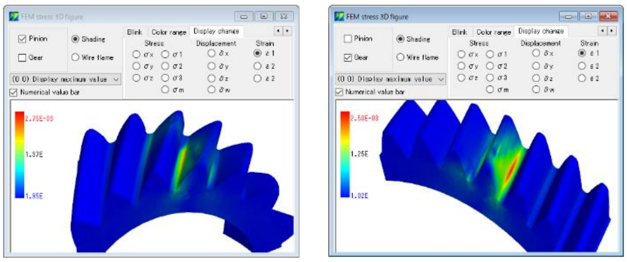
(a) pinion, σ_{1max}=499MPa (b) gear, σ_{1max}=566MPa

Fig.22.46 maximum principal stress



(a) pinion, δ_{max}=28.0μm (b) gear, δ_{max}=46.0μm

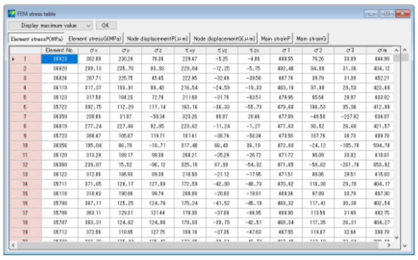
Fig.22.47 displacement



(a) pinion, ε_{1max}=2.75×10^{-3} (b) gear, ε_{1max}=2.50×10^{-3}

Fig.22.48 distortion

In the analysis result table of Fig.22.49, it is understood that the element number of the maximum value σ_{1max}=499MPa of the maximum principal stress of the pinion is 336023. If you enter this number in "Blink" in Fig.22.50, it can be confirmed in the stress distribution chart (▲:flashes). After the FEM analysis result, as shown in Fig.22.51, stress at any position in the tooth width direction can be displayed. Fig.22.51 shows the stress at the tooth width center position (zd=-3 mm).



FEM stress table

Display maximum value | OK

Element stressP(MPa) | Element stressG(MPa) | Node displacementP(μm) | Node displacementG(μm) | Main strainP | Main strainG

	Element No.	σx	σy	σz	τxy	τyz	τzx	σ1	σ2	σ3	σm
1	336023	302.89	230.24	76.36	229.47	-5.25	-4.86	498.55	76.26	33.89	444.99
2	336020	289.13	235.70	93.93	229.04	-12.25	-5.75	493.48	94.88	31.36	434.12
3	336024	287.71	225.75	45.45	222.95	-32.49	-39.50	487.74	39.79	31.39	452.21
4	336119	317.37	193.91	99.43	216.54	-24.59	-19.33	483.19	97.98	29.53	423.68
5	336123	317.58	184.23	72.76	211.68	-31.76	-43.51	479.96	65.64	28.97	433.82
6	335722	392.75	112.20	117.14	163.16	-36.33	-55.73	479.68	106.53	35.96	412.98
7	336359	238.66	31.07	-58.34	323.26	86.87	20.46	477.89	-46.58	-227.92	634.87
8	336019	277.24	227.66	92.85	223.62	-11.24	-1.27	477.63	93.52	26.60	421.57
9	335723	386.47	105.87	119.71	161.61	-38.74	-58.34	473.56	107.76	30.73	409.78
10	336356	195.04	86.79	-16.71	317.48	66.43	36.19	473.03	-24.12	-185.78	594.78
11	336120	313.29	188.17	99.38	208.21	-25.29	-26.72	471.72	95.09	33.82	418.81
12	336360	239.87	15.52	-96.12	325.10	67.93	-54.32	471.65	-59.62	-261.76	653.92
13	336122	312.86	186.93	89.38	218.50	-21.12	-17.96	471.51	88.06	28.51	415.83
14	335711	371.65	128.17	127.88	172.59	-42.00	-48.73	470.02	118.30	29.70	404.17
15	336118	310.43	190.66	99.74	208.09	-20.03	-19.91	469.34	97.89	33.79	407.30
16	335708	367.11	125.25	124.76	175.24	-41.52	-45.19	469.32	117.41	30.38	402.54
17	335706	363.11	129.31	121.44	170.30	-37.09	-44.95	468.90	113.56	31.60	402.75
18	335707	363.31	124.62	124.06	179.03	-39.79	-42.51	468.34	117.35	26.31	404.27
19	335712	372.56	110.95	127.75	169.10	-37.35	-47.63	467.55	119.87	32.64	398.70

Fig.22.49 analysis result list

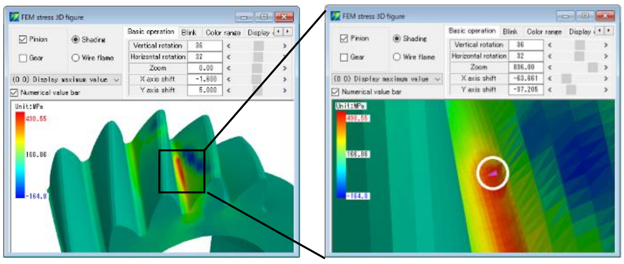
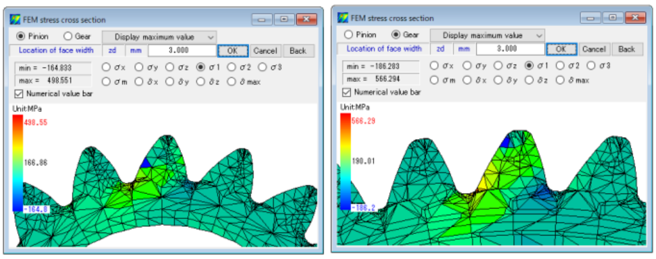


Fig.22.50 pinion, σ_{1max} point, σ_{1max}=499MPa

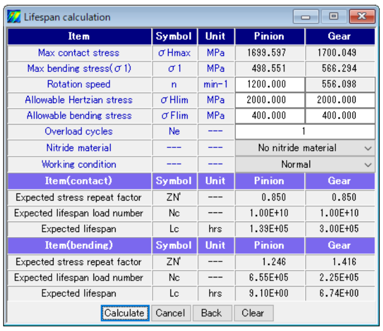


(a) pinion, σ_{1max}=499MPa (b) gear, σ_{1max}=566MPa

Fig.22.51 FEM-section (zd=3mm)

22.16 Lifetime

Calculate lifetime after tooth surface stress analysis and FEM analysis. Fig.45.52 shows the lifetime when the allowable stress value for material's tooth surface strength is σ_{Hlim}=2000 MPa and the allowable stress value for bending strength is σ_{Flim}=400 MPa.



Lifespan calculation

Item	Symbol	Unit	Pinion	Gear
Max contact stress	σHmax	MPa	1699.597	1700.049
Max bending stress(σ1)	σ1	MPa	498.551	566.294
Rotation speed	n	min-1	1200.000	556.098
Allowable Hertzian stress	σHlim	MPa	2000.000	2000.000
Allowable bending stress	σFlim	MPa	400.000	400.000
Overload cycles	Ne	---	1	
Nitride material	---	---	No nitride material	
Working condition	---	---	Normal	
Item(contact)	**Symbol**	**Unit**	**Pinion**	**Gear**
Expected stress repeat factor	ZN'	---	0.850	0.850
Expected lifespan load number	Nc	---	1.00E+10	1.00E+10
Expected lifespan	Lc	hrs	1.39E+05	3.00E+05
Item(bending)	**Symbol**	**Unit**	**Pinion**	**Gear**
Expected stress repeat factor	ZN'	---	1.246	1.416
Expected lifespan load number	Nc	---	6.55E+05	2.25E+05
Expected lifespan	Lc	hrs	9.10E+00	6.74E+00

Calculate | Cancel | Back | Clear

Fig.22.52 lifetime

22.17 Transmission error (option)

Fig.22.53 and Fig.22.54 show the rotation transmission errors and Fourier analysis results within the rotation angle given on the tooth surface analysis setting screen in Fig.22.18.

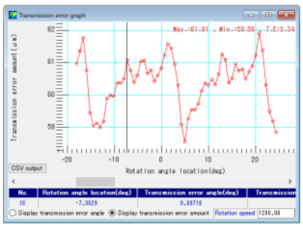


Fig.22.53 transmission error

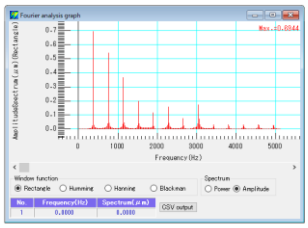


Fig.22.54 Fourier analyses

22.18 Analysis of optimal tooth surface modification (option)

Optimal modification value analysis

As shown in Fig.22.14, when considering the torque and the shaft angle error instead of uniformly determining the tooth surface modification, it is a function that can determine the amount of correction that minimizes the tooth surface stress.

As an example, Fig.22.55 and Fig.22.56 show the optimal tooth surface modification calculated using the torque in Fig. 22.3 and the axis angle error in Fig.22.18 with the gear.

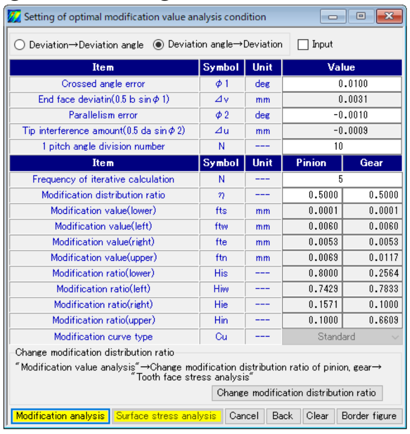
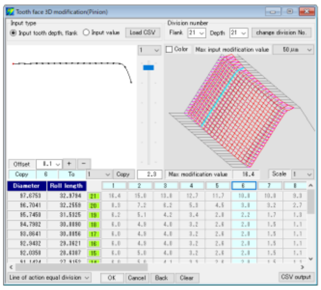
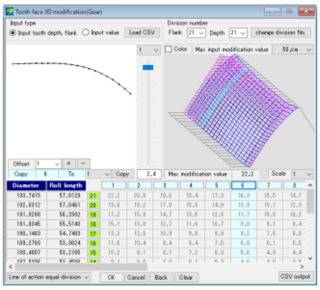


Fig.22.55　modification setting



(a) pinion



(b) gear

Fig.22.56　optimal tooth surface modification

Next, Fig.22.57 of the tooth surface stress analyzed with the tooth profile of Fig.22.56 is 28% lower than σ_{Hmax}=1700 MPa in Fig.22.19. Fig. 22.58 shows the flash temperature and Fig.22.59 shows the friction coefficient distribution.

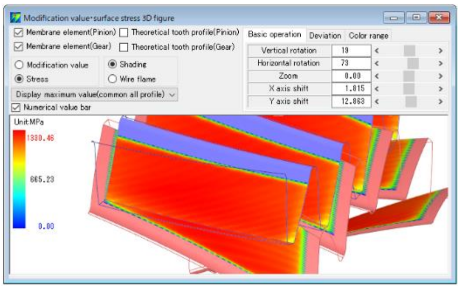
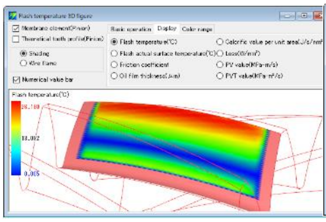
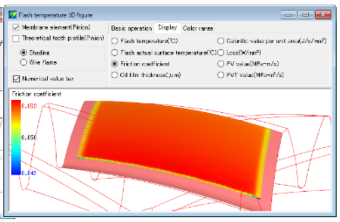


Fig.22.57　tooth surface stress　(σ_{Hmax}=1330MPa)



T_{fl}=26.2(℃)

Fig.22.58　flash temperature



μ_{max}=0.069

Fig.22.59　friction coefficient

22.19　Analysis of the internal-gear (option)

The analysis result of "external gear × internal gear" is shown Fig.22.60 to 22.77

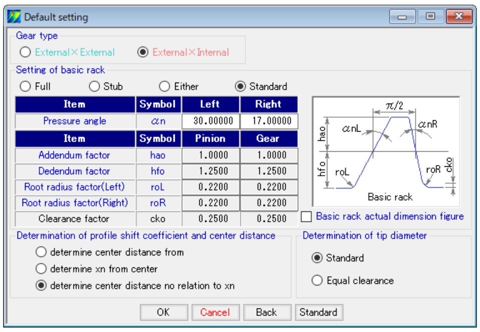


Fig.22.60　basic rack

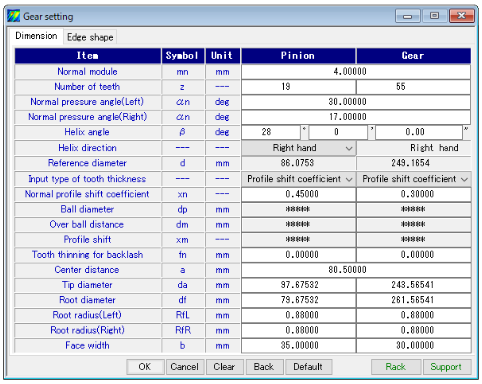


Fig.22.61　gear specification

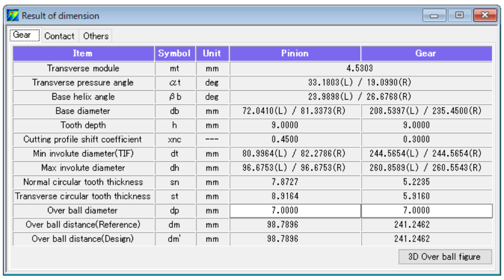


Fig.22.62　dimension result-1

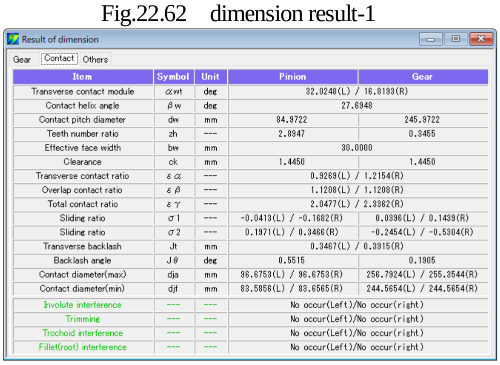


Fig.22.63　dimension result-2

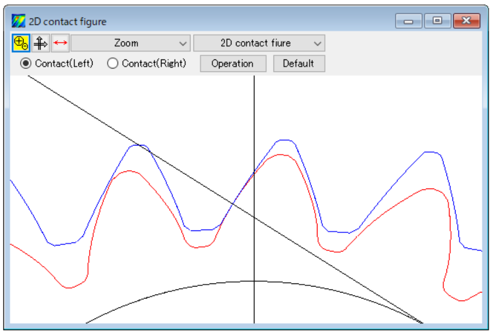
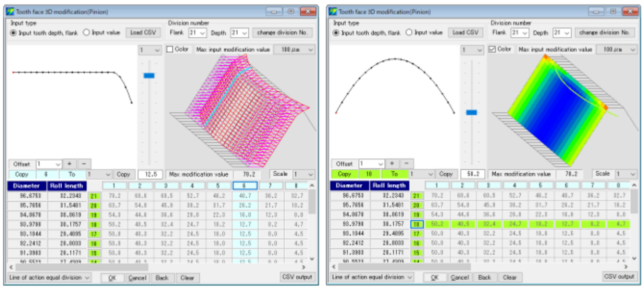
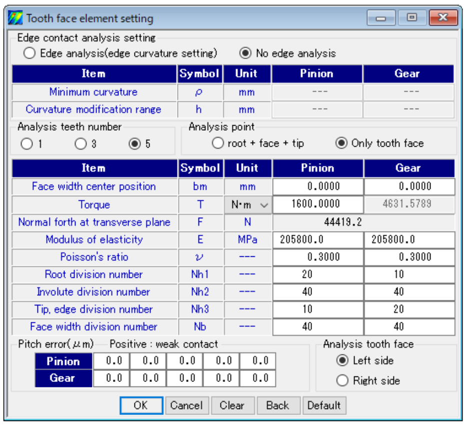


Fig.22.64　meshing drawing



(a) profile modification (b) color palette distribution

Fig.22.65 profile modification (same: Fig.22.15)



Item	Symbol	Unit	Pinion	Gear
Minimum curvature	ρ	mm	---	---
Curvature modification range	h	mm	---	---

Item	Symbol	Unit	Pinion	Gear
Face width center position	bm	mm	0.0000	0.0000
Torque	T	N·m	1600.0000	4631.5783
Normal forth at transverse plane	F	N	44419.2	
Modulus of elasticity	E	MPa	205800.0	205800.0
Poisson's ratio	ν	---	0.3000	0.3000
Root division number	Nh1	---	20	10
Involute division number	Nh2	---	40	40
Tip, edge division number	Nh3	---	10	20
Face width division number	Nb	---	40	40

Pinion	0.0	0.0	0.0	0.0	0.0
Gear	0.0	0.0	0.0	0.0	0.0

Fig.22.66 tooth surface element setting

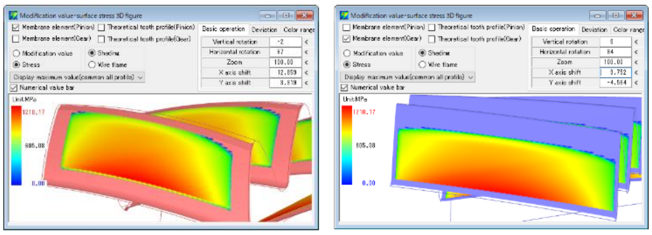
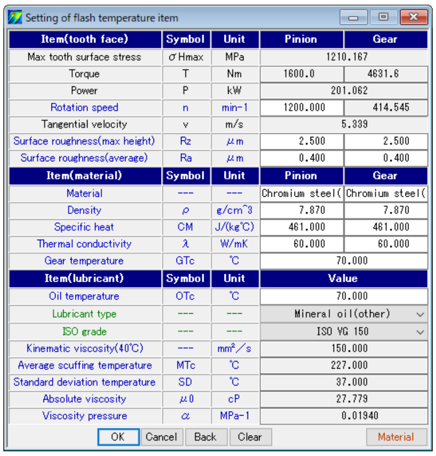
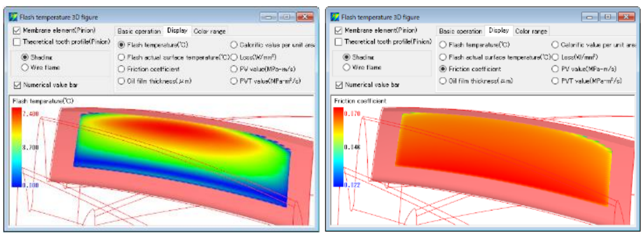


Fig.22.67 tooth surface stress （σ_{Hmax}=1210MPa）



Item(tooth face)	Symbol	Unit	Pinion	Gear
Max tooth surface stress	σHmax	MPa	1210.167	
Torque	T	Nm	1600.0	4631.6
Power	P	kW	201.062	
Rotation speed	n	min-1	1200.000	414.545
Tangential velocity	v	m/s	5.339	
Surface roughness(max height)	Rz	μm	2.500	2.500
Surface roughness(average)	Ra	μm	0.400	0.400
Item(material)	**Symbol**	**Unit**	**Pinion**	**Gear**
Material	---	---	Chromium steel(	Chromium steel(
Density	ρ	g/cm^3	7.870	7.870
Specific heat	CM	J/(kg℃)	461.000	461.000
Thermal conductivity	λ	W/mK	60.000	60.000
Gear temperature	GTc	℃	70.000	
Item(lubricant)	**Symbol**	**Unit**	**Value**	
Oil temperature	OTc	℃	70.000	
Lubricant type	---	---	Mineral oil(other)	
ISO grade	---	---	ISO VG 150	
Kinematic viscosity(40℃)	---	mm²/s	150.000	
Average scuffing temperature	MTc	℃	227.000	
Standard deviation temperature	SD	℃	37.000	
Absolute viscosity	μ0	cP	27.779	
Viscosity pressure	α	MPa-1	0.01940	

Fig.22.68 flash temperature setting



T_{fl}=7.40(℃) μ_{max}=0.070

Fig.22.69 flash temperature Fig.22.70 friction coefficient

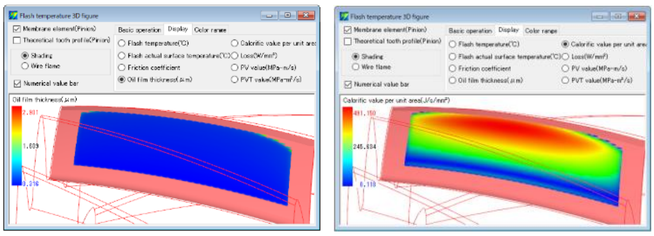
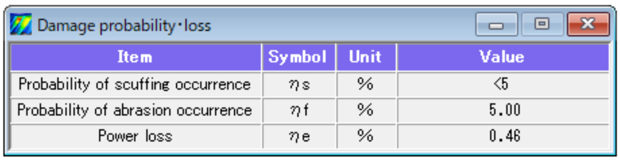
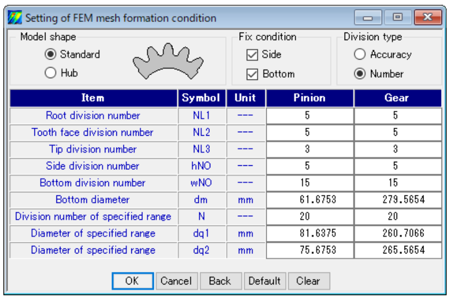


Fig.22.71 oil film thickness Fig.22.72 calorific value



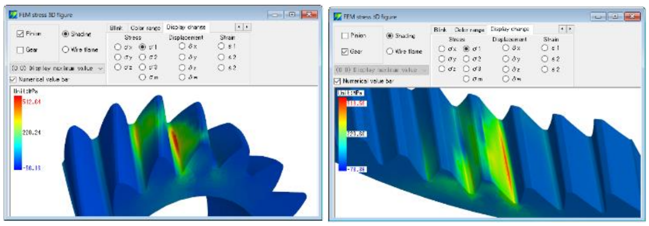
Item	Symbol	Unit	Value
Probability of scuffing occurrence	ηs	%	<5
Probability of abrasion occurrence	ηf	%	5.00
Power loss	ηe	%	0.46

Fig.22.73 damage probability



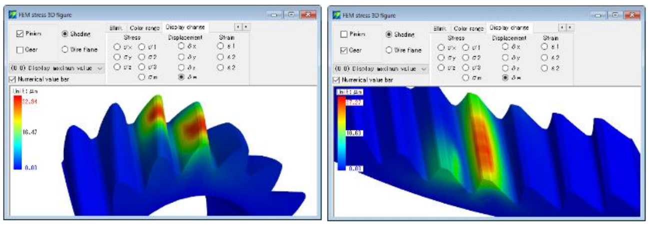
Item	Symbol	Unit	Pinion	Gear
Root division number	NL1	---	5	5
Tooth face division number	NL2	---	5	5
Tip division number	NL3	---	3	3
Side division number	hNO	---	5	5
Bottom division number	wNO	---	15	15
Bottom diameter	dm	mm	61.6753	279.5654
Division number of specified range	N	---	20	20
Diameter of specified range	dq1	mm	81.6375	260.7066
Diameter of specified range	dq2	mm	75.6753	265.5654

Fig.22.74 mesh model setting



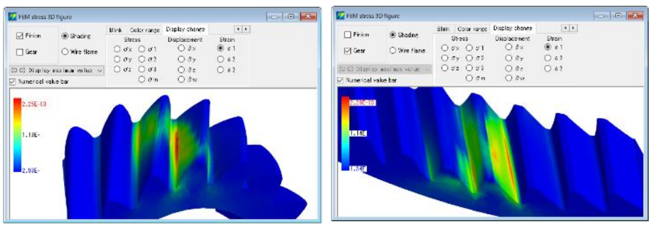
(a) pinion, σ_{1max}=513MPa (b) gear, σ_{1max}=520MPa

Fig.22.75 maximum principal stress



(a) pinion, δ_{max}=32.9μm (b) gear, δ_{max}=37.3μm

Fig.22.76 displacement



(a) pinion, ε_{1max}=2.25×10^{-3} (b) gear, ε_{1max}=2.28×10^{-3}

Fig.22.77 distortion