# [5] Planetary gear design system (Planetary gear and Mechanical paradox gear)



Fig. 5.1 Planetary gear design system

### 5.1 Abstract

This software is a software that can easily design planetary gear s and mechanical paradox gears, and can automatically determine t he combination of the number of teeth, the center distance, etc., a nd can easily design the gear dimensions and gear strength. In add ition, interference check of planetary gears, profile shift factor calcu lation, etc. can be easily calculated. Figure 5.1 shows the whole sc reen of the calculation result.

### 5.2 Gear to apply

(1)Type: Equal arrangement (Planetary, Solar, Star)(2) Material of the gear: Steel, Plastic(3)Tooth profile: Involute

(4)Option : 3K paradox type, Small number of teeth, Double pinion, and Non-equal arrangement

### 5.3 Property (Basic rack)

In the properties, set the tip diameter determination method, basic rack, module or center distance reference, gear accuracy and friction coefficient. Figure 5.2 shows the property screen.

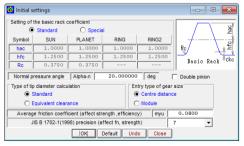


Fig. 5.2 Property (basic rack)

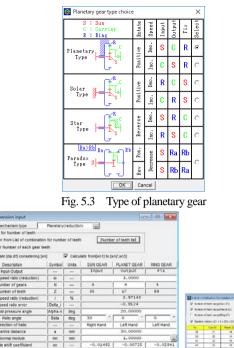
### 5.4 Selection of planetary gear mechanism

Select the planetary gear type shown in Figure 5.3.

(1) The number of planet gears is 1 to 21.

(2) The number of teeth can be selected from the method of direct input

or the number of teeth list calculated from the speed ratio (Fig. 5.5).



9 15 mil	stimeth range	dian 31a	28	m 20	CODE C
2 10.000	of text (was	Part D	1	8 10	Chie
" Acete	al set samp	(Reg II)	-	Fecalit	
2 fantes		2+22+22	Venity and late 5. 11.00		
-	1.021	Please 22	8 mg 27	+18.00 1000	these rate
28	27	18	68	1,2258	1 12119
20	12	14	81	2.8/18	-4.1007
40	. 52	10	54	2.0036	0.00039
- 14	- 19	16	10	3.1218	4.867
44	33	13	58	2.7079	.7.0%2
+2	30	18	82	2 909	-2.080
**	35	. 12	87	1 4141	1.8108
41	· 31	10	28	3.718	1.8525
41.	. 34	14	- 12	3.8251	.5.5524
42	34	18	88	2.8112	.1.8008
48	- 34	10	118	3.0008	1.802
43	- 34	28	- 24	3,98	5.004
56	8	15	81	2.8071	-47819
81		17	10	2.8714	4 1021
84	- 28	18	73	3.8987	2.0/1
82	28.	14		3,2038	8.867
14	- 28	18	14	3,7178	174016
10	- 30	10	88	2.0009	3 P217
20	36	18	12	2.8008	4 38/25

Fig. 5.4 Gear specification (input)

ra mm

OK Undo Clear Close C

10.00000 0.0480 1.6881 42.38460 37.88460

Fig. 5.5 teeth list

(3) You can calculate module distance from center distance or center distance from module.

21.61541

(4) The calculation of the profile shift factor is performed so that the backlash becomes zero from the module and the center distance.

(5) The default value of thinning for backlash is 1/2 of the JIS backlash standard middle value.

(6) The tip circle diameter is calculated from the basic rack and dislocation coefficient set in the property, but it can be changed.

(7) The shape of the tooth root of the external gear is a trochoid based on the basic rack. The tooth root of the internal gear is the input R connection.

(8) Gear tips can be created with a single R.

(9) Changing one profile shift factor changes the remaining ones in tandem, but you can enter each gear individually. The tooth shape can be confirmed by confirming the tooth thickness and the crest in Fig. 5.6. You can also check the tooth profile and clearance after changing the profile shift factor and tip diameter on this screen. The tooth shape at this point is only the tooth surface, and the root shape is not included.

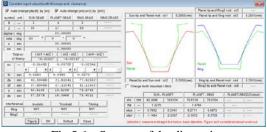


Fig.5.6 Support of the dimension

### 5.5 Gear dimension

The various calculation results are shown in Fig. 5.7 to Fig. 5.10. On this screen, you can check the interference, efficiency, clearance and backlash.

🔏 Gear dimension outpu	ut						- • ×			
Dimensions	Too	th thickne	ss	Pair mes	hing		Efficiency			
Desciption	Desciption		Units	SUN GEAR	PLANET GEAR		RING GEAR			
Transverse pressure a	Alpha-t	deg		22.	79587	7				
Base helix angle		Betab	deg		28.	02432	L			
Transverse circular pitch Pbt			mm		3.3443					
Normal circular pitc	Pbn	mm	2.9521							
Lead	Lead		mm	219,9115	106.	8142	433.5398			
Base diameter	Base diameter		mm	37.2578	18.0	0966	73.4511			
Reference diamete	r	d	mm	40.4145	19.	6299	79.6743			
Minimum involute diamete	er (TIF)	dt	mm	38.6593	18.	2424	77.8816			
Maximum involute diam	neter	dh	mm	42.3847	21.	4269	81.7775			
Addendum		ha	mm	0.9851	0.	9928	1.0294			
Dedendum		hf	mm	1.2649	1.3	2572	1.2206			
Whole depth		h	mm	2.2500	2.1	2500	2.2500			
Addendum modificat	ion	xm	mm	-0.0149	-0.0	0073	-0.0294			
Normal profile shift coef	ficient	xnc		-0.0851	-0.0	0643	0.0539			

Fig.5.7 Result (Gear dimension)

Gear dimension output						- • 💌		
Dimensions	Tooth t	nickness		Pair meshin	9	Efficiency		
Desciption		Symbol	Units	SUN GEAR	PLANET GEAR	RING GEAR		
Normal tooth thickness		sn	mm	1.5089	1.5240	1.5315		
Transverse tooth thickness		st	mm	1.7423	1.7598	1.7685		
Number of teeth spanned		zm		6	3	12		
Base tangent length(standard)		W	mm	16.9637	7.7334	35.3827		
Base tangent length(De	sign)	W	mm	16.9157	7.6944	35.4397		
Measuring ball diamet	er	dp	mm	1.6881	1.7090	1.6609		
Measurement over balls(sta	andard)	dm	mm	42.6297	21.8687	77.3801		
Measurement over balls(d	esign)	dm'	mm	42.4983	21.7696	77.5533		
Caliper depth		Hj	mm	0.9964	1.0162	1.0253		
Caliper tooth thickness(sta	ndard)	Sj	mm	1.5597	1.5646	1.5921		
Caliper tooth thickness(de	esign)	Sj	mm	1.5087	1.5233	1.5221		

Fig.5.8 Result (Tooth thickness)

💑 Gear dimension outpu	t					(	- • ×		
Dimensions	т	ooth thickne	SS	Pair n	Pair meshing		Efficiency		
Desciption		Symbol	Units	SUN GEAF	R PLANE	T GEAR	RING GEAR		
Operating transverse pres	sure	Alpha-wt	deg	22.	6947		22.6947		
Operating helix angle		betaw	deg	29.	9816		29.9816		
Operating pitch diamet	er	dw	mm	40.3846	19.6154	19.615	4 79.6154		
Operating facewidth		bw	mm	10.	0000	10.0000			
Clearance		ck	mm	0.2500	0.2500	0.2501	0.2501		
Contact length		ga	mm	4.	4.2652 4.3641				
Near transverse contact	ratio	Ka1	·	0.5838 0.72		0.7212			
Far transverse contact r	atio	Ka2		0.6916			0.5838		
Transverse contact ra	io	Ka		1.	2754	1.3050			
Overlap ratio		Kb		1.	5915	1.5915			
Total contact ratio		Kc	·	2.	8669		2.8965		
Sliding ratio at tip		Slipa		0.7002	0.5057	0.2565	0.5698		
Sliding ratio at root		Slipf		-1.0229	-2.3357	-1.3245	-0.3450		
Transverse backlash		jnt	mm	0.	0986		0.1088		
Backlash angle		jTheta	deg	0.3031	0.6241	0.6887	0.1697		
Total backlash angle(input	axis)	jTheta'	deg		0.6376	5 (Sun)			
Maximum contact diame	ter	dja	mm	42.3847	21.4269	21.426	9 81.2018		
Minimum contact diame	er	djf	mm	39.0446	18.3343	18.303	6 77.8816		

Fig.5.9 Result (Pair mashing)

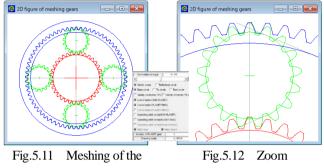
🔒 Gear dimens	[	- • •	
Dimensions	Tooth thickness	Pair meshing	Efficiency
Rotate ratio			
SUN	PLANET	RING	CARRIER
1.0000	-1.0294	• 0.000	0.3365
Efficiency	0.9880		
RING GEAR i	nterference		
Description	F	RING	
Involute	Not oc	currence	
Trochoid	Not oc	currence	
Trimming	Not oc	currence	
Clearance	e(mm)		
Sun tip and Pl	anet root	0.2500(mm)	
Planet tip and	Sun root	0.2500(mm)	
Planet tip and	Ring root	0.2501(mm)	
Ring tip and P	lanet root	0.2501(mm)	

Fig.5.10 Result (Efficiency, etc.)

### 5.6 Tooth profile figure

### 5.6.1 Tooth profile (2D)

The meshing of the gears is displayed in a two-dimensional view as shown in Figure 5.11 and Figure 5.12. Since the auxiliary circle and the common normal can be displayed by the operation screen, it is easy to check the contact position of the tooth surface. You can change the rotation angle of the gear to zoom in.



tooth profile

### 5.6.2 Meshing of a pair tooth profile (2D)

The meshing of one tooth can be confirmed in the two-dimensional view of Fig. 5.13. On this screen, you can check the interference between the internal gear and external gear teeth and the tooth base in more detail. You can change the rotation angle of the gear to zoom in.

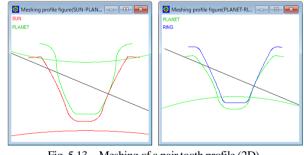


Fig. 5.13 Meshing of a pair tooth profile (2D)

### 5.6.3 rendering

Gear mesh can be displayed in a three-dimensional view as shown in Figure 5.14 and Figure 5.15. In addition, a control form that can be rotated in the X, Y, and Z directions is shown in Figure 5.16.

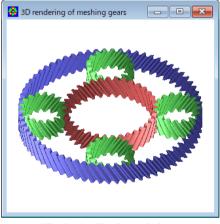


Fig.5.14 Teeth rendering

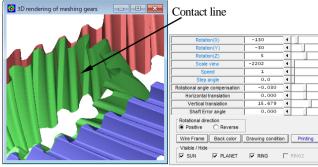


Fig.5.15 profile (Zoom)

Fig.5.16 Control form

### 5.7 Sliding ratio graph

The sliding ratio graph is shown in Fig. 5.17 and Fig. 5.18.

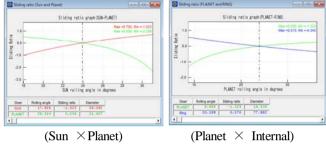


Fig.5.17 sliding ratio graph1 Fig5.18 sliding ratio graph2

### 5.8 Gear strength

### 5.8.1 Initial settings for gear strength calculation

You can select metal material and plastic on the strength initial setting screen shown in Fig. 5.19. Select the allowable stress  $\sigma$ Flim and  $\sigma$ Hlim from Fig. 5.20. Note that  $\sigma_{\text{Flim}}$  and  $\sigma_{\text{Hlim}}$  can be input arbitrary numbers. The torque unit can be selected from N·m, N·cm, kgf·m, kgf·cm and gf·cm.



Fig.5.19 Input (Material)

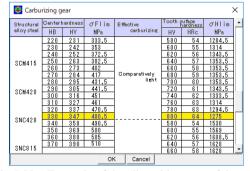


Fig.5.20 Example of the allowable stress of the steel

### 5.8.2 Strength specification input

Enter various values in the strength specification input screen shown in Fig. 5.21. The torque and rotational speed can be set by either input side or output side.

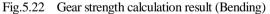
Strength Item(Strength sc		- · · ·					<b>-</b> ×
Description	Symbol	Unit	SUN GEAR	PLANET	GEAR	RING GEAR	Carrier(arm)
Sun input torque	Т	N-m	30.0000	14	.4042	58,102	2 88.102
Sun input rotations	n	rpm	1000.0000	1029	.4118	0.000	336.538
Rotational speed(relativity)	nj	rpm	663.4615	1365	.9502	336.5385	5
Life repetition frequency	L	x1000	10000	205	88	5072	_
Circular speed(relativity)	V	m/s	1.4029	1	. 4029	1.4029	9
Lubricating way			Oil box				]
Temperature	t	C deg	60.0000				
Overload coefficient	Ko		1.0000	1	.0000	1.000	5
Bending safety factor	SF						
Pitting safety factor	SH			1	.1500		
Bearing support type			symmetrica	al with both	axis recei	ving 💌	]
Direction of gear rotation			positive	only			
Profile modification			doesn't execut	• 🔻	doesn	't execute 🔹	OK
Roughness of tooth surface	Rmax	micro-m	6.0000	6	.0000	6.000	Reverse
Tooth contact condition in the load			Good			Clear	
Lubricating oil coefficient	ZL	İ	1.0000 1.0000 1.0000				
Load distribution ratio	Tf			1	.0000		Close

Fig.5.21 Input (Gear strength dimension)

### 5.8.3 Strength calculation result

The intensity calculation result screen is displayed in Fig. 5.22 and Fig. 5.23. The strength calculation also takes into account the efficiency and meshing ratio. The metal gears are subjected to strength calculation based on JGMA 401-01: 1974, JGMA 401-02: 1975. Moreover, the stress value of the resin material adopts the experimental value of the material in consideration of the temperature, life and so on.

UN-PLANET	-			
Bending strength	Tooth surface	e strength		
Description(bending)	Symbol	Unit	SUN GEAR	PLANET GEA
Allowable bending stress	SigmaFlim	MPa	441.5000	441.5000
Effective FaceWidth	b'	mm	10.0000	10.0000
Tooth form factor	YF		2.4262	2.7193
Load distribution factor	Yeps		0.8281	0.8281
Helix angle factor	Ybeta		0.7500	0.7500
Life factor	KL		1.0000	1.0000
Dmension factor	KFx		1.0000	1.0000
Dynamic load factor	Kv		1.0403	1.0403
Speed correction factor	KVo			
Temperature factor	КТ			
Lubrication factor	KLo			
Material factor	KM			
Call circumference force	Ft	N	371.4286	367.1659
Allowable circumference force	Ftlim	N	2347.1505	2094.1576
Bending strength	Sft		6.3193	5.7036
Bending stress	SigmaF	MPa	69.8659	77.4076



Strength result(reference)		1		×
SUN-PLANET	•			
Bending strength	Tooth surfa	ace strengt	<u>h</u>	
Description(pitting)	Symbol	Unit	SUN GEAR	PLANET GEAR
Allowable tooth surface stress	SigmaHlim	MPa	1343.5000	1343.5000
Effective FaceWidth	bw	mm	10.0000	10.0000
Zone factor	ZH		2.2288	2.2288
Material property coefficient	ZM	(MPa)^0.5	189.8000	189.8000
Contact ratio factor	Zeps		0.9100	0.9100
Life factor	KHL		1.0000	1.0000
Roughness factor	ZR		0.9204	0.9204
Smooth velocity factor	ZV		0.9581	0.9581
Hardness ratio factor	ZW		1.0000	1.0000
Load distribution factor	KHbeta		1.0000	1.0000
Dynamic load factor	Ку		1.0404	1.0404
Young modulus	E			
Call circumference force	Fc	N	371.1537	366.8942
Allowable circumference force	Fclim	N	909.7035	909.7035
Tooth surface strength	sfc		2.4510	2.4795
Tooth surface(Hertz) stress	SigmaH	MPa	858.1527	853.2142

Fig.5.23 Gear strength calculation result (Pitting)

### 5.9 Hertz stress graph

Hertz stress graphs are shown in Figure 5.24 and Figure 5.25.



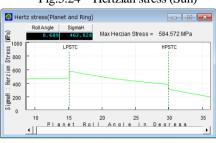


Fig.5.25 Hertzian stress (Planet)

### 5.10 Other

- (1) Tooth profile data of gears can be output.
  - DXF file : 2D, 3D All teeth meshing
  - IGES file : 3D(Tooth)
  - TEXT file : 2-dimensional tooth profile coordinate

(2) You can print dimensional calculation results, strength calculation results, 2D tooth profiles, slip ratio graphs, and Hertz stress graphs.

(3) You can save and load design data.

### 5.11 Mechanical paradox gears (3K type)

A Mechanical paradox gears using a total of four gears of the sun, planets, and two internal teeth is well known. Mechanical paradox gears are very computationally expensive, but can be easily designed using this software. The input is for the sun gear, the fixed for the internal gear 1, and the output for the internal gear 2 type 3K type only.

The number of teeth of internal gear 1 and internal gear 2 determines the same direction deceleration and the reverse direction deceleration. The design example is shown below.

### 5.11.1 Specification of gear specifications

(1) In Properties, select module criteria.

(2) Select the 3K type in Figure 5.3 and proceed to the mechanical paradox gears in Figure 5.26.

(3) Input the design reduction ratio as 135 and the number of planet gears as three.

(4) Display the tooth number list screen, and select the combination of the number of teeth that seems appropriate. (See Figure 5.27)

As selection conditions at this time,

(a) Difference between the actual speed ratio and the design speed ratio error.

(b) The number of teeth must be correct.

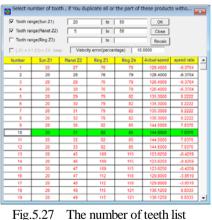
Here we choose  $z_1=20$ ,  $z_2=31$ ,  $z_3=82$ ,  $z_4=85$  as an example.

(5) Then press the Tab key and enter  $\alpha$ =20,  $\beta$ =20,  $m_n$ =1 in order. When the module is entered, the standard center distance, profile shift factor, tip circle diameter and root circle diameter are determined based on the basic rack in Figure 5.2.

(6) The theoretical center distance is 27.6686 mm, but it can be changed according to the purpose. Fig. 5.26 shows the gear specification screen. (7) Once the center distance and module have been determined, you can change the tooth height and tooth thickness. On this screen (Fig.5.28), you can change the profile shift factor and tip diameter while checking the tooth profile. Check the contact of the teeth, interference with the teeth, clearance and internal gear.

Gear dimension input						- • 🛃
Planetary gear type choice	Specific(	reduction	)			
Entry method of number of teeh						
<ul> <li>Select by Design speed ratio[io] a</li> </ul>	nd number	of planet	t gears[N2]	Z1,Z2,Z3 L	ist	
O Direct entry of number of teeth						
<ul> <li>Auto change [da,df] by [xn]</li> </ul>	🔽 Auto c	hange (xi	n2,xn3] by [xn1]			
Description	symbol	unit	SUN GEAR	PLANET GEAR	RING GEAR	RING GEAR
Item	I		Input		Fix	Output
Rate of design speed (reduction)	io			135.0000		
Number of gears	N		1	1		
Number of teeth	Z		20	85		
Rate of actual speed (reduction)	i	%		144.50000		
Speed ratio error	Delta_i					
Normal pressure angle	Alpa-n	deg				
Helix angle	Beta	deg	20 0	• •	• •	
Direction of helix			Right Hand	Left Hand	Left Hand	Left Hand
Centre distance	a	mm		27.55762		
Normal module	mn	mm		1.00000		
Addendum modification coefficient	xn		0.26858	0.17328	0.61513	-0.8138
FaceWidth	b	mm	20.00000	20.00000	10.00000	10.000
Thinning for backlash	fn	mm	0.0390	0.0440	0.0580	0.0590
Ball diameter	dp	mm	1.8178	1.7371	1.6810	1.5728
Tip diameter	da	mm	23.82072 35.33607 86.49284			86.827
Root diameter	df	mm	19.32072	30.83607	90.99284	91.3273
Tip radius	ra	mm	0.00000	0.00000	0.00000	0.0000
Root radius	mm			0.30000	0.3000	

Fig.5.26 Input of gear dimension



The number of teeth list

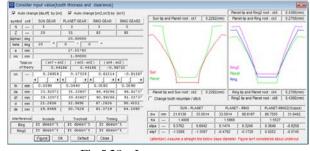


Fig.5.28 Input support screen

(8) Check the efficiency, meshing ratio and slip ratio on the dimension calculation result screen as shown in Figure 5.29-5.32. The efficiency of the mechanical paradox gears in this example is 73.1% as shown in Figure 5.32.

(9) Also, check how much the interference between the external gear and the internal gear can actually be secured by one tooth engagement.

(10) In the case of the example, the dimensions of module 1 have been determined, but it may be necessary to change the size by strength calculation. In that case, change the tooth width or increase the module distance, center distance and tip diameter, etc. The strength calculation should be done carefully as the ratio of torque increases as the rotation ratio increases.

Standard	Th	Thickness			Pair meshing	[	Others	
Desciption	symbol	unit	SUN GE	AR	PLANET GEAR	R	NG GEAR	RING GEAR2
Transverse pressure angle	at	deg			21.172832			
Base helix angle	Betab	deg			18.747237			
Transverse circular pitch	Pbt	mm			3.1175			
Normal circular pitch	Pbn	mm	2.9521					
Lead	Lead	mm	183.7	'080	284.7475	7	53.2030	780.7592
Base diameter	db	mm	19.8	8468	30.7626		81.3719	84.3490
Reference pitch diameter	d	mm	21.2	836	32.9895		87.2626	90.4551
Minimum validity diameter (TIF)	dt	mm	20.1	670	31.6121		86.4929	86.8274
Maximum validity diameter	dh	mm	23.8	3207	35.3361		90.6558	90.9501
Addendum	ha	mm	1.2	686	1.1733		0.3849	1.8139
Dedendum	hf	mm	0.9	9814	1.0767		1.8651	0.4361
Whole depth	h	mm	2.2	500	2.2500		2.2500	2.2500
Addendum modification	xm	mm	0.2	686	0.1733		0.6151	-0.8139
Normal profile shifted coefficient	xnc		0.2	116	0.1090	_	0.6999	-0.7276

Fig.5.29 Result (Gear dimension)

Gear dimension output						
Standard	Thickn	ess	ľ	Pair meshing	Ĭ (	Others
Desciption	symbol	unit	SUN GEAR	PLANET GEAR	RING GEAR	RING GEAR
Normal tooth thickness	sn	mm	1.7248	1.6501	1.0613	2.100
Transverse tooth thickness	st	mm	1.8355	1.7560	1.1294	2.235
Number of teeth spanned	zm	「 I	4	5	12	10
Base tangent length(standard)	W	mm	10.8506	13.9215	35.7414	28.9098
Base tangent length(Design)	W.	mm	10.8116	13.8775	35.7994	28.968
Measuring ball diameter	dp	mm	1.8178	1.7371	1.6810	1.5728
Dimension over balls(standard)	dm	mm	24.4103	35.6976	86.1985	86.7829
Dimension over balls(design)	dm'	mm	24.3235	35.5879	86.3598	86.9894
Caliper depth	Hj	mm	1.3009	1.1925	0.3835	1.8050
Caliper tooth thickness(standard)	Sj	mm	1.7647	1.6964	1.1230	2,163
Caliper tooth thickness(design)	Sř	mm	1.7234	1.6496	1.0573	2.096

Fig.5.30 Result (Tooth thickness)

🚰 Gear dimension output								
Standard		Thic	kness	) I	Pair mes	hing	Othe	rs
Desciption	symbol	unit	SUN GEAF	PLANE	PLANET GEAR		R PLANET	And RING2
Operating transverse pressure	awt	deg	23.	3289		23.3289	13	.5267
Operating helix angle	betaw	deg	20.	2852		20.2852	19	.2433
Operating pitch diameter	dw	mm	21.6138	33.5014	33.5014	88.616	7 86.7555	31.6402
Operating Facewidth	bw	mm	20.0000			10.0000	10	.0000
Clearance	Ck	mm	0.2292	0.2292	0.2708	0.2708	0.4380	0.4380
Contact length	ga	mm	4.	3669		4.9469	4	.8405
Near transverse contact ratio	Ka1		0.	6608		0.9260		.6016
Far transverse contact ratio	Ka2		0.	7400	0.6608		-0	.0490
Transverse contact ratio	Ка		1.	4008	1.5868		1	.5527
Overlap ratio	Kb		2.	1774	1.0887		1	.0887
Total contact ratio	Kc		3.	5781		2.6755	2	.6414
Sliding ratio at tip	Slipa		0.5762	0.6042	0.1474	0.3240	-0.0258	0.3649
Sliding ratio at root	Slipf		-1.5268	-1.3597	-0.4792	-0.172	-0.5745	0.0252
Transverse backlash	jnt	mm	0.	0876		0.1077	0	.1088
Backlash angle	jSita	deg	0.5061	0.3265	0.4012	0.1517	0.1478	0.4052
Total backlash angle(input axis)	jSita'	deg			1.1	.341 (Sun)		
Maximum contact diameter	dja	mm	23.8207	35.3361	35.3361	90.327	5 35.3361	89.6187
Minimum contact diameter	djf	mm	20.3372	31.9564	31.6620	86.492	8 31.7130	86.8274

Fig.5.31 Result (Pair mashing)

🔏 Gear dimen:	sion outp	ut							
Standard	ľΤ	nickne	ss Ĭ	Pair meshing			Others		
Rotate ratio									
SUN	PLANE	т	RING		CARRIE	R	RING2		
1.0000	-0.	3226	0.0	000	0.1	961	0.0069		
Efficiency	0.715	5							
RING GEAR int	erference								
Description	Description		RING		RIN	IG2			
Involute		It	It doesn't		It do				
Trochoid		It	It doesn't		It doesn't				
Triming		It	doesn't		It do	esn't			
Clearance(r	nm)								
Sun tip and Pla	net root	0	. 2292 (mm)	)					
Planet tip and \$	Sun root	0	.2292(mm)	)					
Planet tip and Ring root		0	.2708(mm)	)					
Ring tip and Pla	Ring tip and Planet root			)					
Planet tip and R	ing2 root	0	.4380(mm)	)					
Ring2 tip and Pl	anet root	0	.4380(mm)	)					

Fig.5.32 Result (Efficiency, etc.)

### 5.11.2 Tooth profile (2D)

The meshing figure is shown in Fig. 5.33. In the enlarged view of Fig. 5.34, it can be clearly seen that the planetary gear is engaged with the two internal gears. In addition, you can observe the state of the meshing rotation of the strange planet by the tooth profile rendering shown in Fig. 5.35.

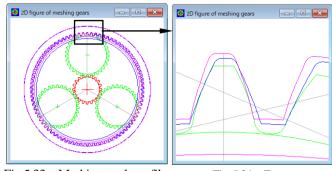
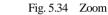


Fig.5.33 Meshing tooth profile



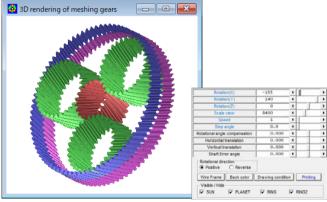


Fig.5.35 Teeth rendering (Gear ratio=135)

## 5.11.3 Mechanical paradox gears example (spur gear)

(1) Gear strength calculation, sliding ratio and Hertz stress graph can be calculated in the same way as planetary gears.

(2) Figure 5.36 shows an example of drawing a mechanical paradox gears with a spur gear.

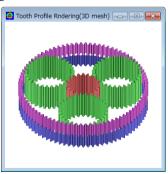


Fig.5.36 Teeth rendering (Spur gear, Gear ratio=93.8)

## 5.12 Small number of teeth (optional)

You can design a planetary gear with 4 or fewer teeth. In the case of a small number of teeth, it is necessary to increase the helix angle because the contact ratio decreases. The following is an example of drawing a planetary gear with 1 sun gear, 1 planet gear and 2 internal gear teeth.

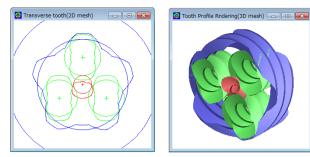


Fig.5.37 Teeth profile(2D)

Fig.5.38 Teeth profile (3D)

# 5.13 Double pinion (option)

Set the double pinion in Figure 5.2 Properties. The design example is shown below.

Gear dimension input ( Doub	le Pinion	)			10	- 0 💌
Planetary gear type choice	Planetary	reduction	- (			
Entry method of number of teeh			A			
( Select by Design speed ratio(o) a	nd number	of planet	gears(N2)	Z1,Z2,Z3 L	lei lei	
C Direct entry of number of teeth						
Auto change [da,df] by [xn]	Auto c	hange (x	12,xn3] by [xn1]			
Description	symbol	unt	SUN GEAR	PLANET	PLANET2	RING GEAR
tem		-	Input	Output	Output	F1x
Rate of design speed (reduction)	10	inter .				
Number of gears	N	1.000	1	3	3	1
Number of teeth	Z		10	12	13	51
Rate of actual speed (reduction)	1	%		-1.83333	1	
Speed ratio error	Deta_i		6	0.0000		
Normal pressure angle	Alpa-n	deg	Second Second			
Helix angle	Beta	deg	20 *	0 '	0 "	
Direction of helix			Right Hand	Left Hand	Right Hand	Right Hand
Centre distance	8	mm	20.00000	16.6	6660	25.33330
Normal module	mn	mm		1.25000		
Addendum modification coefficient	xn		0.01505	0.02257	0.00\$72	0.05635
FaceWidth	D	mm	15.00000	15.00000	15.00000	15.00000
Thinning for backlash	tn	mm	0.0430	0.0390	0.0390	0.0560
Ball diameter	dp	mm	3.0000	3.0000	3.0000	3.0000
Tip diameter	da	mm	26.48162	18.51909	19.81469	65.80000
Root diameter	df	mm	20.85662	12.89409	14.18969	71.10721
Tip radius	ra	mm	0.10000	0.10000	0.10000	0.20000
Root radius	rf	mm				0.35000

Fig.5.39 Input dimension

Gear dimension output							
Standard	Th	ickness	Ŷ	Pair meshing	1	Others	
Desciption	symbol	unt	SUN GEAR	PLANET GEAR	PLANET GEAR2	RNG GEAR	
Transverse pressure angle	at	deg					
Base helx angle	Betab	deg		18.74723	7		
Transverse circular pitch	Pbt	mm		3.8969			
Normal circular pitch	Pbn	mm					
Lead	Lead	mm	206.6716	137.7810	149.2628	\$85.5694	
Base diameter	db	mm	22.3277	14.8851	16.1255	63.2617	
Reference pitch dameter	b	mm	23.9440	15.9627	17.2929	67.8413	
Minimum validity diameter (TIF)	dt	mm	22.3968	14.8937	16.1289	66.0833	
Maximum validity diameter	on	mm	26.3877	18.4364	19.7292	70.7173	
Addendum	ha	mm	1.2688	1.2762	1.2609	1.0207	
Dedendum	hf	mm	1.5437	1.5343	1.5516	1.6329	
Whole depth	h	mm	2.8125	2.8125	2.8125	2.6536	
Addendum modification	×m	mm	0.0188	0.0282	0.0109	0.0704	
Normal profile shifted coefficient	xnc		-0.0352	-0.0219	-0.0369	0.1218	

### Fig.5.40 Result (Gear dimension)

Standard		Thic	kness	1	Pair mest	ning [	Others		
Desciption	symbol	unt	SUN CEA	R PLAT	PLANET GEAR PLANET GEA		2 PLANET2 And RING		
Operating transverse pressure	awt	deg	21.5154			21.5148		.5152	
Operating helix angle	betaw	deg	20.0431			20.0430		.0430	
Operating pitch diameter	đw	mm	24.0000	24.0000 18.0000		17.3333	67.9999	17.3333	
Operating Facewidth	bw	mm	15.0000		1	15.0000		.0000	
Clearance	Ck	mm	0.3121	0.3121	0.3122	0.3122	0.4719	0.3130	
Contact length	ga	mm	5.1358			5.0103	5	. 4226	
Near transverse contact ratio	Kel	-	0.6428			0.6428	0	. 6428	
Far transverse contact ratio	Ka2		0.6751		1	0.6429	0	.7487	
Transverse contact ratio	Ка	-	1	.3179		1.2857		1.3915	
Overlap ratio	Kb	-	1	.3064	1	1.3064		1.3064	
Total contact ratio	Kc	-	2	. 6243	Sec	2.5921		2.6979	
Siding ratio at tip	Sipa		0.9353	0.7676	0.8857	0.9183	0.8928	0.3284	
Silding ratio at root	Slpt		-3.3032	-14.4604	-11.235	-7.7519	-0.4090	-8.3308	
Transverse backlash	Int	mm	0	.0855	S Constant	0.0813	0	.1003	
Backlash angle	(Sta	deg	0.4390	0.6585	0.6260	0.5779	0.1817	0.7129	
Total backlash angle(input axis)	j5ta'	deg	-		1.3	713 (Sun)			
Naxmum contact diameter	dja	mm	26.3877	18.4384	18.4364	19.7292	19.7292	69.9927	
Minimum contact diameter	dif	mm	22.6474	14.0975	14.9090	16.1017	16.1340	66.0833	

Fig.5.41 Result (Tooth thickness)

Gear dimension output											
Standard		Thic	87.655	1	1	Pair mest	hing	1	Others		
Desciption	aymbol	unit	SUN GEA	R	PLANE	TOLAR	T GEAR   PLANET GEAR2		PLANET2 And RING		
Operating transverse pressure	awt	deg	21	21.5154		1	21.5148		21	-5152	
Operating helix angle	betaw	dep	20	.0431			20.0430		20	.0430	
Operating ptch diameter	đa	mm	24.0000	16.0	0000	15.9995	17.33	33	67.9999	17.3333	
Operating Facewidth	bw	mm	15.0000		1	15.0000			.0000		
Clearance	CA	mm	0.3121	03	121	0.3122	0.31	12	0.4719	0.3130	
Contact length	98	mm	5.1358			5.0103		5	. 4226		
Near transverse contact ratio	Kal		0.6428		-		0.6428		0	. 6428	
Far transverse contact ratio	Ka2		0.6751			1	0.6429		0	.7487	
Transverse contact ratio	Ka		1	.3179		1	1.2857	- 3	1.3915		
Overlap ratio	Kb		1	.3064	1. J	1.3064		1.3064			
Total contact ratio	Kc		2	.6243		1	2.5921			2.6979	
Siding ratio at tip	Sipa		0.9353	0.7	876	0.8857	0.91	13	0.8928	0.3284	
Silding ratio at root	Slof		-3.3032	-14.4	4604	-11.2360	-7.75	19	-0.4090	-8.3308	
Transverse backlash	int	mm	Ó	.0855			0.0813		0	. 1003	
Backlash angle	jSta	deg	0.4390	0.6	585	0.6260	0.57	19	0.1817	0.7129	
Total backlash angle(input axis)	j5ta'	deg	-			1.3	713 (Sun	)			
Maximum contact diameter	dja	mm	26.3877	18.4	1364	18.4364	19.72	92	19.7292	69.9927	
Minimum contact diameter	df	mm	22.6474	14.0	1975	14.9090	16.10	17	16.1340	66.0033	

Fig.5.42 Result (Pair mashing)

Gear dimen						
Standard	T	hickne	<b>SS</b>	Pair	meshing	Others
Rotate ratio						
SUN	PLANE	т	PLANET2		CARRIER	RING
1.0000	-2.	8636	1.59	944	-0.545	5 0.000
Efficiency	0.924	8				
RING GEAR int	erference	1				
Descriptio	n		RING			
Involute		It	doesn't			
Trochoid		It	doesn't			
Triming		It	doesn't			
Clearance(	mm)					
Sun tip and Pla	net root	0	.3121(mm)	1		
Planet tip and	Sun root	0	.3121(mm)	٦ ـ	Gear Position	
Planet tip and F	Ring root	0	.3122(mm)			
Ring tip and Pla	net root	0	.3122(mm)			
Planet tip and R	ing2 root	0	.3130(mm)			
Ring2 tip and Pl	anet root	0	.4719(mm)	-		

Fig.5.43 Result (Efficiency, etc.)

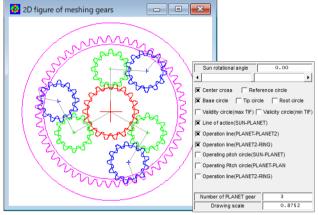


Fig.5.44 Meshing of the tooth profile (2D)

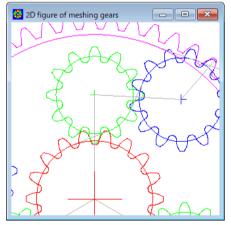


Fig.5.45 Meshing of the tooth profile (Zoom)

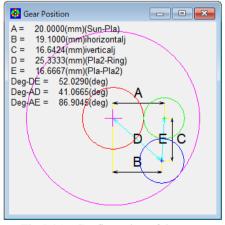
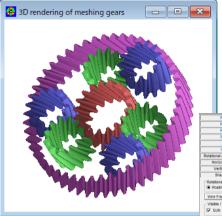


Fig.5.46 Configuration of the gear



Rotati	en/X)	30	1	- 1	
	0000	20	-	- 1	
Rotat	ion(Z)	0	1	1	
Scale	view	8800	4	1	
	eed	1	4	r -	
Step	angle	0.0	4	<u> </u>	
atonal angle	e compensation	0.000	4		
Horizontal	translation	0.000	4		
Vertical b	ranslation	0.000	4		
Shaft En	ror angle	0.000	4		
otational din Positive	C Reverse				
Vice Frame	Back color	Drawing condition	20	Printe	9
/isible / Hide 7 SUN	PLANET	Planet2	φ.	ling	

Fig.5.47 Teeth rendering

Description	Symbol	Unit	SUN GEAR	PLANET GEAR	PLANET GEAR2	RING GEAR	Carrier(arm)
Sun input torque	T	N-m	100.0000	65.3843	69.2901	269.5505	169.550
Sun input rotations	n	rpm	1000.0000	2863.6364	1594.4056	0.0000	545.454
Rotational speed(relativity)	nj	rpm	1545.4545	2318.1818	2139.8601	545.4545	
Life repetition frequency	L	x1000	10000	15000	13846	3529	
Circular speed(relativity)	V	m/s	1.9421 1.9421 1.9421		1.9421	1.9421	
Lubricating way			Gris				
Temperature	t	C deg		60.0000			
Overload coefficient	Ко		1.0000 1.0000 1.0000		1.0000		
Bending safety factor	SF			1.2000			
Pitting safety factor	SH			1.1500			
Bearing support type			symmetric	al with both axis rece	eiving 💌		
Direction of gear rotation			positive	only	•		
Profile modification			doesn't execut	e 🔻 does	n't execute 💌	doesn't exec 🔻	OK
Roughness of tooth surface	Rmax	micro-m	6.0000	6.0000	6.0000	6.0000	Reverse
Tooth contact condition in the load			Good				Clear
Lubricating oil coefficient	ZL	İ	1.0000	1.0000	1.0000	1.0000	Clear
Load distribution ratio	Tf			1,0000			Close

Fig.5.48 Gear strength (Bending)

Bending strength	ľ.	Tooth surface strength								
Description(bending)	Symbol	Unit	SUN GEAR	PLANET GEAR	PLANET GEAR2	RING GEAR				
Allowable bending stress	SigmaFlim	MPa	441.5000	441.5000	441.5000	441.5000				
Effective FaceWidth	b'	mm	15.0000	15.0000	15.0000	15.0000				
Tooth form factor	YF		2.8091	3.2102	3.1421	2.0650				
Load distribution factor	Yeps		0.7588	0.7778	0.7778	0.7186				
Helix angle factor	Ybeta		0.8333	0.8333	0.8333	0.833				
Life factor	KL		1.0000	1.0000	1.0000	1.000				
Dmension factor	KFx		1.0000	1.0000	1.0000	1.0000				
Dynamic load factor	Kv		1.0942	1.0942	1.0942	1.094				
Speed correction factor	KVo									
Temperature factor	KT									
Lubrication factor	KLO									
Material factor	KM									
Call circumference force	Ft	N	2777.7779	2724.3567	2665.0146	2642.6553				
Allowable circumference force	Ftim	N	3549.4064	3030.0017	3095.6166	5097.967				
Bending strength	Sft		1.2778	1.1122	1.1616	1.929				
Bending stress	SigmaF	MPa	345.5194	396.9646	380.0871	228.862				

Fig.5.49 Gear strength (Pitting)

Tooth profile data file output and sliding ratio graph, etc. are equal to the basic software.

# <complex-block>

5.14 Non-equality position of planet gear (Option)

Fig.5.50 Non-equality position of planet gear

The design example of the planetary type (deceleration) nonuniform layout is shown below. In the case of Fig. 5.51, the number of sun teeth is 15, the number of planet teeth is 21, and the number of internal gear teeth is 57 under the condition of equal arrangement. If the number of internal gear teeth is 56, it can be calculated by setting the unequal arrangement shown in Fig. 5.51.

Planetary gear type choice	Planetary	(reduction	1)				
Entry method of number of teeh							
G Select by Design speed ratio[io] and a select by Design speed ratio[io] and a select by Design speed ratio[io].	nd number	of planet	gears[N2]	Z1,Z2,Z3 L	ist		
C Direct entry of number of teeth							
Auto change [da,df] by [xn]	Auto c	hange (x	12,xn3] by [xn1]				
Description	symbol	unit	SUN GEAR	PLANET GEAR	RING GEAF		
Item	<b>□</b>		Input	Output	Fix		
Rate of design speed (reduction)	io			5.0000			
Number of gears	N		1	3	1		
Number of teeth	Z		15	21	57		
Rate of actual speed (reduction)	i	%		4.80000			
Speed ratio error	Delta_i			-4.0000			
Normal pressure angle	Alpa-n	deg		20.00000			
Helix angle	Beta	deg	0 °	• •	0		
Direction of helix							
Centre distance	a	mm	33.00000				
Normal module	mn	mm	1.80000				
Addendum modification coefficient	xn		0.20724	0.14802	0.503		
FaceWidth	b	mm	20.00000	20.00000	20.000		
Thinning for backlash	fn	mm	0.0470	0.0510	0.0670		
Ball diameter	dp	mm	3.0000	3.0000	3.000		
Tip diameter	da	mm	31.34606	41.93287	100.811		
Root diameter	df	mm	23.24606	33.83287	108.911		
Tip radius	ra	mm	0.00000	0.00000	0.000		
Root radius	rf	mm			0.412		
OK Reverse Clear	Close	Consi	der input value(too	th thicness and c	learance)		

Fig.5.51 Equality position of planet gear

The input screen with the number of internal gear teeth changed to 56 is shown in Figure 5.52. The module has mn = 1.5 as in Figure 5.51, so the internal gear profile shift factor is slightly larger. The input screen with the number of internal gear teeth changed to 56 is shown in Figure 5.52. The module has mn = 1.5 as in Figure 5.51, so the internal gear profile shift factor is slightly larger. Figures 5.53 to 5.55 show the dimension results.

Planetary gear type choice	Planetary	(reduction	1)							
Entry method of number of teeh										
C Select by Design speed ratio[io] a	nd number	of planet	t gears[N2]	Z1,Z2,Z3 L	ist					
Direct entry of number of teeth										
Auto change [da,df] by [xn]	Auto c	hange (xr	n2,xn3] by [xn1]							
Description	symbol	unit	SUN GEAR	PLANET GEAR	RING GEAR					
item	Input Output				Fix					
Rate of design speed (reduction) io 5.0000										
Number of gears	N 1 3									
Number of teeth	Number of teeth Z 15 21 56									
Rate of actual speed (reduction) i % 4.73333										
Speed ratio error Delta_i5.3333										
Normal pressure angle										
Helix angle	Beta deg 0 ° 0 ' 0									
Direction of helix	T									
Centre distance	a	mm		33.00000						
Normal module	mn	mm		1.80000						
Addendum modification coefficient	xn		0.20724	0.14802	1.1112					
FaceWidth	b	mm	20.00000	20.00000	20.0000					
Thinning for backlash	fn	mm	0.0470	. 0.0510	0.0670					
Ball diameter	dp	mm	3.0000	3.0000	3.0000					
Tip diameter	da	mm	31.34606	41.93287	101.2005					
Root diameter	df	mm	23.24606	33.83287	109.3005					
Tip radius	ra	mm	0.00000	0.00000	0.0000					
Root radius	rf	mm			0.4125					
OK Reverse Clear	Close	Consi	ider input value(t	ooth thicness and c	learance)					

Fig.5.52 Non-equality position of planet gear

💑 Gear dimension output						- • •	
Standard	Thickness	8	Pair mesi	Pair meshing			
Desciption symbol		unit	SUN GEAR	PLANET	GEAR	RING GEAR	
Transverse pressure angle	at	deg		20.	. 00000	D	
Base helix angle	Betab	deg		0.	. 00000	D	
Transverse circular pitch	Pbt	mm		5.3138			
Normal circular pitch	Pbn	mm		5.3138			
Lead	Lead	mm	0.0000	0.	0000	0.0000	
Base diameter	db	mm	25.3717	35.	5204	94.7210	
Reference pitch diameter	d	mm	27.0000	37.	8000	100.8000	
Minimum validity diameter (TIF)	dt	mm	25.3861	35.	7367	101.2005	
Maximum validity diameter	dh	mm	31.3461	41.	9329	108.8800	
Addendum	ha	mm	2.1730	2.	0664	-0.2003	
Dedendum	hf	mm	1.8770	1.	9836	4.2503	
Whole depth	h	mm	4.0500	4.	0500	4.0500	
Addendum modification	xm	mm	0.3730	0.	2664	2.0003	
Normal profile shifted coefficient	xnc		0.1691	0.	1066	1.1657	

Fig.5.53 Result (Gear dimension)

Standard	Thicknes	ss	Pair meshing		Others		
Desciption	symbol	unit	SUN GEAR PLANE		T GEAR	GEAR RING GEAR	
Operating transverse pres		deg	22.	6897	26.2362		
Operating helix angle	betaw	deg	0.	0000	0.0000		
Operating pitch diameter	er dw	mm	27.5000 38.5000		39.6000	105.6000	
Operating Facewidth	bw	mm	20.	0000	20.0000		
Clearance	ck	mm	0.4105 0.4105		0.6838	0.6838	
Contact length	ga	mm	7.6176		7.9166		
Near transverse contact	atio Ka1		0.6996		1.0400		
Far transverse contact r	atio Ka2		0.	7339	0.4498		
Transverse contact rat	io Ka		1.	4335	1.4898		
Overlap ratio	Kb		0.0000		0.0000		
Total contact ratio	Kc		1.4335		1.4898		
Sliding ratio at tip	Slipa		0.7264 0.8007		0.1341	0.5170	
Sliding ratio at root	Slipf		-4.0172	-2.6550	-1.0706	-0.1548	
Transverse backlash	jnt	mm	0.0980		0.1180		
Backlash angle	jSita	deg	0.4426 0.3162		0.3807	0.1428	
Total backlash angle(input	axis) jSita'	deg	0.9756 (Sun)				
Maximum contact diame	er dja	mm	31.3461	41.9329	41.9329	107.7984	
Minimum contact diamet	er djf	mm	25.5693	36.2134	36,1018	101.2005	

Fig.5.54 Result (Pair mashing)

👶 Gear dimension output 📃 🗖 💌							
Standard	Thickn	ess	Pair meshin	g Others			
Rotate ratio				_			
SUN	PLAN	ET	RING	CARRIER			
1.0000	-0.	3521	0.00	0.2113			
Efficiency	0.98	19					
RING GEAR in	terference	e					
Description			RING				
Involute		It doesn't					
Trochoid		It	doesn't				
Triming		It	doesn't				
Clearance	(mm)						
Sun tip and Planet root			.4105(mm)				
Planet tip and Sun root		0	.4105(mm)				
Planet tip and Ring root		0	.6838(mm)	Non- equality			
Ring tip and P	0	0.6838(mm) Non- ec					

Fig. 5.55 Result (Efficiency, etc.)

By clicking "Uneven layout setting" on the toolbar, Fig. 5.56 is displayed. As for the indication of unequal arrangement, the [A1] gear in Figure 5.56 is the reference gear. Also, since the unequal arrangement angle can not be input arbitrarily, select from the angle table shown in [B] of Fig. 5.57. There are 71 types of arrangement angles of planetary gears in the example.

The arrangement is shown in Fig. 5.58 so that the tip circle of the [A2] gear and [A3] gear does not come in contact with clicking the "minimum arrangement" in Fig. 5.56.

Now, the tooth shape meshing in the case of selecting the second  $10.1408 \circ$  from the angle of "B" in Fig. 5.57 is shown in Fig. 5.59. An enlarged view of [C] is shown in Fig. 5.60, and tooth rendering is shown in Fig. 5.61.

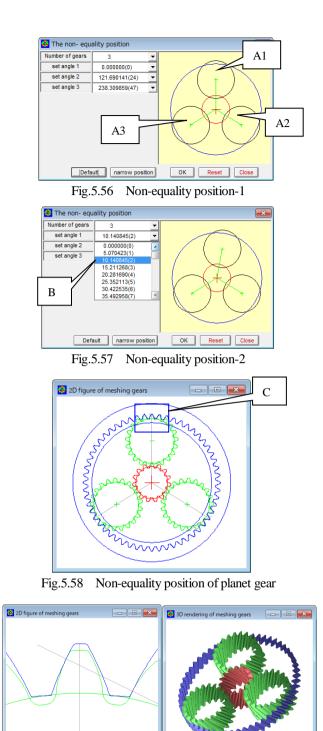
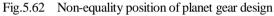


Fig5.59 [C] in Fig.5.58 Fig.5.60 Tooth rendering

In addition, strength calculation, tooth profile data file output, etc. are the same as the basic software. Calculation examples when the number of planets is 5 are shown in Figure 5.62 to 5.64.

Gear dimension input						
Planetary gear type choice	Planetary	(reduction	n)			
Entry method of number of teeh						
C Select by Design speed ratio[io] and the select by Design speed ratio [io] and the select by Design speed ratio [io].	nd number	of plane	t gears[N2]	Z1,Z2,Z3 L	ist	
Direct entry of number of teeth						
Auto change [da,df] by [xn]	🗸 Auto c	hange (x	n2,xn3] by [xn1]			
Description	symbol	unit	SUN GEAR	PLANET GEAR	RING GEAR	
Item			Input	Output	Fix	
Rate of design speed (reduction)	io		5.0000			
Number of gears	N		1	5	1	
Number of teeth	Z		16	14	45	
Rate of actual speed (reduction)	i	%	3.81250			
Speed ratio error	Delta_i		-23.7500			
Normal pressure angle	Alpa-n	deg	20.00000			
Helix angle	Beta	deg	20 °	30 '	0 "	
Direction of helix			Right Hand Left Hand Left Hand		Left Hand	
Centre distance	a	mm	33.00000			
Normal module	mn	mm	2.00000			
Addendum modification coefficient	xn		0.24759 0.28296 0.		0.23548	
FaceWidth	b	mm	20.00000	20.00000	20.00000	
Thinning for backlash	fn	mm	0.0530	0.0510	0.0680	
Ball diameter	dp	mm	4.0000	4.0000	4.0000	
Tip diameter	da	mm	39.15386 35.02490		93.20000	
Root diameter	df	mm	30.15386	26.02490	102.02676	
Tip radius	ra	mm	0.20000	0.20000	0.20000	
Root radius	rf	mm			0.41250	
OK Reverse Clear	Close	Consider input value(tooth thicness and clearance)				
unequality poision of planet gear.						



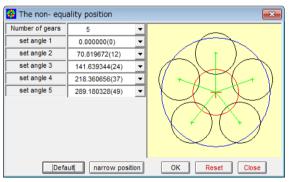


Fig.5.63 Non-equality position-3

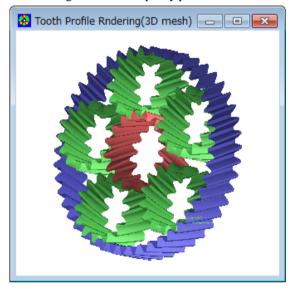


Fig.5.64 Tooth rendering

### 5.15 Tooth profile data file output

The tooth profile of the generated gear can be output as a file in Figure 5.65. Fig. 5.66 and Fig. 5.67 show CAD drawing examples.

