[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 gears and mechanical paradox gears, and can automatically determine the combination of the number of teeth, the center distance, etc., and can easily design the gear dimensions and gear strength. In addition, interference check of planetary gears, profile shift factor calculation, etc. can be easily calculated. Figure 5.1 shows the whole screen 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).
(3) You can calculate module distance from center distance or center distance from module.
(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. 5.3 Type of planetary gear
Fig. 5.4 Gear specification (input)
Fig. 5.5 teeth list
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.

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.

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.

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

(Sun × Planet) (Planet × Internal)

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 $\sigma_{\text{Flim}}$ and $\sigma_{\text{Hlim}}$ 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 $\text{N} \cdot \text{m}$, $\text{N} \cdot \text{cm}$, $\text{kgf} \cdot \text{m}$, $\text{kgf} \cdot \text{cm}$ and $\text{gf} \cdot \text{cm}$.

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.

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.
5.9 Hertz stress graph

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

![Hertz stress graph](image)

Fig.5.24 Hertz stress (Sun)

![Hertz stress graph](image)

Fig.5.25 Hertz 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.

![Input of gear dimension](image)

Fig.5.26 Input of gear dimension

![The number of teeth list](image)

Fig.5.27 The number of teeth list

![Input support screen](image)

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.

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.

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.

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.
5.13 Double pinion (option)

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

Fig. 5.37 Teeth profile (2D)  Fig. 5.38 Teeth profile (3D)

Fig. 5.39 Input dimension

Fig. 5.40 Result (Gear dimension)

Fig. 5.41 Result (Tooth thickness)

Fig. 5.42 Result (Pair mashing)

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

5.14 Non-equality position of planet gear (Option)

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.

The input screen with the number of internal gear teeth changed to 56 is shown in Figure 5.52. The module has \( m_n = 1.5 \) 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 \( m_n = 1.5 \) 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.
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 cannot 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° 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.

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.
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.