3.1 Abstract
This software is a newly developed software that combined both involute (worm gear) and involute (worm and helical gear). In addition, some optional functions are incorporated into the basic software, and various new functions are also added.

3.2 Software structure
Table 3.1 shows software configuration. ○ in the table is included in the basic software and ◎ is optional.

In involute Σ iii (worm gear), the worm's mating gear is a worm wheel, but it can be helical gear. In case of helical gear, please see 3.16 or later.

When ordering, please select necessary software from the price list.

Table 3.1 Software structure

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WG : worm gear, WH : worm and helical gear

3.3 Basic rack (property)
Basic rack of worm gear is shown in Fig.3.2. Reference plane can be selected for a right angle of axial plane or shaft plane. In addition, as shown in Fig.3.2, actual dimensions of the basic rack can be displayed, and then, lead angle can be determined from base circle diameter of the worm, or alternatively, base circle diameter can be determined from lead angle.

3.4 Dimension
Input screen for worm gear dimension is shown in Fig.3.3. As shown in Fig.3.4, tooth profile includes five types such as A, N, K, I and C-type in the standard software. However, since C-type is not applicable to strength calculation standard, it is limited to generating dimensions and tooth form only. In addition, input range is 0.001 to 50 for module, 5 to 30 ° for pressure angle, and 1 to 15 for number of threads. The method of tooth thickness modification can be set by tooth thinning amount or transverse profile shift coefficient as shown in Fig.3.4 (c). In this example, decreased tooth thickness of worm and increased tooth thickness of worm wheel are shown.

3.5 Gear modification (optional)
Worm tooth shape modification can be set as shown in Fig.3.5. As shown in Fig.3.6, worm is given with tooth shape modification of 3 μm at tooth tip and root.
3.6 Tooth profile calculation

Tooth profile calculation condition can be set for wheel processing tool (hob) dimension as shown in Fig.3.7 (a). The number of divisions can be set for displaying tooth profile as shown in Fig.3.7 (b). When applying tooth profile modification to wheel hob, it can be set as shown in Fig.3.8.

![Fig.3.6 Worm tooth modification 2](image)

![Fig.3.7 Tooth profile calculation setup](image)

After tooth profile calculation, dimension result is displayed in Fig.3.11. The three-needle dimension and backlash of worm are calculated based on the actual tooth form considering tooth profile modification.

![Fig.3.10 Contact pattern (No tooth modification)](image)

3.7 Meshing drawing

After tooth profile calculation, tooth profile can be displayed as shown in Fig.3.12. There are enlargement, distance measurement, R-measurement, and rotation functions for tooth form as shown in Fig.3.13.

It is possible to set wheel processing hob as shifted hob (e.g. \( \alpha = 12^\circ \)) as shown in Fig.3.9 (\( m_1=1.975 \) is determined by setting as \( \alpha = 12^\circ \)). This method is adopted as a contact pattern adjustment method. Fig.3.10 shows contact patterns when processing with standard hob and shifted hob, but it shows that the contact pattern of shifted hob is close to the center of the tooth. Please see 3.9 for contact patterns.

![Fig.3.8 Tooth profile modification](image)

![Fig.3.9 Shifted hob setting](image)

![Fig.3.11 Dimension result](image)

![Fig.3.12 Meshing drawing](image)

![Fig.3.13 Tooth meshing & Support form](image)
3.8 Tooth profile rendering

After tooth profile calculation, tooth profile rendering can be displayed as shown in Fig. 3.14. In Fig 3.13, the tooth surfaces are not in contact with each other, but this does not come into contact at the pitch circle area because the tooth surface is in contact with the root and the side surface area of the wheel as shown in Fig. 3.15. The support form in Fig 3.15 has an observation angle, gear position change, enlargement function, and automatic rotation function.

3.9 Contact pattern (optional)

In contact pattern setting shown in Fig. 3.16, shaft mounting tolerance and max. contact clearance (paint thickness) can be defined. In this example, the contact pattern is shown in Fig. 3.17 when max. contact clearance is c=3 μm. Contact pattern changes can be studied by considering tooth profile of worm, tooth profile modification, mounting tolerance, and machined wheel with shifted hob.

In addition, tooth profile can be enlarged and observation angle can be changed by support form at the bottom right of Fig 3.17 (b). Fig 3.18 shows that the contact pattern significantly changes when the lead angle is \( \gamma = 5.74^\circ \).

3.10 Strength calculation

3.10.1 metal-to-metal

Strength dimension is shown in Fig 3.19, and strength calculation result is shown in Fig 3.20. Strength calculation is calculated based on JGMA405-01:1978. Also, kW and W for power, MN · m, kN · m, N · cm for torque can be selected. In addition, tooth surface strength allowable stress coefficient (Sclim) can be arbitrarily defined. Although various coefficients are displayed as standard value, they can be changed arbitrarily. Even if the gears are not applicable to the standards, they can be entered arbitrarily at the judgment of the designer.

3.10.2 Metal-to-resin

When worm is metal and wheel is resin, strength dimension is shown in Fig 3.21. Strength calculation result is shown in Fig 3.22. Strength calculation is based on Lewis’s equation and the tooth surface strength is calculated based on Hertz stress. M90-44 is the standard resin material, but other materials (KT-20, GH - 25, MC nylon) can be selected. For other materials, it is possible to cope with M90 ratio coefficient (ratio with common physical property value).
3.11 Bearing load

Bearing load calculation result is shown in Fig 3.23.

3.12 2D-FEM TOOTH STRESS ANALYSIS (optional)

In FEM setting screen in Fig. 3.24, modulus of longitudinal elasticity, Poisson's ratio, number of divisions and the load (in the example, the value obtained by dividing the circumferential force by $\varepsilon$) can be set.

Fig. 3.25 and Fig. 3.26 show the analysis results of worm and wheel. The maximum value node and element can be displayed in flashing display.

3.13 Transmission error analysis (optional)

Transmission error analysis due to double flank engagement and center distance change analysis due to double flank engagement can be performed. In the example, analysis is performed when wheel is 1 rotation at worm rotation speed 600min⁻¹ while there is no shaft axis mounting error.

Pitch error can be set (maximum value setting or at each tooth) as shown in Fig. 3.28. Transmission error analysis results are shown in Fig. 3.29. Wow flutter (rotation irregularity) is shown in Fig. 3.30, and Fourier analysis result is shown in Fig. 3.31. There is also a function to convert wow flutter to "sound", and analysis result can be exported to CSV file.

3.1.3.1 Transmission error analysis (optional)

Transmission error (TE) analysis is shown in Fig 3.27. Transmission error analysis due to single flank engagement and center distance change analysis due to double flank engagement can be performed. Worm with 1 rotation and wheel with 1 rotation can be selected.

In the example, analysis is performed when wheel is 1 rotation at worm rotation speed 600min⁻¹ while there is no shaft axis mounting error.

Pitch error can be set (maximum value setting or at each tooth) as shown in Fig. 3.28. Transmission error analysis results are shown in Fig. 3.29. Wow flutter (rotation irregularity) is shown in Fig. 3.30, and Fourier analysis result is shown in Fig. 3.31. There is also a function to convert wow flutter to "sound", and analysis result can be exported to CSV file.

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3.14 Tooth surface evaluation (optional)

Tooth surface evaluation has slip velocity graph (Fig 3.33) and Hertz stress graph (Fig 3.34). The slip velocity is calculated from the tooth contact position, and Hertz stress is calculated from the tooth profile at the tooth contact position (tooth deformation is not taken into consideration). Both are valid after strength calculation and transmission error analysis.

3.15 Tooth profile export

Tooth profile file is generated in worm, wheel and tooth form of the tool (hob) as shown in Fig 3.35 (output of arbitrary number of teeth is possible). There are three types of files such as DXF - 2D, DXF - 3D, and IGES - 3D. An example of CAD drawing is shown in Fig 3.36.

3.16 Basic rack

Basic rack of worm gear is shown in Fig 3.38. The reference plane can be selected as a right angle to teeth, or an axial plane.

3.17 Dimension

Fig 3.39 shows input screen for worm & helical gear dimension. As shown in Fig. 3.40 (a), worm's tooth form is included in the standard software in five types such as A, N, K, I and C types. However, since C type is not applicable to the strength calculation standard, it is limited to generating dimensions and tooth shapes only. In addition, input range is 0.001 to 50 for module, 5 to 30 ° for pressure angle, and 1 to 15 for number of threads. The method of adjusting tooth thickness can be set by tooth thinning amount or transverse shift coefficient as shown in Fig 3.40 (c). In this example, decreased tooth thickness in worm and increased tooth thickness in helical gear are shown.
3.18 Gear modification (optional)
As shown in Fig 3.41, tooth profile modification can be given to worm, and tooth surface modification can be given to helical gear. Fig 3.42 and Fig 3.43 show an example of worm's tooth profile setting and helical gear tooth surface modification.

![Fig 3.41 Tooth profile modification (Worm & helical gear)](image)

![Fig 3.42 Worm tooth modification](image)

![Fig 3.43 Helical gear involute/lead modification & topo graph](image)

3.19 Tooth profile calculation
Tooth profile calculation conditions can be set in helical gear processing tool (hob) as shown in Fig 3.44 (a). A number of divisions for displaying tooth profile can be set in Fig 3.44 (b). After tooth profile calculation, dimension result is displayed in Fig 3.45. Three-needle dimension and backlash of worm are calculated based on actual tooth shape considering tooth profile modification. Helical gear is generated based on tooth shape of the tool from Fig 3.44.

![Fig 3.44 Tooth profile calculation setting](image)

3.20 Meshing drawing
After tooth profile calculation, tooth shape can be displayed as shown in Fig 3.46, and there are some functions such as enlargement plotting, distance measurement, R measurement, and rotation function are available as shown in Fig 3.47.

![Fig 3.45 Dimension result](image)

![Fig 3.46 Meshing drawing](image)

3.21 Tooth profile rendering
After tooth profile calculation, tooth profile rendering can be displayed as shown in Fig 3.48. Support form in Fig 3.49 has observation angle, gear position change, enlargement function, automatic rotation function etc.

![Fig 3.47 Tooth meshing & support form](image)

![Fig 3.48 Rendering](image)

![Fig 3.49 Tooth contact](image)
3.22 Contact pattern (optional)

For contact pattern setting in Fig. 3.50, axis mounting error and max contact clearance (paint thickness) can be defined. In this example, Fig. 3.51 shows the contact pattern when max contact clearance is c=3μm. Contact pattern changes can be studied when worm type, tooth profile modification, and shaft mounting error are given.

In addition, support form allows users to enlarge tooth profile and change observation angle at the lower right of support form as shown in Fig 3.51 (b).

(a) Worm 
(b) Wheel

Fig 3.51 Contact pattern

3.23 Strength calculation

Strength dimension is shown in Fig. 3.52, and strength calculation result is shown in Fig 3.53. Bending strength is based on Lewis equation and tooth surface strength is calculated based on Hertz stress. kW and W for power, MN · m, kN · m, N · m, N · cm for torque can be selected.

For material setting, any materials can be selected from Fig 3.52a for both worm and helical gear. Although standard value is displayed for friction coefficient and various coefficients, it can be changed arbitrarily.

Fig 3.52a Material

3.24 Bearing load

Bearing load calculation result is shown in Fig 3.54.

3.25 2D-FEM Tooth stress analysis (optional)

For FEM setting screen in Fig. 3.55, modulus of longitudinal elasticity, Poisson’s ratio, number of divisions and load (in the example, circumscribing force divided by ε) can be defined. Fig 3.56 and Fig. 3.57 show analysis results of worm and helical gear. Maximum value node and element can be displayed in flashing display.

Fig 3.55 FEM analysis setting
3.26 Transmission error (optional)

3.26.1 Transmission error analysis (TE)

As shown in the upper part of Fig. 3.58, transmission error analysis can be performed for analysis due to single tooth flank engagement and center distance change analysis due to double tooth flank engagement. Also, users can select between worm at 1 rotation and helical gear at 1 rotation. In the example, helical gear at 1 rotation at worm rotation speed 600 min\(^{-1}\) is analyzed assuming that there is no shaft mounting error.

Pitch error can be set (maximum value setting, or setting for each tooth) as shown in Fig. 3.58. Transmission error analysis results are shown in Fig. 3.60, and wow flutter (rotation irregularity) is shown in Fig. 3.61, and Fourier analysis result is shown in Fig. 3.62. There is also a function to convert wow flutter to “sound”, and the analysis result can be exported to CSV file.

3.27 Tooth surface evaluation (optional)

In tooth surface evaluation, there are slip velocity graph (Fig. 3.64) and Hertz stress graph (Fig. 3.65). Slip velocity is calculated for the velocity at the tooth contact position, while Hertz stress is calculated from the tooth profile at the tooth contact position (the tooth deformation is not taken into account). Both are valid after strength calculation and transmission error analysis.

3.28 Tooth profile export

Tooth shape file is generated for worm, helical gear and tool (hob) of tooth profile (output of arbitrary number of teeth is possible) as shown in Fig. 3.66. There are three types of files such as DXF - 2D, DXF - 3D, and IGES - 3D. An example of CAD drawing is shown in Fig. 3.67.

3.29 Design data management

The database is compatible with Microsoft Access Database, Microsoft SQL Server and ORACLE MySQL Server. In addition, it is also possible to read design data created by old software such as involute Σ (Worm Gear) and involute Σ (Worm and Helical Gear). The setting screen of the database is shown in Fig. 3.68.

* Microsoft SQL Server and ORACLE MySQL Server must be installed.

3.26.2 Center distance change analysis

Many worm gears are used as single flank contact, but depending on the device, double flank contact may be used. For center distance change analysis in Figure 3.63, it analyzes variation of center distance in consideration of pitch error from Fig. 3.58. In addition, analysis results can be exported to CSV file.
3.30 HELP feature
If there are any questions how to use it during the operation, [F1] key can be pressed on the active screen to display explanation as shown in Fig 3.69.

3.31 worm gear types
Types of worm gear are shown in Fig 3.70 to 3.76. The numerical value in [ ] indicates the software number.