[4] involuteΣ Worm and Helical Gear Design System

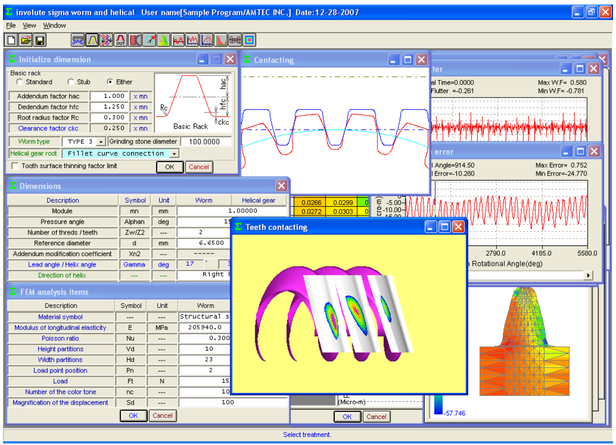


Fig. 4.1 involuteΣ Worm and Helical Gear Design System

4.1 Introduction

The ***involuteΣ Worm and Helical Gear Design System*** is a complete design system for worm and helical gear sets.

4.2. Software Features

Table 4.1 shows the available software features.

Table 4.1. Software Features

Item	Page	Applicable
<1> Basic Rack Setting	18	○
<2> Worm Tooth Profile (Type 1)	18	○
<3> Worm Tooth Profile (Type 3,4)	18	◎
<4> Gear Dimension	18	○
<5> Gear Meshing Drawing	18	○
<6> Tooth Profile Rendering (Image Display)	19	◎
<7> Tooth Profile Rendering (Mounting Error Adjustment)	19	◎
<8> Helical Gear Specification Correction	19	◎
<9> Tooth Profile Data File Output (2D-DXF, 3D-DXF)	20	○
<10> Tooth Profile Data File Output (3D-IGES)	20	◎
<11> Strength Calculation (POM)	18	○
<12> 2D-FEM Tooth Profile Stress Analysis	19	◎
<13> Transmission Error Analysis	19	◎
<14> Fourier Analysis	20	◎
<15> Sliding Speed and Hertzian Stress Graphs	20	◎
<16> Design Data Management	--	○
<17> Tooth Profile Modification	18	◎
<18> Strength Calculation (Polyamide)	18	◎
<19> Tooth Contact Analysis	20	◎

○ (Supported as standard) ◎ (Optional)

4.3 Basic Rack Setting

Fig. 4.2 shows the Basic rack initial dimension setting screen. For the worm type, Type 1, 3, or 4 can be selected.

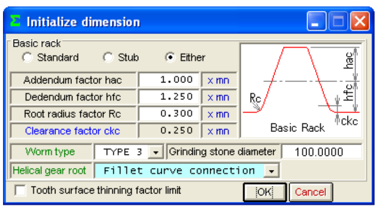


Fig.4.2 Basic Rack Initial Dimension Setting

4.4 Gear Dimension Setting

The user can specify the module, number of starts, number of teeth, pressure angle, and reference tip diameter to calculate the gear dimensions. The center distance and tooth surface thinning factor can be specified as desired. Fig. 4.3 shows the gear dimension setting screen and Fig. 4.4 shows the calculated gear dimensions. The Tooth profile modification screen shown in Fig. 4.4 enables the user to modify the tooth profile of the worm.

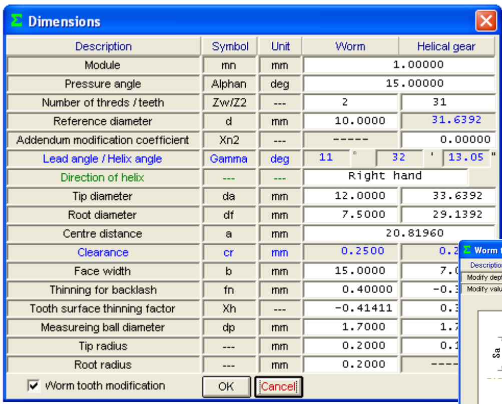


Fig. 4.3 Gear Dimension Settings

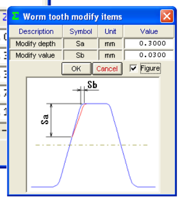


Fig. 4.4 Tooth Profile Modification

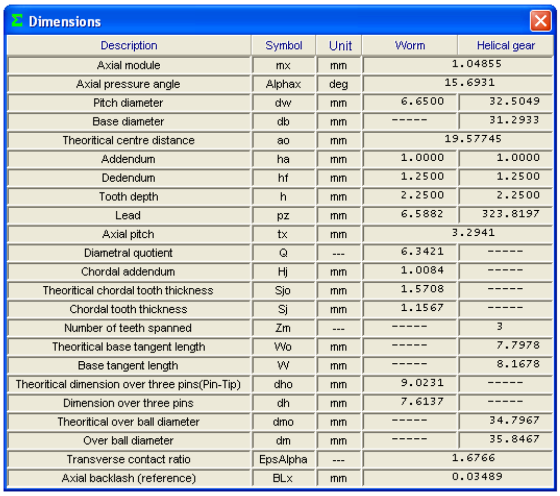


Fig. 4.5 Calculated Worm Gear Dimensions

4.5 Tooth Profile Drawing

Fig. 4.6 shows the cross-sectional tooth profiles of the worm and the helical gear meshed at the axial center of the worm.

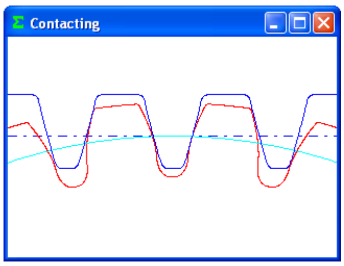
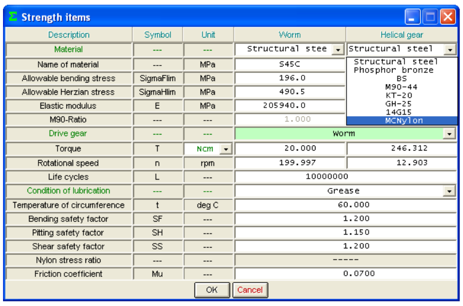


Fig. 4.6 Gear Meshing Drawing

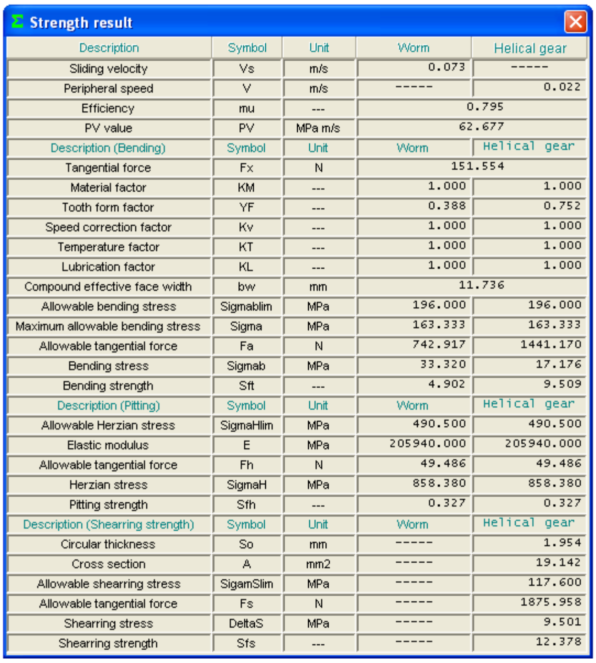
4.6 Strength Calculation

Fig. 4.7 shows the strength setting screen. For helical gears (resin), the System calculates the strength based on the Lewis formula. The stress values are experimental values taking into account the temperature and life cycle of the material. Fig. 4.8 shows the result of the strength calculation. The available material options for helical gears are M90-44, KT-20, GH-25, and Nylon.



Description	Symbol	Unit	Worm	Helical gear
Material	---	---	Structural stee	Structural steel
Name of material	---	MPa	S45C	Structural steel Phosphor bronze BS M90-44 KT-20 GH-25 14G15 MCNylon
Allowable bending stress	SigmaFlim	MPa	196.0	
Allowable Herzian stress	SigmaHlim	MPa	490.5	
Elastic modulus	E	MPa	205940.0	
M90-Ratio	---	---	1.000	
Drive gear	---	---	Worm	
Torque	T	Ncm	20.000	246.312
Rotational speed	n	rpm	199.997	12.903
Life cycles	L	---	10000000	
Condition of lubrication	---	---	Grease	
Temperature of circumference	t	deg C	60.000	
Bending safety factor	SF	---	1.200	
Pitting safety factor	SH	---	1.150	
Shear safety factor	SS	---	1.200	
Nylon stress ratio	---	---	-----	
Friction coefficient	Mu	---	0.0700	

Fig. 4.7 Initial Strength Calculation Settings



Description	Symbol	Unit	Worm	Helical gear
Sliding velocity	Vs	m/s	0.073	-----
Peripheral speed	V	m/s	-----	0.022
Efficiency	mu	---	0.795	
PV value	PV	MPa m/s	62.677	
Description (Bending)	Symbol	Unit	Worm	Helical gear
Tangential force	Fx	N	151.554	
Material factor	KM	---	1.000	1.000
Tooth form factor	YF	---	0.388	0.752
Speed correction factor	Kv	---	1.000	1.000
Temperature factor	KT	---	1.000	1.000
Lubrication factor	KL	---	1.000	1.000
Compound effective face width	bw	mm	11.736	
Allowable bending stress	Sigmablim	MPa	196.000	196.000
Maximum allowable bending stress	Sigma	MPa	163.333	163.333
Allowable tangential force	Fa	N	742.917	1441.170
Bending stress	Sigmab	MPa	33.320	17.176
Bending strength	Sft	---	4.902	9.509
Description (Pitting)	Symbol	Unit	Worm	Helical gear
Allowable Herzian stress	SigmaHlim	MPa	490.500	490.500
Elastic modulus	E	MPa	205940.000	205940.000
Allowable tangential force	Fh	N	49.486	49.486
Herzian stress	SigmaH	MPa	858.380	858.380
Pitting strength	Sfh	---	0.327	0.327
Description (Shearring strength)	Symbol	Unit	Worm	Helical gear
Circular thickness	So	mm	-----	1.954
Cross section	A	mm2	-----	19.142
Allowable shearring stress	SigamSlim	MPa	-----	117.600
Allowable tangential force	Fs	N	-----	1875.958
Shearring stress	DeltaS	MPa	-----	9.501
Shearring strength	Sfs	---	-----	12.378

Fig. 4.8 Strength Calculation Result

4.7 Tooth Profile Rendering

Fig. 4.9 shows a satisfactory tooth contact state. However, care should be taken when designing a gear set because setting a large lead angle may cause double contact or tip contact (as shown in Fig. 4.10) failures.

Faulty tooth contact may also occur in worm and worm wheel gear sets because the tooth profile of the worm wheel is dependent on the diameter of the gear-cutting tool.

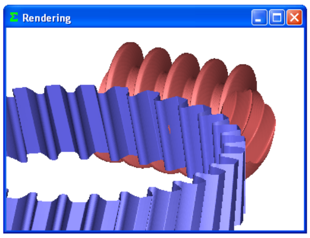


Fig. 4.9 Tooth Profile Rendering (γ =11.5°)

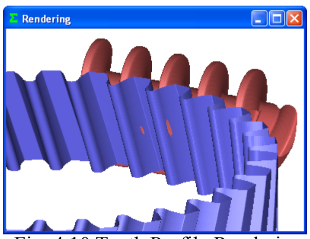


Fig. 4.10 Tooth Profile Rendering (γ =16.5°)

4.8 Helix Angle Correction (Helical Gear)

One way to improve the tooth contact state in Fig. 4.10 is to adjust the pressure angle or helix angle of the helical gear. Fig. 4.11 shows the modified tooth profile rendering image drawn by using the corrected specifications shown in Fig. 4.12 to increase the helix angle of the helical gear by 1 degree.

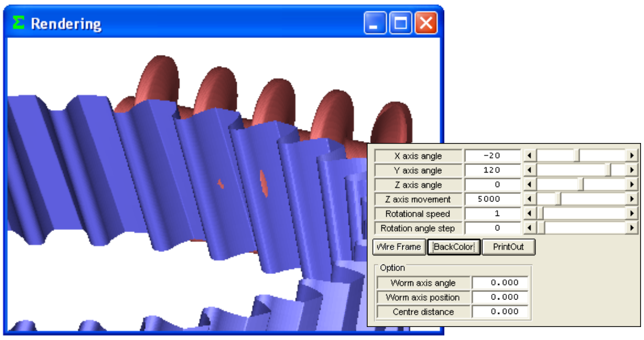
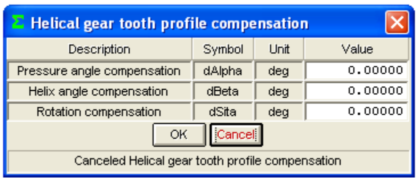


Fig. 4.11 Tooth Profile Rendering (β =17.5°)



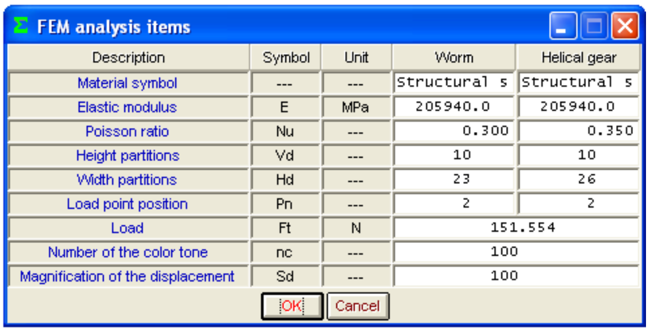
Description	Symbol	Unit	Value
Pressure angle compensation	dAlpha	deg	0.00000
Helix angle compensation	dBeta	deg	0.00000
Rotation compensation	dSita	deg	0.00000

Canceled Helical gear tooth profile compensation

Fig. 4.12 Corrected Specifications

4.9 FEM Tooth Profile Stress Analysis

Stress analysis can be easily performed by simply clicking the [FEM] button after the strength calculation. Fig. 4.13 shows the FEM analysis setting screen. Fig. 4.14 and Fig. 4.15 show the results of FEM analysis on the worm and the helical gear, respectively.



Description	Symbol	Unit	Worm	Helical gear
Material symbol	---	---	Structural s	Structural s
Elastic modulus	E	MPa	205940.0	205940.0
Poisson ratio	Nu	---	0.300	0.350
Height partitions	Vd	---	10	10
Width partitions	Hd	---	23	26
Load point position	Pn	---	2	2
Load	Ft	N	151.554	
Number of the color tone	nc	---	100	
Magnification of the displacement	Sd	---	100	

Fig. 4.13 FEM Analysis Settings

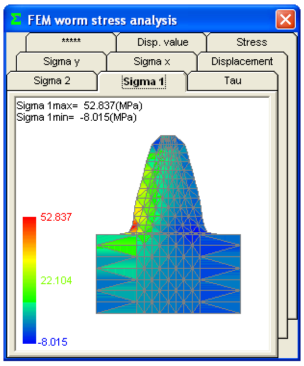


Fig. 4.14 FEM Analysis on Worm (Stress=ó₁)

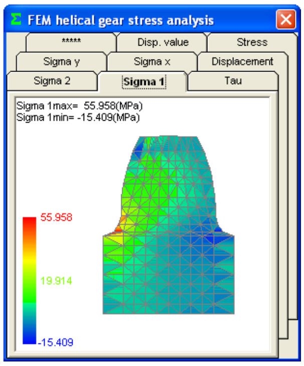


Fig. 4.15 FEM Analysis on Helical Gear (ó₁)

4.10 Transmission Error Analysis

Fig. 4.16 and Fig. 4.17 show the setting screens for transmission error analysis. The graphs in Fig. 4.18 and Fig. 4.19 show the results of analysis on the rotation transmission error and wow and flatter, respectively. These errors were raised by assembling the worm and helical gear pair to have a pitch error and rotating the helical gear by one turn. Fig. 4.20 shows a Fourier analysis graph.

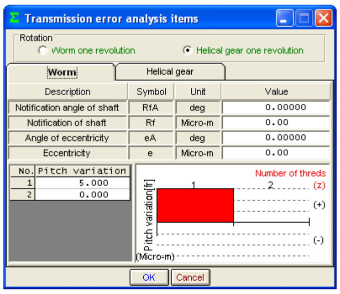


Fig. 4.16 Transmission Error Analysis Settings (Worm)

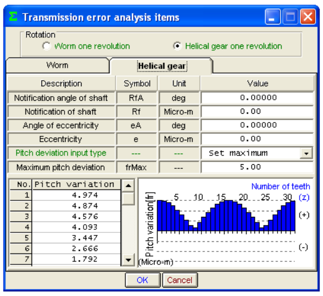


Fig. 4.17 Transmission Error Analysis Settings (Helical Gear)

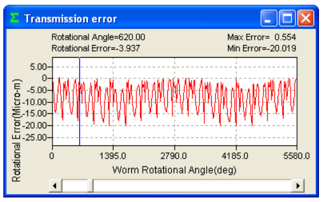


Fig. 4.18 Rotation Transmission Error

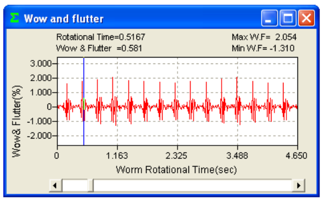


Fig. 4.19 Wow & Flatter

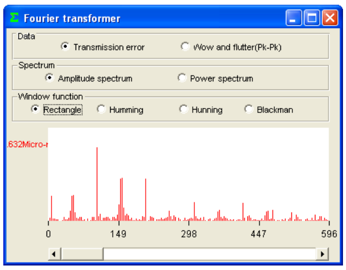


Fig. 4.20 Fourier Analysis

4.11 Sliding Speed and Hertzian Stress Graphs

Fig. 4.21 and Fig. 4.22 are graphs showing the sliding speed and the Hertzian stress, respectively. Because graphs show the results of analysis on the point of contact between the tooth flanks of the worm and helical gear, the optional transmission error analysis feature is required.

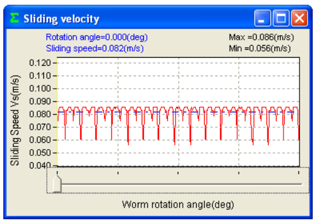


Fig. 4.21 Sliding Speed Graph

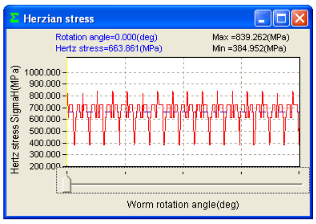


Fig. 4.22 Hertzian Stress Graph

4.12 Bearing Load Calculation

Fig. 4.23 shows the bearing load setting screen; Fig. 4.24 shows the result of the bearing load calculation.

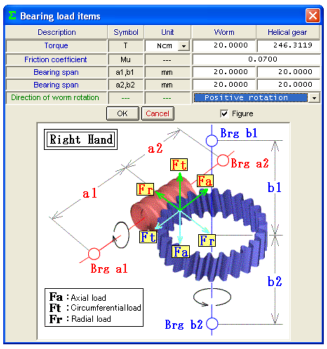


Fig. 4.23 Bearing Load Calculation Settings

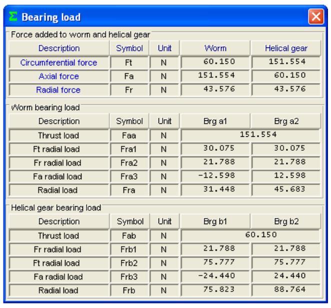


Fig. 4.24 Bearing Load Calculation Result

4.13 Tooth Contact Analysis

An example of contact analysis on the tooth flanks of the worm and helical gear is shown below. The setting screen in Fig. 4.25 provides various settings for tooth contact analysis. In this example, analysis will be made on the tooth contact of the worm and helical gear specified in Fig. 4.3. Here, the number of rotation position partitions is set to "3" although it accepts values in a range of 3 to 20. Fig. 4.26 shows a tooth contact state between the worm and the helical gear and Figs. 4.27 to 4.29 show their tooth contact states by 1/3 pitch. This example, however, does not take the deflection of the teeth and the pitch error into account.

It is noticeable that tooth contact pattern in Fig. 4.26 slightly differs from the tooth profile rendering image shown in Fig. 4.9. The reason for this is that the analysis in this example was made at a fineness that is two times (up to five times allowed) greater than that of the number of tooth profile partitions setting used for the tooth profile rendering image.

In addition to viewing the tooth contact state as a color pattern as shown in Fig. 4.26, to examine it in more detail, the user may click the [Tooth contact value] button in Fig. 4.25 to display the contact clearance values in Fig. 4.30. The slider control bar at the bottom of the screen can be used to change the target rotation position (1 to 3 in this example).

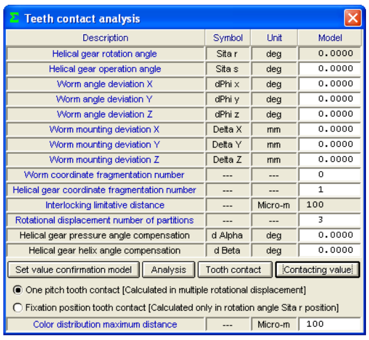


Fig. 4.25 Tooth Contact Analysis Settings

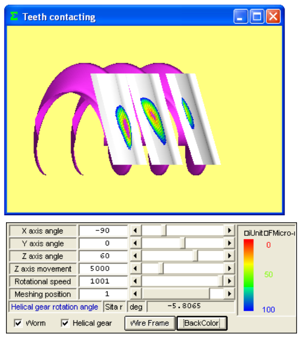


Fig.4.26 Tooth Contact State (Worm and Helical Gear)

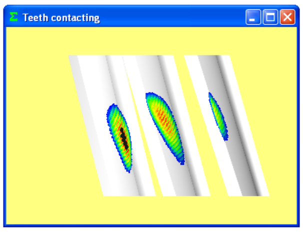


Fig. 4.27 Tooth Contact State 1

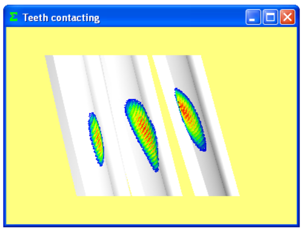


Fig. 4.28 Tooth Contact State 2

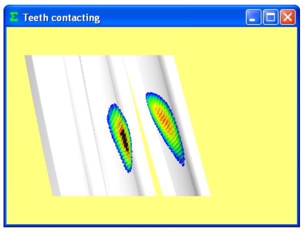


Fig. 4.29 Tooth Contact State 3

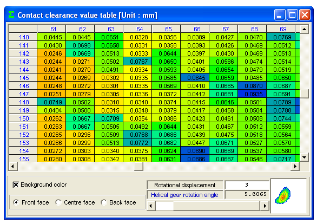


Fig. 4.30 Contact Clearance Values

4.14 Tooth Profile Data File Output

This feature enables the user to output gear meshing drawings into DXF-format files.

Also available is the option to output the tooth profiles of the worm and the helical gear into 3D-IGES-format files.