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User's Manual for Tooth Contact Analysis of Face-Milled Spiral Bevel Gears With Given Machine-Tool Settings

Faydor L. Litvin, Yi Zhang, and Jui-sheng Chen
University of Illinois at Chicago
Chicago, Illinois

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Summary

The main goal of this research project is to develop a computer program that will : (i) simulate the meshing and bearing contact for face-milled spiral bevel gears with *given* machine-tool settings, and (ii) to obtain the output; some of the data is required for hydrodynamic analysis of lubrication. It is assumed that the machine-tool settings and the blank data will be taken from the Gleason summaries.

The theoretical aspects of the program are based on the theory that has been developed in the NASA Contractor Report 4342, AVSCOM Technical Report 90-C-028 entitled " Local Synthesis and Tooth Contact Analysis of Face-Milled Spiral Bevel Gears", By Faydor L. Litvin and Yi Zhang. The difference between the computer programs developed in this report and the previous one is as follows: (i) The mean contact point of tooth surfaces for gears with given machine-tool settings must be determined by the search, while two parameters (H and V) are changed. Parameter H represents the displacement along the pinion axis, and parameter V represents the gear displacement that is perpendicular to the plane drawn through the axes of the pinion and the gear of their initial positions. This means that when parameter V differs from zero, the axis of the pinion and the gear are crossed but not intersected. The method of local synthesis developed in the previous report provides conditions of exact contact of surfaces at the mean point. (ii) In addition to the regular output data (transmission errors and bearing contact), the new computer program provides the information about the contacting force for each contact point, and the sliding and the so-called rolling velocity.

The contents of this report covers the following topics: (i)Instructions for the users how to insert the input data (items from 1.1 to 1.6),(ii) explanations regarding the output data (section 2), (iii) numerical example, and (iv) listing of the program.

1 Input Data

Insert into the program the input data and follow the instrutions given in items from 1.1 to 1.6.

1.1 Control Codes

1.	If V and H check is not desired, set JCL=1. DO not set JCL=3.
2.	For right hand gear JCH=1, for left hand gear JCH=2.
3.	TL1 and TL2 are numbers of extra point on contact path which should not be larger than 2.
4.	MM is the number of contact points.

1.2 Blank Data

Use the blank data given in Gleason's blank data summary.

Terminology		*Description* (Fig.1)
Gleason	UIC	
n	TN1	Pinion number of teeth
N	TN2	Gear number of teeth
E	C	Shaft offset (zero for spiral bevel gear) (mm)
F	FW	Face width of gear (mm)
Σ	GAMMA	Shaft angle (degree)
A	MCD	Cone distance to mean point (mm)
r_R	RGMA1	Pinion root cone angle (degree)
ψ_G	B2	Gear spiral angle (degree)
ψ_P	B1	Pinion spiral angle (degree)
Γ_R	RGMA2	Gear root cone angle (degree)
Γ_O	FGMA2	Gear face cone angle (degree)
Γ	PGMA2	Gear pitch cone angle (degree)
Z_R	D2R	Gear root cone apex beyond pitch apex (mm)
Z_O	D2F	Gear face cone apex beyond pitch apex (mm)
a_{OG}	ADD2	Gear mean addendum (mm)
h_{OG}	DED2	Gear mean dedendum (mm)
h_t	WD	Whole depth (mm)
c	CC	Clearance (mm)
δ	DEL	Elastic approach (experiment datum) (mm)

1.3 Gear Cutter Specifications

According to cutter specifications.input the following data into the program.

Terminology		*Description* (Fig.2)
Gleason	UIC	
r_C	RU2	Gear nominal cutter radius (mm)
W	PW2	Point width of gear cutter (mm)
ϕ_G	ALP2	Blade angle of gear cutter (degree)

1.4 Gear Machine-Tool Settings

According to the machine-tool settings, input the following data into the program.

Terminology		*Description* (Fig.5)
Gleason	UIC	
q	Q2	Basic cradle angle (radian)
S_R	SR2	Radial setting (mm)
X_G	XG2	Machine center to back (mm)
X_B	XB2	Sliding base (mm)
E_M	EM2	Blank offset (mm)
γ_m	GAMA2	Gear machine root angle (radian)
R_a	RAG	Ratio of roll

1.5 Pinion Machine-Tool settings

According to pinion machine-tool settings. input the following data into the program.

Terminology		*Description* (Fig.5)
Gleason	UIC	
R_{CP}	RCF	Point radius (mm)
q	Q1	Basic cradle angle (radian)
		(Q1 is positive for left hand pinion and
		negative for right hand pinion)
S_R	SR1	Radial setting (mm)
X_G	XG1	Machine center to back (mm)
X_B	XB1	Sliding base (mm)
E_M	EM1	Blank offset (mm)
γ_m	GAMA1	pinion machine root angle (radian)
R_a	RAP	Ratio of roll
ϕ_P	ALP1	Blade angle of pinion cutter (degree)
		APL1 is positive for pinion concave side,
		and negative for convex side.

1.6 Angular Velocity and Input Torque of Pinion

Input into the program the pinion angular velocity and the torque applied to the pinion.

Terminology		*Description* (Fig.2)
Gleason	UIC	
T	TORQUE	Input torque of pinion (N-mm)
ω_1	WP	Angular velocity of pinion (radian/sec)

2 Output Data

The output data are considered for two cases: (i) gear convex side, and (ii) gear concave side. For each case, three positions of location of bearing contact are considered (If JCL is set to 1.). Eleven items of output data are considered for each position. The following tables describe all items of the output data.

	Contact Position	Output items
Gear Convex Side	mean point	$1 \sim 11$
	toe	
	heel	
Gear Concave Side	mean point	
	toe	
	heel	

Item	Output	Description
1	V	the change of the offset between the gear and pinion axis (mm)
(Fig.3)	H	the shift of the pinion along its axis (mm)
2	ϕ_2'	the angles of rotation of gears being in meshing (degree)
(Fig.2)	$\Delta\phi_1'$	transmission errors (second)
3	X_c	X value of the contact path in $X_c - Y_c$ plane (mm)
(Fig.1)	Y_c	Y value of the contact path in $X_c - Y_c$ plane (mm)
	$2a$ $(2b)$	dimension of contact ellipse (if it is larger, the value is $2a$, or it is $2b$) (mm)
4	β_1	angle between the above axis and X_c axis (degree)
(Fig.6)	$2b$ $(2a)$	dimension of contact ellipse (if it is smaller, the value is $2b$, or it is $2a$) (mm)
	β_2	angle between the above axis and X_c axis (degree)

Item	Output	Description
	$V_{1\eta}$	projection velocity of pinion in η axis (mm/sec)
5	$V_{1\zeta}$	projection velocity of pinion in ζ axis (mm/sec)
(Fig.7)	$V_{2\eta}$	projection velocity of gear in η axis (mm/sec)
	$V_{2\zeta}$	projection velocity of gear in ζ axis (mm/sec)
6	α	angle between $e_I^{(1)}$ and η (radian)
(Fig.6)	$\sigma^{(12)}$	angle between $e_I^{(1)}$ and $e_I^{(2)}$ (radian)
	$e_\eta^{(1)}$	projection of $e_I^{(1)}$ in η axis
7	$e_\zeta^{(1)}$	projection of $e_I^{(1)}$ in ζ axis
(Fig.6)	$e_\eta^{(2)}$	projection of $e_I^{(2)}$ in η axis
	$e_\zeta^{(2)}$	projection of $e_I^{(2)}$ in ζ axis
	κ_{1I}	principal curvature I of the pinion (1/mm)
8	κ_{1II}	principal curvature II of the pinion (1/mm)
(Fig.8)	κ_{2I}	principal curvature I of the gear (1/mm)
	κ_{2II}	principal curvature II of the gear (1/mm)
9	$(V_1 + V_2)_\eta$	projection rolling velocity in η axis (mm/sec)
(Fig.7)	$(V_1 + V_2)_\zeta$	projection rolling velocity in ζ axis (mm/sec)
10	$(V_1 - V_2)_\eta$	projection sliding velocity in η axis (mm/sec)
(Fig.7)	$(V_1 - V_2)_\zeta$	projection sliding velocity in ζ axis (mm/sec)
11	M	normal force between pinion and gear (N-mm)

3 Numercial Example

A left hand gear is considered in the numercial example. Lists of input and output data are represented in the following tables. For the discussed example, it is shown that transmission errors are very small and the bearing contact is stable for both sides at all three positions, toe, mean, and heel.

CONTROL CODES	
JCL	1
JCH	2
TL1 ; TL2	0.5 ; 1.5
MM	15

BLANK DATA		
	Pinion	Gear
Number of Teeth	19	62
Face Width		36.83
Shaft Angle	95	
Outer Cone Distance		132.399
Root Angle	16.5667	75.4333
Spiral Angle	34.5	34.5
Face Angle		78.4333
Pitch Angle		77.5833
Root Apex Beyond Pitch Apex		-0.87376
Face Apex beyond Pitch Apex		0.0
Addendum		1.8
Dedendum		5.8166
Whole Depth	7.62	7.62
Clearance	0.991	0.991
Elastic approach	0.00635	

GEAR CUTTER SPECIFICATIONS	
Cutter Diameter	190.5
Point width	2.54
Blade Angle	20

GEAR MACHINE-TOOL SETTINGS	
Basic Cradle Angle	52.65884927
Radial Setting	98.73489
Machine center to back	0.0
Sliding base	-0.8456733
Blank offset	0.0
Machine Root Angle	75.43333148
Ratio of roll	1.02323

PINION MATHINE-TOOL SETTINGS		
	Concave	Convex
Cutter Blade Angle	15	-25
Cutter Point Radius	98.06175	92.43733
Cradle Angle	-55.93823623	-55.31136884
Radial Setting	98.50532	96.98392
Machine Center to Back	3.416642	-4.091412
Sliding Base	-0.9741914	1.166590
Blank Offset	5.007493	-3.448327
Machine Root Angle	16.56657615	16.56657617
Ratio of Roll	3.423191	3.1755

Input Torque of Pinion	1.0
Angular Velocity of Pinion	1.0

```
********************************************
* INPUT FOR GEAR CONVEX SIDE               *
********************************************


********************************************
*           INPUT DATA OF PART 1.          *
********************************************


JCL= 2     JCH= 2     TL1=0.50     TL2=1.50     MM=15

********************************************
*           INPUT DATA OF PART 2.          *
********************************************


PINION NUMBER OF TEETH (TN1)=                              19.00000
GEAR NUMBER OF TEETH (TN2)=                                62.00000
SHAFT OFFSET (C)=                                         0.0000000E+00
FACE WIDTH OF GEAR (FW)=                                   36.83000
SHAFT ANGLE (GAMMA)=                                       1.658063
CONE DISTANCE TO MEAN POINT (MCD)=                         113.9190
PINION ROOT CONE ANGLE (RGMA1)=                           0.2891435
PINION SPIRAL ANGLE (B1)=                                 0.6021386
GEAR SPIRAL ANGLE (B2)=                                   0.6021386
GEAR ROOT CONE ANGLE (RGMA2)=                              1.316554
GEAR FACE CONE ANGLE (FGMA2)=                              1.368919
GEAR PITCH CONE ANGLE (PGMA2)=                             1.354084
GEAR ROOT CONE APEX BEYOND PITCH APEX (D2R)=-0.8737600
GEAR FACE CONE APEX BEYOND PITCH APEX (D2F)= 0.0000000E+00
GEAR MEAN ADDENDUM (ADD2)=                                 1.803400
GEAR MEAN DEDENDUM (DED2)=                                 5.816600
WHOLE DEPTH (WD)=                                          7.620000
CLEARANCE (CC)=                                           0.9906000
ELASTIC APPROACH (DEL)=                                   0.6350000E-02

********************************************
*           INPUT DATA OF PART 3.          *
********************************************


GEAR NOMINAL CUTTER RADIUS (RU2)=  95.25000
POINT WIDTH OF GEAR CUTTER (W)=   2.540000
BLADE ANGLE OF GEAR CUTTER (ALP2)= 0.3490659

********************************************
*           INPUT DATA OF PART 4.          *
********************************************


BASIC CRADLE ANGLE (Q2)=                0.9190703
RADIAL SETTING (SR2)=                    98.73489
MACHINE CENTER TO BACK (XG2)=           0.0000000E+00
GEAR MACHINE ROOT ANGLE (GAMA2)=       1.316560
SLIDING BASE (XB2)=                    -0.8456733
BLANK OFFSET (EM2)=                     0.0000000E+00
```

RATIO OF ROLL (RAG)= 1.023230

```
*********************************************
*            INPUT DATA OF PART 5.          *
*********************************************
```

POINT RADIUS (RCF)= 98.06175
BASIC CRADLE ANGLE (Q1)= -0.9763064
RADIAL SETTING (SR1)= 98.50532
MACHINE CENTER TO BACK (XG1)= 3.416642
SLIDING BASE (XB1)= -0.9741914
BLANK OFFSET (EM1)= 5.007493
PINION MACHINE ROOT ANGLE (GAMA1)= 0.2891434
RATIO OF ROLL (RAP)= 3.423191
BLADE ANGLE OF PINION CUTTER (ALP1)= 0.2617994

```
*********************************************
*            INPUT DATA OF PART 6.          *
*********************************************
```

INPUT TORQUE OF PINION (TORQUE)= 1.000000
ANGULAR VELOCITY OF PINION (WP)= 1.000000

```
*********************************************
* OUTPUT FOR GEAR CONVEX SIDE               *
*********************************************
```

```
*******************************************
*    V AND H AT MEAN POSITION (ITEM 1)    *
*******************************************
```

*** V = -0.1509857E-01*** H =-0.2198417

```
**************************************************
* TRANSMISSION ERROR IN A MESHING PERIOD (ITEM 2)*
**************************************************
```

-3.088219	-2.943179
-2.604348	-2.043496
-2.120477	-1.326379
-1.636607	-0.7778609
-1.152736	-0.3846725
-0.6688646	-0.1342003
-0.1849936	-0.1444700E-01
0.2988774	-0.1399405E-01
0.7827483	-0.1219668
1.266619	-0.3280022
1.750490	-0.6222175
2.234361	-0.9951824
2.718232	-1.437891

3.202103	-1.941737
3.685974	-2.498490

****
* CONTACT PATH FOR A PAIR OF TEETH IN MESH (ITEM 3)*
****

-4.988546	2.774248
-4.178916	2.922196
-3.385169	3.074827
-2.606932	3.232112
-1.843840	3.394019
-1.095529	3.560511
-0.3616435	3.731548
0.3581687	3.907084
1.064254	4.087072
1.756953	4.271458
2.436601	4.460187
3.103528	4.653202
3.758057	4.850443
4.400508	5.051845
5.031190	5.257346

****
* DIMENSION AND ORIENTATION OF CONTACT ELLIPSE(ITEM 4)
****

1.014201	91.03602	12.22251	-191.3238
1.010350	91.13529	12.17474	-191.4094
1.005974	91.23857	12.12548	-191.4893
1.001066	91.34577	12.07476	-191.5637
0.9956206	91.45682	12.02266	-191.6326
0.9896293	91.57163	11.96923	-191.6961
0.9830839	91.69012	11.91453	-191.7542
0.9759755	91.81220	11.85864	-191.8071
0.9682941	91.93776	11.80163	-191.8546
0.9600289	92.06672	11.74357	-191.8971
0.9511678	92.19895	11.68454	-191.9344
0.9416975	92.33437	11.62461	-191.9668
0.9316032	92.47286	11.56386	-191.9943
0.9208684	92.61431	11.50237	-192.0170
0.9094750	92.75861	11.44022	-192.0350

****
* VELOCITIES V1 AND V2 ON THE TANGENT PLANE (ITEM 5)*
****

V1*ETA	V1*ZETA	V2*ETA	V2*ZETA
15.21394	-17.90580	15.19737	-12.14940
15.47501	-17.71019	15.45709	-12.27267
15.73434	-17.49887	15.71512	-12.39322
15.99189	-17.27197	15.97149	-12.51103
16.24761	-17.02962	16.22623	-12.62608
16.50146	-16.77197	16.47939	-12.73837
16.75338	-16.49918	16.73098	-12.84788
17.00333	-16.21142	16.98106	-12.95460

17.25126	-15.90884	17.22965	-13.05854
17.49711	-15.59165	17.47678	-13.15968
17.74082	-15.26002	17.72249	-13.25805
17.98234	-14.91414	17.96681	-13.35363
18.22161	-14.55422	18.20978	-13.44645
18.45858	-14.18046	18.45142	-13.53650
18.69318	-13.79307	18.69177	-13.62382

****
* PRINCIPAL DIRECTIONS OF PINION AND GEAR (ITEM 6,7)*
****

ALFA	SIGMA12
-0.3682736E-01	1.231344
-0.3662320E-01	1.233866
-0.3636832E-01	1.236326
-0.3606312E-01	1.238733
-0.3570809E-01	1.241095
-0.3530384E-01	1.243418
-0.3485106E-01	1.245709
-0.3435053E-01	1.247972
-0.3380312E-01	1.250213
-0.3320977E-01	1.252435
-0.3257149E-01	1.254643
-0.3188937E-01	1.256841
-0.3116455E-01	1.259030
-0.3039824E-01	1.261215
-0.2959168E-01	1.263397

E1I*ETA	E1I*ZETA	E2I*ETA	E2I*ZETA
0.9993219	-0.3681903E-01	0.3674628	0.9300382
0.9993294	-0.3661502E-01	0.3649266	0.9310363
0.9993387	-0.3636031E-01	0.3623975	0.9320237
0.9993498	-0.3605530E-01	0.3598680	0.9330032
0.9993625	-0.3570050E-01	0.3573317	0.9339775
0.9993769	-0.3529651E-01	0.3547830	0.9349487
0.9993928	-0.3484401E-01	0.3522168	0.9359184
0.9994101	-0.3434378E-01	0.3496289	0.9368883
0.9994287	-0.3379668E-01	0.3470154	0.9378594
0.9994486	-0.3320367E-01	0.3443732	0.9388328
0.9994696	-0.3256573E-01	0.3416994	0.9398093
0.9994916	-0.3188397E-01	0.3389919	0.9407893
0.9995144	-0.3115951E-01	0.3362485	0.9417733
0.9995380	-0.3039356E-01	0.3334678	0.9427615
0.9995622	-0.2958736E-01	0.3306485	0.9437540

****
* PRINCIPAL CURVATURES OF PINION AND GEAR (ITEM 8)*
****

K1I	K1II	K2I	K2II
0.9470329E-02	-0.4391726E-01	0.4766298E-02	0.1051413E-01
0.9471213E-02	-0.4434718E-01	0.4717669E-02	0.1051364E-01

0.9472441E-02	-0.4483160E-01	0.4671417E-02	0.1051340E-01
0.9474010E-02	-0.4537344E-01	0.4627439E-02	0.1051339E-01
0.9475915E-02	-0.4597600E-01	0.4585638E-02	0.1051361E-01
0.9478153E-02	-0.4664307E-01	0.4545921E-02	0.1051404E-01
0.9480718E-02	-0.4737898E-01	0.4508197E-02	0.1051469E-01
0.9483607E-02	-0.4818868E-01	0.4472381E-02	0.1051554E-01
0.9486812E-02	-0.4907783E-01	0.4438392E-02	0.1051659E-01
0.9490329E-02	-0.5005290E-01	0.4406150E-02	0.1051784E-01
0.9494152E-02	-0.5112133E-01	0.4375580E-02	0.1051928E-01
0.9498273E-02	-0.5229168E-01	0.4346612E-02	0.1052091E-01
0.9502686E-02	-0.5357381E-01	0.4319174E-02	0.1052273E-01
0.9507384E-02	-0.5497917E-01	0.4293203E-02	0.1052473E-01
0.9512361E-02	-0.5652106E-01	0.4268633E-02	0.1052691E-01

```
***************************************************
*  ROLLING VELOCITY OF PINION AND GEAR (ITEM 9)   *
***************************************************
```

(V1+V2)*ETA	(V1+V2)*ZETA
30.41130	-30.05520
30.93210	-29.98286
31.44946	-29.89209
31.96338	-29.78299
32.47384	-29.65570
32.98084	-29.51034
33.48436	-29.34706
33.98439	-29.16602
34.48091	-28.96738
34.97389	-28.75133
35.46331	-28.51806
35.94915	-28.26777
36.43139	-28.00067
36.91000	-27.71697
37.38495	-27.41690

```
***************************************************
*  SLIDING VELOCITY OF PINION AND GEAR (ITEM 10)  *
***************************************************
```

(V1-V2)*ETA	(V1-V2)*ZETA
0.1656693E-01	-5.756396
0.1792098E-01	-5.437523
0.1922410E-01	-5.105656
0.2040192E-01	-4.760942
0.2137699E-01	-4.403537
0.2206909E-01	-4.033602
0.2239561E-01	-3.651304
0.2227185E-01	-3.256813
0.2161140E-01	-2.850307
0.2032647E-01	-2.431965
0.1832825E-01	-2.001971
0.1552724E-01	-1.560512
0.1183357E-01	-1.107777
0.7157357E-02	-0.6439589

```
    0.1408966E-02    -0.1692504

************************************************
*  NORMAL FORCE AT POINT  M  (UNIT: N) (ITEM 11) *
************************************************

 0.3848752E-01
 0.3833808E-01
 0.3819583E-01
 0.3806043E-01
 0.3793156E-01
 0.3780892E-01
 0.3769222E-01
 0.3758120E-01
 0.3747561E-01
 0.3737520E-01
 0.3727976E-01
 0.3718907E-01
 0.3710293E-01
 0.3702115E-01
 0.3694356E-01

      *****************************************
      *     V AND H CHECK AT TOE POSITION     *
      *****************************************

    *** V =   0.1104179E-01*** H = 0.1475838

************************************************
* TRANSMISSION ERROR IN A MESHING PERIOD (ITEM 2)*
************************************************

    -6.304543          -4.643300
    -5.820672          -3.240368
    -5.336801          -2.114416
    -4.852930          -1.246871
    -4.369059         -0.6201609
    -3.885188         -0.2176513
    -3.401317         -0.2357677E-01
    -2.917446         -0.2298568E-01
    -2.433575         -0.2016861
    -1.949704         -0.5461967
    -1.465833          -1.043701
   -0.9819622          -1.682006
   -0.4980913          -2.449502
   -0.1422031E-01      -3.335126
    0.4696507          -4.328330

*************************************************
* CONTACT PATH FOR A PAIR OF TEETH IN MESH (ITEM 3)*
*************************************************

    -14.79623          2.672390
```

-13.89134	2.800297
-13.00329	2.932353
-12.13169	3.068554
-11.27614	3.208894
-10.43624	3.353361
-9.611628	3.501939
-8.801936	3.654611
-8.006807	3.811354
-7.225897	3.972144
-6.458866	4.136953
-5.705386	4.305750
-4.965133	4.478504
-4.237793	4.655177
-3.523058	4.835733

****

* DIMENSION AND ORIENTATION OF CONTACT ELLIPSE(ITEM 4)

****

0.9342850	91.32118	12.03970	-189.0370
0.9320679	91.40155	11.99685	-189.1354
0.9293616	91.48543	11.95305	-189.2292
0.9261612	91.57278	11.90833	-189.3184
0.9224608	91.66355	11.86270	-189.4028
0.9182543	91.75769	11.81618	-189.4827
0.9135345	91.85515	11.76878	-189.5580
0.9082938	91.95586	11.72054	-189.6288
0.9025237	92.05978	11.67149	-189.6951
0.8962147	92.16683	11.62166	-189.7570
0.8893565	92.27695	11.57109	-189.8145
0.8819377	92.39006	11.51981	-189.8676
0.8739455	92.50610	11.46786	-189.9165
0.8653659	92.62498	11.41529	-189.9612
0.8561833	92.74664	11.36213	-190.0017

****

* VELOCITIES V1 AND V2 ON THE TANGENT PLANE (ITEM 5)*

****

V1*ETA	V1*ZETA	V2*ETA	V2*ZETA
12.49053	-15.84543	12.45828	-10.64443
12.74950	-15.71510	12.71879	-10.77400
13.00697	-15.57017	12.97780	-10.90143
13.26293	-15.41076	13.23532	-11.02670
13.51733	-15.23697	13.49138	-11.14979
13.77016	-15.04889	13.74599	-11.27069
14.02137	-14.84665	13.99916	-11.38938
14.27094	-14.63036	14.25094	-11.50585
14.51882	-14.40015	14.50133	-11.62008
14.76498	-14.15614	14.75035	-11.73208
15.00937	-13.89847	14.99803	-11.84183
15.25197	-13.62727	15.24439	-11.94933
15.49272	-13.34269	15.48946	-12.05457
15.73159	-13.04488	15.73325	-12.15755
15.96852	-12.73397	15.97578	-12.25827

```
*******************************************************
*  PRINCIPAL DIRECTIONS OF PINION AND GEAR (ITEM 6,7)*
*****************************************************
```

ALFA	SIGMA12
-0.2701725E-01	1.217351
-0.2699822E-01	1.221544
-0.2693962E-01	1.225527
-0.2684147E-01	1.229323
-0.2670385E-01	1.232953
-0.2652691E-01	1.236436
-0.2631090E-01	1.239788
-0.2605610E-01	1.243024
-0.2576290E-01	1.246156
-0.2543172E-01	1.249197
-0.2506306E-01	1.252156
-0.2465748E-01	1.255042
-0.2421558E-01	1.257865
-0.2373804E-01	1.260630
-0.2322558E-01	1.263346

E1I*ETA	E1I*ZETA	E2I*ETA	E2I*ZETA
0.9996351	-0.2701396E-01	0.3713502	0.9284929
0.9996356	-0.2699494E-01	0.3674359	0.9300488
0.9996372	-0.2693636E-01	0.3636743	0.9315262
0.9996398	-0.2683825E-01	0.3600441	0.9329353
0.9996435	-0.2670067E-01	0.3565263	0.9342853
0.9996482	-0.2652380E-01	0.3531045	0.9355839
0.9996539	-0.2630786E-01	0.3497639	0.9368379
0.9996606	-0.2605315E-01	0.3464917	0.9380531
0.9996682	-0.2576005E-01	0.3432762	0.9392345
0.9996766	-0.2542898E-01	0.3401075	0.9403866
0.9996859	-0.2506044E-01	0.3369764	0.9415131
0.9996960	-0.2465498E-01	0.3338750	0.9426174
0.9997068	-0.2421321E-01	0.3307963	0.9437022
0.9997183	-0.2373581E-01	0.3277339	0.9447701
0.9997303	-0.2322349E-01	0.3246825	0.9458231

```
*****************************************************
*  PRINCIPAL CURVATURES OF PINION AND GEAR (ITEM 8)*
*****************************************************
```

K1I	K1II	K2I	K2II
0.9547515E-02	-0.5187293E-01	0.5706113E-02	0.1051651E-01
0.9547210E-02	-0.5222542E-01	0.5635820E-02	0.1051372E-01
0.9547191E-02	-0.5263860E-01	0.5568637E-02	0.1051134E-01
0.9547457E-02	-0.5311493E-01	0.5504425E-02	0.1050935E-01
0.9548006E-02	-0.5365734E-01	0.5443053E-02	0.1050771E-01
0.9548836E-02	-0.5426921E-01	0.5384395E-02	0.1050640E-01
0.9549944E-02	-0.5495445E-01	0.5328332E-02	0.1050541E-01
0.9551329E-02	-0.5571760E-01	0.5274750E-02	0.1050472E-01
0.9552988E-02	-0.5656386E-01	0.5223542E-02	0.1050431E-01
0.9554916E-02	-0.5749922E-01	0.5174603E-02	0.1050416E-01

0.9557112E-02	-0.5853057E-01	0.5127837E-02	0.1050428E-01
0.9559571E-02	-0.5966582E-01	0.5083149E-02	0.1050464E-01
0.9562289E-02	-0.6091412E-01	0.5040450E-02	0.1050524E-01
0.9565262E-02	-0.6228600E-01	0.4999655E-02	0.1050607E-01
0.9568486E-02	-0.6379371E-01	0.4960682E-02	0.1050712E-01

```
**************************************************
*  ROLLING VELOCITY OF PINION AND GEAR (ITEM 9)  *
**************************************************
```

(V1+V2)*ETA	(V1+V2)*ZETA
24.94881	-26.48986
25.46829	-26.48910
25.98477	-26.47161
26.49825	-26.43747
27.00871	-26.38676
27.51614	-26.31958
28.02054	-26.23603
28.52187	-26.13621
29.02014	-26.02023
29.51533	-25.88822
30.00741	-25.74030
30.49636	-25.57660
30.98218	-25.39726
31.46483	-25.20243
31.94430	-24.99225

```
**************************************************
*  SLIDING VELOCITY OF PINION AND GEAR (ITEM 10) *
**************************************************
```

(V1-V2)*ETA	(V1-V2)*ZETA
0.3225195E-01	-5.201004
0.3070541E-01	-4.941093
0.2917069E-01	-4.668740
0.2760270E-01	-4.384060
0.2595343E-01	-4.087172
0.2417214E-01	-3.778201
0.2220556E-01	-3.457271
0.1999809E-01	-3.124515
0.1749203E-01	-2.780065
0.1462774E-01	-2.424060
0.1134391E-01	-2.056639
0.7577749E-02	-1.677945
0.3265218E-02	-1.288126
-0.1658745E-02	-0.8873275
-0.7260007E-02	-0.4757013

```
**************************************************
*  NORMAL FORCE AT POINT  M  (UNIT: N) (ITEM 11) *
**************************************************
```

0.4066712E-01
0.4043412E-01

```
 0.4021163E-01
 0.3999911E-01
 0.3979605E-01
 0.3960198E-01
 0.3941647E-01
 0.3923909E-01
 0.3906946E-01
 0.3890723E-01
 0.3875204E-01
 0.3860358E-01
 0.3846156E-01
 0.3832568E-01
 0.3819568E-01

      ******************************************
      *      V AND H CHECK AT HEEL POSITION    *
      ******************************************

   *** V = -0.2141119E-01*** H =-0.4525389

************************************************
* TRANSMISSION ERROR IN A MESHING PERIOD (ITEM 2)*
************************************************

    -1.024484          -1.900525
   -0.5406131          -1.308069
   -0.5674212E-01     -0.8412886
    0.4271288         -0.4886614
    0.9109998         -0.2392326
     1.394871         -0.8258194E-01
     1.878742         -0.8791722E-02
     2.362613         -0.8416808E-02
     2.846484         -0.7245624E-01
     3.330355         -0.1923263
     3.814226         -0.3598352
     4.298097         -0.5671586
     4.781968         -0.8068172
     5.265839          -1.071655
     5.749709          -1.354818

*************************************************
* CONTACT PATH FOR A PAIR OF TEETH IN MESH (ITEM 3)*
*************************************************

     1.332605           2.739108
     2.075327           2.903572
     2.802574           3.073139
     3.514733           3.247755
     4.212188           3.427361
     4.895320           3.611891
     5.564507           3.801275
     6.220120           3.995439
     6.862530           4.194307
```

7.492099	4.397796
8.109185	4.605824
8.714140	4.818304
9.307307	5.035149
9.889023	5.256270
10.45962	5.481576

****
* DIMENSION AND ORIENTATION OF CONTACT ELLIPSE(ITEM 4)
****

1.076365	90.73886	12.49311	-193.1057
1.071309	90.85493	12.43721	-193.1776
1.065697	90.97539	12.37933	-193.2429
1.059520	91.10013	12.31959	-193.3020
1.052774	91.22904	12.25808	-193.3547
1.045449	91.36199	12.19492	-193.4013
1.037537	91.49885	12.13024	-193.4418
1.029031	91.63950	12.06414	-193.4763
1.019918	91.78381	11.99674	-193.5050
1.010189	91.93163	11.92818	-193.5279
0.9998303	92.08283	11.85857	-193.5453
0.9888285	92.23727	11.78803	-193.5571
0.9771680	92.39480	11.71668	-193.5637
0.9648313	92.55528	11.64463	-193.5650
0.9517988	92.71856	11.57200	-193.5613

****
* VELOCITIES V1 AND V2 ON THE TANGENT PLANE (ITEM 5)*
****

V1*ETA	V1*ZETA	V2*ETA	V2*ZETA
17.02936	-19.58255	17.03932	-13.24622
17.29040	-19.33576	17.29556	-13.36285
17.54958	-19.07220	17.55007	-13.47621
17.80682	-18.79207	17.80289	-13.58628
18.06208	-18.49556	18.05405	-13.69307
18.31528	-18.18287	18.30362	-13.79656
18.56636	-17.85423	18.55163	-13.89677
18.81526	-17.50987	18.79812	-13.99371
19.06191	-17.15002	19.04315	-14.08739
19.30622	-16.77493	19.28674	-14.17782
19.54814	-16.38486	19.52895	-14.26504
19.78759	-15.98006	19.76980	-14.34906
20.02450	-15.56080	20.00935	-14.42992
20.25878	-15.12735	20.24762	-14.50765
20.49038	-14.67998	20.48464	-14.58228

****
* PRINCIPAL DIRECTIONS OF PINION AND GEAR (ITEM 6,7)*
****

ALFA	SIGMA12
-0.4549908E-01	1.231981

-0.4510908E-01	1.233979
-0.4465888E-01	1.235961
-0.4414939E-01	1.237934
-0.4358162E-01	1.239900
-0.4295670E-01	1.241864
-0.4227587E-01	1.243828
-0.4154049E-01	1.245795
-0.4075196E-01	1.247769
-0.3991182E-01	1.249749
-0.3902163E-01	1.251740
-0.3808305E-01	1.253742
-0.3709777E-01	1.255757
-0.3606755E-01	1.257786
-0.3499418E-01	1.259830

E1I*ETA	E1I*ZETA	E2I*ETA	E2I*ZETA
0.9989651	-0.4548338E-01	0.3749232	0.9270559
0.9989828	-0.4509378E-01	0.3727091	0.9279482
0.9990030	-0.4464404E-01	0.3704504	0.9288523
0.9990256	-0.4413505E-01	0.3681438	0.9297689
0.9990505	-0.4356782E-01	0.3657864	0.9306988
0.9990775	-0.4294349E-01	0.3633760	0.9316426
0.9991065	-0.4226328E-01	0.3609105	0.9326004
0.9991373	-0.4152854E-01	0.3583887	0.9335725
0.9991698	-0.4074069E-01	0.3558092	0.9345586
0.9992036	-0.3990122E-01	0.3531714	0.9355586
0.9992388	-0.3901173E-01	0.3504748	0.9365722
0.9992749	-0.3807384E-01	0.3477192	0.9375987
0.9993120	-0.3708926E-01	0.3449047	0.9386377
0.9993496	-0.3605974E-01	0.3420315	0.9396885
0.9993878	-0.3498704E-01	0.3391001	0.9407503

****
* PRINCIPAL CURVATURES OF PINION AND GEAR (ITEM 8)*
****

K1I	K1II	K2I	K2II
0.9405825E-02	-0.3885064E-01	0.4209941E-02	0.1051821E-01
0.9407868E-02	-0.3930641E-01	0.4173548E-02	0.1051863E-01
0.9410304E-02	-0.3981314E-01	0.4139174E-02	0.1051925E-01
0.9413129E-02	-0.4037382E-01	0.4106733E-02	0.1052006E-01
0.9416335E-02	-0.4099185E-01	0.4076140E-02	0.1052106E-01
0.9419916E-02	-0.4167110E-01	0.4047315E-02	0.1052225E-01
0.9423862E-02	-0.4241597E-01	0.4020182E-02	0.1052363E-01
0.9428167E-02	-0.4323148E-01	0.3994665E-02	0.1052518E-01
0.9432821E-02	-0.4412338E-01	0.3970694E-02	0.1052692E-01
0.9437816E-02	-0.4509824E-01	0.3948201E-02	0.1052883E-01
0.9443143E-02	-0.4616359E-01	0.3927120E-02	0.1053092E-01
0.9448791E-02	-0.4732813E-01	0.3907387E-02	0.1053318E-01
0.9454750E-02	-0.4860191E-01	0.3888943E-02	0.1053562E-01
0.9461012E-02	-0.4999658E-01	0.3871729E-02	0.1053822E-01
0.9467566E-02	-0.5152576E-01	0.3855689E-02	0.1054100E-01

****
* ROLLING VELOCITY OF PINION AND GEAR (ITEM 9) *

```
**************************************************


     (V1+V2)*ETA      (V1+V2)*ZETA

      34.06868         -32.82877
      34.58597         -32.69861
      35.09965         -32.54841
      35.60971         -32.37835
      36.11613         -32.18862
      36.61890         -31.97943
      37.11799         -31.75100
      37.61338         -31.50358
      38.10505         -31.23740
      38.59296         -30.95275
      39.07709         -30.64989
      39.55740         -30.32912
      40.03385         -29.99072
      40.50640         -29.63500
      40.97502         -29.26226

**************************************************
*  SLIDING VELOCITY OF PINION AND GEAR (ITEM 10) *
**************************************************


     (V1-V2)*ETA      (V1-V2)*ZETA

   -0.9957557E-02     -6.336331
   -0.5160084E-02     -5.972908
   -0.4951693E-03     -5.595996
    0.3933997E-02     -5.205791
    0.8021374E-02     -4.802494
    0.1165858E-01     -4.386312
    0.1473541E-01     -3.957460
    0.1714034E-01     -3.516159
    0.1876099E-01     -3.062632
    0.1948465E-01     -2.597109
    0.1919872E-01     -2.119820
    0.1779110E-01     -1.630999
    0.1515068E-01     -1.130881
    0.1116768E-01    -0.6197011
    0.5734029E-02    -0.9769675E-01

**************************************************
*  NORMAL FORCE AT POINT  M  (UNIT: N) (ITEM 11) *
**************************************************

 0.3746020E-01
 0.3735450E-01
 0.3725446E-01
 0.3715980E-01
 0.3707029E-01
 0.3698569E-01
 0.3690577E-01
 0.3683034E-01
 0.3675920E-01
 0.3669216E-01
```

```
0.3662905E-01
0.3656970E-01
0.3651397E-01
0.3646169E-01
0.3641274E-01

*********************************************
* INPUT FOR GEAR CONCAVE SIDE               *
*********************************************


*********************************************
*           INPUT DATA OF PART 1.           *
*********************************************


JCL= 2     JCH= 2     TL1=0.50     TL2=1.50     MM=15

*********************************************
*           INPUT DATA OF PART 2.           *
*********************************************


PINION NUMBER OF TEETH (TN1)=                          19.00000
GEAR NUMBER OF TEETH (TN2)=                            62.00000
SHAFT OFFSET (C)=                                      0.0000000E+00
FACE WIDTH OF GEAR (FW)=                               36.83000
SHAFT ANGLE (GAMMA)=                                   1.658063
CONE DISTANCE TO MEAN POINT (MCD)=                     113.9190
PINION ROOT CONE ANGLE (RGMA1)=                        0.2891435
PINION SPIRAL ANGLE (B1)=                              0.6021386
GEAR SPIRAL ANGLE (B2)=                                0.6021386
GEAR ROOT CONE ANGLE (RGMA2)=                          1.316554
GEAR FACE CONE ANGLE (FGMA2)=                          1.368919
GEAR PITCH CONE ANGLE (PGMA2)=                         1.354084
GEAR ROOT CONE APEX BEYOND PITCH APEX (D2R)=-0.8737600
GEAR FACE CONE APEX BEYOND PITCH APEX (D2F)= 0.0000000E+00
GEAR MEAN ADDENDUM (ADD2)=                             1.803400
GEAR MEAN DEDENDUM (DED2)=                             5.816600
WHOLE DEPTH (WD)=                                      7.620000
CLEARANCE (CC)=                                        0.9906000
ELASTIC APPROACH (DEL)=                                0.6350000E-02

*********************************************
*           INPUT DATA OF PART 3.           *
*********************************************


GEAR NOMINAL CUTTER RADIUS (RU2)=  95.25000
POINT WIDTH OF GEAR CUTTER (W)=  2.540000
BLADE ANGLE OF GEAR CUTTER (ALP2)=-0.3490659

*********************************************
*           INPUT DATA OF PART 4.           *
*********************************************


BASIC CRADLE ANGLE (Q2)=                 0.9190703
```

```
RADIAL SETTING (SR2)=                        98.73489
MACHINE CENTER TO BACK (XG2)=               0.0000000E+00
GEAR MACHINE ROOT ANGLE (GAMA2)=  1.316560
SLIDING BASE (XB2)=                        -0.8456733
BLANK OFFSET (EM2)=                         0.0000000E+00
RATIO OF ROLL (RAG)=                         1.023230

********************************************
*           INPUT DATA OF PART 5.          *
********************************************


POINT RADIUS (RCF)=                          92.43733
BASIC CRADLE ANGLE (Q1)=                    -0.9653655
RADIAL SETTING (SR1)=                        96.98392
MACHINE CENTER TO BACK (XG1)=               -4.091412
SLIDING BASE (XB1)=                          1.166590
BLANK OFFSET (EM1)=                         -3.448327
PINION MACHINE ROOT ANGLE (GAMA1)=          0.2891434
RATIO OF ROLL (RAP)=                       3.175500
BLADE ANGLE OF PINION CUTTER (ALP1)=   -0.4363323

********************************************
*           INPUT DATA OF PART 6.          *
********************************************


INPUT TORQUE OF PINION (TORQUE)=  1.000000
ANGULAR VELOCITY OF PINION (WP)=  1.000000

********************************************
* OUTPUT FOR GEAR CONCAVE SIDE             *
********************************************



    ******************************************
    *     V AND H AT MEAN POSITION (ITEM 1)  *
    ******************************************



  *** V = -0.5910321E-02*** H = 0.1932238



************************************************
* TRANSMISSION ERROR IN A MESHING PERIOD (ITEM 2)*
************************************************

  -3.331903         2.050649
  -2.848032         1.392358
  -2.364161        0.8828519
  -1.880290        0.5051904
  -1.396419        0.2434497
 -0.9125485        0.8264243E-01
 -0.4286775        0.8642705E-02
  0.5519344E-01    0.8117856E-02
```

0.5390644	0.6846496E-01
1.022935	0.1777525
1.506806	0.3246666
1.990677	0.4984615
2.474548	0.6889142
2.958419	0.8862820
3.442290	1.081264

****
* CONTACT PATH FOR A PAIR OF TEETH IN MESH (ITEM 3)*
****

-4.334323	4.874241
-3.617848	4.728720
-2.920511	4.576689
-2.241572	4.418399
-1.580314	4.254104
-0.9360392	4.084058
-0.3080727	3.908513
0.3042388	3.727720
0.9015258	3.541927
1.484396	3.351378
2.053433	3.156312
2.609198	2.956964
3.152230	2.753562
3.683045	2.546331
4.202135	2.335486

****
* DIMENSION AND ORIENTATION OF CONTACT ELLIPSE(ITEM 4)
****

12.39062	-164.7643	0.8885608	-88.55036
12.30416	-164.7914	0.9025001	-88.69157
12.21580	-164.8281	0.9163900	-88.83733
12.12578	-164.8743	0.9302197	-88.98737
12.03435	-164.9295	0.9439794	-89.14144
11.94172	-164.9936	0.9576595	-89.29929
11.84812	-165.0662	0.9712514	-89.46065
11.75377	-165.1470	0.9847469	-89.62527
11.65886	-165.2357	0.9981384	-89.79292
11.56359	-165.3321	1.011419	-89.96335
11.46812	-165.4359	1.024582	-90.13633
11.37264	-165.5468	1.037621	-90.31162
11.27728	-165.6646	1.050531	-90.48900
11.18219	-165.7889	1.063306	-90.66826
11.08750	-165.9195	1.075942	-90.84919

****
* VELOCITIES V1 AND V2 ON THE TANGENT PLANE (ITEM 5)*
****

V1*ETA	V1*ZETA	V2*ETA	V2*ZETA
-13.77887	15.26909	-13.53769	15.27052
-14.24390	15.50196	-13.58825	15.49640
-14.71777	15.73338	-13.63258	15.71985

-15.20023	15.96354	-13.67081	15.94094
-15.69101	16.19261	-13.70307	16.15972
-16.18985	16.42077	-13.72950	16.37628
-16.69648	16.64818	-13.75026	16.59067
-17.21067	16.87503	-13.76548	16.80294
-17.73217	17.10145	-13.77530	17.01317
-18.26073	17.32761	-13.77989	17.22139
-18.79614	17.55365	-13.77937	17.42767
-19.33815	17.77970	-13.77390	17.63204
-19.88657	18.00590	-13.76362	17.83455
-20.44118	18.23237	-13.74867	18.03525
-21.00177	18.45923	-13.72920	18.23417

****
* PRINCIPAL DIRECTIONS OF PINION AND GEAR (ITEM 6,7)*
****

ALFA	SIGMA12
1.526822	0.2069932
1.525116	0.2085789
1.523386	0.2100576
1.521634	0.2114326
1.519860	0.2127075
1.518066	0.2138857
1.516254	0.2149707
1.514426	0.2159661
1.512582	0.2168755
1.510724	0.2177023
1.508853	0.2184499
1.506970	0.2191219
1.505078	0.2197214
1.503176	0.2202519
1.501267	0.2207164

E1I*ETA	E1I*ZETA	E2I*ETA	E2I*ZETA
0.4395983E-01	0.9990333	-0.1622981	0.9867418
0.4566402E-01	0.9989569	-0.1621795	0.9867613
0.4739219E-01	0.9988764	-0.1619315	0.9868020
0.4914284E-01	0.9987918	-0.1615588	0.9868631
0.5091448E-01	0.9987030	-0.1610663	0.9869436
0.5270563E-01	0.9986101	-0.1604589	0.9870425
0.5451485E-01	0.9985130	-0.1597415	0.9871589
0.5634069E-01	0.9984116	-0.1589189	0.9872916
0.5818177E-01	0.9983060	-0.1579960	0.9874398
0.6003670E-01	0.9981962	-0.1569775	0.9876022
0.6190415E-01	0.9980821	-0.1558680	0.9877779
0.6378283E-01	0.9979638	-0.1546722	0.9879658
0.6567145E-01	0.9978413	-0.1533946	0.9881650
0.6756881E-01	0.9977146	-0.1520396	0.9883744
0.6947370E-01	0.9975838	-0.1506114	0.9885930

****
* PRINCIPAL CURVATURES OF PINION AND GEAR (ITEM 8)*
****

K1I	K1II	K2I	K2II
0.9205147E-02	0.6017203E-01	0.9340912E-02	-0.4635866E-02
0.9213766E-02	0.5821804E-01	0.9347798E-02	-0.4620605E-02
0.9223483E-02	0.5635662E-01	0.9355060E-02	-0.4608094E-02
0.9234267E-02	0.5458307E-01	0.9362685E-02	-0.4598217E-02
0.9246086E-02	0.5289286E-01	0.9370658E-02	-0.4590862E-02
0.9258906E-02	0.5128165E-01	0.9378966E-02	-0.4585927E-02
0.9272693E-02	0.4974529E-01	0.9387593E-02	-0.4583315E-02
0.9287413E-02	0.4827980E-01	0.9396527E-02	-0.4582936E-02
0.9303031E-02	0.4688141E-01	0.9405754E-02	-0.4584704E-02
0.9319510E-02	0.4554653E-01	0.9415260E-02	-0.4588542E-02
0.9336817E-02	0.4427175E-01	0.9425032E-02	-0.4594377E-02
0.9354917E-02	0.4305385E-01	0.9435059E-02	-0.4602139E-02
0.9373774E-02	0.4188977E-01	0.9445327E-02	-0.4611767E-02
0.9393356E-02	0.4077663E-01	0.9455824E-02	-0.4623201E-02
0.9413629E-02	0.3971168E-01	0.9466539E-02	-0.4636388E-02

```
*************************************************
*  ROLLING VELOCITY OF PINION AND GEAR (ITEM 9)  *
*************************************************
```

(V1+V2)*ETA	(V1+V2)*ZETA
-27.31656	30.53961
-27.83215	30.99837
-28.35035	31.45324
-28.87104	31.90448
-29.39408	32.35233
-29.91935	32.79705
-30.44674	33.23885
-30.97615	33.67797
-31.50747	34.11462
-32.04062	34.54900
-32.57551	34.98132
-33.11205	35.41174
-33.65019	35.84046
-34.18985	36.26762
-34.73096	36.69340

```
*************************************************
*  SLIDING VELOCITY OF PINION AND GEAR (ITEM 10) *
*************************************************
```

(V1-V2)*ETA	(V1-V2)*ZETA
-0.2411782	-0.1425491E-02
-0.6556447	0.5558897E-02
-1.085194	0.1353003E-01
-1.529427	0.2260066E-01
-1.987943	0.3288242E-01
-2.460341	0.4448523E-01
-2.946222	0.5751676E-01
-3.445192	0.7208197E-01
-3.956861	0.8828265E-01

-4.480844	0.1062171
-5.016764	0.1259798
-5.564253	0.1476612
-6.122950	0.1713475
-6.692502	0.1971203
-7.272567	0.2250570

```
***************************************************
*  NORMAL FORCE AT POINT  M  (UNIT: N) (ITEM 11) *
***************************************************
```

0.3895180E-01
0.3880367E-01
0.3866304E-01
0.3852945E-01
0.3840248E-01
0.3828174E-01
0.3816687E-01
0.3805753E-01
0.3795341E-01
0.3785423E-01
0.3775970E-01
0.3766959E-01
0.3758365E-01
0.3750168E-01
0.3742348E-01

```
*******************************************
*      V AND H CHECK AT TOE POSITION      *
*******************************************
```

*** V = -0.2199081E-01*** H =-0.1498285

```
***************************************************
* TRANSMISSION ERROR IN A MESHING PERIOD (ITEM 2)*
***************************************************
```

-6.479857	5.646869
-5.995986	3.915876
-5.512115	2.539149
-5.028244	1.487950
-4.544373	0.7354329
-4.060502	0.2564900
-3.576631	0.2760954E-01
-3.092760	0.2674785E-01
-2.608889	0.2332125
-2.125018	0.6275558
-1.641147	1.191478
-1.157276	1.907736
-0.6734054	2.760067
-0.1895344	3.733106
0.2943366	4.812325

```
****************************************************
* CONTACT PATH FOR A PAIR OF TEETH IN MESH (ITEM 3)*
****************************************************
```

-14.59955	4.300153
-13.70885	4.206852
-12.84143	4.106810
-11.99648	4.000193
-11.17321	3.887170
-10.37086	3.767920
-9.588687	3.642623
-8.825969	3.511464
-8.082014	3.374630
-7.356151	3.232312
-6.647727	3.084700
-5.956114	2.931986
-5.280705	2.774362
-4.620910	2.612020
-3.976164	2.445150

```
*******************************************************
* DIMENSION AND ORIENTATION OF CONTACT ELLIPSE(ITEM 4)
*******************************************************
```

12.26161	-167.2240	0.8281227	-88.85987
12.19695	-167.1849	0.8409137	-88.95893
12.13043	-167.1553	0.8537310	-89.06287
12.06216	-167.1349	0.8665627	-89.17154
11.99225	-167.1238	0.8793973	-89.28474
11.92081	-167.1215	0.8922239	-89.40230
11.84797	-167.1280	0.9050322	-89.52402
11.77385	-167.1430	0.9178122	-89.64971
11.69858	-167.1663	0.9305545	-89.77919
11.62229	-167.1977	0.9432501	-89.91226
11.54510	-167.2370	0.9558905	-90.04872
11.46714	-167.2840	0.9684676	-90.18839
11.38853	-167.3384	0.9809740	-90.33108
11.30940	-167.4001	0.9934023	-90.47658
11.22987	-167.4687	1.005746	-90.62472

```
*****************************************************
* VELOCITIES V1 AND V2 ON THE TANGENT PLANE (ITEM 5)*
*****************************************************
```

V1*ETA	V1*ZETA	V2*ETA	V2*ZETA
-12.49251	12.63339	-11.72954	12.62788
-12.89104	12.88382	-11.81994	12.87051
-13.29923	13.13203	-11.90446	13.11037
-13.71688	13.37816	-11.98317	13.34751
-14.14377	13.62235	-12.05614	13.58202
-14.57969	13.86475	-12.12346	13.81395
-15.02442	14.10551	-12.18520	14.04338
-15.47775	14.34476	-12.24146	14.27036
-15.93947	14.58265	-12.29233	14.49495
-16.40935	14.81932	-12.33789	14.71723
-16.88720	15.05491	-12.37825	14.93724

-17.37280	15.28956	-12.41351	15.15505
-17.86594	15.52339	-12.44377	15.37070
-18.36642	15.75653	-12.46914	15.58424
-18.87403	15.98911	-12.48971	15.79574

```
***************************************************
*  PRINCIPAL DIRECTIONS OF PINION AND GEAR (ITEM 6,7)*
***************************************************
```

ALFA	SIGMA12
1.538418	0.1619096
1.537058	0.1641130
1.535672	0.1662131
1.534260	0.1682117
1.532824	0.1701109
1.531365	0.1719129
1.529884	0.1736199
1.528382	0.1752342
1.526861	0.1767581
1.525320	0.1781942
1.523762	0.1795447
1.522188	0.1808123
1.520599	0.1819994
1.518995	0.1831085
1.517379	0.1841422

E1I*ETA	E1I*ZETA	E2I*ETA	E2I*ZETA
0.3237235E-01	0.9994759	-0.1291697	0.9916225
0.3373185E-01	0.9994309	-0.1300058	0.9915132
0.3511747E-01	0.9993832	-0.1307133	0.9914202
0.3652821E-01	0.9993326	-0.1312952	0.9913433
0.3796304E-01	0.9992791	-0.1317546	0.9912824
0.3942089E-01	0.9992227	-0.1320946	0.9912371
0.4090067E-01	0.9991632	-0.1323186	0.9912072
0.4240125E-01	0.9991007	-0.1324300	0.9911924
0.4392151E-01	0.9990350	-0.1324323	0.9911921
0.4546031E-01	0.9989661	-0.1323289	0.9912059
0.4701649E-01	0.9988941	-0.1321234	0.9912333
0.4858891E-01	0.9988189	-0.1318195	0.9912737
0.5017642E-01	0.9987404	-0.1314206	0.9913267
0.5177789E-01	0.9986586	-0.1309305	0.9913916
0.5339219E-01	0.9985736	-0.1303526	0.9914677

```
***************************************************
*  PRINCIPAL CURVATURES OF PINION AND GEAR (ITEM 8)*
***************************************************
```

KII	KIII	K2I	K2II
0.9417293E-02	0.6878357E-01	0.9391830E-02	-0.5604308E-02
0.9419303E-02	0.6659819E-01	0.9395637E-02	-0.5558711E-02
0.9422272E-02	0.6450378E-01	0.9399841E-02	-0.5517228E-02
0.9426191E-02	0.6249711E-01	0.9404431E-02	-0.5479653E-02
0.9431049E-02	0.6057491E-01	0.9409398E-02	-0.5445795E-02

0.9436831E-02	0.5873390E-01	0.9414731E-02	-0.5415477E-02
0.9443523E-02	0.5697080E-01	0.9420419E-02	-0.5388534E-02
0.9451107E-02	0.5528237E-01	0.9426451E-02	-0.5364813E-02
0.9459566E-02	0.5366541E-01	0.9432816E-02	-0.5344172E-02
0.9468881E-02	0.5211680E-01	0.9439504E-02	-0.5326478E-02
0.9479030E-02	0.5063349E-01	0.9446504E-02	-0.5311608E-02
0.9489992E-02	0.4921254E-01	0.9453805E-02	-0.5299447E-02
0.9501746E-02	0.4785108E-01	0.9461396E-02	-0.5289888E-02
0.9514269E-02	0.4654637E-01	0.9469266E-02	-0.5282831E-02
0.9527539E-02	0.4529573E-01	0.9477405E-02	-0.5278183E-02

```
**************************************************
*  ROLLING VELOCITY OF PINION AND GEAR (ITEM 9)  *
**************************************************
```

(V1+V2)*ETA	(V1+V2)*ZETA
-24.22205	25.26127
-24.71098	25.75433
-25.20369	26.24240
-25.70005	26.72568
-26.19991	27.20437
-26.70315	27.67871
-27.20962	28.14889
-27.71921	28.61512
-28.23179	29.07761
-28.74725	29.53655
-29.26546	29.99215
-29.78631	30.44460
-30.30971	30.89408
-30.83556	31.34077
-31.36375	31.78485

```
**************************************************
*  SLIDING VELOCITY OF PINION AND GEAR (ITEM 10) *
**************************************************
```

(V1-V2)*ETA	(V1-V2)*ZETA
-0.7629746	0.5504713E-02
-1.071105	0.1330707E-01
-1.394778	0.2166311E-01
-1.733714	0.3064666E-01
-2.087628	0.4033390E-01
-2.456228	0.5080286E-01
-2.839216	0.6213290E-01
-3.236288	0.7440423E-01
-3.647140	0.8769747E-01
-4.071463	0.1020932
-4.508948	0.1176715
-4.959284	0.1345116
-5.422163	0.1526917
-5.897278	0.1722881
-6.384322	0.1933757

```
**************************************************
```

```
*  NORMAL FORCE AT POINT  M  (UNIT: N) (ITEM 11) *
**************************************************

 0.4135705E-01
 0.4110269E-01
 0.4086155E-01
 0.4063279E-01
 0.4041560E-01
 0.4020927E-01
 0.4001311E-01
 0.3982650E-01
 0.3964888E-01
 0.3947970E-01
 0.3931848E-01
 0.3916475E-01
 0.3901809E-01
 0.3887812E-01
 0.3874445E-01


      *******************************************
      *     V AND H CHECK AT HEEL POSITION      *
      *******************************************


    *** V = -0.1072102      *** H = 0.3093568


**************************************************
* TRANSMISSION ERROR IN A MESHING PERIOD (ITEM 2)*
**************************************************

    -1.223451        -0.1868333
   -0.7395799        -0.1786354
   -0.2557089        -0.1488280
    0.2281620        -0.1072738
    0.7120330        -0.6331230E-01
     1.195904        -0.2580818E-01
     1.679775        -0.3194979E-02
     2.163646        -0.3515138E-02
     2.647517        -0.3445618E-01
     3.131388        -0.1033835
     3.615259        -0.2173702
     4.099130        -0.3832238
     4.583001        -0.6075109
     5.066872        -0.8965790
     5.550743         -1.256577

***************************************************
* CONTACT PATH FOR A PAIR OF TEETH IN MESH (ITEM 3)*
***************************************************

     2.481835         5.284603
     3.045159         5.084887
     3.593482         4.879732
     4.127532         4.669468
```

4.648001	4.454409
5.155545	4.234862
5.650791	4.011120
6.134327	3.783465
6.606713	3.552167
7.068477	3.317483
7.526114	3.079660
7.962095	2.838932
8.394860	2.595522
8.818824	2.349644
9.234379	2.101499

****
* DIMENSION AND ORIENTATION OF CONTACT ELLIPSE(ITEM 4)
****

12.67801	-162.8305	0.9321738	-88.25093
12.55430	-162.9362	0.9471072	-88.43828
12.43025	-163.0506	0.9619018	-88.62901
12.30618	-163.1733	0.9765501	-88.82277
12.18239	-163.3039	0.9910454	-89.01927
12.05913	-163.4421	1.005382	-89.21820
11.93663	-163.5875	1.019554	-89.41927
11.81510	-163.7397	1.033557	-89.62221
11.69473	-163.8985	1.047387	-89.82676
11.57565	-164.0634	1.061039	-90.03266
11.45801	-164.2343	1.074511	-90.23969
11.34192	-164.4107	1.087800	-90.44763
11.22746	-164.5925	1.100902	-90.65626
11.11472	-164.7793	1.113816	-90.86539
11.00375	-164.9710	1.126539	-91.07482

****
* VELOCITIES V1 AND V2 ON THE TANGENT PLANE (ITEM 5)*
****

V1*ETA	V1*ZETA	V2*ETA	V2*ZETA
-14.69587	17.12870	-14.89398	17.09233
-15.22100	17.34087	-14.89786	17.29917
-15.75361	17.55275	-14.89582	17.50404
-16.29341	17.76453	-14.88806	17.70701
-16.84010	17.97641	-14.87481	17.90813
-17.39342	18.18855	-14.85626	18.10746
-17.95311	18.40110	-14.83261	18.30504
-18.51893	18.61421	-14.80406	18.50092
-19.09064	18.82803	-14.77080	18.69514
-19.66801	19.04267	-14.73299	18.88773
-20.25084	19.25826	-14.69083	19.07873
-20.83892	19.47489	-14.64446	19.26816
-21.43206	19.69266	-14.59407	19.45606
-22.03008	19.91167	-14.53979	19.64244
-22.63281	20.13199	-14.48177	19.82733

****
* PRINCIPAL DIRECTIONS OF PINION AND GEAR (ITEM 6,7)*
****

ALFA	SIGMA12
1.516874	0.2434202
1.514893	0.2441374
1.512896	0.2447581
1.510884	0.2452872
1.508858	0.2457299
1.506821	0.2460909
1.504773	0.2463750
1.502717	0.2465865
1.500653	0.2467298
1.498583	0.2468090
1.496508	0.2468280
1.494429	0.2467906
1.492347	0.2467001
1.490264	0.2465602
1.488180	0.2463739

E1I*ETA	E1I*ZETA	E2I*ETA	E2I*ZETA
0.5389615E-01	0.9985465	-0.1883658	0.9820989
0.5587397E-01	0.9984378	-0.1871247	0.9823362
0.5786813E-01	0.9983242	-0.1857721	0.9825929
0.5987695E-01	0.9982058	-0.1843146	0.9828673
0.6189878E-01	0.9980824	-0.1827585	0.9831578
0.6393209E-01	0.9979543	-0.1811102	0.9834628
0.6597536E-01	0.9978213	-0.1793756	0.9837807
0.6802717E-01	0.9976835	-0.1775603	0.9841099
0.7008615E-01	0.9975409	-0.1756699	0.9844491
0.7215102E-01	0.9973937	-0.1737096	0.9847969
0.7422051E-01	0.9972419	-0.1716844	0.9851520
0.7629346E-01	0.9970854	-0.1695991	0.9855131
0.7836873E-01	0.9969244	-0.1674583	0.9858792
0.8044526E-01	0.9967590	-0.1652662	0.9862490
0.8252201E-01	0.9965892	-0.1630270	0.9866216

****
* PRINCIPAL CURVATURES OF PINION AND GEAR (ITEM 8)*
****

K1I	K1II	K2I	K2II
0.9013079E-02	0.5499739E-01	0.9305260E-02	-0.4072346E-02
0.9030890E-02	0.5316148E-01	0.9315314E-02	-0.4077720E-02
0.9049740E-02	0.5142343E-01	0.9325681E-02	-0.4085075E-02
0.9069574E-02	0.4977690E-01	0.9336343E-02	-0.4094329E-02
0.9090340E-02	0.4821599E-01	0.9347284E-02	-0.4105406E-02
0.9111987E-02	0.4673519E-01	0.9358487E-02	-0.4118237E-02
0.9134464E-02	0.4532936E-01	0.9369935E-02	-0.4132756E-02
0.9157724E-02	0.4399376E-01	0.9381615E-02	-0.4148904E-02
0.9181720E-02	0.4272393E-01	0.9393511E-02	-0.4166626E-02
0.9206407E-02	0.4151576E-01	0.9405609E-02	-0.4185874E-02
0.9231744E-02	0.4036541E-01	0.9417897E-02	-0.4206602E-02
0.9257688E-02	0.3926931E-01	0.9430363E-02	-0.4228769E-02
0.9284202E-02	0.3822416E-01	0.9442994E-02	-0.4252338E-02

0.9311249E-02	0.3722686E-01	0.9455780E-02	-0.4277276E-02
0.9338792E-02	0.3627456E-01	0.9468710E-02	-0.4303552E-02

```
**************************************************
*  ROLLING VELOCITY OF PINION AND GEAR (ITEM 9)  *
**************************************************
```

(V1+V2)*ETA	(V1+V2)*ZETA
-29.58985	34.22104
-30.11886	34.64003
-30.64943	35.05678
-31.18147	35.47154
-31.71491	35.88454
-32.24968	36.29600
-32.78573	36.70614
-33.32300	37.11514
-33.86144	37.52317
-34.40101	37.93040
-34.94167	38.33698
-35.48338	38.74305
-36.02613	39.14872
-36.56987	39.55412
-37.11458	39.95933

```
**************************************************
*  SLIDING VELOCITY OF PINION AND GEAR (ITEM 10) *
**************************************************
```

(V1-V2)*ETA	(V1-V2)*ZETA
0.1981134	0.3636853E-01
-0.3231402	0.4169912E-01
-0.8577949	0.4870884E-01
-1.405342	0.5752866E-01
-1.965289	0.6828290E-01
-2.537161	0.8108911E-01
-3.120500	0.9605789E-01
-3.714867	0.1132929
-4.319841	0.1328908
-4.935017	0.1549414
-5.560011	0.1795276
-6.194455	0.2067259
-6.837995	0.2366060
-7.490297	0.2692313
-8.151041	0.3046592

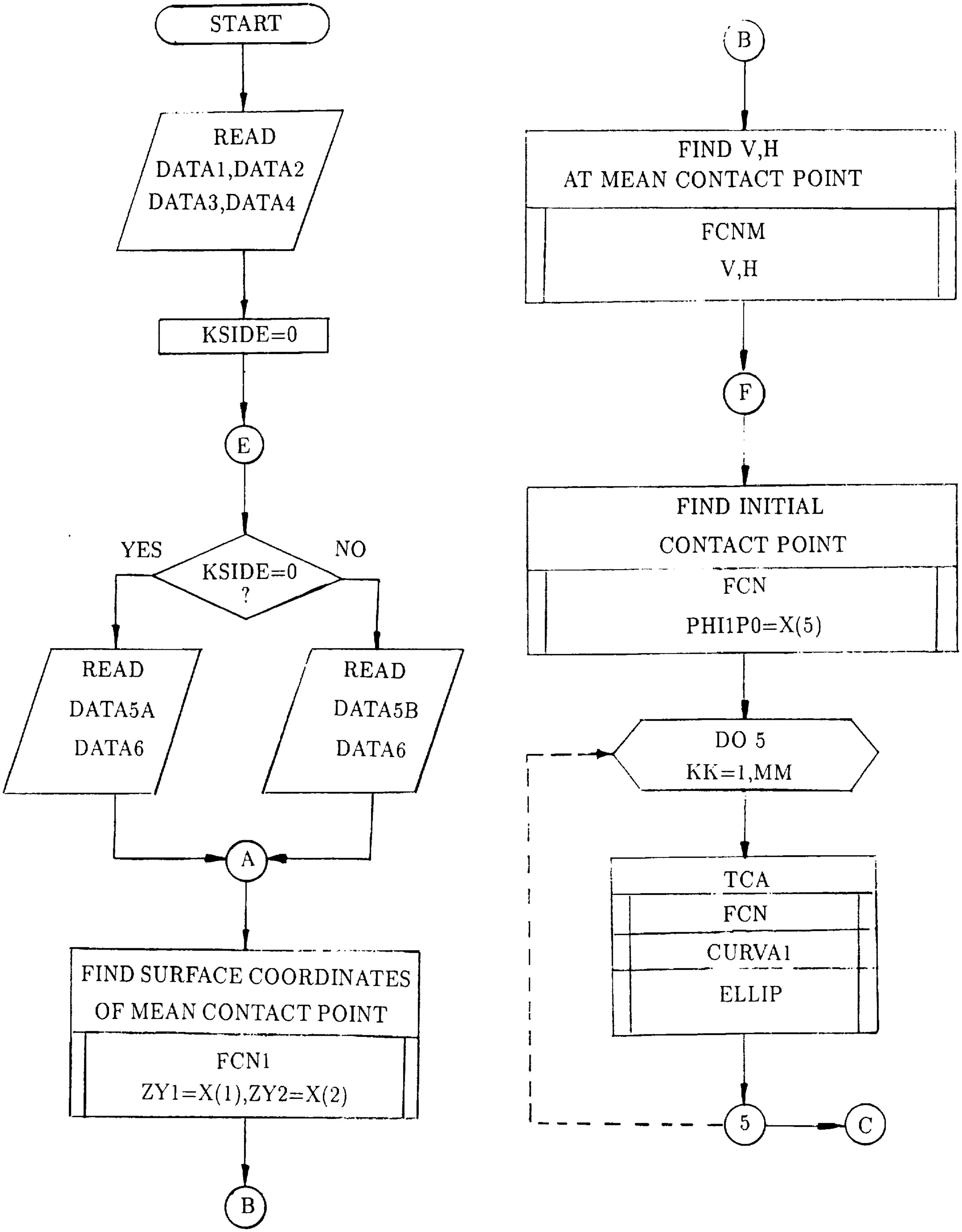
```
**************************************************
*  NORMAL FORCE AT POINT  M  (UNIT: N) (ITEM 11) *
**************************************************
```

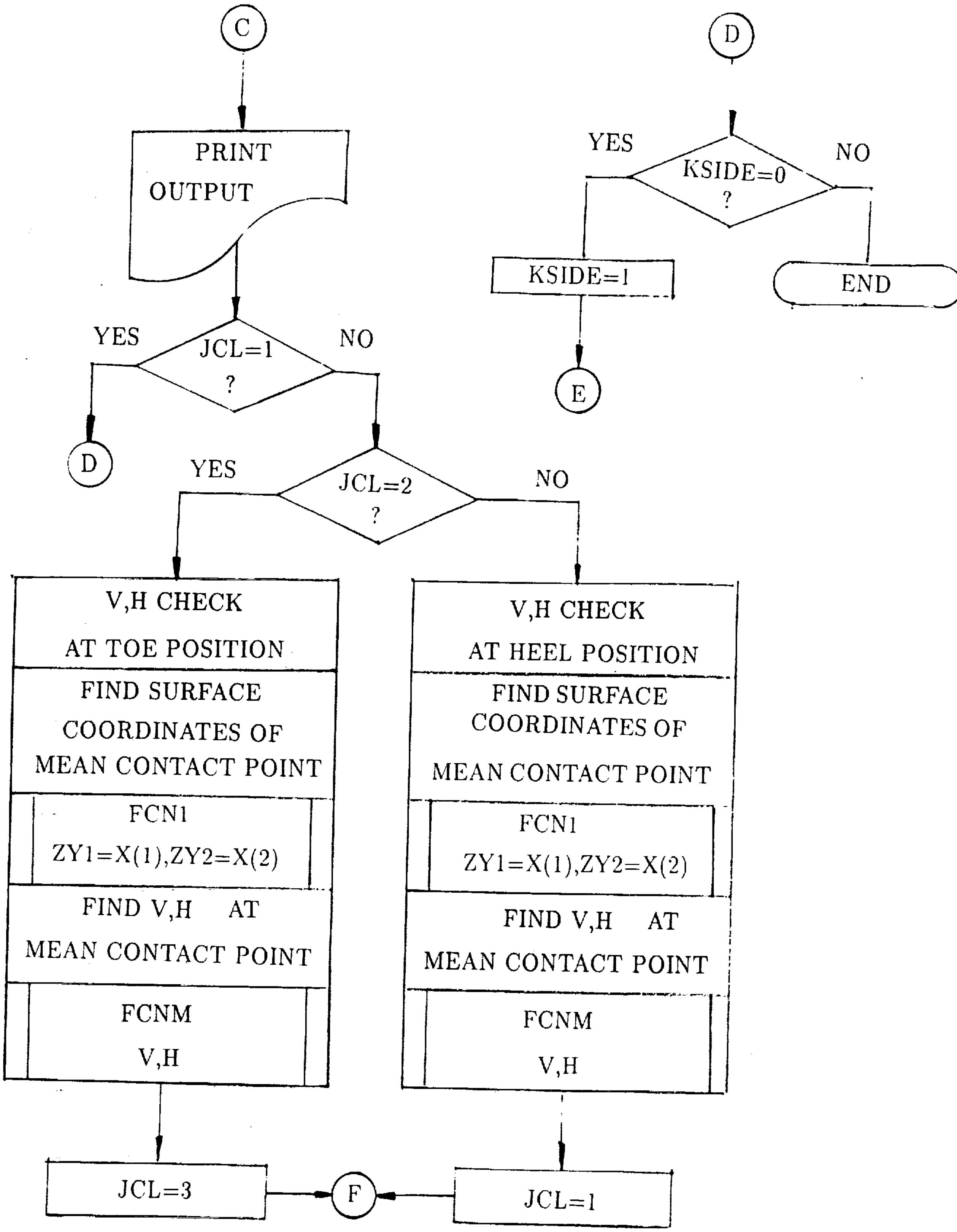
0.3776804E-01
0.3767704E-01
0.3759053E-01
0.3750825E-01
0.3742996E-01

0.3735542E-01
0.3728443E-01
0.3721680E-01
0.3715233E-01
0.3709088E-01
0.3703228E-01
0.3697641E-01
0.3692312E-01
0.3687231E-01
0.3682385E-01

4 Program Flow Chart

FLOW CHART OF COMPUTER PROGRAM





C
PRINT
OUTPUT
YES
JCL=1
?
NO
D
YES
JCL=2
?
NO
V,H CHECK
AT TOE POSITION
FIND SURFACE
COORDINATES OF
MEAN CONTACT POINT
FCN1
ZY1=X(1),ZY2=X(2)
FIND V,H AT
MEAN CONTACT POINT
FCNM
V,H
JCL=3
F
V,H CHECK
AT HEEL POSITION
FIND SURFACE
COORDINATES OF
MEAN CONTACT POINT
FCN1
ZY1=X(1),ZY2=X(2)
FIND V,H AT
MEAN CONTACT POINT
FCNM
V,H
JCL=1
D
YES
KSIDE=0
?
NO
KSIDE=1
E
END

5 Listing of Computer Program

```
C      ***********************************************************
C      *   THIS PROGRAM DESIGNATED FOT THE TOOTH CONTACT ANALYSIS *
C      *                 OF THE SPIRAL BEVEL GEARS                *
C      ***********************************************************



       IMPLICIT REAL*8(A-H,O-Z)
       REAL*8 KS,KQ,KII,KIII,K2I,K2II,KFI,KFII,KD,KF,KH,mcd
       REAL*8 M11,M12,M13,L11,L12,L13,L14,M21,M22,M23,L21,L22,L23,L24,
      &N11,N12,N21,N22
       real*8 xi(5),x(5),f(5)
       EXTERNAL FCN1,FCN,FCNM,CURVA1,ELLIP
       DIMENSION CH(3),P(3),E1EF(3),ESN(3),EQN(3),W1VT2(3),WV12(3),
      $W2VT1(3),EFIH(3),EFIIH(3),RH(3),GNH(3),E2IH(3),E2IIH(3),PI2P(20),
      &E1IH(3),E1IIH(3),EFI(3),EFII(3),E1I(3),E1II(3),GN(3),EFE1(3),
      &ERR(20),XCP(20),YCP(20),AX1(20),AX2(20),ANG1(20),ANG2(20),
      &VTT1(3),VTT2(3),VPT1(20),VPT2(20),VGT1(20),VGT2(20),
      &AALFA(20),ALO12(20),AK1I(20),AK1II(20),AK2I(20),AK2II(20),
      &VRT1(20),VRT2(20),VST1(20),VST2(20),FORCEM(20),VVV1(3),VVV2(3),
      &E1IETA(20),E1IZETA(20),E2IETA(20),E2IZETA(20)
C
       COMMON/A1/CNST,TN1,TN2,C,FW,GAMMA,x1,r1,mcd
       COMMON/A2/B1,RGMA1,FGMA1,PGMA1,D1R,D1F,ADD1,DED1
       COMMON/A3/B2,RGMA2,FGMA2,PGMA2,D2R,D2F,ADD2,DED2,WD,CC,D2P
       COMMON/A4/SR2,Q2,RC2,PW2,XB2,XG2,EM2,GaMA2,CR2,ALP2,PHI2,PHI2P
       COMMON/A5/SG,XM,YM,ZM,XNM,YNM,ZNM,X2M,Y2M,Z2M,XN2M,YN2M,ZN2M,
      &XNH2,YNH2,ZNH2,XH2,YH2,ZH2
       COMMON/A6/ES(3),EQ(3),CN(3),W1(3),W2(3),W12(3),VT1(3),VT2(3),
      $V12(3),KS,KQ,KF,KH,EF(3),EH(3),SIGSF,PI21
       COMMON/A7/SR1,Q1,Rcf,PW1,XB1,XG1,EM1,GaMA1,CR1,ALP1,PHI1,PHI1P
       COMMON/A8/SF,XM1,YM1,ZM1,XNM1,YNM1,ZNM1,X1M,Y1M,Z1M,
      &XN1M,YN1M,ZN1M,XNH1,YNH1,ZNH1,XH1,YH1,ZH1
       COMMON/A9/PHI2PO,OX,OZ,XO,ZO,RHO,ALP,V,H,CRIT,PCRIT
       COMMON/A10/K1I,K1II,K2I,K2II,DEL,E1IH,E1IIH,E2IH,E2IIH,GNH,
      &A2P,B2P,TAU1R,TAU2R,A2L,B2L
       COMMON/A11/RAM,PSI1,C2,D6,E24,F120,CX6,DX24,EX120,RU1,DELT,RUP,
      $RA1,CPF,DPF,EPF,FPF
CAA.........................................................
       COMMON/A12/ETA(3),ZETA(3)
       COMMON/A13/VTH1(3),VTH2(3)
       COMMON/A15/XHH1,YHH1,ZHH1,XHH2,YHH2,ZHH2
       COMMON/A16/SIG12,ALP12
C      COMMON/A17/WP
CAA.....................................................
C...............................................................
C
C                         INPUT THE VARIABLES
C...............................................................
       NAMELIST/DATA1/JCL,JCH,TL1,TL2,MM
       NAMELIST/DATA2/TN1,TN2,C,FW,GAMMA,MCD,RGMA1,B1,
      *B2,RGMA2,FGMA2,PGMA2,D2R,D2F,ADD2,DED2,WD,CC,DEL
       NAMELIST/DATA3/RU2,PW2,ALP2
       NAMELIST/DATA4/Q2,SR2,XG2,XB2,EM2,GAMA2,RAG
       NAMELIST/DATA5/RCF,Q1,SR1,XG1,XB1,EM1,GAMA1,RAP,ALP1
       NAMELIST/DATA6/TORQUE,WP
```

```
C...................................................................
C
      CNST=DARCOS(-1.0D00)/180.0D00
      READ(90,DATA1)
      READ(90,DATA2)
      READ(90,DATA3)
      READ(90,DATA4)
      READ(90,DATA5)
      READ(90,DATA6)
      SGN=DSIN(ALP1)/DABS(DSIN(ALP1))
      KSIDE=0
      GAMMA=GAMMA*CNST
      B1=B1*CNST
      B2=B2*CNST
      RGMA2=RGMA2*CNST
      FGMA2=FGMA2*CNST
      PGMA2=PGMA2*CNST
      ALP2=ALP2*CNST
      Q2=Q2*CNST
      GAMA2=GAMA2*CNST
      RGMA1=RGMA1*CNST
      DC2=2.0*RU2
      ALP1=ALP1*CNST
C
      GOTO 1989
 1990 CONTINUE
C
      READ(88,DATA5)
      ALP1=ALP1*CNST
      SGN=DSIN(ALP1)/DABS(DSIN(ALP1))
      KSIDE=1
      JCL=2
 1989 Q1=Q1*CNST
      GAMA1=GAMA1*CNST
      C2=0.00
      CR2=1.0/RAG
      RC2=RU2-SGN*PW2/2.0
      ALP2= SGN*ALP2
      TN11=8.0
      DELT=0.0
      RHO=0.00
      HG=MCD*DCOS(PGMA2-RGMA2)-RU2*DSIN(B2)
      VG=RU2*DCOS(B2)
C
C...  DEFINE THE MEAN CONTACT POINT
C
      V=0.000
      H=0.000
      FA=FGMA2-PGMA2
      RA=PGMA2-RGMA2
      HM=CC+WD-0.5*FW*(DTAN(FA)+DTAN(RA))
      DED2R=DED2-0.5*FW*DTAN(RA)
      XL=MCD*DCOS(PGMA2)+(DED2R-HM/2.0)*DSIN(PGMA2)
      RL=MCD*DSIN(PGMA2)-(DED2R-HM/2.0)*DCOS(PGMA2)
C...
      AGL=DATAN(RL/XL)
      OX=-DSQRT(XL**2+RL**2)*DCOS(AGL-RGMA2)
      OY=-D2R*DSIN(RGMA2)
```

```
C
C
C
C...  FIND SURFACE COORDINATES OF THE MEAN CONTACT POINT
C
      ERRREL=0.1D-10
      N=2
      ITMAX=200
      IF (JCH.EQ.1) THEN
      Q2=-Q2
      XI(1)=270.0*CNST+B2
      ELSE
      XI(1)=B2
      END IF
      XI(2)=0.0
      CALL DNEQNF(FCN1,ERRREL,N,ITMAX,XI,X,FNORM)
      TH=X(1)
      PH=X(2)
      ZY1=X(1)
      ZY2=X(2)
      THIG=TH
C
C...AAA...
      RA1=RAP
      CR1=1.0/RAP
      C2=0.0
      D6=0.0
      E24=0.0
      F120=0.0
      CPF=0.0
      DPF=0.0
      EPF=0.0
      FPF=0.0
      IF (JCH.EQ.1) THEN
      THF=90.*CNST-B1
      ELSE
      THF=270.*CNST+B1
      ENDIF
      N=3
      ERRREL=0.1D-10
      ITMAX=200
      XI(1)=0.0
      XI(2)=THF
      XI(3)= 0.0
      CALL DNEQNF(FCNM,ERRREL,N,ITMAX,XI,X,FNORM)
      PHI2P0=X(1)
      XI(1)=ZY1
      XI(2)=ZY2
      XI(3)=X(2)
      XI(4)=X(3)
      XI(5)=PHI1P
      IF (KSIDE.EQ.0.0) THEN
      WRITE(9,1311)
 1311 FORMAT(/2X,'************************************************',/
     &        2X,'* INPUT FOR GEAR CONVEX SIDE                   *',/
     &        2X,'************************************************',/)
      ELSE
      WRITE(9,1312)
```

```
 1312 FORMAT(/2X,'*********************************************',/
     &        2X,'* INPUT FOR GEAR CONCAVE SIDE                *',/
     &        2X,'*********************************************',/)
      ENDIF
      WRITE(9,1001)
 1001 FORMAT(/2X,'*********************************************',/
     &        2X,'*               INPUT DATA OF PART 1.        *',/
     &        2X,'*********************************************',/)
      WRITE(9,1002) ICL,JCH,TL1,TL2,MM
 1002 FORMAT(/2X,'JCL=',I2,5X,'JCH=',I2,5X,'TL1=',F4.2,5X,
     &'TL2=',F4.2,5X,'MM=',I2)
      WRITE(9,1003)
 1003 FORMAT(/2X,'*********************************************',/
     &        2X,'*               INPUT DATA OF PART 2.        *',/
     &        2X,'*********************************************',/)
      WRITE(9,1004)TN1,TN2,C,FW,GAMMA,MCD,RGMA1,B1,B2,RGMA2,FGMA2,PGMA2,
     &D2R,D2F,ADD2,DED2,WD,CC,DEL
 1004 FORMAT(/2X,'PINION NUMBER OF TEETH (TN1)=',15X,G14.7,
     &/2X,'GEAR NUMBER OF TEETH (TN2)=',17X,G14.7,
     &/2X,'SHAFT OFFSET (C)=',27X,G14.7,
     &/2X,'FACE WIDTH OF GEAR (FW)=',20X,G14.7,
     &/2X,'SHAFT ANGLE (GAMMA)=',24X,G14.7,
     &/2X,'CONE DISTANCE TO MEAN POINT (MCD)=',10X,G14.7,
     &/2X,'PINION ROOT CONE ANGLE (RGMA1)=',13X,G14.7,
     &/2X,'PINION SPIRAL ANGLE (B1)=',19X,G14.7,
     &/2X,'GEAR SPIRAL ANGLE (B2)=',21X,G14.7,
     &/2X,'GEAR ROOT CONE ANGLE (RGMA2)=',15X,G14.7,
     &/2X,'GEAR FACE CONE ANGLE (FGMA2)=',15X,G14.7,
     &/2X,'GEAR PITCH CONE ANGLE (PGMA2)=',14X,G14.7,
     &/2X,'GEAR ROOT CONE APEX BEYOND PITCH APEX (D2R)=',G14.7,
     &/2X,'GEAR FACE CONE APEX BEYOND PITCH APEX (D2F)=',G14.7,
     &/2X,'GEAR MEAN ADDENDUM (ADD2)=',18X,G14.7,
     &/2X,'GEAR MEAN DEDENDUM (DED2)=',18X,G14.7,
     &/2X,'WHOLE DEPTH (WD)=',27X,G14.7,
     &/2X,'CLEARANCE (CC)=',29X,G14.7,
     &/2X,'ELASTIC APPROACH (DEL)=',21X,G14.7)
      WRITE(9,1005)
 1005 FORMAT(/2X,'*********************************************',/
     &        2X,'*               INPUT DATA OF PART 3.        *',/
     &        2X,'*********************************************',/)
      WRITE(9,1006)RU2,PW2,ALP2
 1006 FORMAT(/2X,'GEAR NOMINAL CUTTER RADIUS (RU2)=',G14.7,
     &/2X,'POINT WIDTH OF GEAR CUTTER (W)=',1X,G14.7,
     &/2X,'BLADE ANGLE OF GEAR CUTTER (ALP2)=',G14.7)
      WRITE(9,1007)
 1007 FORMAT(/2X,'*********************************************',/
     &        2X,'*               INPUT DATA OF PART 4.        *',/
     &        2X,'*********************************************',/)
      WRITE(9,1008)Q2,SR2,XG2,GAMA2,XB2,EM2,RAG
 1008 FORMAT(/2X,'BASIC CRADLE ANGLE (Q2)=',10X,G14.7,
     &/2X,'RADIAL SETTING (SR2)=',13X,G14.7,
     &/2X,'MACHINE CENTER TO BACK (XG2)=',5X,G14.7,
     &/2X,'GEAR MACHINE ROOT ANGLE (GAMA2)=',G14.7,
     &/2X,'SLIDING BASE (XB2)=',15X,G14.7,
     &/2X,'BLANK OFFSET (EM2)=',15X,G14.7,
     &/2X,'RATIO OF ROLL (RAG)=',14X,G14.7)
      WRITE(9,1009)
 1009 FORMAT(/2X,'*********************************************',/
```

```
     &         2X,'*             INPUT DATA OF PART 5.            *',/
     &         2X,'*********************************************',/)
      WRITE(9,1010)RCF,Q1,SR1,XG1,XB1,EM1,GAMA1,RAP,ALP1
 1010 FORMAT(/2X,'POINT RADIUS (RCF)=',17X,G14.7,
     &/2X,'BASIC CRADLE ANGLE (Q1)=',12X,G14.7,
     &/2X,'RADIAL SETTING (SR1)=',15X,G14.7,
     &/2X,'MACHINE CENTER TO BACK (XG1)=',7X,G14.7,
     &/2X,'SLIDING BASE (XB1)=',17X,G14.7,
     &/2X,'BLANK OFFSET (EM1)=',17X,G14.7,
     &/2X,'PINION MACHINE ROOT ANGLE (GAMA1)=',5X,G14.7,
     &/2X,'RATIO OF ROLL (RAP)=',14X,G14.7,
     &/2X,'BLADE ANGLE OF PINION CUTTER (ALP1)=',3X,G14.7)
      WRITE(9,1011)
 1011 FORMAT(/2X,'*********************************************',/
     &         2X,'*             INPUT DATA OF PART 6.            *',/
     &         2X,'*********************************************',/)
      WRITE(9,1012)TORQUE,WP
 1012 FORMAT(/2X,'INPUT TORQUE OF PINION (TORQUE)=',G14.7,
     &/2X,'ANGULAR VELOCITY OF PINION (WP)=',G14.7)
      IF (KSIDE.EQ.0.0) THEN
      WRITE(9,131)
  131 FORMAT(/2X,'*********************************************',/
     &        2X,'* OUTPUT FOR GEAR CONVEX SIDE                   *',/
     &        2X,'*********************************************',/)
      ELSE
      WRITE(9,331)
  331 FORMAT(/2X,'*********************************************',/
     &        2X,'* OUTPUT FOR GEAR CONCAVE SIDE                  *',/
     &        2X,'*********************************************',/)
      ENDIF
      WRITE(9,2149)
2149  FORMAT(//6X,'*******************************************',/
     &         6X,'*     V AND H AT MEAN POSITION (ITEM 1)   *',/
     &         6X,'*******************************************',/)
      WRITE(9,2139) V,H
2139  FORMAT(//4X,'*** V = ',G14.7,'*** H =',G14.7//)
C...
C...  CALL TCA
C
C...
C...  DEFINE THE INITIAL POINT
C...
C...
C
C...  FIND THE INITIAL CONTACT POINT
C
 5555 N=5
      ERRREL=0.1D-10
      ITMAX=200
      PHI2P=PHI2P0
      CALL DNEQNF(FCN,ERRREL,N,ITMAX,XI,X,FNORM)
      PHI1P0=X(5)
C
C
C
C
      PHI2P1=PHI2P0-180.0*CNST/TN2-TL1*180.0*CNST/(6.0*TN2)
      PHI2P2=PHI2P0+180.0*CNST/TN2+TL2*180.0*CNST/(6.0*TN2)
```

```
      KK=1
      PHI2P=PHI2P1
  333 CONTINUE
      CALL DNEQNF(FCN,ERRREL,N,ITMAX,XI,X,FNORM)
C...AAA...
C
      DO 461 I=1,3
      VVV1(I)=VTH1(I)
      VVV2(I)=VTH2(I)
  461 CONTINUE
C     YYH1=YHH1
C     ZZH1=ZHH1
C
C...AAA...
      XI(1)=X(1)
      XI(2)=X(2)
      XI(3)=X(3)
      XI(4)=X(4)
      XI(5)=X(5)
C
C...  find the transmission error
C
C      ERRR=PHI2P-PHI2PO-TN1/TN2*(X(5)-PHI1PO)
       ERRR=PHI2P-PHI2PO+TN1/TN2*(X(5)-PHI1PO)
      ERR(KK)=3600.0*ERRR/CNST
      PI2P(KK)=PHI2P
C
C...  COMPUTE THE CONTACT PATH
C
      x1c= x2m
      r1c= dsqrt(y2m**2+z2m**2)
      xcp(KK)= x1c*dcos(rgma2)+r1c*dsin(rgma2)+ox
      ycp(KK)=-x1c*dsin(rgma2)+r1c*dcos(rgma2)+oy
C
C...  COMPUTE THE PRINCIPAL DIRECTIONS AND CURVATURES OF GEAR
C
      TH=X(1)
      PH=X(2)
      ST=DSIN(TH)
      CT=DCOS(TH)
      SH=DSIN(PH)
      CS=DCOS(PH)
      SP=DSIN(ALP2)
      CP=DCOS(ALP2)
      SM=DSIN(GAMA2)
      CM=DCOS(GAMA2)
C
C...  DEFINE VECTORS TO COMPUTE THE SECOND ORDER PROPERTY OF GEAR
C
      ES(1)=-DSIN(TH-PH)
      ES(2)= DCOS(TH-PH)
      ES(3)= 0.0
      EQ(1)=-SP*DCOS(TH-PH)
      EQ(2)=-SP*DSIN(TH-PH)
      EQ(3)=-CP
      CN(1)=XNM
      CN(2)=YNM
      CN(3)=ZNM
```

```
      KS=CP/(RC2-SG*SP)
      KQ=0.0
      W1(1)=-CM
      W1(2)= 0.0
      W1(3)=-SM
      W2(1)= 0.0
      W2(2)= 0.0
      W2(3)=-CR2
      VT1(1)= YM*SM+EM2*SM
      VT1(2)=-XM*SM+(ZM-XB2)*CM
      VT1(3)=-YM*CM-EM2*CM
      VT2(1)= YM*CR2
      VT2(2)=-XM*CR2
      VT2(3)= 0.0
      DO 110 I=1,3
      W12(I)=W1(I)-W2(I)
      V12(I)=VT1(I)-VT2(I)
  110 CONTINUE
C
C
      PI21=0.0
      CALL CURVA1
      K2I=KF
      K2II=KH
      AK2I(KK)=K2I
      AK2II(KK)=K2II
      PHI2=PH/CR2
      sh2=dsin(phi2)
      ch2=dcos(phi2)
      xX= CM*ef(1)+SM*ef(3)
      yY= ef(2)
      zZ=-SM*ef(1)+CM*ef(3)
      ef(1)=xx
      ef(2)= CH2*yY-SH2*zZ
      ef(3)= SH2*yY+CH2*zZ
c
      xX= CM*eh(1)+SM*eh(3)
      yY= eh(2)
      zZ=-SM*eh(1)+CM*eh(3)
      eh(1)=xx
      eh(2)= CH2*yY-SH2*zZ
      eh(3)= SH2*yY+CH2*zZ
C...
      CHP=DCOS(PHI2P)
      SHP=DSIN(PHI2P)
      CMM=DCOS(GAMMA)
      SMM=DSIN(GAMMA)
      XX= ef(1)
      YY=-ef(2)*CHP+ef(3)*shp
      ZZ=-ef(2)*SHP-ef(3)*chp
      E2IH(1)= XX*CMM+ZZ*SMM
      E2IH(2)= YY
      E2IH(3)=-XX*SMM+ZZ*CMM
C...
      XX= eh(1)
      YY=-eh(2)*CHP+eh(3)*shp
      ZZ=-eh(2)*SHP-eh(3)*chp
      E2IIH(1)= XX*CMM+ZZ*SMM
```

```
      E2IIH(2)= YY
      E2IIH(3)=-XX*SMM+ZZ*CMM
C
C...  COMPUTE THE PRINCIPAL DIRECTIONS AND CURVATURES OF PINION
C
      TH1=X(3)
      PH1=X(4)
      STP=DSIN(TH1+PH1)
      CTP=DCOS(TH1+PH1)
      SP1=DSIN(ALP1)
      CP1=DCOS(ALP1)
      SM1=DSIN(GAMA1)
      CM1=DCOS(GAMA1)
C
C...  DEFINE VECTORS TO COMPUTE THE SECOND ORDER PROPERTY OF PINION
C
      ES(1)=-STP
      ES(2)= CTP
      ES(3)= 0.0
      EQ(1)= SP1*CTP
      EQ(2)= SP1*STP
      EQ(3)=-CP1
      CN(1)=XNM1
      CN(2)=YNM1
      CN(3)=ZNM1
      KS=CP1/(RCF+SF*SP1)
      KQ=0.0
      W1(1)= CM1
      W1(2)= 0.0
      W1(3)= SM1
      W2(1)= 0.0
      W2(2)= 0.0
      W2(3)= CRIT
      VT1(1)=-YM1*SM1-EM1*SM1
      VT1(2)= XM1*SM1-(ZM1-XB1)*CM1
      VT1(3)= YM1*CM1+EM1*CM1
      VT2(1)=-YM1*CRIT
      VT2(2)= XM1*CRIT
      VT2(3)= 0.0
      DO 210 I=1,3
      W12(I)=W1(I)-W2(I)
      V12(I)=VT1(I)-VT2(I)
  210 CONTINUE
C
C
      PI21=PCRIT
      CALL CURVA1
C     WRITE(90,12) KF,KH,SIGSF
      KII=KF
      KIII=KH
      AKII(KK)=KII
      AKIII(KK)=KIII
C     PHI1=PH1/CR1
      SH1=DSIN(PHI1)
      CH1=DCOS(PHI1)
      XX= CM1*EF(1)+SM1*EF(3)
      yY= ef(2)
      ZZ=-SM1*EF(1)+CM1*EF(3)
```

```
      ef(1)=xx
      EF(2)= CH1*YY+SH1*ZZ
      EF(3)=-SH1*YY+CH1*ZZ
c
      XX= CM1*EH(1)+SM1*EH(3)
      yY= eh(2)
      ZZ=-SM1*EH(1)+CM1*EH(3)
      eh(1)=xx
      EH(2)= CH1*YY+SH1*ZZ
      EH(3)=-SH1*YY+CH1*ZZ
C...
      CH1P=DCOS(X(5))
      SH1P=DSIN(X(5))
      E1IH(1)=EF(1)
      E1IH(2)= CH1P*EF(2)-SH1P*EF(3)
      E1IH(3)= SH1P*EF(2)+CH1P*EF(3)
      E1IIH(1)=EH(1)
      E1IIH(2)= CH1P*EH(2)-SH1P*EH(3)
      E1IIH(3)= SH1P*EH(2)+CH1P*EH(3)
      DO 109 I=1,3
      E1IH(I)=-E1IH(I)
      E1IIH(I)=-E1IIH(I)
 109  CONTINUE
C
C...  COMPUTE THE DIMENSION AND ORIENTATION OF THE CONTACT ELLIPSE
C
      GNH(1)=XNH2
      GNH(2)=YNH2
      GNH(3)=ZNH2
      CALL ELLIP
C...AAA.............
C
C...COMPUTE ROLLING VELOCITY AND SLIDING VELOCITY BETWEEN PINION AND
C   GEAR
C
C...AAA.............
      CC1=0.0
      DD1=0.0
      EE1=0.0
      CC2=0.0
      DD2=0.0
      EE2=0.0
      DO 1777 I=1,3
      CC1=ETA(I)*VVV1(I)+CC1
      DD1=ZETA(I)*VVV1(I)+DD1
      EE1=GNH(I)*VVV1(I)+EE1
      CC2=ETA(I)*VVV2(I)+CC2
      DD2=ZETA(I)*VVV2(I)+DD2
      EE2=GNH(I)*VVV2(I)+EE2
 1777 CONTINUE
      VTT1(1)=CC1*WP
      VTT1(2)=DD1*WP
      VTT1(3)=EE1*WP
      VTT2(1)=CC2*WP
      VTT2(2)=DD2*WP
      VTT2(3)=EE2*WP
      CC3=CC1-CC2
      DD3=DD1-DD2
```

```
      EE3=EE1 EE2
C
      VPT1(KK)=VTT1(1)
      VPT2(KK)=VTT1(2)
      VGT1(KK)=VTT2(1)
      VGT2(KK)=VTT2(2)
      VRT1(KK)=VPT1(KK)+VGT1(KK)
      VRT2(KK)=VPT2(KK)+VGT2(KK)
      VST1(KK)=VPT1(KK)-VGT1(KK)
      VST2(KK)=VPT2(KK)-VGT2(KK)
      FORCE1=GNH(3)*YHH1-GNH(2)*ZHH1
      FORCEM(KK)=DABS(TORQUE/FORCE1)
C
C
C...AAA.................
C...AAA....
      AALFA(KK)=ALP12
      ALO12(KK)=SIG12
      E1IETA(KK)=DCOS(ALP12)
      E1IZETA(KK)=DSIN(ALP12)
      E2IETA(KK)=DCOS(ALP12+SIG12)
      E2IZETA(KK)=DSIN(ALP12+SIG12)


C...AAA....
      AX1(KK)=A2L
      AX2(KK)=B2L
      ANG1(KK)=TAU1R
      ANG2(KK)=TAU2R

      KK=KK+1
      PHI2P=PHI2P+(2.+(TL2+TL1)/6.)*180.*CNST/TN2/(MM-1)
      IF(PHI2P.LE.(PHI2P2+0.0001)) GOTO 333
C...AAA
C     WRITE(93,441)
C...AAA
      WRITE(9,441)
441   FORMAT(/,'****************************************************',
     &        /,'* TRANSMISSION ERROR IN A MESHING PERIOD (ITEM 2)*',
     $        /,'****************************************************',/)
C
      DO 444 I=1,KK-1
      PI2P(I)=PI2P(I)/CNST
      WRITE(9,555) PI2P(I),ERR(I)
555   FORMAT(3X,3(G14.7,3X))
444   CONTINUE
C
      WRITE(9,551)
551   FORMAT(/,'****************************************************',
     &        /,'* CONTACT PATH FOR A PAIR OF TEETH IN MESH (ITEM 3)*',
     $        /,'****************************************************',/)
      DO 666 I=1,KK-1
      WRITE(9,747) XCP(I),YCP(I)
 747   FORMAT(3X,2(G14.7,3X))
 666   CONTINUE
C
      WRITE(9,661)
661   FORMAT(/,'****************************************************',
```

```
     &        /,'* DIMENSION AND ORIENTATION OF CONTACT ELLIPSE(ITEM 4)',
     $       /,'*******************************************************',/)
      DO 888 I=1,KK-1
      WRITE(9,889) AX1(I),ANG1(I),AX2(I),ANG2(I)
 889   FORMAT(3X,4(G14.7,3X))
 888   CONTINUE
C...AAA.....
C
C
      WRITE(9,1043)
 1043 FORMAT(/,'*******************************************************',
     &        /,'* VELOCITIES V1 AND V2 ON THE TANGENT PLANE (ITEM 5)*',
     $        /,'*******************************************************',/)
      WRITE(9,1222)
 1222 FORMAT(/,7X,'V1*ETA',9X,'V1*ZETA',10X,'V2*ETA',11X,'V2*ZETA',/)

      DO 1555 I=1,KK-1
      WRITE(9,1432) VPT1(I),VPT2(I),VGT1(I),VGT2(I)
 1432  FORMAT(3X,4(G14.7,3X))
 1555  CONTINUE
C
C...AAA.....
C
C
      WRITE(9,1672)
 1672 FORMAT(/,'*******************************************************',
     &        /,'*  PRINCIPAL DIRECTIONS OF PINION AND GEAR (ITEM 6,7)*',
     $        /,'*******************************************************',/)
      WRITE(9,1433)
 1433 FORMAT(/,7X,'ALFA',11X,'SIGMA12',/)
      DO 1699 I=1,KK-1
      WRITE(9,1683) AALFA(I),ALO12(I)
 1683  FORMAT(3X,2(G14.7,3X))
 1699  CONTINUE
      WRITE(9,1703)
 1703 FORMAT(/,4X,'E1I*ETA',12X,'E1I*ZETA',8X,'E2I*ETA',9X,'E2I*ZETA',/)
      DO 1711 I=1,KK-1
      WRITE(9,1708) E1IETA(I),E1IZETA(I),E2IETA(I),E2IZETA(I)
 1708  FORMAT(3X,4(G14.7,3X))
 1711  CONTINUE
C
C...AAA.....
C
      WRITE(9,1721)
 1721 FORMAT(/,'*******************************************************',
     &        /,'*  PRINCIPAL CURVATURES OF PINION AND GEAR (ITEM 8)*',
     $        /,'*******************************************************',/)
      WRITE(9,1733)
 1733 FORMAT(/,8X,'K1I',14X,'K1II',12X,'K2I',14X,'K2II',/)
      DO 1784 I=1,KK-1
      WRITE(9,1765) AK1I(I),AK1II(I),AK2I(I),AK2II(I)
 1765  FORMAT(3X,4(G14.7,3X))
 1784  CONTINUE
C
C
      WRITE(9,1833)
 1833 FORMAT(/,'*******************************************************',
     &        /,'*  ROLLING VELOCITY OF PINION AND GEAR (ITEM 9)   *',
```

```
     $         /,'****************************************************',/)
      WRITE(9,1835)
 1835 FORMAT(/,4X,'(V1+V2)*ETA',4X,'(V1+V2)*ZETA',/)
      DO 1845 I=1,KK-1
      WRITE(9,1842) VRT1(I),VRT2(I)
 1842  FORMAT(3X,2(G14.7,3X))
 1845  CONTINUE
C
C
      WRITE(9,1913)
 1913 FORMAT(/,'****************************************************',
     &         /,'*  SLIDING VELOCITY OF PINION AND GEAR (ITEM 10) *',
     $         /,'****************************************************',/)
      WRITE(9,1928)
 1928 FORMAT(/,4X,'(V1-V2)*ETA',4X,'(V1-V2)*ZETA',/)
      DO 1935 I=1,KK-1
      WRITE(9,1930) VST1(I),VST2(I)
 1930  FORMAT(3X,2(G14.7,3X))
 1935  CONTINUE
C
      WRITE(9,2041)
 2041 FORMAT(/,'****************************************************',
     &         /,'*  NORMAL FORCE AT POINT  M  (UNIT: N) (ITEM 11) *',
     $         /,'****************************************************',/)
      DO 2085 I=1,KK-1
      WRITE(9,2058) FORCEM(I)
 2058  FORMAT(G14.7)
 2085  CONTINUE
C
C...AAA.....
       IF(JCL.EQ.1) GOTO 1111
       IF(JCL.EQ.3) GOTO 1113
C
C...   V AND H CHECK FOR TOE POSITION
C
      HMT=WD+CC-3.0/4.0*FW*(DTAN(FA)+DTAN(RA))
      DED2T=DED2-3.0/4.0*FW*DTAN(RA)
      TMCD=MCD-0.25*FW
      XL=TMCD*DCOS(PGMA2)+(DED2T-HMT/2.0)*DSIN(PGMA2)
      RL=TMCD*DSIN(PGMA2)-(DED2T-HMT/2.0)*DCOS(PGMA2)
C
C...  FIND THE MEAN CONTACT POINT ON THE GEAR SURFACE
C
      ERRREL=0.1D-7
      N=2
      ITMAX=200
      IF (JCH.EQ.1) THEN
      XI(1)=270.0*CNST+B2
      ELSE
      XI(1)=B2
C     XI(1)=90.0*CNST-B2
      END IF
      XI(2)=0.0
      CALL DNEQNF(FCN1,ERRREL,N,ITMAX,XI,X,FNORM)
      TH=X(1)
      PH=X(2)
      ZY1=X(1)
      ZY2=X(2)
```

```
      N=3
      ERRREL=0.1D-10
      ITMAX=200
      XI(1)=0.0
      XI(2)=THF
      XI(3)= 0.0
      CALL DNEQNF(FCNM,ERRREL,N,ITMAX,XI,X,FNORM)
      PHI2PO=X(1)
      XI(1)=ZY1
      XI(2)=ZY2
      XI(3)=X(2)
      XI(4)=X(3)
      XI(5)=PHI1P
      WRITE(9,149)
 149  FORMAT(//6X,'*******************************************',/
     &          6X,'*      V AND H CHECK AT TOE POSITION      *',/
     &          6X,'*******************************************',/)
      WRITE(9,139) V,H
 139  FORMAT(//4X,'*** V = ',G14.7,'*** H =',G14.7//)
C...
      JCL=3
      GO TO 5555
C
C...   V AND H CHECK FOR HEEL POSITION
C
 1113 HMH=WD+CC-0.16*FW*(DTAN(FA)+DTAN(RA))
      DED2H=DED2-0.16*FW*DTAN(RA)
      HMCD=MCD+0.16*FW
      XL=HMCD*DCOS(PGMA2)+(DED2H-HMH/2.0)*DSIN(PGMA2)
      RL=HMCD*DSIN(PGMA2)-(DED2H-HMH/2.0)*DCOS(PGMA2)
      ERRREL=0.1D-7
      N=2
      ITMAX=200
      IF (JCH.EQ.1) THEN
      XI(1)=270.0*CNST+B2
      ELSE
C     XI(1)=90.0*CNST-B2
      XI(1)=B2
      END IF
      XI(2)=0.0
      CALL DNEQNF(FCN1,ERRREL,N,ITMAX,XI,X,FNORM)
      TH=X(1)
      PH=X(2)
      ZY1=X(1)
      ZY2=X(2)
C...  FIND THE V AND H VALUE FOR HEEL POSITION
      N=3
      ERRREL=0.1D-10
      ITMAX=200
      XI(1)=0.00
      XI(2)=THF
      XI(3)= 0.0
      CALL DNEQNF(FCNM,ERRREL,N,ITMAX,XI,X,FNORM)
      PHI2PO=X(1)
      XI(1)=ZY1
      XI(2)=ZY2
      XI(3)=X(2)
      XI(4)=X(3)
```

```
      XI(5)=PHI1P
      WRITE(9,159)
  159 FORMAT(//6X,'*****************************************',/
     &         6X,'*     V AND H CHECK AT HEEL POSITION     *',/
     &         6X,'*****************************************',/)
      WRITE(9,169) V,H
  169 FORMAT(//4X,'*** V = ',G14.7,'*** H =',G14.7//)
C...
      JCL=1
      GOTO 5555
 1111 CONTINUE
      IF(KSIDE.EQ.0) GOTO 1990
      STOP
      END
C
C...  FCN1 IS TO FIND THE MEAN CONTACT POINT
C
      SUBROUTINE FCN1(X,F,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      INTEGER N
      REAL*8 X(N),F(N),mcd
      COMMON/A1/CNST,TN1,TN2,C,FW,GAMMA,x1,r1,mcd
      COMMON/A3/B2,RGMA2,FGMA2,PGMA2,D2R,D2F,ADD2,DED2,WD,CC,D2P
      COMMON/A4/SR2,Q2,RC2,PW2,XB2,XG2,EM2,GaMA2,CR2,ALP2,PHI2,PHI2P
      COMMON/A5/SG,XM,YM,ZM,XNM,YNM,ZNM,X2M,Y2M,Z2M,XN2M,YN2M,ZN2M,
     &XNH2,YNH2,ZNH2,XH2,YH2,ZH2
      TH=X(1)
      PH=X(2)
      SP=DSIN(ALP2)
      CP=DCOS(ALP2)
      SM=DSIN(GAMA2)
      CM=DCOS(GAMA2)
      STP=DSIN(TH-PH)
      CTP=DCOS(TH-PH)
      XNM=-CP*CTP
      YNM=-CP*STP
      ZNM= SP
      AA1=RC2*STP+SR2*DSIN(-Q2-PH)
      AA2=RC2*CTP+SR2*DCOS(-Q2-PH)
      AX=-EM2*SM
      AY= XB2*CM
      AZ= EM2*CM
C
C...  FIND SG
C
      T1= XNM*(AX-AA1*(SM-CR2))+YNM*(AY+AA2*(SM-CR2))+ZNM*(AZ+AA1*CM)
      T2=-XNM*(SM-CR2)*SP*STP+YNM*((SM-CR2)*SP*CTP-CP*CM)+ZNM*CM*SP*STP
      SG=T1/T2
      XM= (RC2-SG*SP)*CTP+SR2*DCOS(-Q2-PH)
      YM= (RC2-SG*SP)*STP+SR2*DSIN(-Q2-PH)
      ZM=-SG*CP
      xX= CM*XM+SM*ZM-XG2-XB2*SM
      yY= YM+EM2
      zZ=-SM*XM+CM*ZM-XB2*CM
      XN= CM*XNM+SM*ZNM
      YN= YNM
      ZN=-SM*XNM+CM*ZNM
      PHI2=PH/CR2
```

```
      sh2=dsin(phi2)
      ch2=dcos(phi2)
      X2M= xX
      Y2M= CH2*yY-SH2*zZ
      Z2M= SH2*yY+CH2*zZ
      XN2M= XN
      YN2M= CH2*YN-SH2*ZN
      ZN2M= SH2*YN+CH2*ZN
      F(1)=X2M-XL
      F(2)=Yy**2+Zz**2-RL**2
      RETURN
      END
C...
C...  SUBROUTINE CURVA1 IS TO COMPUTE THE CURVATURE OF THE
C...              GENERATED SURFAFE
C...
      SUBROUTINE CURVA1
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 KS,KQ,KF,KH
      DIMENSION ESN(3),EQN(3),W1VT2(3),WV12(3),W2VT1(3)
      COMMON/A6/ES(3),EQ(3),CN(3),W1(3),W2(3),W12(3),VT1(3),VT2(3),
     $V12(3),KS,KQ,KF,KH,EF(3),EH(3),SIGSF,PI21
C...
      ESN(1)= CN(2)*ES(3)-CN(3)*ES(2)
      ESN(2)= (CN(1)*ES(3)-CN(3)*ES(1))
      ESN(3)= CN(1)*ES(2)-CN(2)*ES(1)
C...
      EQN(1)= CN(2)*EQ(3)-CN(3)*EQ(2)
      EQN(2)= (CN(1)*EQ(3)-CN(3)*EQ(1))
      EQN(3)= CN(1)*EQ(2)-CN(2)*EQ(1)
C...
      W1VT2(1)= W1(2)*VT2(3)-W1(3)*VT2(2)
      W1VT2(2)=-(W1(1)*VT2(3)-W1(3)*VT2(1))
      W1VT2(3)= W1(1)*VT2(2)-W1(2)*VT2(1)
C...
      W2VT1(1)= W2(2)*VT1(3)-W2(3)*VT1(2)
      W2VT1(2)=-(W2(1)*VT1(3)-W2(3)*VT1(1))
      W2VT1(3)= W2(1)*VT1(2)-W2(2)*VT1(1)
C...
      WV12(1)= W12(2)*V12(3)-W12(3)*V12(2)
      WV12(2)=-(W12(1)*V12(3)-W12(3)*V12(1))
      WV12(3)= W12(1)*V12(2)-W12(2)*V12(1)
C...
      V12S=0.0
      V12Q=0.0
      WNES=0.0
      WNEQ=0.0
      VWN= 0.0
      W1TN=0.0
      W2TN=0.0
      VT2N=0.0
C...
      DO 1 I=1,3
      V12S= V12(I)*ES(I)+V12S
      V12Q= V12(I)*EQ(I)+V12Q
      WNES= W12(I)*ESN(I)+WNES
      WNEQ= W12(I)*EQN(I)+WNEQ
      VWN = CN(I)*WV12(I)+VWN
```

```
      W1TN= CN(I)*W1VT2(I)+W1TN
      W2TN= CN(I)*W2VT1(I)+W2TN
      VT2N= CN(I)*VT2(I)+VT2N
  1   CONTINUE
C...
C...   COMPUTE THE CURVATURE OF THE GENERATED SURFACE
C...
      A13=-KS*V12S-WNES
      A23=-KQ*V12Q-WNEQ
      A33=KS*V12S**2+KQ*V12Q**2-VWN-W1TN+W2TN+PI21*VT2N/W2(3)
      T1=2.0D00*A13*A23
      T2=A23**2-A13**2+(KS-KQ)*A33
      SIG1F=0.5D00*DATAN2(T1,T2)
      KF=0.50D00*(KS+KQ)-0.5D00*(A13**2+A23**2)/A33
     &+A13*A23/(A33*DSIN(2.0D00*SIG1F))
      KH= KF-2.0D00*A13*A23/(A33*DSIN(2.0D00*SIG1F))
      SIGSF=SIG1F
      DO 2 I=1,3
      EF(I)= DCOS(SIG1F)*ES(I)-DSIN(SIG1F)*EQ(I)
      EH(I)= DSIN(SIG1F)*ES(I)+DCOS(SIG1F)*EQ(I)
  2   CONTINUE
      RETURN
      END
C
C...
C...  THE FOLLOWING IS THE SUBROUTINE FOR STRAIGHT BLADE
C...
      SUBROUTINE FCN(X,F,N)
      IMPLICIT REAL*8(A-H,O-Z)
      real*8 x(N),f(N)
      DIMENSION CH(3),P(3),E1EF(3),ESN(3),EQN(3),W1VT2(3),WV12(3),
     $W2VT1(3),EFIH(3),EFIIH(3),RH(3),GNH(3),E2IH(3),E2IIH(3),
     &E1IH(3),E1IIH(3),EFI(3),EFII(3),E1I(3),E1II(3),GN(3),EFE1(3),
     &ERR(20),XP(20),YP(20)
      COMMON/A1/CNST,TN1,TN2,C,FW,GAMMA,x1,r1,mcd
      COMMON/A2/B1,RGMA1,FGMA1,PGMA1,D1R,D1F,ADD1,DED1
      COMMON/A3/B2,RGMA2,FGMA2,PGMA2,D2R,D2F,ADD2,DED2,WD,CC,D2P
      COMMON/A4/SR2,Q2,RC2,PW2,XB2,XG2,EM2,GaMA2,CR2,ALP2,PHI2,PHI2P
      COMMON/A5/SG,XM,YM,ZM,XNM,YNM,ZNM,X2M,Y2M,Z2M,XN2M,YN2M,ZN2M,
     &XNH2,YNH2,ZNH2,XH2,YH2,ZH2
      COMMON/A6/ES(3),EQ(3),CN(3),W1(3),W2(3),W12(3),VT1(3),VT2(3),
     $V12(3),KS,KQ,KF,KH,EF(3),EH(3),SIGSF,PI21
      COMMON/A7/SR1,Q1,Rcf,PW1,XB1,XG1,EM1,GaMA1,CR1,ALP1,PHI1,PHI1P
      COMMON/A8/Sf,XM1,YM1,ZM1,XNM1,YNM1,ZNM1,X1M,Y1M,Z1M,
     &XN1M,YN1M,ZN1M,XNH1,YNH1,ZNH1,XH1,YH1,ZH1
      COMMON/A9/PHI2P0,OX,OZ,XO,ZO,RHO,ALP,V,H,CRIT,PCRIT
      COMMON/A11/RAM,PSI1,C2,D6,E24,F120,CX6,DX24,EX120,RU1,DELT,RUP,
     $RA1,CPF,DPF,EPF,FPF
C...AAA................
C
      COMMON/A13/VTH1(3),VTH2(3)
      COMMON/A15/XHH1,YHH1,ZHH1,XHH2,YHH2,ZHH2
C
C...AAA.................
      TH=X(1)
      PH=X(2)
      SP=DSIN(ALP2)
      CP=DCOS(ALP2)
```

```
      SM=DSIN(GAMA2)
      CM=DCOS(GAMA2)
      STP=DSIN(TH-PH)
      CTP=DCOS(TH-PH)
      XNM=-CP*CTP
      YNM=-CP*STP
      ZNM= SP
      AA1=RC2*STP+SR2*DSIN(-Q2-PH)
      AA2=RC2*CTP+SR2*DCOS(-Q2-PH)
      AX=-EM2*SM
      AY= XB2*CM
      AZ= EM2*CM
C
C...  FIND SG
C
      T1= XNM*(AX-AA1*(SM-CR2))+YNM*(AY+AA2*(SM-CR2))+ZNM*(AZ+AA1*CM)
      T2=-XNM*(SM-CR2)*SP*STP+YNM*((SM-CR2)*SP*CTP-CP*CM)+ZNM*CM*SP*STP
      SG=T1/T2
      XM= (RC2-SG*SP)*CTP+SR2*DCOS(-Q2-PH)
      YM= (RC2-SG*SP)*STP+SR2*DSIN(-Q2-PH)
      ZM=-SG*CP
C     XM=-SG*SP*CTP+AA2
C     YM=-SG*SP*STP+AA1
C     ZM=-SG*CP
      xX= CM*XM+SM*ZM-XG2-XB2*SM
      yY= YM+EM2
      zZ=-SM*XM+CM*ZM-XB2*CM
      XN= CM*XNM+SM*ZNM
      YN= YNM
      ZN=-SM*XNM+CM*ZNM
      PHI2=PH/CR2
      sh2=dsin(phi2)
      ch2=dcos(phi2)
      X2M= xX
      Y2M= CH2*yY-SH2*zZ
      Z2M= SH2*yY+CH2*zZ
      XN2M= XN
      YN2M= CH2*YN-SH2*ZN
      ZN2M= SH2*YN+CH2*ZN
      CMM=DCOS(GAMMA)
      SMM=DSIN(GAMMA)
      CHP=DCOS(PHI2P)
      SHP=DSIN(PHI2P)
      XX= X2M
      YY=-Y2M*CHP+Z2M*SHP
      ZZ=-Y2M*SHP-Z2M*CHP
      XH2= XX*CMM+ZZ*SMM
      YH2= YY+C+V
      ZH2=-XX*SMM+ZZ*CMM
C...
      XX= XN2M
      YY=-YN2M*CHP+ZN2M*SHP
      ZZ=-YN2M*SHP-ZN2M*CHP
      XNH2= XX*CMM+ZZ*SMM
      YNH2= YY
      ZNH2=-XX*SMM+ZZ*CMM
C
C...  DEFINE THE PINION SURFACE
```

```
C
      TH1=X(3)
      PH1=X(4)
      SP1=DSIN(-ALP1)
      CP1=DCOS(-ALP1)
      SM1=DSIN(GAMA1)
      CM1=DCOS(GAMA1)
      STP=DSIN(TH1+PH1)
      CTP=DCOS(TH1+PH1)
      XNM1=-CP1*CTP
      YNM1=-CP1*STP
      ZNM1= SP1
      AB1=RCF*STP+SR1*DSIN(-Q1+PH1)
      AB2=RCF*CTP+SR1*DCOS(-Q1+PH1)
      AXX=-EM1*SM1
      AYY= XB1*CM1
      AZZ= EM1*CM1
C
C...  FIND SF,CRIT,PF,PPF,PCRIT
C
      DDD=DABS(PH1)
      IF(DDD.LE.0.001) GOTO 6
      PHI1=RA1*(PH1-CPF*PH1**2-DPF*PH1**3-EPF*PH1**4-FPF*PH1**5)
      PF=RA1*(1.0-2.0*CPF*PH1-3.0*DPF*PH1**2
     $-4.0*EPF*PH1**3-5.0*FPF*PH1**4)
      PPF=-RA1*(2.0*CPF+6.0*DPF*PH1+12.0*EPF*PH1**2+20.0*FPF*PH1**3)
      CRIT=1.0/PF
      PCRIT=-PPF/PF**3
      GOTO 7
 6    PHI1=RA1*PH1
      CRIT=CR1
      PCRIT=2.0*CPF/(RA1**2)
 7    CONTINUE
      T1= XNM1*(AXX-AB1*(SM1-CRIT))+
     &YNM1*(AYY+AB2*(SM1-CRIT))+ZNM1*(AZZ+AB1*CM1)
      T2=-XNM1*(SM1-CRIT)*SP1*STP+
     &YNM1*((SM1-CRIT)*SP1*CTP-CP1*CM1)+ZNM1*CM1*SP1*STP
      SF=T1/T2
C
      XM1= (RCF-SF*SP1)*CTP+SR1*DCOS(-Q1+PH1)
      YM1= (RCF-SF*SP1)*STP+SR1*DSIN(-Q1+PH1)
      ZM1=-SF*CP1
      xX= CM1*XM1+SM1*ZM1-XG1-XB1*SM1
      yY= YM1+EM1
      zZ=-SM1*XM1+CM1*ZM1-XB1*CM1
      XN1=CM1*XNM1+SM1*ZNM1
      YN1=YNM1
      ZN1=-SM1*XNM1+CM1*ZNM1
      sh1=dsin(phi1)
      ch1=dcos(phi1)
      X1M= xX
      Y1M= CH1*yY+SH1*zZ
      Z1M=-SH1*yY+CH1*zZ
      XN1M= XN1
      YN1M= CH1*YN1+SH1*ZN1
      ZN1M=-SH1*YN1+CH1*ZN1
      PHI1P= X(5)
      sh1P=dsin(phi1P)
```

```
      ch1P=dcos(phi1P)
      XH1= X1M+H
      YH1= CH1P*Y1M-SH1P*Z1M
      ZH1= SH1P*Y1M+CH1P*Z1M
      XNH1= XN1M
      YNH1= CH1P*YN1M-SH1P*ZN1M
      ZNH1= SH1P*YN1M+CH1P*ZN1M
C...AAA
C
      XHH1= XH1-H
      YHH1= YH1
      ZHH1= ZH1
      XHH2= XH2
      YHH2= YH2-V
      ZHH2= ZH2
C
      R12=TN1/TN2
      CMM=DCOS(GAMMA)
      SMM=DSIN(GAMMA)
      VTH1(1)= 0.0D00
      VTH1(2)= ZHH1
      VTH1(3)=-YHH1
      VTH2(1)= R12*(YHH2)*SMM
      VTH2(2)=-R12*(XHH2*SMM+ZHH2*CMM)
      VTH2(3)= R12*(YHH2)*CMM
   12 FORMAT(3X,3(G14.7,2X))
C
C...AAA...............
      F(1)=XH2-XH1
      F(2)=YH2-YH1
      F(3)=ZH2-ZH1
      F(4)=XNH2-XNH1
      F(5)=YNH2-YNH1
      RETURN
      END
C...  ***********************************************************
C...  * SUBROUTINE ELLIP IS TO DETERMINE THE SIZE AND ORINTATION *
C...  *               OF THE CONTACT ELLIPSE                     *
C...  ***********************************************************
C...
      SUBROUTINE ELLIP
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 KS,KQ,K1I,K1II,K2I,K2II
      DIMENSION RO(3),ETA2(3),ZETA2(3),E1E2(3)
      DIMENSION E1IH(3),E1IIH(3),E2IH(3),E2IIH(3),GNH(3)
      COMMON/A1/CNST,TN1,TN2,C,FW,GAMMA,x1,r1,mcd
      COMMON/A3/B2,RGMA2,FGMA2,PGMA2,D2R,D2F,ADD2,DED2,WD,CC,D2P
      COMMON/A4/SR2,Q2,RC2,PW2,XB2,XG2,EM2,GaMA2,CR2,ALP2,PHI2,PHI2P
      COMMON/A5/SG,XM,YM,ZM,XNM,YNM,ZNM,X2M,Y2M,Z2M,XN2M,YN2M,ZN2M,
     &XNH2,YNH2,ZNH2,XH2,YH2,ZH2
      COMMON/A9/PHI2P0,OX,OZ,XO,ZO,RHO,ALP,V,H,CRIT,PCRIT
      COMMON/A10/K1I,K1II,K2I,K2II,DEL,E1IH,E1IIH,E2IH,E2IIH,GNH,
     &A2P,B2P,TAU1R,TAU2R,A2L,B2L
      COMMON/A12/ETA(3),ZETA(3)
      COMMON/A16/SIG12,ALP12
      CNST=DARCOS(-1.0D00)/180.00
C...
      E1E2(1)= E1IH(2)*E2IH(3)-E1IH(3)*E2IH(2)
```

```
      E1E2(2)=-(E1IH(1)*E2IH(3)-E1IH(3)*E2IH(1))
      E1E2(3)= E1IH(1) *E2IH(2)-E1IH(2)*E2IH(1)
C...
      T1=0.0
      T2=0.0
      DO 1 I=1,3
      T1= E1IH(I)*E2IH(I)+T1
      T2= GNH(I)*E1E2(I)+T2
 1    CONTINUE
C...
      T1=T1+1.0D00
      SIG12=2.0D00*DATAN2(T2,T1)
C...
      SK1= K1I+K1II
      SK2= K2I+K2II
      SG1= K1I-K1II
      SG2= K2I-K2II
C...
      T1=SG1-SG2*DCOS(2.0D00*SIG12)
      T2=SG2*DSIN(2.0D00*SIG12)
      T3=DSQRT(SG1**2+SG2**2-2.0D00*SG1*SG2*DCOS(2.0D00*SIG12))
C...
      TX=T2/T3
      TY=T1/T3+1.0D00
      ALP12=DATAN2(TX,TY)
C...
C...  THE DIRECTION AND LENGTH OF THE AXES OF CONTACT ELLIPSE
C...
C     DEL=0.00700D00
      AL=0.25D00*(SK1-SK2-T3)
      BL=0.25D00*(SK1-SK2+T3)
      AL=DABS(AL)
      BL=DABS(BL)
      A2L=2.0D00*DSQRT(DEL/AL)
      B2L=2.0D00*DSQRT(DEL/BL)
C...
C...
      DO 2 I=1,3
      ETA(I)  = DCOS(ALP12)*E1IH(I)-DSIN(ALP12)*E1IIH(I)
      ZETA(I)= DSIN(ALP12)*E1IH(I)+DCOS(ALP12)*E1IIH(I)
 2    CONTINUE
C...
C...  DETERMINE THE PROJECTION OF CONTACT ELLIPS IN AXIAL SECTION
C...
      CHP=DCOS(PHI2P)
       SHP=DSIN(PHI2P)
C...
      CMM=DCOS(GAMMA)
      SMM=DSIN(GAMMA)
C...
      XX= ETA(1)*CMM-ETA(3)*SMM
      YY= ETA(2)
      ZZ= ETA(1)*SMM+ETA(3)*CMM
      ETA2(1)= XX
      ETA2(2)=-YY*CHP-ZZ*SHP
      ETA2(3)= YY*SHP-ZZ*CHP
C...
      XX= ZETA(1)*CMM-ZETA(3)*SMM
```

```
      YY= ZETA(2)
      ZZ= ZETA(1)*SMM+ZETA(3)*CMM
      ZETA2(1)= XX
      ZETA2(2)=-YY*CHP-ZZ*SHP
      ZETA2(3)= YY*SHP-ZZ*CHP
C...
      RO(2)=Y2M/DSQRT(Z2M**2+Y2M**2)
      RO(3)=Z2M/DSQRT(Z2M**2+Y2M**2)
      RO(1)=0.0D00
C...
      T11=0.0D00
       T12=0.0D00
      DO 3 I=1,3
      T12= ETA2(I)*RO(I)+T12
      T11=ZETA2(I)*RO(I)+T11
  3   CONTINUE
C...
      TAU1=DATAN2(T11,ZETA2(1))
      TAU2=DATAN2(T12,ETA2(1))
C...
      A2P=A2L*ZETA2(1)/DCOS(TAU1)
      B2P=B2L*ETA2(1)/DCOS(TAU2)
C...
      TAU1R=(TAU1-RGMA2)/CNST
      TAU2R=(TAU2-RGMA2)/CNST
      RETURN
      END
C...
C...  THE FOLLOWING IS THE V-H CHECK SUBROUTINE FOR STRAIGHT BLADE
C...
      SUBROUTINE FCNM(X,F,N)
      IMPLICIT REAL*8(A-H,O-Z)
      real*8 x(N),f(N)
      COMMON/A1/CNST,TN1,TN2,C,FW,GAMMA,x1,r1,mcd
      COMMON/A5/SG,XM,YM,ZM,XNM,YNM,ZNM,X2M,Y2M,Z2M,XN2M,YN2M,ZN2M,
     &XNH2,YNH2,ZNH2,XH2,YH2,ZH2
      COMMON/A7/SR1,Q1,Rcf,PW1,XB1,XG1,EM1,GaMA1,CR1,ALP1,PHI1,PHI1P
      COMMON/A9/PHI2PO,OX,OZ,XO,ZO,RHO,ALP,V,H,CRIT,PCRIT
      COMMON/A11/RAM,PSI1,C2,D6,E24,F120,CX6,DX24,EX120,RU1,DELT,RUP,
     $RA1,CPF,DPF,EPF,FPF
      COMMON/A17/TTTT,VVTT(3)
      CM=DCOS(GAMMA)
      SM=DSIN(GAMMA)
      CHP=DCOS(X(1))
      SHP=DSIN(X(1))
      XX= X2M
      YY=-Y2M*CHP+Z2M*SHP
      ZZ=-Y2M*SHP-Z2M*CHP
      XH2= XX*CM+ZZ*SM
      YH2= YY+C
      ZH2=-XX*SM+ZZ*CM
C...
      XX= XN2M
      YY=-YN2M*CHP+ZN2M*SHP
      ZZ=-YN2M*SHP-ZN2M*CHP
      XNH2= XX*CM+ZZ*SM
      YNH2= YY
      ZNH2=-XX*SM+ZZ*CM
```

```
C...
C
C...  DEFINE THE PINION SURFACE
C
      TH1=X(2)
      PH1=X(3)
      SP1=DSIN(-ALP1)
      CP1=DCOS(-ALP1)
      SM1=DSIN(GAMA1)
      CM1=DCOS(GAMA1)
      STP=DSIN(TH1+PH1)
      CTP=DCOS(TH1+PH1)
      XNM1=-CP1*CTP
      YNM1=-CP1*STP
      ZNM1= SP1
      AB1=RCF*STP+SR1*DSIN(-Q1+PH1)
      AB2=RCF*CTP+SR1*DCOS(-Q1+PH1)
      AXX=-EM1*SM1
      AYY= XB1*CM1
      AZZ= EM1*CM1
C
C...  FIND SF,CRIT,PF,PPF,PCRIT
C
      PHI1=RA1*(PH1-CPF*PH1**2-DPF*PH1**3-EPF*PH1**4-FPF*PH1**5)
      PF=RA1*(1.0-2.0*CPF*PH1-3.0*DPF*PH1**2
     $-4.0*EPF*PH1**3-5.0*FPF*PH1**4)
      PPF=-RA1*(2.0*CPF+6.0*DPF*PH1+12.0*EPF*PH1**2+20.0*FPF*PH1**3)
      CRIT=1.0/PF
      PCRIT=-PPF/PF**3
C
      T1= XNM1*(AXX-AB1*(SM1-CRIT))+
     &YNM1*(AYY+AB2*(SM1-CRIT))+ZNM1*(AZZ+AB1*CM1)
      T2=-XNM1*(SM1-CRIT)*SP1*STP+
     &YNM1*((SM1-CRIT)*SP1*CTP-CP1*CM1)+ZNM1*CM1*SP1*STP
      SF=T1/T2
      XM1= (RCF-SF*SP1)*CTP+SR1*DCOS(-Q1+PH1)
      YM1= (RCF-SF*SP1)*STP+SR1*DSIN(-Q1+PH1)
      ZM1=-SF*CP1
      xX= CM1*XM1+SM1*ZM1-XG1-XB1*SM1
      yY= YM1+EM1
      zZ=-SM1*XM1+CM1*ZM1-XB1*CM1
      XN1=CM1*XNM1+SM1*ZNM1
      YN1=YNM1
      ZN1=-SM1*XNM1+CM1*ZNM1
      sh1=dsin(phi1)
      ch1=dcos(phi1)
      X1M= xX
      Y1M= CH1*yY+SH1*zZ
      Z1M=-SH1*yY+CH1*zZ
      XN1M= XN1
      YN1M= CH1*YN1+SH1*ZN1
      ZN1M=-SH1*YN1+CH1*ZN1
      TT=YN1M**2+ZN1M**2
      SH1P=(-ZN1M*YNH2+YN1M*ZNH2)/TT
      CH1P=( YN1M*YNH2+ZN1M*ZNH2)/TT
      PHI1P=2.0D00*DATAN2(SH1P,(1.0D00+CH1P))
      XH1= X1M
      YH1= CH1P*Y1M-SH1P*Z1M
```

```
      ZH1= SH1P*Y1M+CH1P*Z1M
      XNH1= XN1M
      YNH1= CH1P*YN1M-SH1P*ZN1M
      ZNH1= SH1P*YN1M+CH1P*ZN1M
      V=-(YH2-YH1)
      H=XH2-XH1
C...
      F(1)=ZH2-ZH1
      F(2)=XNH2-XNH1
C
C
C...
      R12=TN1/TN2
      V12X=0.0-YH2*SM*R12
      V12Y= ZH1+R12*(XH2*SM+ZH2*CM)
      V12Z=-YH1-R12*YH2*CM
      F(3)=XNH2*V12X+YNH2*V12Y+ZNH2*V12Z
      TTTT=F(3)
      RETURN
      END
```

6 Appendix A

Determination of mean contact point

1. Definition of mean contact point

As shown in Fig.1, the mean point on gear tooth surface is defined by XL and RL, which can be calculated by the given blank data.

$$\left.\begin{aligned} XL &= A\cos\Gamma + (h_{OG} - \tfrac{h_m+c}{2})\sin\Gamma \\ RL &= A\sin\Gamma - (h_{OG} - \tfrac{h_m+c}{2})\cos\Gamma \end{aligned}\right\} \tag{1}$$

Suppose that the gear tooth surface is represented in system S_2, which is rigidly connected the gear, then say, θ_G^* and ϕ_P^*, the surface coordinates corresponding the mean point, can be solved from the following equation system

$$\left.\begin{aligned} &X_2(\theta_G^*, \phi_P^*) = XL \\ &{Y_2}^2(\theta_G^*, \phi_P^*) + {Z_2}^2(\theta_G^*, \phi_P^*) = (RL)^2 \end{aligned}\right\} \tag{2}$$

Knowing surface parameters θ_G^* and ϕ_P^*, we then can calculate the surface unit normal at the mean point.

$$\mathbf{n}^{(2)} = \mathbf{n}^{(2)}(\theta_G^*, \phi_P^*) \tag{3}$$

2. Condition of tooth tangency at the mean point

The gear and the pinion are installed as shown in Fig.2 and Fig.3. In order for the mean point to be in contact, two adjustments, H and V are introduced as shown. H is the shift of the pinion along its axis and is positive as shown; V is the change of the offset between the gear and pinion axis. After the introduction of V and H, the position vectors of the points on the gear and pinion tooth surface can be represented as:

$$[\mathbf{r}_h^{(2)}]^* = \mathbf{r}_h^{(2)} + V\mathbf{j}_h \tag{4}$$

$$[\mathbf{r}_h^{(1)}]^* = \mathbf{r}_h^{(1)} + H\mathbf{i}_h \tag{5}$$

where

$$\mathbf{r}_h^{(2)} = [M_{h2}]\mathbf{r}^{(2)} = \mathbf{r}_h^{(2)}(\theta_G^*, \phi_P^*, \phi_2') \tag{6}$$

$$\mathbf{r}_h^{(1)} = [M_{h1}]\mathbf{r}^{(1)} = \mathbf{r}_h^{(1)}(\theta_F^*, \phi_F^*, \phi_1') \tag{7}$$

The introduction of V and H does not affect the orientation of the unit normal, which are represented in S_h as

$$\mathbf{n}_h^{(2)} = \mathbf{n}_h^{(2)}(\theta_G^*, \phi_P^*, \phi_2') \tag{8}$$

$$\mathbf{n}_h^{(1)} = \mathbf{n}_h^{(1)}(\theta_F^*, \phi_F^*, \phi_1') \tag{9}$$

For the mean point to be in tangency, the following conditions must be obseved.

$$[\mathbf{r}_h^{(2)}(\theta_G^*, \phi_P^*, \phi_2')]^* = [\mathbf{r}_h^{(1)}(\theta_F^*, \phi_F^*, \phi_1')]^* \tag{10}$$

$$\mathbf{n}_h^{(2)}(\theta_G^*, \phi_P^*, \phi_2') = \mathbf{n}_h^{(1)}(\theta_F^*, \phi_F^*, \phi_1') \tag{11}$$

Equation (10) yields:

$$V = Y_h^{(1)}(\theta_G^*, \phi_P^*, \phi_2') - Y_h^{(2)}(\theta_F^*, \phi_F^*, \phi_1') \tag{12}$$

$$H = X_h^{(2)}(\theta_G^*, \phi_P^*, \phi_2') - X_h^{(1)}(\theta_F^*, \phi_F^*, \phi_1') \tag{13}$$

$$Z_h^{(2)}(\theta_G^*, \phi_P^*, \phi_2') - Z_h^{(1)}(\theta_F^*, \phi_F^*, \phi_1') = 0 \tag{14}$$

Equation (11) yield:

$$\left.\begin{aligned} \cos\phi_1' &= \frac{-n_{hy}^{(2)} n_{1z}^{(1)} + n_{hz}^{(2)} n_{1y}^{(1)}}{(n_{1y}^{(1)})^2 + (n_{1z}^{(1)})^2} \\ \sin\phi_1' &= \frac{n_{hy}^{(2)} n_{1y}^{(1)} + n_{hz}^{(2)} n_{1z}^{(1)}}{(n_{1y}^{(1)})^2 + (n_{1z}^{(1)})^2} \end{aligned}\right\} \tag{15}$$

$$\mathbf{n}_{hx}^{(2)}(\theta_G^*, \phi_P^*, \phi_2') - \mathbf{n}_{hx}^{(1)}(\theta_F^*, \phi_F^*, \phi_1') = 0 \tag{16}$$

At the mean contact point, we require that the exact gear ratio is observed. From this condition, we may derive a equation of following pattern.

$$f(\theta_G^*, \phi_P^*, \phi_2', \theta_F^*, \phi_F^*, \phi_1') = 0 \tag{17}$$

Combining equation (14),(16) and (17), we may solve for ϕ_2', θ_F^*, ϕ_F^* considering θ_G^*, ϕ_P^* are known and ϕ_1' is represented in terms of other unknown by equation (15). After ϕ_2', θ_F^*, ϕ_F^* are solved, V, H and ϕ_1' can be determined by equations (12),(13) and (15).

The data for the surface parameter θ_F^*, ϕ_F^*, θ_G^* and ϕ_P^*, motion parameter ϕ_2' and ϕ_1' at the mean point, are used as the initial guess for other contact point. The interval of computation can be chosen as

$$\phi_2'^* - \frac{\pi}{N_2} \le \phi_2' \le \phi_2'^* + \frac{\pi}{N_2} \tag{18}$$

Choosing ϕ_2' from the above interval, and solving the tooth tangency equation at each value of ϕ_2', one can obtain the path of contact and the transmission errors.

References

[1] Gleason Works: Understanding Tooth Contact Analysis. Rochester, NY 14692, Publication No. SD 3139, 1981.

[2] Litvin, F.L. and Gutman, Y.: Methods of Synthesis and Analysis for Hypoid Gear Drives of "Formate" and "Helixform," Parts 1-3. ASME Journal of Mechanical Design. Vol. 103, January 1981, pp. 83-113.

[3] Litvin, F.L.: Theory of Gearing. NASA RP-1212 (AVSCOM Technical Report 88-C-035), 1989.

[4] Litvin, F.L., Zhang, Y.: Local Synthesis and Tooth Contact Analysis of Face-Milled Spiral Bevel Gears. NASA Contractor Report 4342 (AVSCOM Technical Report 90-C-028).

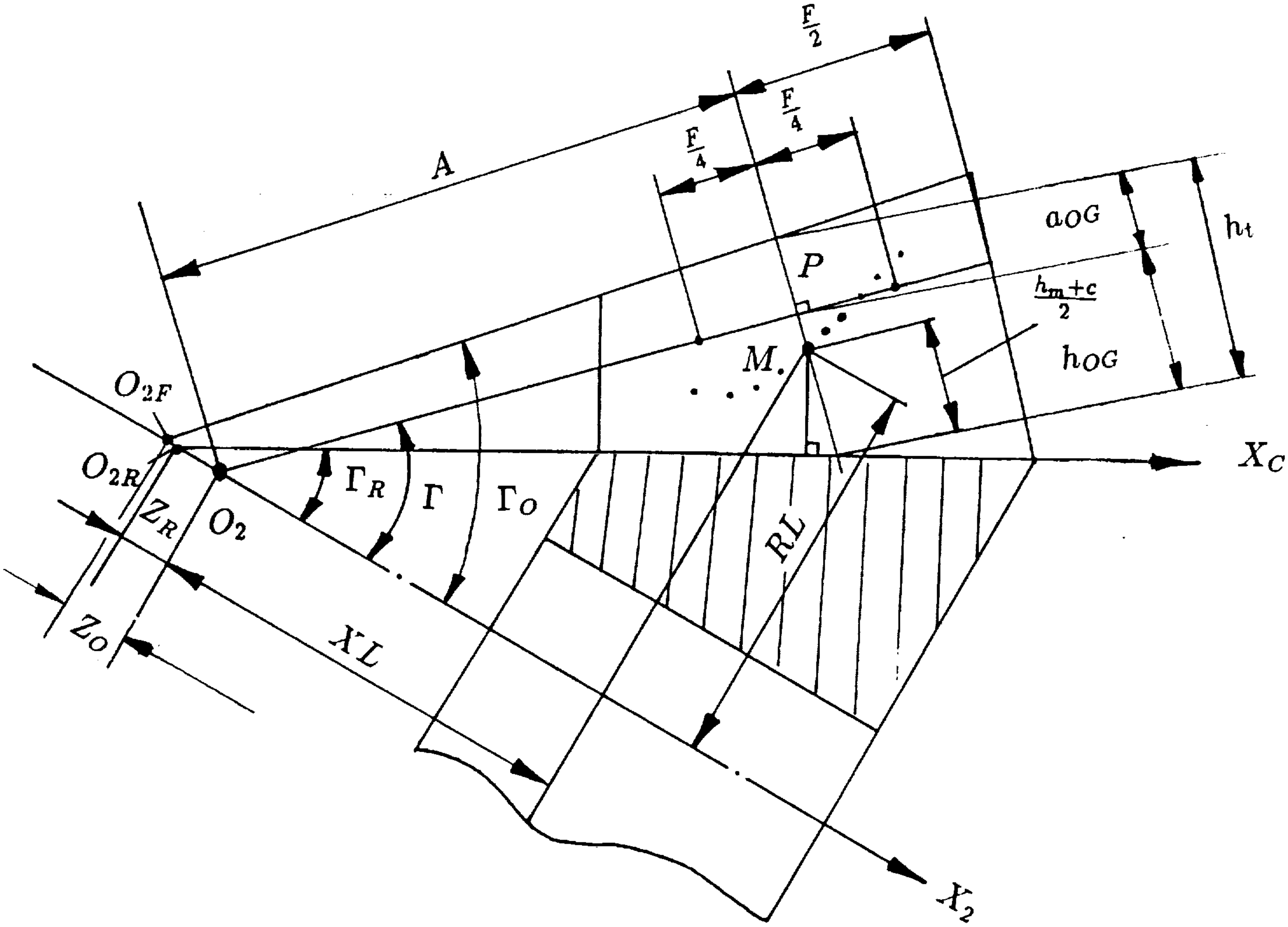


Fig. 1 Mean Contact Point

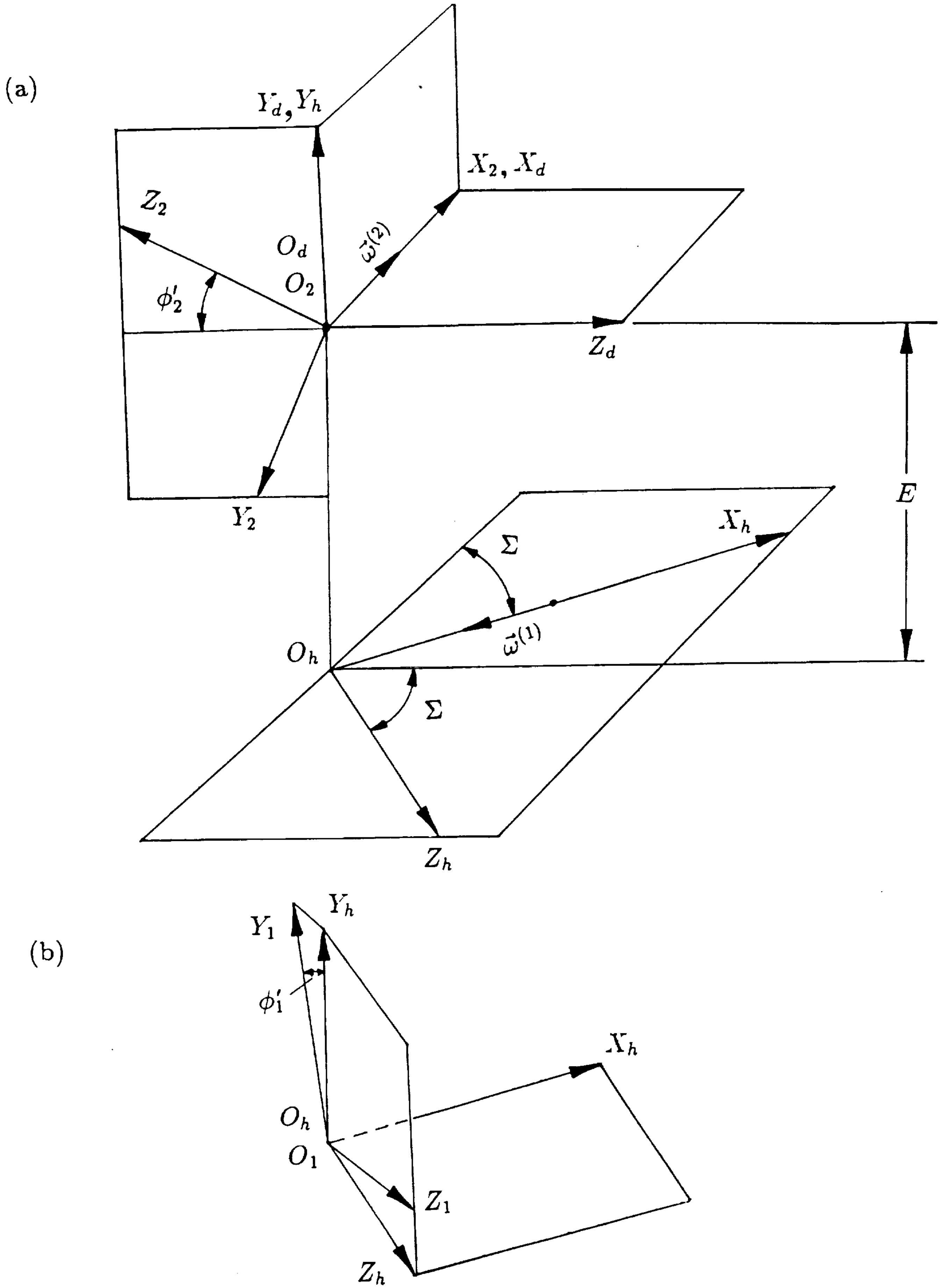


Fig. 2 Coordinate Systems for Simulation of Meshing

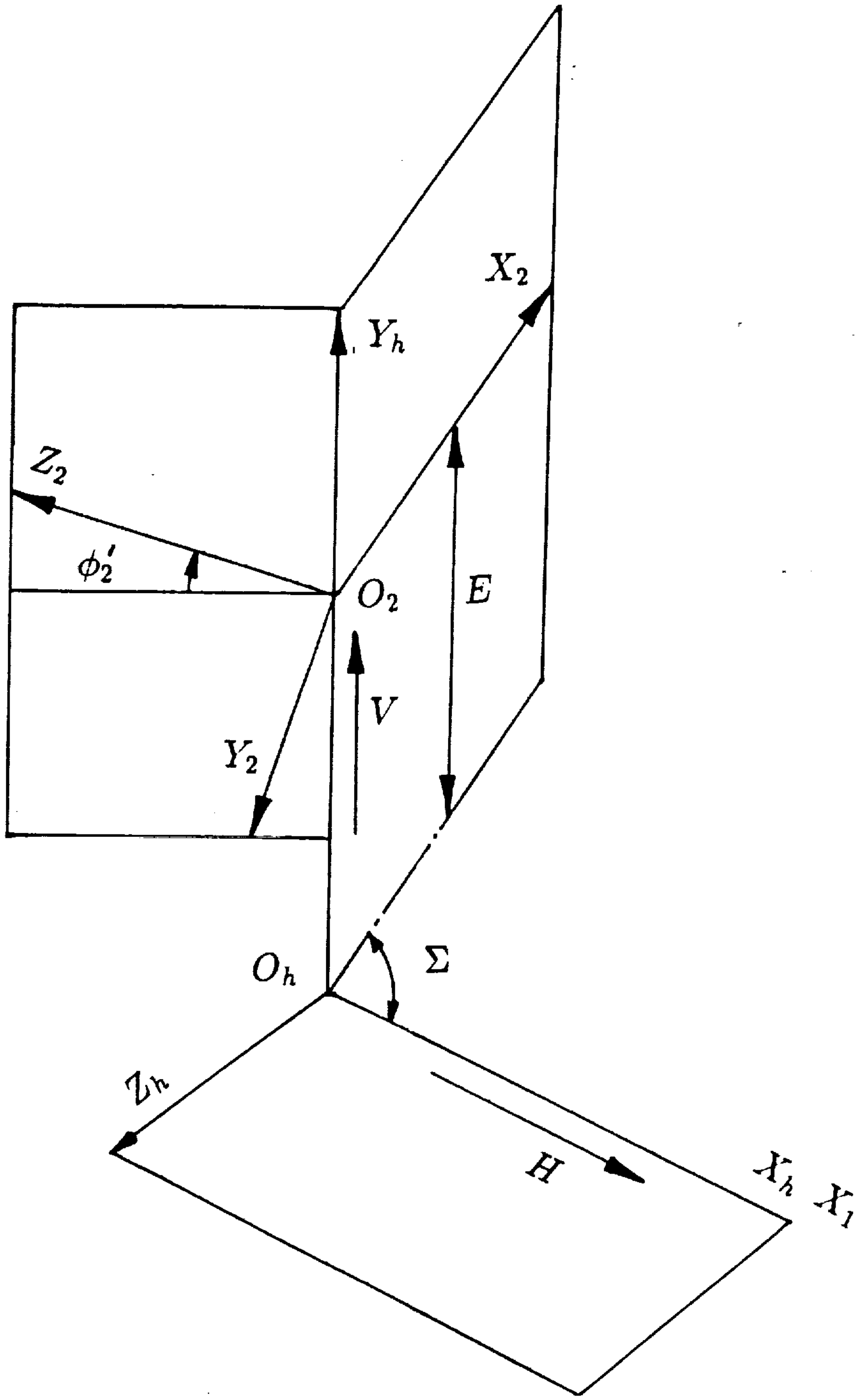


Fig. 3 Gear-Pinion Misalignment

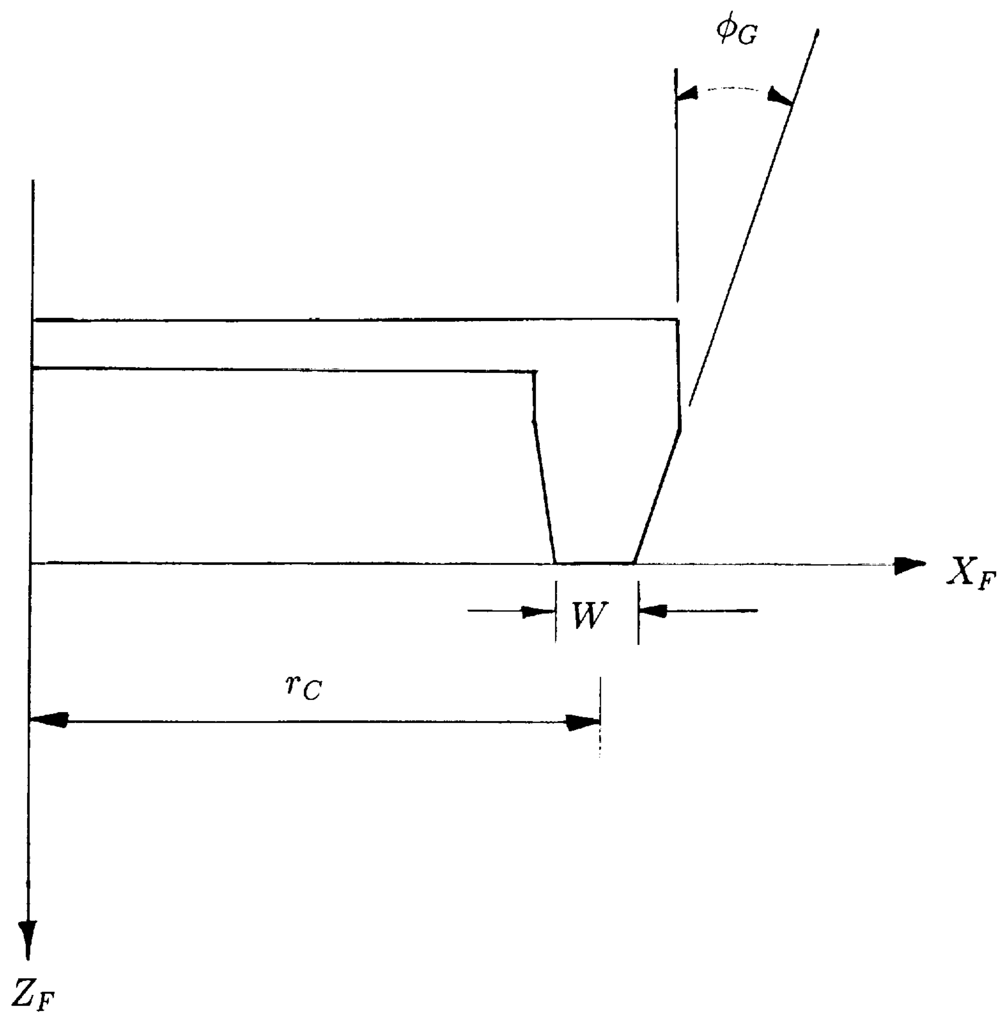


Fig.4 Cutter Specification

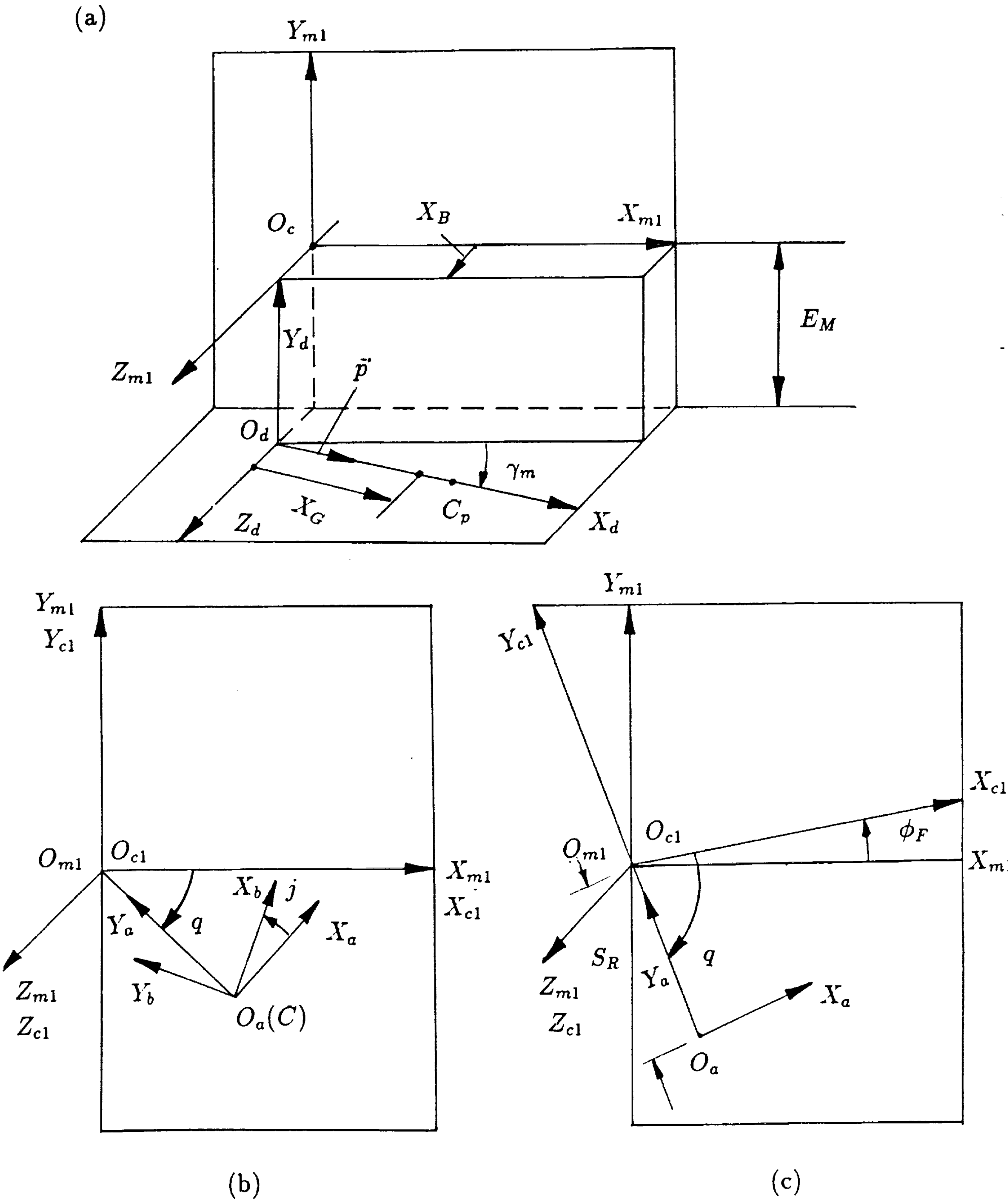


Fig. 5 Coordinate Systems and Pinion and Cradle Settings

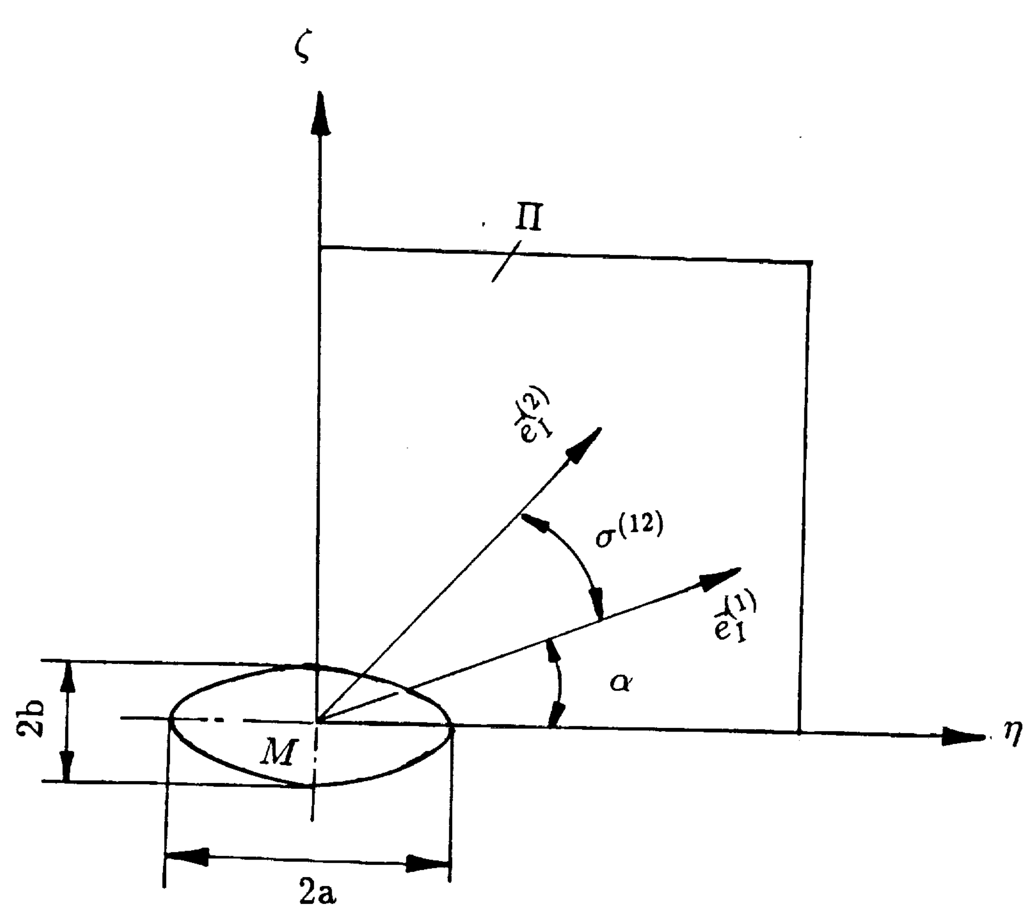


Fig. 6 Orientation of Contact Ellipse

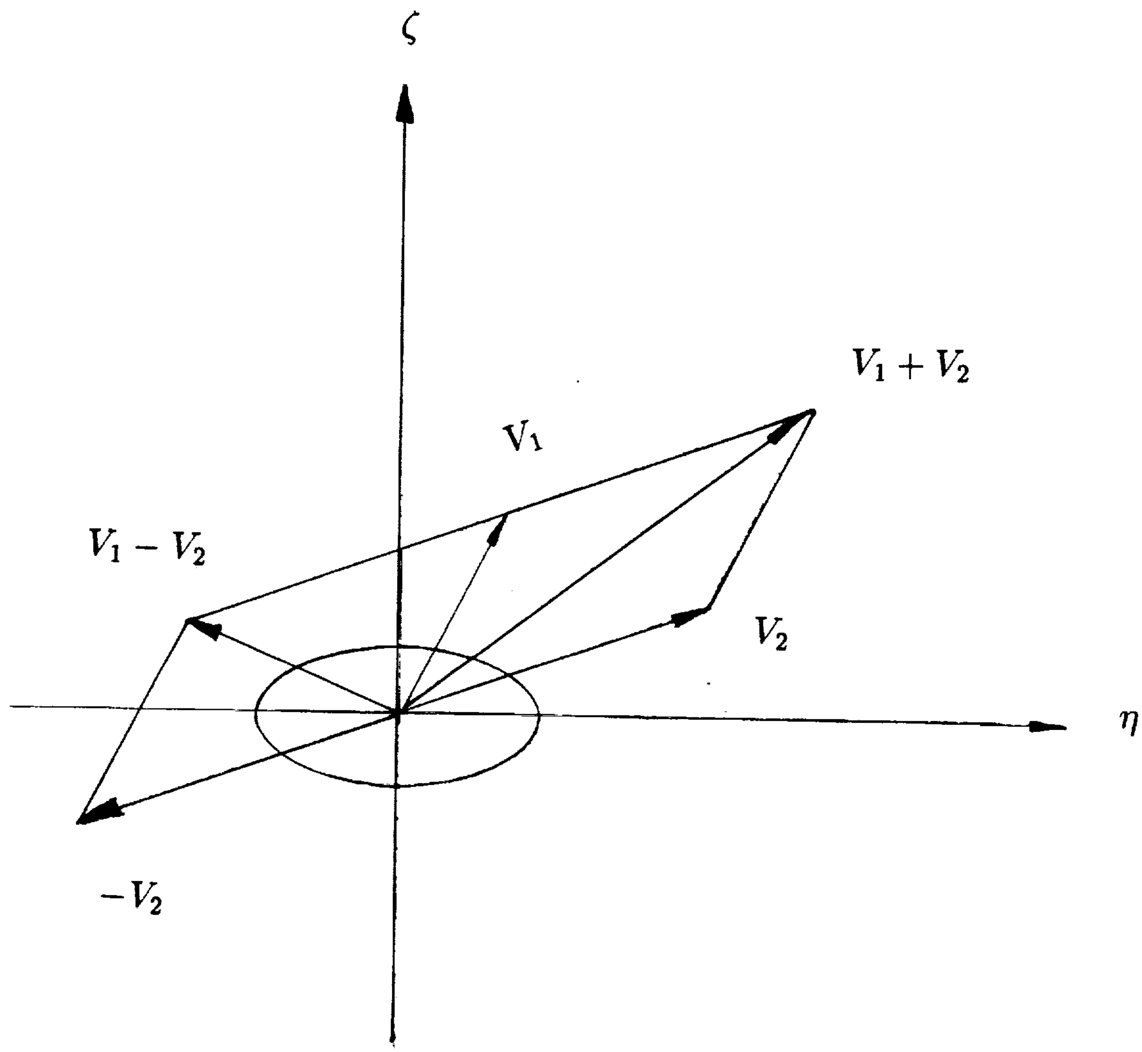
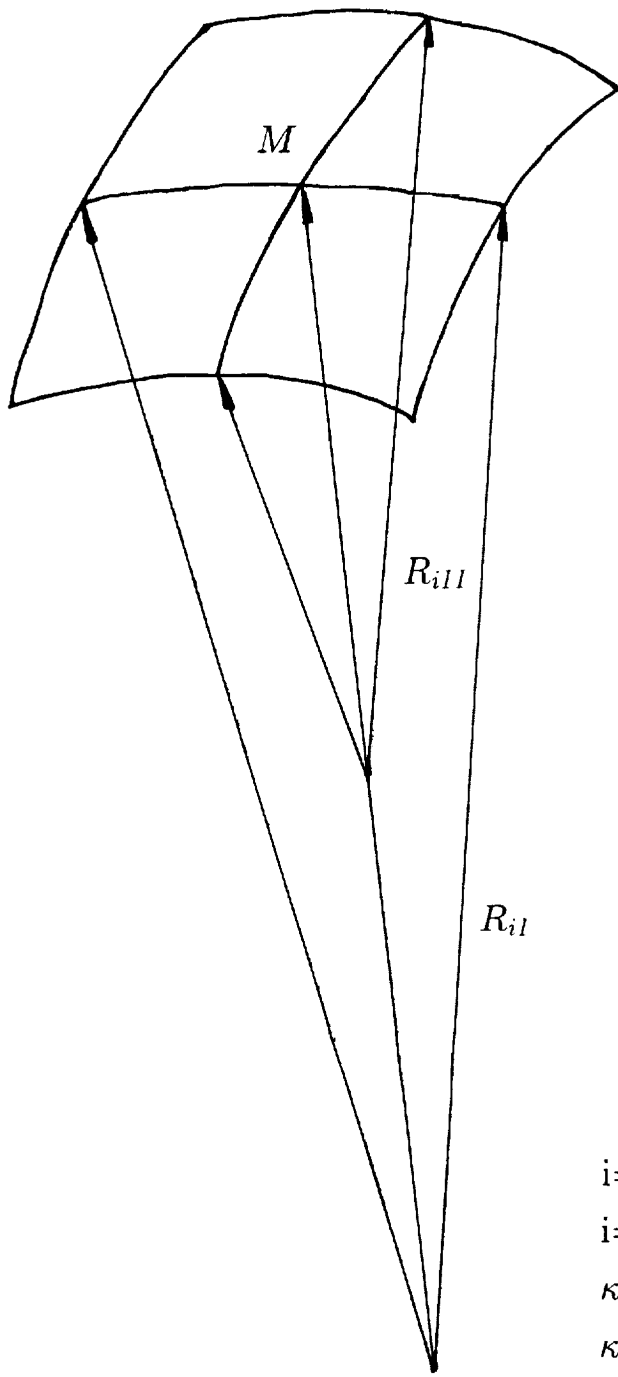


Fig. 7 Velocity in the tangent plane



i=1 pinion

i=2 gear

$\kappa_{iI} = 1/R_{iI}$

$\kappa_{iII} = 1/R_{iII}$

Fig.8 Principal Curvature

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6. AUTHOR(S)
Faydor L. Litvin, Yi Zhang, and Jui-sheng Chen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Illinois at Chicago
Department of Mechanical Engineering
Chicago, Illinois 60616

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13. ABSTRACT ***(Maximum 200 words)***

The main goal of this research project is to develop a computer program that will: (i) simulate the meshing and bearing contact for face-milled spiral bevel gears with *given* machine-tool settings, and (ii) to obtain the output; some of the data is required for hydrodynamic analysis. It is assumed that the machine-tool settings and the blank data will be taken from the Gleason summaries. The theoretical aspects of the program are based on the theory that has been developed in the NASA Contractor Report 4342, AVSCOM Technical Report 90-C-028 entitled "Local Synthesis and Tooth Contact Analysis of Face-Milled Spiral Bevel Gears", by Faydor L. Litvin and Yi Zhang. The difference between the computer programs developed in this report and the previous one is as follows: (i) The mean contact point of tooth surfaces for gears with given machine-tool settings must be determined iteratively, while two parameters (H and V) are changed. Parameter H represents the displacement along the pinion axis, and parameter V represents the gear displacement that is perpendicular to the plane drawn through the axes of the pinion and the gear of their initial positions. This means that when parameter V differs from zero, the axis of the pinion and the gear are crossed but not intersected. The method of local synthesis developed in the previous report provides conditions of exact contact of surfaces at the mean point. (ii) In addition to the regular output data (transmission errors and bearing contact), the new computer program provides information about the contacting force for each contact point, and the sliding and the so-called rolling velocity. The contents of this report covers the following topics: (i) Instructions for the users how to insert the input data (ii) explanations regarding the output data, (iii) numerical example, and (iv) listing of the program.

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