```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

m = 30;
N1 = 36; N2 = 40; N2p = 21; N3 = 30; N3p = 24; N4 = 18; N5 = 14;

r1 = m * N1 / 2;
r2 = m * N2 / 2;
r2p = m * N2p / 2;
r3 = m * N3 / 2;
r3p = m * N3p / 2;
r4 = m * N4 / 2;
r5 = m * N5 / 2;
r6 = r5 + 2 r4 + r3p;

rA = {0, 0, 0};
rB = {0, r1, 0};
rC = {xC, r1 + r2, 0};
rD = {xD, r1 + r2 - r2p, 0};
rE = {xE, r1 + r2 - r2p - r3, 0};
rF = {xF, r1 + r2 - r2p - r3 - r3p, 0};
rG = {xG, r1 + r2 - r2p - r3 - r3p - r4, 0};
rH = {xH, r1 + r2 - r2p - r3 - r3p - 2 r4, 0};
rJ = {xJ, r1 + r2 - r2p - r3 - r3p - 2 r4 - r5, 0};
rK = {xJ, r1 + r2 - r2p - r3 - r3p - 2 r4 - 2 r5, 0};
rL = {xL, r1 + r2 - r2p - r3, 0};

n1 = 320;(*rpm*)
n01 = -n1;

n2 = -n1 r1 / r2;
n3 = -n2 r2p / r3;
n30 = n3;

phi = N[Pi] / 9;

"a)----------"
int1 = {N1, N2p, N3p, N4};
int2 = {N2, N3, N4, N5};
disp1 = {"1", "2p", "3p", "4"};
disp2 = {"2", "3", "4", "5"};
disp = {"1-2", "2p-3", "3p-4", "4-5"};

For[i = 1, i ≤ 4, i++,
  Print["interference ", disp[[i]]];
  r1 = m int1[[i]] / 2;
  r2 = m int2[[i]] / 2;
  c12 = r1 + r2;
  rb1 = r1 Cos[phi];
```

```
  rb2 = r2 Cos[phi];
  a = m;
  ra1 = r1 + a;
  ra2 = r2 + a;
  Print["ra", disp1[[i]], "=", ra1, " mm"];
  Print["ra", disp2[[i]], "=", ra2, " mm"];
  ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
  ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
  Print["ramax", disp1[[i]], "=", ramax1, " mm"];
  Print["ramax", disp2[[i]], "=", ramax2, " mm"];
  If[ramax1 > ra1,
   Print["No interference ", disp[[i]]], Print["Interference ", disp[[i]]]];
  If[ramax2 > ra2, Print["No interference ", disp[[i]]],
   Print["Interference ", disp[[i]]]];
  CR12 = (Sqrt[ra1^2 - rb1^2] + Sqrt[ra2^2 - rb2^2] - c12 Sin[phi]) / (N[Pi] m Cos[phi]);
  Print["CR", disp[[i]], "=", CR12];
 ];

"interference 5-0"
r0 = r3p + 2 r4 + 2 r5;
N0 = 2 r0 / m;
r0 = m N0 / 2;
r5 = m N5 / 2;
c50 = r0 - r5;
rb0 = r0 Cos[phi];
rb5 = r5 Cos[phi];
a = m;
ra0 = r0 - a;
ra5 = r5 + a;
Print["ra0=", ra0, " mm"];
Print["ra5=", ra5, " mm"];
ramax0 = Sqrt[rb0^2 + c50^2 * Sin[phi]^2];
ramax5 = Sqrt[rb5^2 + c50^2 * Sin[phi]^2];
Print["ramax0=", ramax0, " mm"];
Print["ramax5=", ramax5, " mm"];
If[ramax0 > ra0, Print["No interference 5-0"], Print["Interference 5-0"]];
If[ramax5 > ra5, Print["No interference 5-0"], Print["Interference 5-0"]];
CR50 = (Sqrt[ra5^2 - rb5^2] - Sqrt[ra0^2 - rb0^2] + c50 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR50=", CR50];


"b)-------------"

"contour I: 0-E-3-F-4-G-6-L-0"
ω30 = {n30, 0, 0};
ω43 = {n43, 0, 0};
ω64 = {n64, 0, 0};
ω06 = {n06, 0, 0};

"ω30+ω43+ω64+ω06=0 (1)"
eq1x = (ω30 + ω43 + ω64 + ω06)[[1]] == 0; Print[eq1x, " (1)"];
```

```
"rE x ω30 + rF x ω43 + rG x ω64 + rL x ω06=0 (2)"
eq1k = (Cross[rE, ω30] + Cross[rF, ω43] + Cross[rG, ω64] + Cross[rL, ω06])[[3]] == 0;
Print[eq1k, " (2)"];

"contour II: 6-G-4-H-5-J-6"

ω46 = {-n64, 0, 0};
ω54 = {n54, 0, 0};
ω65 = {n65, 0, 0};

"ω46+ω54+ω65=0 (3)"
eq2x = (ω46 + ω54 + ω65)[[1]] == 0; Print[eq2x, " (3)"];
"rG x ω46 + rH x ω54 + rJ x ω65 = 0 (4)"
eq2k = (Cross[rG, ω46] + Cross[rH, ω54] + Cross[rJ, ω65])[[3]] == 0; Print[eq2k, " (4)"];
"contour III: 0-L-6-J-5-K-0"

ω60 = {-n06, 0, 0};
ω56 = {-n65, 0, 0};
ω05 = {n05, 0, 0};

"ω60+ω56+ω05=0 (3)"
eq3x = (ω60 + ω56 + ω05)[[1]] == 0; Print[eq3x, " (5)"];
"rL x ω60 + rJ x ω56 + rK x ω05 = 0 (6)"
eq3k = (Cross[rL, ω60] + Cross[rJ, ω56] + Cross[rK, ω05])[[3]] == 0; Print[eq3k, " (6)"];
eqns = {eq1x, eq1k, eq2x, eq2k, eq3x, eq3k};
sol = {n05, n65, n06, n64, n54, n43};
"solutions"
solution = N[Solve[eqns, sol]]
Print["n6 = ", -n06 /. solution[[1]], " rpm"];

n6 = -n06 /. solution[[1]];
n4 = n3 + n43 /. solution[[1]];
n5 = n4 + n54 /. solution[[1]];

"---- rpms ----"
Print["n1 = ", N[n1], " rpm"];
Print["n2 = ", N[n2], " rpm"];
Print["n3 = ", N[n3], " rpm"];
Print["n4 = ", N[n4], " rpm"];
Print["n5 = ", N[n5], " rpm"];
Print["n6 = ", N[n6], " rpm"];

"c)-------------"
(* Link 6 *)
Print["Link 6"];
phi = N[Pi] / 9;
LJ = rJ - rL;
LG = rG - rL;
Mext = -600 {Sign[n6], 0, 0};
F56 = {0, F56y, F56z};
F46 = {0, F46y, F46z};
```

```
(*Sum of moments for 6 wrt L*)
SM6L = Cross[LJ, F56] + Cross[LG, F46] + Mext;
eq1 = SM6L[[1]] == 0;
Print["sum of moments for 6 wrt L :  LJ x F56 + LG x F46 + Mext = 0"]
Print[eq1, " (1)"];

(* Link 5 *)
Print["Link 5"];
JK = rK - rJ;
JH = rH - rJ;
F65 = -F56;
F45 = {0, -Ft45 * Tan[phi], Ft45};
F05 = {0, Ft05 * Tan[phi], Ft05};
(*Sum of moments for 5 wrt J *)
SM5J = Cross[JK, F05] + Cross[JH, F45];
eq2 = SM5J[[1]] == 0;
Print["sum of moments for 5 wrt J :  JK x F05 + JH x F45 = 0"]
Print[eq2, " (2)"]
(*Sum of forces for 5 *)
SF5 = F05 + F45 + F65;
eq3 = SF5[[2]] == 0;
eq4 = SF5[[3]] == 0;
Print["sum of forces for 5 :  F05 + F45 + F65 = 0"]
Print[eq3, " (3)"]
Print[eq4, " (4)"]

(* Link 4 *)
Print["Link 4"];
GF = {0, r4, 0};
GH = {0, -r4, 0};
F64 = -F46;
F54 = -F45;
F3p4 = {0, Ft3p4 * Tan[phi], Ft3p4};
(*Sum of moments for 4 wrt G *)
SM4G = Cross[GF, F3p4] + Cross[GH, F54];
eq5 = SM4G[[1]] == 0;
Print["sum of moments for 4 wrt G :  GF x F3p4 + GH x F54 = 0"]
Print[eq5, " (5)"]
(*Sum of forces for 4 *)
SF4 = F54 + F3p4 + F64;
eq6 = SF4[[2]] == 0;
eq7 = SF4[[3]] == 0;
Print["sum of forces for 4 :  F54 + F3p4 + F64 = 0"]
Print[eq6, " (6)"]
Print[eq7, " (7)"]

sol =
  Solve[{eq1, eq2, eq3, eq4, eq5, eq6, eq7}, {F46y, F46z, F56y, F56z, Ft45, Ft05, Ft3p4}];

f45 = F45 /. sol[[1]];
f05 = F05 /. sol[[1]];
```

```
f3p4 = F3p4 /. sol[[1]];
f46 = F46 /. sol[[1]];
f56 = F56 /. sol[[1]];

Print["-----------"]
Print["From Eqs.(1)-(7) => "]

Print["F45 = ", f45, " N"];
Print["F05 = ", f05, " N"];
Print["F3p4 = ", f3p4, " N"];
Print["F46 = ", f46, " N"];
Print["F56 = ", f56, " N"];

(* Link 3 *)
Print["Link 3"];
F43p = -f3p4;
F2p3 = {0, Ft2p3 * Tan[phi], Ft2p3};
rO3 = {xO3, r1 + r2 - r2p - r3, 0};
O3F = rF - rO3;
O3D = rD - rO3;
SM3O3 = Cross[O3F, F43p] + Cross[O3D, F2p3];
eq8 = SM3O3[[1]] == 0;
Print["sum of moments for 3 wrt O3 :  O3F x F43p + O3D x F2p3 = 0"]
solFt2p3 = Solve[eq8, Ft2p3];
Print[eq8, " (8) => Ft2p3 =  ", Ft2p3 /. solFt2p3[[1]], " N"];
f2p3 = F2p3 /. solFt2p3[[1]];
Print["F2p3 = ", f2p3, " N"];
Print["F03 =  - F2p3 - F43p = ", - F43p - f2p3, " N"];

(* Link 2 *)
Print["Link 2"];
F32p = -f2p3;
F12 = {0, -Ft12 * Tan[phi], Ft12};
rO2 = {xO2, r1 + r2, 0};
O2D = rD - rO2;
O2B = rB - rO2;
SM2O2 = Cross[O2D, F32p] + Cross[O2B, F12];
eq9 = SM2O2[[1]] == 0;
Print["sum of moments for 2 wrt O2 :  O2D x F32p + O2B x F12 = 0"]
solFt12 = Solve[eq9, Ft12];
Print[eq9, " (9) => Ft212 =  ", Ft12 /. solFt12[[1]], " N"];
f12 = F12 /. solFt12[[1]];
Print["F12 = ", f12, " N"];
Print["F02 =  - F32p - F12 = ", - F32p - f12, " N"];

(* Link 1 *)
Print["Link 1"];
F21 = -f12;
Mmot = {Mmotx, 0, 0};
Mmot = -Cross[rB, F21];
```

```
Print["sum of moments for 1 wrt A :  AB x F21 + Mmot = 0"]
Print["Mmot =  - AB x F21 = ", Mmot, " N m"];
```

```
a)----------
interference 1-2
ra1=570 mm
ra2=630 mm
ramax1=639.932 mm
ramax2=685.502 mm
No interference 1-2
No interference 1-2
CR1-2=1.70299
interference 2p-3
ra2p=345 mm
ra3=480 mm
ramax2p=395.065 mm
ramax3=497.263 mm
No interference 2p-3
No interference 2p-3
CR2p-3=1.61132
interference 3p-4
ra3p=390 mm
ra4=300 mm
ramax3p=401.084 mm
ramax4=332.868 mm
No interference 3p-4
No interference 3p-4
CR3p-4=1.56583
interference 4-5
ra4=300 mm
ra5=240 mm
ramax4=302.199 mm
ramax5=256.696 mm
```

No interference 4–5

No interference 4–5

CR4–5=1.49625

interference 5–0

ra0=1290 mm

ra5=240 mm

ramax0=1297.19 mm

ramax5=427.866 mm

No interference 5–0

No interference 5–0

CR50=1.8286

b) ----------

contour I: 0–E–3–F–4–G–6–L–0

ω30+ω43+ω64+ω06=0 (1)

$\frac{1008}{5}$ + n06 + n43 + n64 == 0 (1)

rE x ω30 + rF x ω43 + rG x ω64 + rL x ω06=0 (2)

−75600 − 375 n06 − 15 n43 + 255 n64 == 0 (2)

contour II: 6–G–4–H–5–J–6

ω46+ω54+ω65=0 (3)

n54 − n64 + n65 == 0 (3)

rG x ω46 + rH x ω54 + rJ x ω65 = 0 (4)

525 n54 − 255 n64 + 735 n65 == 0 (4)

contour III: 0–L–6–J–5–K–0

ω60+ω56+ω05=0 (3)

n05 − n06 − n65 == 0 (5)

rL x ω60 + rJ x ω56 + rK x ω05 = 0 (6)

945 n05 + 375 n06 − 735 n65 == 0 (6)

solutions

{{n05 → −399.6, n65 → −475.2, n06 → 75.6, n64 → 369.6, n54 → 844.8, n43 → −646.8}}

n6 = −75.6 rpm

---- rpms ----

n1 = 320. rpm

n2 = -288. rpm

n3 = 201.6 rpm

n4 = -445.2 rpm

n5 = 399.6 rpm

n6 = -75.6 rpm

c)----------

Link 6

sum of moments for 6 wrt L : LJ x F56 + LG x F46 + Mext = 0

600 - 630 F46z - 1110 F56z == 0 (1)

Link 5

sum of moments for 5 wrt J : JK x F05 + JH x F45 = 0

-210 Ft05 + 210 Ft45 == 0 (2)

sum of forces for 5 : F05 + F45 + F65 = 0

-F56y + 0.36397 Ft05 - 0.36397 Ft45 == 0 (3)

-F56z + Ft05 + Ft45 == 0 (4)

Link 4

sum of moments for 4 wrt G : GF x F3p4 + GH x F54 = 0

270 Ft3p4 + 270 Ft45 == 0 (5)

sum of forces for 4 : F54 + F3p4 + F64 = 0

-F46y + 0.36397 Ft3p4 + 0.36397 Ft45 == 0 (6)

-F46z + Ft3p4 - Ft45 == 0 (7)

From Eqs.(1)-(7) =>

F45 = {0, -0.227481, 0.625} N

F05 = {0, 0.227481, 0.625} N

F3p4 = {0, -0.227481, -0.625} N

F46 = {0, 0., -1.25} N

F56 = {0, 0., 1.25} N

Link 3

sum of moments for 3 wrt O3 : O3F x F43p + O3D x F2p3 = 0

```
187.5 + 1110 Ft2p3 == 0  (8)  => Ft2p3 =  -0.168919 N

F2p3 = {0, -0.0614815, -0.168919} N

F03 =  - F2p3 - F43p = {0, -0.166, -0.456081} N

Link 2

sum of moments for 2 wrt O2 :  O2D x F32p + O2B x F12 = 0

58.277 + 60 Ft12 == 0  (9)  => Ft212 =  -0.971284 N

F12 = {0, 0.353518, -0.971284} N

F02 =  - F32p - F12 = {0, -0.415, 0.802365} N

Link 1

sum of moments for 1 wrt A :  AB x F21 + Mmot = 0

Mmot =  - AB x F21 = {-524.493, 0., 0.} N m
```

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

m = 24;
N1 = 22; N2 = 18; N3 = 20; N4 = 54;

r1 = m * N1 / 2;
r2 = m * N2 / 2;
r3 = m * N3 / 2;
r3p = m * N3 / 2;
r4 = m * N4 / 2;
r5 = r2 + r3;

rA = {0, 0, 0};
rB = {0, r1, 0};
rC = {xC, r1 + r2, 0};
rD = {xD, r1 + 2 r2 , 0};
rE = {xE, r1 + 2 r2 + r3, 0};
rF = {xF, r1 + 2 r2 , 0};
rG = {xG, 0, 0};

n1 = 290; (*rpm*)
n5 = 110;(*rpm*)
n10 = n1;
n05 = -n5;

phi = N[Pi] / 9;

"a)----------"
n = 6;
c5 = 6;
c4 = 4;
M = 3 n - 2 c5 - c4;
Print["M=", M];


"b)----------"
int1 = {N1, N2, N3};
int2 = {N2, N3, N4};
disp1 = {"1", "2", "3"};
disp2 = {"2", "3", "4"};
disp = {"1-2", "2-3", "3-4"};

For[i = 1, i ≤ 3, i++,
  Print["interference ", disp[[i]]];
  r1 = m int1[[i]] / 2;
  r2 = m int2[[i]] / 2;
  c12 = r1 + r2;
  rb1 = r1 Cos[phi];
```

```
  rb2 = r2 Cos[phi];
  a = m;
  ra1 = r1 + a;
  ra2 = r2 + a;
  Print["ra", disp1[[i]], "=", ra1, " mm"];
  Print["ra", disp2[[i]], "=", ra2, " mm"];
  ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
  ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
  Print["ramax", disp1[[i]], "=", ramax1, " mm"];
  Print["ramax", disp2[[i]], "=", ramax2, " mm"];
  If[ramax1 > ra1,
   Print["No interference ", disp[[i]]], Print["Interference ", disp[[i]]]];
  If[ramax2 > ra2, Print["No interference ", disp[[i]]],
   Print["Interference ", disp[[i]]]];
  CR12 = (Sqrt[ra1^2 - rb1^2] + Sqrt[ra2^2 - rb2^2] - c12 Sin[phi]) / (N[Pi] m Cos[phi]);
  Print["CR", disp[[i]], "=", CR12];
 ];


"c)-------------"


"contour I: 0-A-1-B-2-D-3-F-4-G-0"

ω10 = {n10, 0, 0};
ω21 = {n21, 0, 0};
ω32 = {n32, 0, 0};
ω43 = {n43, 0, 0};
ω04 = {n04, 0, 0};

"ω10+ω21+ω32+ω43+ω04=0 (1)"
eq1x = (ω10 + ω21 + ω32 + ω43 + ω04)[[1]] == 0; Print[eq1x, " (1)"];
"rA x ω10 + rB x ω21 + rD x ω32 + rF x ω43 + rG x ω04 = 0 (2)"
eq1k =
 (Cross[rA, ω10] + Cross[rB, ω21] + Cross[rD, ω32] + Cross[rF, ω43] + Cross[rG, ω04])[[3]] ==
  0; Print[eq1k, " (2)"];

"contour II: 2-D-3-E-5-C-2"

ω53 = {n53, 0, 0};
ω25 = {n25, 0, 0};

"ω32+ω53+ω25=0 (3)"
eq2x = (ω32 + ω53 + ω25)[[1]] == 0; Print[eq2x, " (3)"];
"rD x ω32 + rE x ω53 + rC x ω25 = 0 (4)"
eq2k = (Cross[rD, ω32] + Cross[rE, ω53] + Cross[rC, ω25])[[3]] == 0; Print[eq2k, " (4)"];

"contour III: 0-A-1-B-2-C-5-G-0"

ω52 = {-n25, 0, 0};
ω05 = {n05, 0, 0};
```

```
"ω10+ω21+ω52+ω05=0 (3)"
eq3x = (ω10 + ω21 + ω52 + ω05)[[1]] == 0; Print[eq3x, " (5)"];
"rA x ω10 + rB x ω21 + rC x ω52 + rG x ω05 = 0 (6)"
eq3k = (Cross[rA, ω10] + Cross[rB, ω21] + Cross[rC, ω52] + Cross[rG, ω05])[[3]] == 0;
Print[eq3k, " (6)"];

eqns = {eq1x, eq1k, eq2x, eq2k, eq3x, eq3k};
sol = {n21, n32, n43, n04, n53, n25};
"solutions"
solution = N[Solve[eqns, sol]]
Print["n4 = ", -n04 /. solution[[1]], " rpm"];
n4 = -n04 /. solution[[1]];


"d)-------------"


(* Link 4 *)
Print["Link 4"];
phi = N[Pi] / 9;
GF = rF - rG;
Mext = -800. {Sign[n4], 0, 0};
F3p4 = {0, -F3p4t Tan[phi], F3p4t};
(*Sum of moments for 4 wrt G*)
SM4G = Cross[GF, F3p4] + Mext;
eq1 = SM4G[[1]] == 0;
Print["sum of moments for 4 wrt G :  GF x F3p4 + Mext = 0"]
Print[eq1, " (1)"];
sol = Solve[eq1, F3p4t];
f3p4 = F3p4 /. sol[[1]];
Print["F3p4 = ", f3p4]

(* Link 3 *)
Print["Link 3"];
ED = rD - rE;
EF = rF - rE;
F23 = {0, F23t Tan[phi], F23t};
f43p = -f3p4;
(*Sum of moments for 3 wrt E*)
SM3E = Cross[ED, F23] + Cross[EF, f43p];
eq2 = SM3E[[1]] == 0;
Print["sum of moments for 3 wrt E :  ED x F23 + EFxF43p = 0"]
Print[eq2, " (2)"];
sol = Solve[eq2, F23t];
f23 = F23 /. sol[[1]];
Print["F23 = ", f23]
f53 = -f23 - f43p;

(* Link 2 *)
Print["Link 2"];
```

```
CD = rD - rC;
CA = rA - rC;
f32 = -f23;
F12 = {0, -F12t Tan[phi], F12t};
(*Sum of moments for 2 wrt C*)
SM2C = Cross[CD, f32] + Cross[CA, F12];
eq3 = SM2C[[1]] == 0;
Print["sum of moments for 2 wrt C :  CD x F32 + CA x F12 = 0"]
Print[eq3, " (3)"];
sol = Solve[eq3, F12t];
f12 = F12 /. sol[[1]];
Print["F12 = ", f12]
f52 = -f12 - f32;

(* Link 1 *)
Print["Link 1"];
AB = rB - rA;
f21 = -f12;
(*Sum of moments for 1 wrt A*)
M1 = -Cross[AB, f21];
Print["sum of moments for 1 wrt A :  AB x F21 + M1 = 0"]
Print["M1=", M1[[1]] " N m "];

(* Link 5 *)
Print["Link 5"];
GE = rE - rG;
GC = rC - rG;
f35 = -f53;
f25 = -f52;
(*Sum of moments for 5 wrt G*)
M5 = -Cross[GE, f35] - Cross[GC, f25];
Print["sum of moments for 5 wrt G :  GE x F35 + GC x F25 + M5 = 0"]
Print["M5 = ", M5[[1]] "N m"];
```

```
a)--------------

M=2

b)--------------

interference 1-2

ra1=288 mm

ra2=240 mm

ramax1=297.481 mm

ramax2=261.055 mm

No interference 1-2
```

No interference 1–2

CR1–2=1.55523

interference 2–3

ra2=240 mm

ra3=264 mm

ramax2=255.973 mm

ramax3=274.201 mm

No interference 2–3

No interference 2–3

CR2–3=1.5433

interference 3–4

ra3=264 mm

ra4=672 mm

ramax3=378.291 mm

ramax4=680.461 mm

No interference 3–4

No interference 3–4

CR3–4=1.66229

c)----------

contour I: 0–A–1–B–2–D–3–F–4–G–0

ω10+ω21+ω32+ω43+ω04=0 (1)

290 + n04 + n21 + n32 + n43 == 0 (1)

rA x ω10 + rB x ω21 + rD x ω32 + rF x ω43 + rG x ω04 = 0 (2)

−264 n21 − 696 n32 − 696 n43 == 0 (2)

contour II: 2–D–3–E–5–C–2

ω32+ω53+ω25=0 (3)

n25 + n32 + n53 == 0 (3)

rD x ω32 + rE x ω53 + rC x ω25 = 0 (4)

−480 n25 − 696 n32 − 936 n53 == 0 (4)

contour III: 0–A–1–B–2–C–5–G–0

ω10+ω21+ω52+ω05=0 (3)

```
180 + n21 - n25 == 0  (5)

rA x ω10 + rB x ω21 + rC x ω52 + rG x ω05 = 0  (6)

-264 n21 + 480 n25 == 0  (6)

solutions

{{n21 → -400., n32 → 418., n43 → -266.276, n04 → -41.7241, n53 → -198., n25 → -220.}}

n4 = 41.7241 rpm

d) ----------

Link 4

sum of moments for 4 wrt G :  GF x F3p4 + Mext = 0

-800. + 696 F3p4t == 0  (1)

F3p4 = {0, -0.418357, 1.14943}

Link 3

sum of moments for 3 wrt E :  ED x F23 + EFxF43p = 0

275.862 - 240 F23t == 0  (2)

F23 = {0, 0.418357, 1.14943}

Link 2

sum of moments for 2 wrt C :  CD x F32 + CA x F12 = 0

-248.276 - 480 F12t == 0  (3)

F12 = {0, 0.18826, -0.517241}

Link 1

sum of moments for 1 wrt A :  AB x F21 + M1 = 0

M1=-136.552  N m

Link 5

sum of moments for 5 wrt G :  GE x F35 + GC x F25 + M5 = 0

M5 = 800. N m
```

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

m = 24;
N1 = 15; N2 = 27; N2p = 18; N3 = 24; N3p = 16;

r1 = m * N1 / 2;
r2 = m * N2 / 2;
r2p = m * N2p / 2;
r3 = m * N3 / 2;
r3p = m * N3p / 2;

rA = {0, 0, 0};
rB = {xB, 0, 0};
rC = {xC, r1, 0};
rD = {xD, r1 + r2 , 0};
rE = {xE, r1 + r2 + r2p, 0};
rF = {xF, r1 + r2 + r2p + r3 , 0};
rG = {xG, r1 + r2 + r2p + r3 + r3p, 0};
rH = {xH, 0, 0};

n1 = 440;(*rpm*)
n5 = 80;(*rpm*)
n10 = n1;
n05 = -n5;


phi = N[Pi] / 9;

"a)----------"
int1 = {N1, N2p};
int2 = {N2, N3};
disp1 = {"1", "2p"};
disp2 = {"2", "3"};
disp = {"1-2", "2p-3"};

For[i = 1, i ≤ 2, i++,
  Print["interference ", disp[[i]]];
  r1 = m int1[[i]] / 2;
  r2 = m int2[[i]] / 2;
  c12 = r1 + r2;
  rb1 = r1 Cos[phi];
  rb2 = r2 Cos[phi];
  a = m;
  ra1 = r1 + a;
  ra2 = r2 + a;
  Print["ra", disp1[[i]], "=", ra1, " mm"];
  Print["ra", disp2[[i]], "=", ra2, " mm"];
  ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
```

```
  ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
  Print["ramax", disp1[[i]], "=", ramax1, " mm"];
  Print["ramax", disp2[[i]], "=", ramax2, " mm"];
  If[ramax1 > ra1,
   Print["No interference ", disp[[i]]], Print["Interference ", disp[[i]]]];
  If[ramax2 > ra2, Print["No interference ", disp[[i]]],
   Print["Interference ", disp[[i]]]];
  CR12 = (Sqrt[ra1^2 - rb1^2] + Sqrt[ra2^2 - rb2^2] - c12 Sin[phi]) / (N[Pi] m Cos[phi]);
  Print["CR", disp[[i]], "=", CR12];
 ];

Print["interference 3p-4"];
r1 = r3p;
r2 = r1 + r2 + r2p + r3 + r3p;
c12 = r1 + r2;
rb1 = r1 Cos[phi];
rb2 = r2 Cos[phi];
a = m;
ra1 = r1 + a;
ra2 = r2 - a;
Print["ra3p=", ra1, " mm"];
Print["ra4=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax3p=", ramax1, " mm"];
Print["ramax4=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 3p-4"], Print["Interference 3p-4"]];
If[ramax2 > ra2, Print["No interference 3p-4"], Print["Interference 3p-4"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR3p-4=", CR12];

"b)-------------"

"contour I: 0-B-1-C-2-D-5-A-0"

ω10 = {n10, 0, 0};
ω21 = {n21, 0, 0};
ω52 = {n52, 0, 0};
ω05 = {n05, 0, 0};

"ω10+ω21+ω52+ω05=0 (1)"
eq1x = (ω10 + ω21 + ω52 + ω05)[[1]] == 0; Print[eq1x, " (1)"];
"rB x ω10 + rC x ω21 + rD x ω52 + rA x ω05 = 0 (2)"
eq1k = (Cross[rB, ω10] + Cross[rC, ω21] + Cross[rD, ω52] + Cross[rA, ω05])[[3]] == 0;
Print[eq1k, " (2)"];

"contour II: 2-E-3-F-5-D-2"

ω32 = {n32, 0, 0};
ω53 = {n53, 0, 0};
ω25 = {-n52, 0, 0};
```

```
"ω32+ω53+ω25=0 (3)"
eq2x = (ω32 + ω53 + ω25)[[1]] == 0; Print[eq2x, " (3)"];
"rE x ω32 + rF x ω53 + rD x ω25 = 0 (4)"
eq2k = (Cross[rE, ω32] + Cross[rF, ω53] + Cross[rD, ω25])[[3]] == 0; Print[eq2k, " (4)"];

"contour III: 0-H-4-G-3-F-5-A-0"

ω40 = {n40, 0, 0};
ω32 = {n34, 0, 0};

"ω40+ω32+ω53+ω05=0 (3)"
eq3x = (ω40 + ω32 + ω53 + ω05)[[1]] == 0; Print[eq3x, " (5)"];
"rH x ω40 + rG x ω32 + rF x ω53 + rA x ω05 = 0 (6)"
eq3k = (Cross[rH, ω40] + Cross[rG, ω32] + Cross[rF, ω53] + Cross[rA, ω05])[[3]] == 0;
Print[eq3k, " (6)"];

eqns = {eq1x, eq1k, eq2x, eq2k, eq3x, eq3k};
sol = {n21, n52, n32, n40, n53, n34};
"solutions"
solution = N[Solve[eqns, sol]]
Print["n4 = ", n40 /. solution[[1]], " rpm"];

n4 = n40 /. solution[[1]];

"c)-------------"

(* Link 4 *)
Print["Link 4"];
phi = N[Pi] / 9;
HG = rG - rH;
Mext = -1000 {Sign[n4], 0, 0};
F3p4 = {0, F3p4t Tan[phi], F3p4t};
(*Sum of moments for 4 wrt H*)
SM4H = Cross[HG, F3p4] + Mext;
eq1 = SM4H[[1]] == 0;
Print["sum of moments for 4 wrt H :  HG x F3p4 + Mext = 0"]
Print[eq1, " (1)"];
sol = Solve[eq1, F3p4t];
f3p4 = F3p4 /. sol[[1]];
Print["f3p4=", f3p4];

(* Link 3 *)
Print["Link 3"];
FE = rE - rF;
FG = rG - rF;
f43p = -f3p4;
F2p3 = {0, -F2p3t Tan[phi], F2p3t};
(*Sum of moments for 3 wrt F*)
SM3F = Cross[FG, f43p] + Cross[FE, F2p3];
eq2 = SM3F[[1]] == 0;
```

```
Print["sum of moments for 3 wrt F :  FG x F43p + FE x F2p3 = 0"]
Print[eq2, " (2)"];
sol = Solve[eq2, F2p3t];
f2p3 = F2p3 /. sol[[1]];
f53 = -f2p3 - f43p;
Print["f2p3=", f2p3];

(* Link 2 *)
Print["Link 2"];
DC = rC - rD;
DE = rE - rD;
f32p = -f2p3;
F12 = {0, F12t Tan[phi], F12t};
(*Sum of moments for 2 wrt D*)
SM2D = Cross[DC, F12] + Cross[DE, f32p];
eq3 = SM2D[[1]] == 0;
Print["sum of moments for 2 wrt D :  DE x F32p + DC x F12 = 0"]
Print[eq3, " (3)"];
sol = Solve[eq3, F12t];
f12 = F12 /. sol[[1]];
f52 = -f32p - f12;
Print["f12=", f12];

(* Link 1 *)
Print["Link 1"];
BC = rC - rB;
f21 = -f12;
(*Sum of moments for 1 wrt B*)
M1 = -Cross[BC, f21];
Print["sum of moments for 1 wrt B :  BC x F21 + M1 = 0"]
Print["M1=", M1[[1]] "Nm"];

(* Link 5 *)
Print["Link 5"];
AD = rD - rA;
AF = rF - rA;
f35 = -f53;
f25 = -f52;
(*Sum of moments for 5 wrt A*)
M5 = -Cross[AD, f25] - Cross[AF, f35];
Print["sum of moments for 5 wrt A :  AD x F25 + AF x F35 + M5 = 0"]
Print["M5=", M5[[1]] "Nm"];
```

```
a)----------

interference 1-2

ra1=204 mm

ra2=348 mm

ramax1=241.504 mm
```

ramax2=349.872 mm

No interference 1–2

No interference 1–2

CR1–2=1.55555

interference 2p–3

ra2p=240 mm

ra3=312 mm

ramax2p=266.294 mm

ramax3=320.867 mm

No interference 2p–3

No interference 2p–3

CR2p–3=1.56583

interference 3p–4

ra3p=216 mm

ra4=1152 mm

ramax3p=501.465 mm

ramax4=1200.05 mm

No interference 3p–4

No interference 3p–4

CR3p–4=3.6868

b) ----------

contour I: 0–B–1–C–2–D–5–A–0

$\omega 10+\omega 21+\omega 52+\omega 05=0$ (1)

$360 + n21 + n52 == 0$ (1)

$rB \times \omega 10 + rC \times \omega 21 + rD \times \omega 52 + rA \times \omega 05 = 0$ (2)

$-180\, n21 - 504\, n52 == 0$ (2)

contour II: 2–E–3–F–5–D–2

$\omega 32+\omega 53+\omega 25=0$ (3)

$n32 - n52 + n53 == 0$ (3)

$rE \times \omega 32 + rF \times \omega 53 + rD \times \omega 25 = 0$ (4)

$-720\, n32 + 504\, n52 - 1008\, n53 == 0$ (4)

contour III: 0–H–4–G–3–F–5–A–0

$\omega 40+\omega 32+\omega 53+\omega 05=0$ (3)

$-80 + n34 + n40 + n53 == 0$ (5)

rH x $\omega 40$ + rG x $\omega 32$ + rF x $\omega 53$ + rA x $\omega 05$ = 0 (6)

$-1200\, n34 - 1008\, n53 == 0$ (6)

solutions

{{n21 → −560., n52 → 200., n32 → 350., n40 → 104., n53 → −150., n34 → 126.}}

n4 = 104. rpm

c) ----------

Link 4

sum of moments for 4 wrt H : HG x F3p4 + Mext = 0

$-1000 + 1200\, F3p4t == 0$ (1)

f3p4={0, 0.303309, $\frac{5}{6}$}

Link 3

sum of moments for 3 wrt F : FG x F43p + FE x F2p3 = 0

$-160. - 288\, F2p3t == 0$ (2)

f2p3={0, 0.202206, −0.555556}

Link 2

sum of moments for 2 wrt D : DE x F32p + DC x F12 = 0

$120. - 324\, F12t == 0$ (3)

f12={0, 0.134804, 0.37037}

Link 1

sum of moments for 1 wrt B : BC x F21 + M1 = 0

M1=66.6667 Nm

Link 5

sum of moments for 5 wrt A : AD x F25 + AF x F35 + M5 = 0

M5=933.333 Nm

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

m = 26;
N1 = 11; N2 = 22; N2p = 17; N3 = 51; N3p = 12; N4 = 32;

r1 = m * N1 / 2;
r2 = m * N2 / 2;
r2p = m * N2p / 2;
r3 = m * N3 / 2;
r3p = m * N3p / 2;
r4 = m * N4 / 2;
r5 = r3p + r4;

rA = {0, 0, 0};
rB = {xB, r1, 0};
rC = {xC, r1 + r2, 0};
rD = {xD, r1 + r2 + r2p, 0};
rE = {xE, 0, 0};
rF = {xF, r3p , 0};
rG = {xG, r3p + r4, 0};
rH = {xH, r3p + 2 r4, 0};
rI = {xI, 0, 0};

n1 = 550;(*rpm*)
n10 = n1;
n2 = -n1 r1 / r2;
n2p = n2;
n3 = -n2p r2p / r3;
n30 = n3;


phi = N[Pi] / 9;

"a)-------------"
int1 = {N1, N2p, N3p};
int2 = {N2, N3, N4};
disp1 = {"1", "3p"};
disp2 = {"2", "4"};
disp = {"1-2", "3p-4"};

For[i = 1, i ≤ 2, i++,
  Print["interference ", disp[[i]]];
  r1 = m int1[[i]] / 2;
  r2 = m int2[[i]] / 2;
  c12 = r1 + r2;
  rb1 = r1 Cos[phi];
  rb2 = r2 Cos[phi];
  a = m;
```

```
  ra1 = r1 + a;
  ra2 = r2 + a;
  Print["ra", disp1[[i]], "=", ra1, " mm"];
  Print["ra", disp2[[i]], "=", ra2, " mm"];
  ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
  ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
  Print["ramax", disp1[[i]], "=", ramax1, " mm"];
  Print["ramax", disp2[[i]], "=", ramax2, " mm"];
  If[ramax1 > ra1,
   Print["No interference ", disp[[i]]], Print["Interference ", disp[[i]]]];
  If[ramax2 > ra2, Print["No interference ", disp[[i]]],
   Print["Interference ", disp[[i]]]];
  CR12 = (Sqrt[ra1^2 - rb1^2] + Sqrt[ra2^2 - rb2^2] - c12 Sin[phi]) / (N[Pi] m Cos[phi]);
  Print["CR", disp[[i]], "=", CR12];
 ];

Print["interference 2p-3"];
r1 = r2p;
r2 = r3;
c12 = r1 + r2;
rb1 = r1 Cos[phi];
rb2 = r2 Cos[phi];
a = m;
ra1 = r1 + a;
ra2 = r2 - a;
Print["ra2p=", ra1, " mm"];
Print["ra3=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax2p=", ramax1, " mm"];
Print["ramax3=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 2p-3"], Print["Interference 2p-3"]];
If[ramax2 > ra2, Print["No interference 2p-3"], Print["Interference 2p-3"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR2p-3=", CR12];

Print["interference 4-0"];
r1 = r4;
r2 = r3p + 2 r4;
c12 = r1 + r2;
rb1 = r1 Cos[phi];
rb2 = r2 Cos[phi];
a = m;
ra1 = r1 + a;
ra2 = r2 - a;
Print["ra4=", ra1, " mm"];
Print["ra0=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax4=", ramax1, " mm"];
Print["ramax0=", ramax2, " mm"];
```

```
If[ramax1 > ra1, Print["No interference 4-0"], Print["Interference 4-0"]];
If[ramax2 > ra2, Print["No interference 4-0"], Print["Interference 4-0"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR4-0=", CR12];

"b)-------------"

"contour I: 0-A-1-B-2-D-3-E-0"

ω10 = {n10, 0, 0};
ω21 = {n21, 0, 0};
ω32 = {n32, 0, 0};
ω03 = {-n30, 0, 0};

"ω10+ω21+ω32+ω03=0 (1)"
eq1x = (ω10 + ω21 + ω32 + ω03)[[1]] == 0; Print[eq1x, " (1)"];
"rA x ω10 + rB x ω21 + rD x ω32 + rE x ω03 = 0 (2)"
eq1k = (Cross[rA, ω10] + Cross[rB, ω21] + Cross[rD, ω32] + Cross[rE, ω03])[[3]] == 0;
Print[eq1k, " (2)"];

"contour II: 0-E-3-F-4-H-0"

ω30 = {n30, 0, 0};
ω43 = {n43, 0, 0};
ω04 = {n04, 0, 0};

"ω30+ω43+ω04=0 (3)"
eq2x = (ω30 + ω43 + ω04)[[1]] == 0; Print[eq2x, " (3)"];
"rE x ω30 + rF x ω43 + rH x ω04 = 0 (4)"
eq2k = (Cross[rE, ω30] + Cross[rF, ω43] + Cross[rH, ω04])[[3]] == 0; Print[eq2k, " (4)"];

"contour III: 0-H-4-G-5-I-0"

ω40 = {-n04, 0, 0};
ω54 = {n54, 0, 0};
ω05 = {n05, 0, 0};

"ω40+ω54+ω05=0 (3)"
eq3x = (ω40 + ω54 + ω05)[[1]] == 0; Print[eq3x, " (5)"];
"rH x ω40 + rG x ω54 + rI x ω05 = 0 (6)"
eq3k = (Cross[rH, ω40] + Cross[rG, ω54] + Cross[rI, ω05])[[3]] == 0; Print[eq3k, " (6)"];

eqns = {eq1x, eq1k, eq2x, eq2k, eq3x, eq3k};
sol = {n21, n32, n43, n04, n54, n05};
"solutions"
solution = N[Solve[eqns, sol]]
Print["n5 = ", -n05 /. solution[[1]], " rpm"];

"c)-------------"

(* Link 1 *)
```

```
Print["Link 1"];
phi = N[Pi] / 9;
AB = rB - rA;
H = 4; (* kW *)
M1 = {-9549 H / n1, 0, 0};
F21 = {0, -F21t Tan[phi], F21t};
(*Sum of moments for 1 wrt A*)
SM1A = Cross[AB, F21] + M1;
eq1 = SM1A[[1]] == 0;
Print["sum of moments for 1 wrt A :  AB x F21 + M1 = 0"]
Print[eq1, " (1)"];
sol = Solve[eq1, F21t];
f21 = F21 /. sol[[1]];
f01 = -f21;
Print["f21=", f21];

(* Link 2 *)
Print["Link 2"];
CB = rB - rC;
CD = rD - rC;
f12 = -f21;
F32p = {0, F32pt Tan[phi], F32pt};
(*Sum of moments for 2 wrt C*)
SM2C = Cross[CB, f12] + Cross[CD, F32p];
eq2 = SM2C[[1]] == 0;
Print["sum of moments for 2 wrt C :  CB x F12 + CD x F32p = 0"]
Print[eq2, " (2)"];
sol = Solve[eq2, F32pt];
f32p = F32p /. sol[[1]];
f02 = -f12 - f32p;
Print["f32p=", f32p];

(* Link 3 *)
Print["Link 3"];
ED = rD - rE;
EF = rF - rE;
f2p3 = -f32p;
F43p = {0, -F43pt Tan[phi], F43pt};
(*Sum of moments for 3 wrt E*)
SM3E = Cross[ED, f2p3] + Cross[EF, F43p];
eq3 = SM3E[[1]] == 0;
Print["sum of moments for 3 wrt E : ED x F2p3 + EF x F43p = 0"]
Print[eq3, " (3)"];
sol = Solve[eq3, F43pt];
f43p = F43p /. sol[[1]];
f03 = -f43p - f2p3;
Print["f43p=", f43p];

(* Link 4 *)
Print["Link 4"];
GF = rF - rG;
```

```
GH = rH - rG;
f3p4 = -f43p;
F04 = {0, F04t Tan[phi], F04t};
(*Sum of moments for 4 wrt G*)
SM4G = Cross[GF, f3p4] + Cross[GH, F04];
eq4 = SM4G[[1]] == 0;
Print["sum of moments for 4 wrt G : GF x F3p4 + GH x F04 = 0"]
Print[eq4, " (4)"];
sol = Solve[eq4, F04t];
f04 = F04 /. sol[[1]];
f54 = -f04 - f3p4;
Print["f04=", f04];

(* Link 5 *)
f05 = f54;

Print["F21 = ", f21, " N"];
Print["F01 = ", f01, " N"];
Print["F32p = ", f32p, " N"];
Print["F02 = ", f02, " N"];
Print["F43p = ", f43p, " N"];
Print["F03 = ", f03, " N"];
Print["F04 = ", f04, " N"];
Print["F54 = ", f54, " N"];
Print["F05 = ", f05, " N"];
```

```
a)--------------

interference 1-2

ra1=169 mm

ra2=312 mm

ramax1=198.961 mm

ramax2=306.197 mm

No interference 1-2

Interference 1-2

CR1-2=1.48842

interference 3p-4

ra3p=247 mm

ra4=689 mm

ramax3p=366.798 mm

ramax4=692.504 mm

No interference 3p-4
```

No interference 3p-4

CR3p-4=1.63645

interference 2p-3

ra2p=247 mm

ra3=637 mm

ramax2p=366.798 mm

ramax3=692.504 mm

No interference 2p-3

No interference 2p-3

CR2p-3=3.95187

interference 4-0

ra4=442 mm

ra0=962 mm

ramax4=619.194 mm

ramax0=1045.25 mm

No interference 4-0

No interference 4-0

CR4-0=5.66097

b)----------

contour I: 0-A-1-B-2-D-3-E-0

$\omega 10+\omega 21+\omega 32+\omega 03=0$ (1)

$\frac{1375}{3}$ + n21 + n32 == 0 (1)

rA x $\omega 10$ + rB x $\omega 21$ + rD x $\omega 32$ + rE x $\omega 03$ = 0 (2)

-143 n21 - 650 n32 == 0 (2)

contour II: 0-E-3-F-4-H-0

$\omega 30+\omega 43+\omega 04=0$ (3)

$\frac{275}{3}$ + n04 + n43 == 0 (3)

rE x $\omega 30$ + rF x $\omega 43$ + rH x $\omega 04$ = 0 (4)

-988 n04 - 156 n43 == 0 (4)

contour III: 0-H-4-G-5-I-0

$\omega 40+\omega 54+\omega 05=0$ (3)

$-n04 + n05 + n54 == 0 \quad (5)$

rH x ω40 + rG x ω54 + rI x ω05 = 0 (6)

$988\, n04 - 572\, n54 == 0 \quad (6)$

solutions

$\{\{n21 \to -587.607, n32 \to 129.274, n43 \to -108.854, n04 \to 17.1875, n54 \to 29.6875, n05 \to -12.5\}\}$

n5 = 12.5 rpm

c) ----------

Link 1

sum of moments for 1 wrt A : AB x F21 + M1 = 0

$-\frac{19098}{275} + 143\, F21t == 0 \quad (1)$

$f21=\left\{0, -0.17676, \frac{19098}{39325}\right\}$

Link 2

sum of moments for 2 wrt C : CB x F12 + CD x F32p = 0

$138.895 + 221\, F32pt == 0 \quad (2)$

f32p={0, −0.228749, −0.628482}

Link 3

sum of moments for 3 wrt E : ED x F2p3 + EF x F43p = 0

$408.513 + 156\, F43pt == 0 \quad (3)$

f43p={0, 0.95312, −2.61868}

Link 4

sum of moments for 4 wrt G : GF x F3p4 + GH x F04 = 0

$-1089.37 + 416\, F04t == 0 \quad (4)$

f04={0, 0.95312, 2.61868}

$F21 = \left\{0, -0.17676, \frac{19098}{39325}\right\}$ N

$F01 = \left\{0, 0.17676, -\frac{19098}{39325}\right\}$ N

F32p = {0, −0.228749, −0.628482} N

F02 = {0, 0.0519884, 1.11413} N

F43p = {0, 0.95312, −2.61868} N

F03 = {0, −1.18187, 1.99019} N

F04 = {0, 0.95312, 2.61868} N

F54 = {0, 0., −5.23735} N

```
F05 = {0, 0., -5.23735} N
```

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

m = 28;
N1 = 60; N2 = 25; N2p = 15; N3 = 20; N4 = 90;

r1 = m * N1 / 2;
r2 = m * N2 / 2;
r2p = m * N2p / 2;
r3 = m * N3 / 2;
r3p = r3;
r4 = m * N4 / 2;
r5 = 2 r2p + r3;

rA = {0, 0, 0};
rB = {xB, r1, 0};
rC = {xC, r1 - r2, 0};
rD = {xD, r1 - r2 + r2p, 0};
rE = {xE, r1 - r2 + r2p + r3, 0};
rF = {xF, r1 - r2 + r2p + 2 r3, 0};
rG = {xG, 0, 0};
rH = {xH, 0, 0};

n1 = 100; (*rpm*)
n5 = -150; (*rpm*)
n10 = n1;
n50 = n5;
n05 = -n5;


phi = N[Pi] / 9;

"a)----------"

Print["interference 1-2"];
r1 = r1;
r2 = r2;
c12 = r1 + r2;
rb1 = r1 Cos[phi];
rb2 = r2 Cos[phi];
a = m;
ra1 = r1 - a;
ra2 = r2 + a;
Print["ra1=", ra1, " mm"];
Print["ra2=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax1=", ramax1, " mm"];
Print["ramax2=", ramax2, " mm"];
```

```
If[ramax1 > ra1, Print["No interference 1-2"], Print["Interference 1-2"]];
If[ramax2 > ra2, Print["No interference 1-2"], Print["Interference 1-2"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR1-2=", CR12];

Print["interference 2p-3"];
r1 = r2p;
r2 = r3;
c12 = r1 + r2;
rb1 = r1 Cos[phi];
rb2 = r2 Cos[phi];
a = m;
ra1 = r1 + a;
ra2 = r2 + a;
Print["ra2p=", ra1, " mm"];
Print["ra3=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax2p=", ramax1, " mm"];
Print["ramax3=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 2p-3"], Print["Interference 2p-3"]];
If[ramax2 > ra2, Print["No interference 2p-3"], Print["Interference 2p-3"]];
CR12 = (Sqrt[ra1^2 - rb1^2] + Sqrt[ra2^2 - rb2^2] - c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR2p-3=", CR12];

Print["interference 3p-4"];
r1 = r3p;
r2 = r4;
c12 = r1 + r2;
rb1 = r1 Cos[phi];
rb2 = r2 Cos[phi];
a = m;
ra1 = r1 + a;
ra2 = r2 - a;
Print["ra3p=", ra1, " mm"];
Print["ra4=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax3p=", ramax1, " mm"];
Print["ramax4=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 3p-4"], Print["Interference 3p-4"]];
If[ramax2 > ra2, Print["No interference 3p-4"], Print["Interference 3p-4"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR3p-4=", CR12];

"b)----------"

"contour I: 0-A-1-B-2-C-5-H-0"

ω10 = {n10, 0, 0};
ω21 = {n21, 0, 0};
```

```
ω52 = {n52, 0, 0};
ω05 = {n05, 0, 0};

"ω10+ω21+ω52+ω05=0 (1)"
eq1x = (ω10 + ω21 + ω52 + ω05)[[1]] == 0; Print[eq1x, " (1)"];
"rA x ω10 + rB x ω21 + rC x ω52 + rH x ω05 = 0 (2)"
eq1k = (Cross[rA, ω10] + Cross[rB, ω21] + Cross[rC, ω52] + Cross[rH, ω05])[[3]] == 0;
Print[eq1k, " (2)"];

"contour II: 0-G-4-F-3-E-5-H-0"

ω40 = {n40, 0, 0};
ω34 = {n34, 0, 0};
ω53 = {n53, 0, 0};

"ω40+ω34+ω53+ω05=0 (3)"
eq2x = (ω40 + ω34 + ω53 + ω05)[[1]] == 0; Print[eq2x, " (3)"];
"rG x ω40 + rF x ω34 + rE x ω53 + rH x ω05 = 0 (4)"
eq2k = (Cross[rG, ω40] + Cross[rF, ω34] + Cross[rE, ω53] + Cross[rH, ω05])[[3]] == 0;
Print[eq2k, " (4)"];

"contour III: 5-E-3-D-2-C-5"

ω35 = {-n53, 0, 0};
ω23 = {n23, 0, 0};

"ω35+ω23+ω52=0 (3)"
eq3x = (ω35 + ω23 + ω52)[[1]] == 0; Print[eq3x, " (5)"];
"rE x ω35 + rD x ω23 + rC x ω52 = 0 (6)"
eq3k = (Cross[rE, ω35] + Cross[rD, ω23] + Cross[rC, ω52])[[3]] == 0; Print[eq3k, " (6)"];

eqns = {eq1x, eq1k, eq2x, eq2k, eq3x, eq3k};
sol = {n21, n52, n53, n23, n40, n34};
"solutions"
solution = N[Solve[eqns, sol]]
Print["n4 = ", n40 /. solution[[1]], " rpm"];
n4 = n40 /. solution[[1]];

"c)-------------"

(* Link 4 *)
Print["Link 4"];
phi = N[Pi] / 9;
GF = rF - rG;
Mext = -1000 {Sign[n4], 0, 0};
F3p4 = {0, -F3p4t Tan[phi], F3p4t};
(*Sum of moments for 4 wrt G*)
SM4G = Cross[GF, F3p4] + Mext;
eq1 = SM4G[[1]] == 0;
Print["sum of moments for 4 wrt G :  GF x F3p4 + Mext = 0"]
Print[eq1, " (1)"];
```

```
sol = Solve[eq1, F3p4t];
f3p4 = F3p4 /. sol[[1]];
Print["f3p4=", f3p4];

(* Link 3 *)
Print["Link 3"];
ED = rD - rE;
EF = rF - rE;
F2p3 = {0, F2p3t Tan[phi], F2p3t};
f43p = -f3p4;
(*Sum of moments for 3 wrt E*)
SM3E = Cross[ED, F2p3] + Cross[EF, f43p];
eq2 = SM3E[[1]] == 0;
Print["sum of moments for 3 wrt E :  ED x F2p3 + EFxF43p = 0"]
Print[eq2, " (2)"];
sol = Solve[eq2, F2p3t];
f2p3 = F2p3 /. sol[[1]];
f53 = -f2p3 - f43p;
Print["f2p3=", f2p3];

(* Link 2 *)
Print["Link 2"];
CD = rD - rC;
CB = rB - rC;
f32p = -f2p3;
F12 = {0, -F12t Tan[phi], F12t};
(*Sum of moments for 2 wrt C*)
SM2C = Cross[CD, f32p] + Cross[CB, F12];
eq3 = SM2C[[1]] == 0;
Print["sum of moments for 2 wrt C :  CD x F32p + CB x F12 = 0"]
Print[eq3, " (3)"];
sol = Solve[eq3, F12t];
f12 = F12 /. sol[[1]];
f52 = -f12 - f32p;
Print["f12=", f12];

(* Link 1 *)
Print["Link 1"];
AB = rB - rA;
f21 = -f12;
(*Sum of moments for 1 wrt A*)
M1 = -Cross[AB, f21];
Print["sum of moments for 1 wrt A :  AB x F21 + M1 = 0"]
Print["M1=", M1[[1]] "Nm"];
Print["f21=", f21];
Print["f01=", -f21];

(* Link 5 *)
Print["Link 5"];
HE = rE - rH;
HC = rC - rH;
```

```
f35 = -f53;
f25 = -f52;
(*Sum of moments for 5 wrt H*)
M5 = -Cross[HE, f35] - Cross[HC, f25];
Print["sum of moments for 5 wrt H :  HE x F35 + HC x F25 + M5 = 0"]
Print["M5=", M5[[1]] "Nm"];
Print["f35=", f35];
Print["f25=", f25];
Print["f05=", -f35 - f25];
```

```
a)--------------

interference 1-2

ra1=812 mm

ra2=378 mm

ramax1=888.095 mm

ramax2=523.28 mm

No interference 1-2

No interference 1-2

CR1-2=4.97425

interference 2p-3

ra2p=238 mm

ra3=308 mm

ramax2p=258.897 mm

ramax3=311.954 mm

No interference 2p-3

No interference 2p-3

CR2p-3=1.51914

interference 3p-4

ra3p=308 mm

ra4=1232 mm

ramax3p=588.773 mm

ramax4=1295.88 mm

No interference 3p-4

No interference 3p-4

CR3p-4=4.18976
```

b) ----------

contour I: 0–A–1–B–2–C–5–H–0

$\omega 10+\omega 21+\omega 52+\omega 05=0$ (1)

250 + n21 + n52 == 0 (1)

rA x ω10 + rB x ω21 + rC x ω52 + rH x ω05 = 0 (2)

−840 n21 − 490 n52 == 0 (2)

contour II: 0–G–4–F–3–E–5–H–0

$\omega 40+\omega 34+\omega 53+\omega 05=0$ (3)

150 + n34 + n40 + n53 == 0 (3)

rG x ω40 + rF x ω34 + rE x ω53 + rH x ω05 = 0 (4)

−1260 n34 − 980 n53 == 0 (4)

contour III: 5–E–3–D–2–C–5

$\omega 35+\omega 23+\omega 52=0$ (3)

n23 + n52 − n53 == 0 (5)

rE x ω35 + rD x ω23 + rC x ω52 = 0 (6)

−700 n23 − 490 n52 + 980 n53 == 0 (6)

solutions

{{n21 → 350., n52 → −600., n53 → 450., n23 → 1050., n40 → −250., n34 → −350.}}

n4 = −250. rpm

c) ----------

Link 4

sum of moments for 4 wrt G : GF x F3p4 + Mext = 0

1000 + 1260 F3p4t == 0 (1)

f3p4={0, 0.288865, $-\frac{50}{63}$}

Link 3

sum of moments for 3 wrt E : ED x F2p3 + EFxF43p = 0

222.222 − 280 F2p3t == 0 (2)

f2p3={0, 0.288865, 0.793651}

Link 2

sum of moments for 2 wrt C : CD x F32p + CB x F12 = 0

```
-166.667 + 350 F12t == 0 (3)

f12={0, -0.173319, 0.47619}

Link 1

sum of moments for 1 wrt A :  AB x F21 + M1 = 0

M1=400. Nm

f21={0, 0.173319, -0.47619}

f01={0, -0.173319, 0.47619}

Link 5

sum of moments for 5 wrt H :  HE x F35 + HC x F25 + M5 = 0

M5=-1400. Nm

f35={0, 0., 1.5873}

f25={0, -0.462184, -0.31746}

f05={0, 0.462184, -1.26984}
```

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

m = 22;
N1 = 11; N2 = 19; N3 = 40; N4 = 29; N5 = 24;

r1 = m * N1 / 2;
r2 = m * N2 / 2;
r3 = m * N3 / 2;
r4 = m * N4 / 2;
r5 = m * N5 / 2;
r6 = r4 + 2 r5;

rA = {0, 0, 0};
rB = {xB, r1, 0};
rC = {xC, r1 + r2, 0};
rD = {xD, r1 + r2 , 0};
rE = {xE, r1 + 2 r2, 0};
rF = {xF, 0, 0};
rG = {xG, 0, 0};
rH = {xH, -r4, 0};
rI = {xI, -r4 - r5, 0};
rJ = {xJ, -r4 - 2 r5, 0};
rK = {xK, 0, 0};

n1 = 200;(*rpm*)
n10 = n1;


phi = N[Pi] / 9;

"a)----------"
int1 = {N1, N4};
int2 = {N2, N5};
disp1 = {"1", "4"};
disp2 = {"2", "5"};
disp = {"1-2", "4-5"};

For[i = 1, i ≤ 2, i++,
  Print["interference ", disp[[i]]];
  r1 = m int1[[i]] / 2;
  r2 = m int2[[i]] / 2;
  c12 = r1 + r2;
  rb1 = r1 Cos[phi];
  rb2 = r2 Cos[phi];
  a = m;
  ra1 = r1 + a;
  ra2 = r2 + a;
  Print["ra", disp1[[i]], "=", ra1, " mm"];
```

```
  Print["ra", disp2[[i]], "=", ra2, " mm"];
  ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
  ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
  Print["ramax", disp1[[i]], "=", ramax1, " mm"];
  Print["ramax", disp2[[i]], "=", ramax2, " mm"];
  If[ramax1 > ra1,
   Print["No interference ", disp[[i]]], Print["Interference ", disp[[i]]]];
  If[ramax2 > ra2, Print["No interference ", disp[[i]]],
   Print["Interference ", disp[[i]]]];
  CR12 = (Sqrt[ra1^2 - rb1^2] + Sqrt[ra2^2 - rb2^2] - c12 Sin[phi]) / (N[Pi] m Cos[phi]);
  Print["CR", disp[[i]], "=", CR12];
 ];

Print["interference 2p-3"];
r1 = r2;
r2 = r1 + 2 r2;
c12 = r1 + r2;
rb1 = r1 Cos[phi];
rb2 = r2 Cos[phi];
a = m;
ra1 = r1 + a;
ra2 = r2 - a;
Print["ra2p=", ra1, " mm"];
Print["ra3=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax2p=", ramax1, " mm"];
Print["ramax3=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 2p-3"], Print["Interference 2p-3"]];
If[ramax2 > ra2, Print["No interference 2p-3"], Print["Interference 2p-3"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR2p-3=", CR12];

Print["interference 5-6"];
r1 = r5;
r2 = r6;
c12 = r1 + r2;
rb1 = r1 Cos[phi];
rb2 = r2 Cos[phi];
a = m;
ra1 = r1 + a;
ra2 = r2 - a;
Print["ra5=", ra1, " mm"];
Print["ra6=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax5=", ramax1, " mm"];
Print["ramax6=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 5-6"], Print["Interference 5-6"]];
If[ramax2 > ra2, Print["No interference 5-6"], Print["Interference 5-6"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
```

```
Print["CR5-6=", CR12];

"b)-------------"


"contour I: 0-A-1-B-2-E-0"
ω10 = {n10, 0, 0};
ω21 = {n21, 0, 0};
ω02 = {n02, 0, 0};

"ω10+ω21+ω02=0 (1)"
eq1x = (ω10 + ω21 + ω02)[[1]] == 0; Print[eq1x, " (1)"];
"rA x ω10 + rB x ω21 + rE x ω02 = 0 (2)"
eq1k = (Cross[rA, ω10] + Cross[rB, ω21] + Cross[rE, ω02])[[3]] == 0; Print[eq1k, " (2)"];

"contour II: 0-E-2-D-4-F-0"
ω20 = {-n02, 0, 0};
ω42 = {n42, 0, 0};
ω04 = {n04, 0, 0};

"ω20+ω42+ω04=0 (3)"
eq2x = (ω20 + ω42 + ω04)[[1]] == 0; Print[eq2x, " (3)"];
"rE x ω20 + rD x ω42 + rF x ω04 = 0 (4)"
eq2k = (Cross[rE, ω20] + Cross[rD, ω42] + Cross[rF, ω04])[[3]] == 0; Print[eq2k, " (4)"];

"contour III: 0-F-4-H-5-I-0"
ω40 = {-n04, 0, 0};
ω54 = {n54, 0, 0};
ω05 = {n05, 0, 0};

"ω40+ω54+ω05=0 (5)"
eq3x = (ω40 + ω54 + ω05)[[1]] == 0; Print[eq3x, " (5)"];
"rF x ω40 + rH x ω54 + rI x ω05 = 0 (6)"
eq3k = (Cross[rF, ω40] + Cross[rH, ω54] + Cross[rI, ω05])[[3]] == 0; Print[eq3k, " (6)"];

"contour IV: 0-I-5-J-6-K-0"
ω50 = {-n05, 0, 0};
ω65 = {n65, 0, 0};
ω06 = {n06, 0, 0};

"ω50+ω65+ω06=0 (7)"
eq4x = (ω50 + ω65 + ω06)[[1]] == 0; Print[eq4x, " (7)"];
"rI x ω50 + rJ x ω65 + rK x ω06 = 0 (8)"
eq4k = (Cross[rI, ω50] + Cross[rJ, ω65] + Cross[rK, ω06])[[3]] == 0; Print[eq4k, " (8)"];

eqns = {eq1x, eq1k, eq2x, eq2k, eq3x, eq3k, eq4x, eq4k};
sol = {n21, n02, n42, n04, n54, n05, n65, n06};
"solutions"
solution = N[Solve[eqns, sol]]
Print["n6 = ", n06 /. solution[[1]], " rpm"];
```

```
n6 = n06 /. solution[[1]];

"c)-------------"

(* Link 6 *)
Print["Link 6"];
phi = N[Pi] / 9;
KJ = rJ - rK;
Mext = -900 {Sign[n6], 0, 0};
F56 = {0, F56t Tan[phi], F56t};
(*Sum of moments for 6 wrt K*)
SM6K = Cross[KJ, F56] + Mext;
eq1 = SM6K[[1]] == 0;
Print["sum of moments for 6 wrt K :  KJ x F56 + Mext = 0"]
Print[eq1, " (1)"];
sol = Solve[eq1, F56t];
f56 = F56 /. sol[[1]];
f06 = -f56;
Print["f56=", f56];

(* Link 5 *)
Print["Link 5"];
IH = rH - rI;
IJ = rJ - rI;
f65 = -f56;
F45 = {0, -F45t Tan[phi], F45t}
(*Sum of moments for 5 wrt I*)
SM5I = Cross[IH, F45] + Cross[IJ, f65];
eq2 = SM5I[[1]] == 0;
Print["sum of moments for 5 wrt I :  IH x F45 + IJ x F65 = 0"]
Print[eq2, " (2)"];
sol = Solve[eq2, F45t];
f45 = F45 /. sol[[1]];
f05 = -f45 - f65;
Print["f45=", f45];

(* Link 4 *)
Print["Link 4"];
GD = rD - rG;
GH = rH - rG;
f54 = -f45;
F24 = {0, -F24t Tan[phi], F24t}
(*Sum of moments for 4 wrt G*)
SM4G = Cross[GD, F24] + Cross[GH, f54];
eq3 = SM4G[[1]] == 0;
Print["sum of moments for 4 wrt G :  GD x F24 + GH x F54 = 0"]
Print[eq3, " (3)"];
sol = Solve[eq3, F24t];
f24 = F24 /. sol[[1]];
f04 = -f24 - f54;
Print["f24=", f24];
```

```
(* Link 2 *)
Print["Link 2"];
BC = rC - rB;
BE = rE - rB;
f42 = -f24;
F02p = {0, F02pt Tan[phi], F02pt}
(*Sum of moments for 2 wrt B*)
SM2B = Cross[BC, f42] + Cross[BE, F02p];
eq4 = SM2B[[1]] == 0;
Print["sum of moments for 2 wrt B :  BC x F42 + BE x F02p = 0"]
Print[eq4, " (4)"];
sol = Solve[eq4, F02pt];
f02p = F02p /. sol[[1]];
f12 = -f02p - f42;
Print["f02p=", f02p];

(* Link 1 *)
Print["Link 1"];
AB = rB - rA;
f21 = -f12;
(*Sum of moments for 1 wrt A*)
M1 = -Cross[AB, f21];
Print["sum of moments for 1 wrt A :  AB x F21 + M1 = 0"]
f01 = -f21;

Print["M1 = ", M1[[1]], " Nm"];
Print["F01 = ", f01, " N"];
Print["F21 = ", f21, " N"];
Print["F42 = ", f42, " N"];
Print["F02p = ", f02p, " N"];
Print["F54 = ", f54, " N"];
Print["F04 = ", f04, " N"];
Print["F24 = ", f24, " N"];
Print["F65 = ", f65, " N"];
Print["F05 = ", f05, " N"];
Print["F06 = ", f06, " N"];
```

```
a)----------

interference 1-2

ra1=143 mm

ra2=231 mm

ramax1=160.21 mm

ramax2=226.517 mm

No interference 1-2

Interference 1-2
```

CR1-2=1.46994

interference 4-5

ra4=341 mm

ra5=286 mm

ramax4=360.023 mm

ramax5=318.281 mm

No interference 4-5

No interference 4-5

CR4-5=1.62392

interference 2p-3

ra2p=286 mm

ra3=770 mm

ramax2p=438.166 mm

ramax3=827.245 mm

No interference 2p-3

No interference 2p-3

CR2p-3=4.7111

interference 5-6

ra5=286 mm

ra6=825 mm

ramax5=453.796 mm

ramax6=881.973 mm

No interference 5-6

No interference 5-6

CR5-6=4.69902

b)----------

contour I: 0-A-1-B-2-E-0

$\omega 10+\omega 21+\omega 02=0$ (1)

$200 + n02 + n21 == 0$ (1)

rA x $\omega 10$ + rB x $\omega 21$ + rE x $\omega 02$ = 0 (2)

$-539\, n02 - 121\, n21 == 0$ (2)

contour II: 0-E-2-D-4-F-0

$\omega 20+\omega 42+\omega 04=0$ (3)

$-n02+n04+n42==0$ (3)

rE x $\omega 20$ + rD x $\omega 42$ + rF x $\omega 04$ = 0 (4)

$539\,n02-330\,n42==0$ (4)

contour III: 0-F-4-H-5-I-0

$\omega 40+\omega 54+\omega 05=0$ (5)

$-n04+n05+n54==0$ (5)

rF x $\omega 40$ + rH x $\omega 54$ + rI x $\omega 05$ = 0 (6)

$583\,n05+319\,n54==0$ (6)

contour IV: 0-I-5-J-6-K-0

$\omega 50+\omega 65+\omega 06=0$ (7)

$-n05+n06+n65==0$ (7)

rI x $\omega 50$ + rJ x $\omega 65$ + rK x $\omega 06$ = 0 (8)

$-583\,n05+847\,n65==0$ (8)

solutions

$\{\{n21\to -257.895,\ n02\to 57.8947,\ n42\to 94.5614,$
$\ \ n04\to -36.6667,\ n54\to -80.9722,\ n05\to 44.3056,\ n65\to 30.496,\ n06\to 13.8095\}\}$

n6 = 13.8095 rpm

c) ----------

Link 6

sum of moments for 6 wrt K : KJ x F56 + Mext = 0

$-900-847\,F56t==0$ (1)

$f56=\left\{0,\ -0.386745,\ -\frac{900}{847}\right\}$

Link 5

$\{0,\ -0.36397\,F45t,\ F45t\}$

sum of moments for 5 wrt I : IH x F45 + IJ x F65 = 0

$-280.519+264\,F45t==0$ (2)

$f45=\{0,\ -0.386745,\ 1.06257\}$

Link 4

$\{0,\ -0.36397\,F24t,\ F24t\}$

sum of moments for 4 wrt G : GD x F24 + GH x F54 = 0

$338.961 + 330\,F24t == 0 \quad (3)$

f24={0, 0.373854, −1.02715}

Link 2

{0, 0.36397 F02pt, F02pt}

sum of moments for 2 wrt B : BC x F42 + BE x F02p = 0

$214.675 + 418\,F02pt == 0 \quad (4)$

f02p={0, −0.186927, −0.513577}

Link 1

sum of moments for 1 wrt A : AB x F21 + M1 = 0

M1 = −62.1429 Nm

F01 = {0, 0.560781, −0.513577} N

F21 = {0, −0.560781, 0.513577} N

F42 = {0, −0.373854, 1.02715} N

F02p = {0, −0.186927, −0.513577} N

F54 = {0, 0.386745, −1.06257} N

F04 = {0, −0.760599, 2.08973} N

F24 = {0, 0.373854, −1.02715} N

$F65 = \left\{0, 0.386745, \frac{900}{847}\right\}$ N

F05 = {0, 0., −2.12515} N

$F06 = \left\{0, 0.386745, \frac{900}{847}\right\}$ N

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

m = 20;
N1 = 28; N2 = 21; N2p = 16;

r1 = m * N1 / 2;
r2 = m * N2 / 2;
r2p = m * N2p / 2;
r3 = r1 + 2 r2;
r4 = r1 + r2;

rA = {0, 0, 0};
rB = {xB, r3, 0};
rC = {xC, r3 - r2, 0};
rD = {xD, r3 - 2 r2 , 0};
rE = {xE, r3 - 2 r2 - r1, 0};
rF = {xF, r3 - r2 + r2p, 0};
rG = {xG, 0, 0};

n1 = 370;(*rpm*)
n10 = n1;


phi = N[Pi] / 9;

"a)----------"
int1 = {N1};
int2 = {N2};
disp1 = {"1"};
disp2 = {"2"};
disp = {"1-2"};

For[i = 1, i ≤ 1, i++,
  Print["interference ", disp[[i]]];
  r1 = m int1[[i]] / 2;
  r2 = m int2[[i]] / 2;
  c12 = r1 + r2;
  rb1 = r1 Cos[phi];
  rb2 = r2 Cos[phi];
  a = m;
  ra1 = r1 + a;
  ra2 = r2 + a;
  Print["ra", disp1[[i]], "=", ra1, " mm"];
  Print["ra", disp2[[i]], "=", ra2, " mm"];
  ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
  ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
  Print["ramax", disp1[[i]], "=", ramax1, " mm"];
  Print["ramax", disp2[[i]], "=", ramax2, " mm"];
```

```
  If[ramax1 > ra1,
   Print["No interference ", disp[[i]]], Print["Interference ", disp[[i]]]];
  If[ramax2 > ra2, Print["No interference ", disp[[i]]],
   Print["Interference ", disp[[i]]]];
  CR12 = (Sqrt[ra1^2 - rb1^2] + Sqrt[ra2^2 - rb2^2] - c12 Sin[phi]) / (N[Pi] m Cos[phi]);
  Print["CR", disp[[i]], "=", CR12];
 ];

Print["interference 3-2"];
c12 = r3 + r2;
rb1 = r3 Cos[phi];
rb2 = r2 Cos[phi];
a = m;
ra1 = r3 - a;
ra2 = r2 + a;
Print["ra3=", ra1, " mm"];
Print["ra2=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax3=", ramax1, " mm"];
Print["ramax2=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 3-2"], Print["Interference 3-2"]];
If[ramax2 > ra2, Print["No interference 3-2"], Print["Interference 3-2"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR3-2=", CR12];

Print["interference 2p-0"];
r0 = r1 + r2 + r2p;
c12 = r2p + r0;
rb1 = r2p Cos[phi];
rb2 = r0 Cos[phi];
a = m;
ra1 = r2p + a;
ra2 = r0 - a;
Print["ra2p=", ra1, " mm"];
Print["ra0=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax2p=", ramax1, " mm"];
Print["ramax0=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 2p-0"], Print["Interference 2p-0"]];
If[ramax2 > ra2, Print["No interference 2p-0"], Print["Interference 2p-0"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR2p-0=", CR12];

"b)----------"

"contour I: 0-E-1-D-2-B-3-A-0"

ω10 = {n10, 0, 0};
ω21 = {n21, 0, 0};
```

```
ω32 = {n32, 0, 0};
ω03 = {n03, 0, 0};

"ω10+ω21+ω32+ω03=0 (1)"
eq1x = (ω10 + ω21 + ω32 + ω03)[[1]] == 0; Print[eq1x, " (1)"];
"rE x ω10 + rD x ω21 + rB x ω32 + rA x ω03 = 0 (2)"
eq1k = (Cross[rE, ω10] + Cross[rD, ω21] + Cross[rB, ω32] + Cross[rA, ω03])[[3]] == 0;
Print[eq1k, " (2)"];

"contour II: 0-F-2-B-3-A-0"

ω20 = {n20, 0, 0};

"ω20+ω32+ω03=0 (3)"
eq2x = (ω20 + ω32 + ω03)[[1]] == 0; Print[eq2x, " (3)"];
"rF x ω20 + rB x ω32 + rA x ω03 = 0 (4)"
eq2k = (Cross[rF, ω20] + Cross[rB, ω32] + Cross[rA, ω03])[[3]] == 0; Print[eq2k, " (4)"];

"contour III: 0-G-4-C-2-F-0"

ω40 = {n40, 0, 0};
ω24 = {n24, 0, 0};
ω02 = {-n20, 0, 0};

"ω40+ω24+ω02=0 (3)"
eq3x = (ω40 + ω24 + ω02)[[1]] == 0; Print[eq3x, " (5)"];
"rG x ω40 + rC x ω24 + rF x ω02 = 0 (6)"
eq3k = (Cross[rG, ω40] + Cross[rC, ω24] + Cross[rF, ω02])[[3]] == 0; Print[eq3k, " (6)"];

eqns = {eq1x, eq1k, eq2x, eq2k, eq3x, eq3k};
sol = {n21, n32, n03, n20, n40, n24};
"solutions"
solution = N[Solve[eqns, sol]]
Print["n4 = ", n40 /. solution[[1]], " rpm"];

n4 = n40 /. solution[[1]];

"c)-------------"

(* Link 4 *)
Print["Link 4"];
phi = N[Pi] / 9;
GC = rC - rG;
Mext = -800 {Sign[n4], 0, 0};
F24 = {0, F24x, F24y};
(*Sum of moments for 4 wrt G*)
SM4G = Cross[GC, F24] + Mext;
eq1 = SM4G[[1]] == 0;
Print["sum of moments for 4 wrt G :  GC x F24 + Mext = 0"]
Print[eq1, " (1)"];
```

```
(* Link 2 *)
Print["Link 2"];
FB = rB - rF;
FC = rC - rF;
FD = rD - rF;
F32 = {0, -F32t Tan[phi], F32t};
F12 = {0, F12t Tan[phi], F12t};
F02 = {0, -F02t Tan[phi], F02t};
(*Sum of moments for 2 wrt F*)
SM2F = Cross[FB, F32] + Cross[FC, -F24] + Cross[FD, F12];
eq2 = SM2F[[1]] == 0;
Print["sum of moments for 2 wrt F :  FB x F32 + FC x F42 + Fd x F12 = 0"]
Print[eq2, " (2)"];
eqF2 = -F24 + F32 + F12 + F02;
eq3 = eqF2[[2]] == 0;
eq4 = eqF2[[3]] == 0;
Print[eq3, " (3)"];
Print[eq4, " (4)"];

(* Link 3 *)
Print["Link 3"];
(*Sum of moments for 3 wrt AA*)
SM3A = Cross[rB, -F32];
eq5 = SM3A[[1]] == 0;
Print["sum of moments for 3 wrt A :  AB x (-F32) = 0"]
Print[eq5, " (5)"];

sol = Solve[{eq1, eq2, eq3, eq4, eq5}, {F24y, F12t, F32t, F02t, F24x}];
Print["F24=", F24 /. sol[[1]]];
Print["F32=", F32 /. sol[[1]]];
Print["F12=", F12 /. sol[[1]]];
Print["F02=", F02 /. sol[[1]]];

(* Link 1 *)
Print["Link 1"];
ED = rD - rE;
F21 = -F12 /. sol[[1]];
(*Sum of moments for 1 wrt E*)
M1 = -Cross[ED, F21];
Print["M1=", M1[[1]]];
```

```
a)----------

interference 1-2

ra1=300 mm

ra2=230 mm

ramax1=311.954 mm
```

ramax2=258.897 mm

No interference 1–2

No interference 1–2

CR1–2=1.60357

interference 3–2

ra3=680 mm

ra2=230 mm

ramax3=727.702 mm

ramax2=368.525 mm

No interference 3–2

No interference 3–2

CR3–2=6.19017

interference 2p–0

ra2p=180 mm

ra0=630 mm

ramax2p=315.205 mm

ramax0=670.691 mm

No interference 2p–0

No interference 2p–0

CR2p–0=3.75418

b) ----------

contour I: 0–E–1–D–2–B–3–A–0

$\omega 10+\omega 21+\omega 32+\omega 03=0$ (1)

370 + n03 + n21 + n32 == 0 (1)

rE x ω10 + rD x ω21 + rB x ω32 + rA x ω03 = 0 (2)

−280 n21 − 700 n32 == 0 (2)

contour II: 0–F–2–B–3–A–0

$\omega 20+\omega 32+\omega 03=0$ (3)

n03 + n20 + n32 == 0 (3)

rF x ω20 + rB x ω32 + rA x ω03 = 0 (4)

−650 n20 − 700 n32 == 0 (4)

contour III: 0–G–4–C–2–F–0

$\omega 40+\omega 24+\omega 02=0$ (3)

$-n20+n24+n40==0$ (5)

rG x $\omega 40$ + rC x $\omega 24$ + rF x $\omega 02$ = 0 (6)

$650\,n20-490\,n24==0$ (6)

solutions

$\{\{n21\to -650.,\ n32\to 260.,\ n03\to 20.,\ n20\to -280.,\ n40\to 91.4286,\ n24\to -371.429\}\}$

n4 = 91.4286 rpm

c) ----------

Link 4

sum of moments for 4 wrt G : GC x F24 + Mext = 0

$-800+490\,F24y==0$ (1)

Link 2

sum of moments for 2 wrt F : FB x F32 + FC x F42 + Fd x F12 = 0

$-370\,F12t+160\,F24y+50\,F32t==0$ (2)

$-0.36397\,F02t+0.36397\,F12t-F24x-0.36397\,F32t==0$ (3)

$F02t+F12t-F24y+F32t==0$ (4)

Link 3

sum of moments for 3 wrt A : AB x (–F32) = 0

$-700\,F32t==0$ (5)

F24={0, –0.0803023, 1.63265}

F32={0, 0., 0.}

F12={0, 0.256967, 0.706012}

F02={0, –0.33727, 0.926641}

Link 1

M1=197.683

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

m = 42;
N1 = 75; N2 = 35; N2p = 20; N3 = 11; N4 = 13; N5 = 50;

r1 = m * N1 / 2;
r2 = m * N2 / 2;
r2p = m * N2p / 2;
r3 = m * N3 / 2;
r4 = m * N4 / 2;
r5 = m * N5 / 2;

rA = {0, 0, 0};
rB = {xB, r1, 0};
rC = {xC, r1 - r2, 0};
rD = {xD, r1 - r2 + r2p , 0};
rE = {xE, 0, 0};
rF = {xF, r3, 0};
rG = {xG, r3 + r4, 0};
rH = {xH, r3 + 2 r4, 0};
rI = {xI, 0, 0};

n1 = 720;(*rpm*)
n10 = n1;
phi = N[Pi] / 9;

"a)----------"
Print["interference 1-2"];
c12 = r1 + r2;
rb1 = r1 Cos[phi];
rb2 = r2 Cos[phi];
a = m;
ra1 = r1 - a;
ra2 = r2 + a;
Print["ra1=", ra1, " mm"];
Print["ra2=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax1=", ramax1, " mm"];
Print["ramax2=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 1-2"], Print["Interference 1-2"]];
If[ramax2 > ra2, Print["No interference 1-2"], Print["Interference 1-2"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR1-2=", CR12];

Print["interference 2p-0"];
r0 = r1 - r2 + r2p;
c12 = r0 + r2p;
```

```
rb1 = r2p Cos[phi];
rb2 = r0 Cos[phi];
a = m;
ra1 = r2p + a;
ra2 = r0 - a;
Print["ra2p=", ra1, " mm"];
Print["ra0=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax2p=", ramax1, " mm"];
Print["ramax0=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 2p-0"], Print["Interference 2p-0"]];
If[ramax2 > ra2, Print["No interference 2p-0"], Print["Interference 2p-0"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR2p-0=", CR12];

Print["interference 3-4"];
c12 = r3 + r4;
rb1 = r3 Cos[phi];
rb2 = r4 Cos[phi];
a = m;
ra1 = r3 + a;
ra2 = r4 + a;
Print["ra3=", ra1, " mm"];
Print["ra4=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax3=", ramax1, " mm"];
Print["ramax4=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 3-4"], Print["Interference 3-4"]];
If[ramax2 > ra2, Print["No interference 3-4"], Print["Interference 3-4"]];
CR12 = (Sqrt[ra1^2 - rb1^2] + Sqrt[ra2^2 - rb2^2] - c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR3-4=", CR12];

Print["interference 4-5"];
c12 = r4 + r5;
rb1 = r4 Cos[phi];
rb2 = r5 Cos[phi];
a = m;
ra1 = r4 + a;
ra2 = r5 - a;
Print["ra4=", ra1, " mm"];
Print["ra5=", ra2, " mm"];
ramax1 = Sqrt[rb1^2 + c12^2 * Sin[phi]^2];
ramax2 = Sqrt[rb2^2 + c12^2 * Sin[phi]^2];
Print["ramax4=", ramax1, " mm"];
Print["ramax5=", ramax2, " mm"];
If[ramax1 > ra1, Print["No interference 4-5"], Print["Interference 4-5"]];
If[ramax2 > ra2, Print["No interference 4-5"], Print["Interference 4-5"]];
CR12 = (Sqrt[ra1^2 - rb1^2] - Sqrt[ra2^2 - rb2^2] + c12 Sin[phi]) / (N[Pi] m Cos[phi]);
Print["CR4-5=", CR12];
```

```
"b)-------------"

"contour I: 0-A-1-C-2-D-0"
ω10 = {n10, 0, 0};
ω21 = {n21, 0, 0};
ω02 = {n02, 0, 0};

"ω10+ω21+ω02=0 (1)"
eq1x = (ω10 + ω21 + ω02)[[1]] == 0; Print[eq1x, " (1)"];
"rA x ω10 + rC x ω21 + rD x ω02 = 0 (2)"
eq1k = (Cross[rA, ω10] + Cross[rC, ω21] + Cross[rD, ω02])[[3]] == 0; Print[eq1k, " (2)"];

"contour II: 0-D-2-C-3-E-0"
ω20 = {-n02, 0, 0};
ω32 = {n32, 0, 0};
ω03 = {n03, 0, 0};

"ω20+ω32+ω03=0 (3)"
eq2x = (ω20 + ω32 + ω03)[[1]] == 0; Print[eq2x, " (3)"];
"rD x ω20 + rC x ω32 + rE x ω03 = 0 (4)"
eq2k = (Cross[rD, ω20] + Cross[rC, ω32] + Cross[rE, ω03])[[3]] == 0; Print[eq2k, " (4)"];

"contour III: 0-E-3-F-4-G-0"
ω30 = {-n03, 0, 0};
ω43 = {n43, 0, 0};
ω04 = {n04, 0, 0};

"ω30+ω43+ω04=0 (5)"
eq3x = (ω30 + ω43 + ω04)[[1]] == 0; Print[eq3x, " (5)"];
"rE x ω30 + rF x ω43 + rG x ω04 = 0 (6)"
eq3k = (Cross[rE, ω30] + Cross[rF, ω43] + Cross[rG, ω04])[[3]] == 0; Print[eq3k, " (6)"];

eqns = {eq1x, eq1k, eq2x, eq2k, eq3x, eq3k};
sol = {n21, n02, n32, n03, n43, n04};
"solutions"
solution = N[Solve[eqns, sol]]
n4 = -n04 /. solution[[1]];
n5 = -n4 r4 / r5;
Print["n5 = ", n5 , " rpm"];


"c)-------------"
(* Link 5 *)
Print["Link 5"];
phi = N[Pi] / 9;
IH = rH - rI;
Mext = -500 {Sign[n5], 0, 0};
F45 = {0, -F45t * Tan[phi], F45t};
(*Sum of moments for 5 wrt I*)
SM5I = Cross[IH, F45] + Mext;
eq1 = SM5I[[1]] == 0;
```

```
Print["sum of moments for 5 wrt I :  IH x F45 + Mext = 0"]
Print[eq1, " (1)"];
sol = Solve[eq1, F45t];
f45 = F45 /. sol[[1]];
f05 = -f45;

(* Link 4 *)
Print["Link 4"];
GH = rH - rG;
GF = rF - rG;
F34 = {0, F34t * Tan[phi], F34t};
(*Sum of moments for 4 wrt G*)
SM4G = Cross[GH, -f45] + Cross[GF, F34];
eq2 = SM4G[[1]] == 0;
Print["sum of moments for 4 wrt G :  GH x F54 + GF x F34 = 0"]
Print[eq2, " (2)"];
sol = Solve[eq2, F34t];
f34 = F34 /. sol[[1]];
f04 = f45 - f34;

(* Link 3 *)
Print["Link 3"];
f23 = f34;

(* Link 2 *)
Print["Link 2"];
DB = rB - rD;
DC = rC - rD;
F12 = {0, F12t * Tan[phi], F12t};
(*Sum of moments for 2 wrt D*)
SM2D = Cross[DB, F12] + Cross[DC, -f23];
eq3 = SM2D[[1]] == 0;
Print["sum of moments for 2 wrt D :  DB x F12 + DC x F32 = 0"]
Print[eq3, " (3)"];
sol = Solve[eq3, F12t];
f12 = F12 /. sol[[1]];
f02p = f23 - f12;

(* Link 1 *)
Print["Link 1"];
AB = rB - rA;
(*Sum of moments for 1 wrt A*)
M1 = -Cross[AB, -f12];
f01 = f12;

Print["F45=", f45, " N"];
Print["F05=", f05, " N"];
Print["F04=", f04, " N"];
Print["F34=", f34, " N"];
Print["F23=", f23, " N"];
Print["F12=", f12, " N"];
```

```
Print["F02p=", f02p, " N"];
Print["F01=", f01, " N"];
Print["M1=", M1[[1]], " Nm"];
```

a)----------

interference 1-2

ra1=1533 mm

ra2=777 mm

ramax1=1677.69 mm

ramax2=1049.4 mm

No interference 1-2

No interference 1-2

CR1-2=6.72373

interference 2p-0

ra2p=462 mm

ra0=1218 mm

ramax2p=697.082 mm

ramax0=1316.07 mm

No interference 2p-0

No interference 2p-0

CR2p-0=4.26677

interference 3-4

ra3=273 mm

ra4=315 mm

ramax3=277.188 mm

ramax4=309.071 mm

No interference 3-4

Interference 3-4

CR3-4=1.41929

interference 4-5

ra4=315 mm

ra5=1008 mm

ramax4=520.154 mm

ramax5=1085.49 mm

No interference 4-5

No interference 4-5

CR4-5=3.46042

b)----------

contour I: 0-A-1-C-2-D-0

ω10+ω21+ω02=0 (1)

720 + n02 + n21 == 0 (1)

rA x ω10 + rC x ω21 + rD x ω02 = 0 (2)

-1260 n02 - 840 n21 == 0 (2)

contour II: 0-D-2-C-3-E-0

ω20+ω32+ω03=0 (3)

-n02 + n03 + n32 == 0 (3)

rD x ω20 + rC x ω32 + rE x ω03 = 0 (4)

1260 n02 - 840 n32 == 0 (4)

contour III: 0-E-3-F-4-G-0

ω30+ω43+ω04=0 (5)

-n03 + n04 + n43 == 0 (5)

rE x ω30 + rF x ω43 + rG x ω04 = 0 (6)

-504 n04 - 231 n43 == 0 (6)

solutions

{{n21 → -2160., n02 → 1440., n32 → 2160., n03 → -720., n43 → -1329.23, n04 → 609.231}}

n5 = 158.4 rpm

c)----------

Link 5

sum of moments for 5 wrt I : IH x F45 + Mext = 0

-500 + 777 F45t == 0 (1)

Link 4

sum of moments for 4 wrt G : GH x F54 + GF x F34 = 0

-175.676 - 273 F34t == 0 (2)

Link 3

Link 2

sum of moments for 2 wrt D : DB x F12 + DC x F32 = 0

$-270.27+315\,\text{F12t}==0\quad(3)$

Link 1

$\text{F45}=\left\{0,\,-0.234215,\,\frac{500}{777}\right\}$ N

$\text{F05}=\left\{0,\,0.234215,\,-\frac{500}{777}\right\}$ N

F04={0, 0., 1.287} N

F34={0, −0.234215, −0.643501} N

F23={0, −0.234215, −0.643501} N

F12={0, 0.312287, 0.858001} N

F02p={0, −0.546502, −1.5015} N

F01={0, 0.312287, 0.858001} N

M1=1351.35 Nm

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

m = 33;
N1 = 12; N2 = 17; N3 = 20; N4 = 11; N4p = 17; N5 = 51;

r1 = m * N1 / 2;
r2 = m * N2 / 2;
r3 = m * N3 / 2;
r4 = m * N4 / 2;
r4p = m * N4p / 2;
r5 = m * N5 / 2;

rA = {0, 0, 0};
rB = {xB, -r1, 0};
rC = {xC, -r1 - r2, 0};
rD = {xD, -r1 - 2 r2 , 0};
rE = {xE, 0, 0};
rF = {xF, 0, 0};
rG = {xG, r3, 0};
rH = {xH, r3 + r4, 0};
rI = {xI, r3 + r4, 0};
rJ = {xJ, r3 + r4 + r4p, 0};
rK = {xK, r3 + r4 + r4p - r5, 0};

n1 = 319;(*rpm*)
n10 = n1;

"a)-------------"

"contour I: 0-A-1-B-2-D-0"
ω10 = {n10, 0, 0};
ω21 = {n21, 0, 0};
ω02 = {n02, 0, 0};

"ω10+ω21+ω02=0 (1)"
eq1x = (ω10 + ω21 + ω02)[[1]] == 0; Print[eq1x, " (1)"];
"rA x ω10 + rB x ω21 + rD x ω02 = 0 (2)"
eq1k = (Cross[rA, ω10] + Cross[rB, ω21] + Cross[rD, ω02])[[3]] == 0; Print[eq1k, " (2)"];

"contour II: 0-D-2-C-3-E-0"
ω20 = {-n02, 0, 0};
ω32 = {n32, 0, 0};
ω03 = {n03, 0, 0};

"ω20+ω32+ω03=0 (3)"
eq2x = (ω20 + ω32 + ω03)[[1]] == 0; Print[eq2x, " (3)"];
"rD x ω20 + rC x ω32 + rE x ω03 = 0 (4)"
eq2k = (Cross[rD, ω20] + Cross[rC, ω32] + Cross[rE, ω03])[[3]] == 0; Print[eq2k, " (4)"];
```

```
eqns = {eq1x, eq1k, eq2x, eq2k}
sol = {n21, n02, n32, n03}
"solutions"
solution = N[Solve[eqns, sol]]

n3 = -n03 /. solution[[1]];
n4 = n3 r3 / r4;
n5 = n4 r4p / r5;

Print["n5 = ", n5, " rpm"];

"b)----------"
(* Link 1 *)
Print["Link 1"];
H = 2;
M = 9549 H / n1;
M1 = -M {Sign[n1], 0, 0};
phi = N[Pi] / 9;
AB = rB - rA;
F21 = {0, -F21t * Tan[phi], F21t};
(*Sum of moments for 1 wrt A*)
SM1A = Cross[AB, F21] + M1;
eq1 = SM1A[[1]] == 0;
Print["sum of moments for 1 wrt A :  AB x F21 + M1 = 0"]
Print[eq1, " (1)"];
sol = Solve[eq1, F21t];
f21 = F21 /. sol[[1]];
f01 = -f21;

(* Link 2 *)
Print["Link 2"];
CB = rB - rC;
CD = rD - rC;
F02 = {0, F02t * Tan[phi], F02t};
(*Sum of moments for 2 wrt C*)
SM2C = Cross[CB, -f21] + Cross[CD, F02];
eq2 = SM2C[[1]] == 0;
Print["sum of moments for 2 wrt C :  CB x F12 + CD x F02 = 0"]
Print[eq2, " (2)"];
sol = Solve[eq2, F02t];
f02 = F02 /. sol[[1]];
f32 = f21 - f02;

(* Link 3 *)
f43 = f32;

(* Link 4 *)
f54p = f43;

(* Link 5 *)
```

```
f05 = f54p;


Print["F01=", f01, " N"];
Print["F21=", f21, " N"];
Print["F32=", f32, " N"];
Print["F02=", f02, " N"];
Print["F43=", f43, " N"];
Print["F54p=", f54p, " N"];
Print["F05=", f05, " N"];
```

a) ----------

contour I: 0–A–1–B–2–D–0

$\omega 10+\omega 21+\omega 02=0$ (1)

$319 + n02 + n21 == 0$ (1)

$rA \times \omega 10 + rB \times \omega 21 + rD \times \omega 02 = 0$ (2)

$759\, n02 + 198\, n21 == 0$ (2)

contour II: 0–D–2–C–3–E–0

$\omega 20+\omega 32+\omega 03=0$ (3)

$-n02 + n03 + n32 == 0$ (3)

$rD \times \omega 20 + rC \times \omega 32 + rE \times \omega 03 = 0$ (4)

$-759\, n02 + \frac{957\, n32}{2} == 0$ (4)

$\left\{319 + n02 + n21 == 0,\ 759\, n02 + 198\, n21 == 0,\ -n02 + n03 + n32 == 0,\ -759\, n02 + \frac{957\, n32}{2} == 0\right\}$

{n21, n02, n32, n03}

solutions

$\{\{n21 \to -431.588,\ n02 \to 112.588,\ n32 \to 178.588,\ n03 \to -66.\}\}$

n5 = 40. rpm

b) ----------

Link 1

sum of moments for 1 wrt A : AB x F21 + M1 = 0

$-\frac{19098}{319} - 198\, F21t == 0$ (1)

Link 2

sum of moments for 2 wrt C : CB x F12 + CD x F02 = 0

$84.8135 - \frac{561\, F02t}{2} == 0$ (2)

$$F01=\left\{0,\ -0.110052,\ \frac{1061}{3509}\right\}\ \text{N}$$

$$F21=\left\{0,\ 0.110052,\ -\frac{1061}{3509}\right\}\ \text{N}$$

$$F32=\{0,\ 1.38778\times10^{-17},\ -0.604731\}\ \text{N}$$

$$F02=\{0,\ 0.110052,\ 0.302365\}\ \text{N}$$

$$F43=\{0,\ 1.38778\times10^{-17},\ -0.604731\}\ \text{N}$$

$$F54p=\{0,\ 1.38778\times10^{-17},\ -0.604731\}\ \text{N}$$

$$F05=\{0,\ 1.38778\times10^{-17},\ -0.604731\}\ \text{N}$$

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];
m = 24;
N1 = 22; N2 = 20; N2p = 35; N4 = 15; N5 = 16;
r1 = m * N1 / 2;
r2 = m * N2 / 2;
r2p = m * N2p / 2;
r3 = r1 + r2 + r2p;
r4 = m * N4 / 2;
r5 = m * N5 / 2;
r6 = r4 + 2 r5;
rA = {0, 0, 0};
rB = {0, r1, 0};
rC = {xC, r1 + r2, 0};
rD = {xD, r1 + r2 + r2p, 0};
rE = {xE, 0, 0};
rF = {xF, r4, 0};
rG = {xG, r4 + r5, 0};
rH = {xH, r4 + 2 r5, 0};
rJ = {xJ, 0, 0};
n3 = 200;(*rpm*)
n6 = 150; (*rpm*)
n03 = -n3;
n60 = n6;


"contour I: 0-A-1-B-2-C-4-E-0"

ω10 = {n10, 0, 0};
ω21 = {n21, 0, 0};
ω42 = {n42, 0, 0};
ω04 = {n04, 0, 0};

"ω10+ω21+ω42+ω04=0 (1)"
eq1x = (ω10 + ω21 + ω42 + ω04)[[1]] == 0; Print[eq1x, " (1)"];
"rB x ω21 + rC x ω42 = 0 (2)"
eq1k = (Cross[rB, ω21] + Cross[rC, ω42])[[3]] == 0; Print[eq1k, " (2)"];

"contour II: 0-A-1-B-2-D-3-E-0"

ω32 = {n32, 0, 0};
ω03 = {n03, 0, 0};

"ω10+ω21+ω32+ω03=0 (3)"
eq2x = (ω10 + ω21 + ω32 + ω03)[[1]] == 0; Print[eq2x, " (3)"];
"rB x ω21 + rD x ω32 = 0 (4)"
eq2k = (Cross[rB, ω21] + Cross[rD, ω32])[[3]] == 0; Print[eq2k, " (4)"];

"contour III: 0-J-6-H-5-G-3-E-0"
```

```
ω60 = {n60, 0, 0};
ω56 = {n56, 0, 0};
ω35 = {n35, 0, 0};


"ω60+ω56+ω35+ω03=0 (3)"
eq3x = (ω60 + ω56 + ω35 + ω03)[[1]] == 0; Print[eq3x, " (5)"];
"rH x ω56 + rG x ω35 = 0 (6)"
eq3k = (Cross[rH, ω56] + Cross[rG, ω35])[[3]] == 0; Print[eq3k, " (6)"];

"contour IIII: 3-D-2-C-4-F-5-G-3"

ω23 = -ω32;
ω54 = {n54, 0, 0};

"ω23+ω42+ω54+ω35=0 (7)"
eq4x = (ω23 + ω42 + ω54 + ω35)[[1]] == 0; Print[eq4x, " (7)"];
"rD x ω23 + rC x ω42 + rF x ω54 + rG x ω35= 0 (8)"
eq4k = (Cross[rD, ω23] + Cross[rC, ω42] + Cross[rF, ω54] + Cross[rG, ω35])[[3]] == 0;
Print[eq4k, " (8)"];
"equations"
eqns = {eq1x, eq1k, eq2x, eq2k, eq3x, eq3k, eq4x, eq4k}
sol = {n10, n21, n42, n04, n32, n56, n35, n54};
"solutions"
solution = N[Solve[eqns, sol]]
Print["n1 = ", n10 /. solution[[1]], " rpm"];


contour I: 0-A-1-B-2-C-4-E-0

ω10+ω21+ω42+ω04=0 (1)

n04 + n10 + n21 + n42 == 0 (1)

rB x ω21 + rC x ω42 = 0 (2)

-264 n21 - 504 n42 == 0 (2)

contour II: 0-A-1-B-2-D-3-E-0

ω10+ω21+ω32+ω03=0 (3)

-200 + n10 + n21 + n32 == 0 (3)

rB x ω21 + rD x ω32 = 0 (4)

-264 n21 - 924 n32 == 0 (4)

contour III: 0-J-6-H-5-G-3-E-0

ω60+ω56+ω35+ω03=0 (3)

-50 + n35 + n56 == 0 (5)
```

$$rH \times \omega 56 + rG \times \omega 35 = 0 \quad (6)$$

$$-372\, n35 - 564\, n56 == 0 \quad (6)$$

contour IIII: 3–D–2–C–4–F–5–G–3

$$\omega 23+\omega 42+\omega 54+\omega 35=0 \quad (7)$$

$$-n32 + n35 + n42 + n54 == 0 \quad (7)$$

$$rD \times \omega 23 + rC \times \omega 42 + rF \times \omega 54 + rG \times \omega 35= 0 \quad (8)$$

$$924\, n32 - 372\, n35 - 504\, n42 - 180\, n54 == 0 \quad (8)$$

equations

$$\{n04 + n10 + n21 + n42 == 0,\ -264\, n21 - 504\, n42 == 0,\ -200 + n10 + n21 + n32 == 0,\ -264\, n21 - 924\, n32 == 0,\ -50 + n35 + n56 == 0,\ -372\, n35 - 564\, n56 == 0,\ -n32 + n35 + n42 + n54 == 0,\ 924\, n32 - 372\, n35 - 504\, n42 - 180\, n54 == 0\}$$

solutions

$$\{\{n10 \to 670.,\ n21 \to -658.,\ n42 \to 344.667,\ n04 \to -356.667,\ n32 \to 188.,\ n56 \to -96.875,\ n35 \to 146.875,\ n54 \to -303.542\}\}$$

$$n1 = 670.\ rpm$$

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

(*Input data*)

n10 = 600;
M1 = 16;
m = 2. 10^-3;
fi = 20 N[Pi] / 180;
N2 = 20;
N4 = 70;
r2 = m N2 / 2;
r4 = m N4 / 2;
r1 = r4 - 2 r2;

Print["sun gear speed n1 = ", n10, " rpm"];
Print["input torque  M1 = ", M1, " Nm"];
Print["module m = ", m, " m"];
Print["pressure angle fi = ", fi, " rad"];
Print["planet gear N2 = ", N2, " teeth"];
Print["ring gear N4 = ", N4 " teeth"];
Print["r2 = m N2/2 = ", r2, " m"];
Print["r4 = m N4/2 = ", r4, " m"];
Print["r1 = r4-2 r2 = ", r1, " m"];
d1 = 2 r1;
d2 = 2 r2;
d4 = 2 r4;

(* Position of joint B *)
xB = 0;
yB = r1;
rB = {xB, yB, 0};

(* Position of joint C *)
xC = 0;
yC = r1 + r2;
rC = {xC, yC, 0};

(* Position of joint E *)
xE = 0;
yE = r1 + 2 r2;
rE = {xE, yE, 0};

(* Position of joint D *)
rD = {xD, 0, 0};

" Contour 0-1-2-0 "

(*Relative velocities*)
```

```
n10v = {n10, 0, 0};
n21vSol = {n21Sol, 0, 0};
n02vSol = {n02Sol, 0, 0};

"n10 + n21 + n0 = 0"
"rB x n21 + rE x n02 = 0"
eqIk = (n10v + n21vSol + n02vSol)[[1]] == 0;
eqIi = (Cross[rB, n21vSol] + Cross[rE, n02vSol])[[3]] == 0;

solI = Solve[{eqIk, eqIi}, {n21Sol, n02Sol}];
n21v = n21vSol /. solI[[1]];
n02v = n02vSol /. solI[[1]];

Print["n21 = ", n21v, " rpm"];
Print["n02 = ", n02v, " rpm"];

(*Absolute velocities*)

n20v = -n02v;

Print["n20 = ", n20v, "rpm"];

" Contour 0-2-3-0 "

(*Relative velocities*)

n32vSol = {n32Sol, 0, 0};
n03vSol = {n03Sol, 0, 0};

"n20 + n32 + n03 = 0 "
"rE x n20 +  rC x n32 = 0"
eqIk = (n20v + n32vSol + n03vSol)[[1]] == 0;
eqIi = (Cross[rE, n20v] + Cross[rC, n32vSol])[[3]] == 0;

solI = Solve[{eqIk, eqIi}, {n32Sol, n03Sol}];
n32v = n32vSol /. solI[[1]];
n03v = n03vSol /. solI[[1]];

Print["n32 = ", n32v, " rpm"];
Print["n03 = ", n03v, " rpm"];

(*Absolute velocities*)
n30v = -n03v;
Print["n30 = ", n30v, " rpm"];
Print["arm speed n3 = ", n30v[[1]], " rpm"];

"-----------------------------------------------"

"force analysis"
```

```
"two planets"

"sun gear 1"
Ft21 = -M1 / d1;
Print["tangential force Ft21 = -M1/d1 = ", Ft21, " N"];
Fr21 = Ft21 Tan[fi];
Print["radial force Fr21 = Ft21 Tan[fi] = ", Fr21, " N"];

"planet gear 2"
Ft12 = -Ft21;
Print["tangential force Ft12 = -Ft21 = ", Ft12, " N"];
"Ft12 r2 - Ft42 r2 = 0"
Ft42 = Ft12;
Print["tangential force Ft42 = Ft12 = ", Ft12, " N"];
"F32 + Ft12 + Ft42 = 0"
F32 = -2 Ft12;
Print["force F32 = -2 Ft12 = ", F32, " N"];
Fr12 = Ft12 Tan[fi];
Print["radial force Fr12 = Ft12 Tan[fi] = ", Fr12, " N"];
Fr42 = -Ft42 Tan[fi];
Print["radial force Fr42 =- Ft42 Tan[fi] = ", Fr42, " N"];

"arm 3"
F23 = -F32;
Print["force F23 = -F32 = ", F23, " N"];
M3 = -F23 (d1 + d2);
Print["output torque M3 = -F23 (d1+d2) = ", M3, " Nm"];
Print["radial load on the bearing of each planet |F32| = ", Abs[F32], " N"];
Print["radial load on the bearing of other elements  = ", 0, " N"];

"ring gear 4"
Ft24 = -Ft42;
Print["tangential force Ft24 = -Ft42 = ", Ft24, " N"];
Fr24 = -Ft24 Tan[fi];
Print["radial force Fr24 = -Ft24 Tan[fi] = ", Fr24, " N"];
M4 = -Ft24 d4;
Print["brake torque M4 =- Ft24 d4 = ", M4, " Nm"];

"-----------------------------------------------"

"one planet"

"sun gear 1"
Ft21 = -M1 / r1;
Print["tangential force Ft21 = -M1/r1 = ", Ft21, " N"];
Fr21 = Ft21 Tan[fi];
Print["radial force Fr21 = Ft21 Tan[fi] = ", Fr21, " N"];

"planet gear 2"
Ft12 = -Ft21;
Print["tangential force Ft12 = -Ft21 = ", Ft12, " N"];
```

```
"Ft12 r2 – Ft42 r2 = 0"
Ft42 = Ft12;
Print["tangential force Ft42 = Ft12 = ", Ft12, " N"];
"F32 + Ft12 + Ft42 = 0"
F32 = –2 Ft12;
Print["force F32 = –2 Ft12 = ", F32, " N"];
Fr12 = Ft12 Tan[fi];
Print["radial force Fr12 = Ft12 Tan[fi] = ", Fr12, " N"];
Fr42 = –Ft42 Tan[fi];
Print["radial force Fr42 =– Ft42 Tan[fi] = ", Fr42, " N"];

"arm 3"
F23 = –F32;
Print["force F23 = –F32 = ", F23, " N"];
M3 = –F23 (d1 + d2);
Print["output torque M3 = –F23 (d1+d2) = ", M3, " Nm"];
Print["radial load on the bearing of each planet |F32| = ", Abs[F32], " N"];
Print["radial load on the bearing of other elements  = ", 0, " N"];

"ring gear 4"
Ft24 = –Ft42;
Print["tangential force Ft24 = –Ft42 = ", Ft24, " N"];
Fr24 = –Ft24 Tan[fi];
Print["radial force Fr24 = –Ft24 Tan[fi] = ", Fr24, " N"];
M4 = –Ft24 d4;
Print["brake torque M4 =– Ft24 d4 = ", M4, " Nm"];
```

```
sun gear speed n1 = 600 rpm

input torque  M1 = 16 Nm

module m = 0.002 m

pressure angle fi = 0.349066 rad

planet gear N2 = 20 teeth

ring gear N4 = 70  teeth

r2 = m N2/2 = 0.02 m

r4 = m N4/2 = 0.07 m

r1 = r4–2 r2 = 0.03 m

 Contour 0–1–2–0

n10 + n21 + n0 = 0

rB x n21 + rE x n02 = 0

n21 = {–1050., 0, 0} rpm

n02 = {450., 0, 0} rpm
```

n20 = {−450., 0, 0}rpm

Contour 0−2−3−0

n20 + n32 + n03 = 0

rE x n20 + rC x n32 = 0

n32 = {630., 0, 0} rpm

n03 = {−180., 0, 0} rpm

n30 = {180., 0, 0} rpm

arm speed n3 = 180. rpm

---

force analysis

two planets

sun gear 1

tangential force Ft21 = −M1/d1 = −266.667 N

radial force Fr21 = Ft21 Tan[fi] = −97.0587 N

planet gear 2

tangential force Ft12 = −Ft21 = 266.667 N

Ft12 r2 − Ft42 r2 = 0

tangential force Ft42 = Ft12 = 266.667 N

F32 + Ft12 + Ft42 = 0

force F32 = −2 Ft12 = −533.333 N

radial force Fr12 = Ft12 Tan[fi] = 97.0587 N

radial force Fr42 =− Ft42 Tan[fi] = −97.0587 N

arm 3

force F23 = −F32 = 533.333 N

output torque M3 = −F23 (d1+d2) = −53.3333 Nm

radial load on the bearing of each planet |F32| = 533.333 N

radial load on the bearing of other elements = 0 N

ring gear 4

tangential force Ft24 = −Ft42 = −266.667 N

radial force Fr24 = −Ft24 Tan[fi] = 97.0587 N

brake torque M4 =− Ft24 d4 = 37.3333 Nm

---

one planet

sun gear 1

tangential force Ft21 = −M1/r1 = −533.333 N

radial force Fr21 = Ft21 Tan[fi] = −194.117 N

planet gear 2

tangential force Ft12 = −Ft21 = 533.333 N

Ft12 r2 − Ft42 r2 = 0

tangential force Ft42 = Ft12 = 533.333 N

F32 + Ft12 + Ft42 = 0

force F32 = −2 Ft12 = −1066.67 N

radial force Fr12 = Ft12 Tan[fi] = 194.117 N

radial force Fr42 =− Ft42 Tan[fi] = −194.117 N

arm 3

force F23 = −F32 = 1066.67 N

output torque M3 = −F23 (d1+d2) = −106.667 Nm

radial load on the bearing of each planet |F32| = 1066.67 N

radial load on the bearing of other elements = 0 N

ring gear 4

tangential force Ft24 = −Ft42 = −533.333 N

radial force Fr24 = −Ft24 Tan[fi] = 194.117 N

brake torque M4 =− Ft24 d4 = 74.6667 Nm

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

(*Input data*)
(*pressure angle ϕ=14.5 deg full-depth involute*)

σ0p = 20000; (*endurance strength cast steel psi*)
σ0g = 8000; (*endurance strength cast iron psi*)
i = -3.5;(*transmission ratio*)
ϕ = 14.5 π / 180;
n = 1500;(*rpm*)
H = 35.; (*hp*);

Print["endurance strength for pinion -  σ0p = ", σ0p, " psi"];
Print["endurance strength for gear - σ0g = ", σ0g, " psi"];
Print["transmission ratio i = ", i];
Print["pressure angle ϕ = ", ϕ, " rad = ", ϕ 180 / π, " deg"];
Print["speed of the pinion n = ", n, " rpm"];
Print["power trasmitted by the pinion H = ", H, " hp"];

Np = 16;
Print["select Np = ", Np, " teeth" ];
Ng = -i Np;
Print["Ng = -i Np = ", Ng, " teeth" ];

γp = 0.081;
Print["form factor γp = ", γp ];
γg = 0.111;
Print["form factor γg = ", γg ];

Fp = σ0p γp;
Print["load carrying capacity pinion: Fp = σ0p  γp = ", Fp, " psi"];
Fg = σ0g γg;
Print["load carrying capacity gear: Fg = σ0g  γg = ", Fg, " psi"];
If[Fp < Fg, Print["Fp<Fg => pinion is weaker"];
  γ = γp; σ0  = σ0p ,
  Print["Fp>Fg => gear is weaker"];
  Np = Ng; γ = γg; σ0  = σ0g ];

Mt = 63000 H / n;
Print["moment trasmitted Mt=63000 H/n = ", Mt, " lb-in"];

k = 4;
Print["face width factor k = ", k]
σ = σ0 / 2.;
Print["assume allowable stress σ = σ0/2 = ", σ, " psi"];
"σ=(2 Mt Pd^3 )/(k π^2 γ N) =>"
eq1 = σ == (2 Mt Pd^3 ) / (k π^2 γ Np)
Pds = Solve[eq1, Pd];
```

```
Print["Pd = ", Pd /. Pds[[3]]];
P = Input["Select diametral pitch Pd"];
Print["Pd = ", P];

dp = N[Np / P];
Print["pitch diameter dp = Np/Pd = ", dp, " in"];
V = dp π n / 12.;
Print["pitch line velocity V = dp π n/12 = ", V, " ft/min"];
If[V < 2000, σ = 600 σ0 / (600 + V);
  Print["allowable stress for V<2000 ft/min is σ = 600 σ0/(600+V) = ", σ, " psi"]
 ];
If[2000 < V < 4000, σ = 1200 σ0 / (1200 + V);
  Print[
   "allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = ", σ, " psi"]
 ];
If[V > 4000, σ = 78 σ0 / (78 + V^0.5);
  Print["allowable stress for V>4000 ft/min is σ = 78 σ0/(78+V^0.5)  = ", σ, " psi"]
 ];

σi = (2 Mt P^3 ) / (k π^2 γ Np);
Print["induced stress σi=(2 Mt Pd^3 )/(k π^2 γ Np) = ", σi, " psi"];
While[σi > σ,
  Print[
   "σi>σ => weak because the induced stress is greater than the allowable stress"];
  P = Input["Select a stronger diametral pitch Pd"];
  Print["Pd = ", P];

  dp = N[Np / P];
  Print["pitch diameter pinion: dp = Np/Pd = ", dp , " in"];
  V = dp π n / 12.;
  Print["pitch line velocity V = dp π n/12 = ", V, " ft/min"];
  If[V < 2000, σ = 600 σ0 / (600 + V);
   Print["allowable stress for V<2000 ft/min is σ = 600 σ0/(600+V) = ", σ, " psi"]
  ];
  If[2000 < V < 4000, σ = 1200 σ0 / (1200 + V);
   Print["allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = ",
    σ, " psi"]
  ];
  If[V > 4000, σ = 78 σ0 / (78 + V^0.5);
   Print[
    "allowable stress for V>4000 ft/min is σ = 78 σ0/(78+V^0.5)  = ", σ, " psi"]
  ];

  σi = (2 Mt P^3 ) / (k π^2 γ Np);
  Print["induced stress σi=(2 Mt Pd^3 )/(k π^2 γ Np) = ", σi, " psi"]
 ];
Print["σi<σ => strong because the induced stress is less than the allowable stress"]

"k is reduced from the maximum value k=4"
"σ=(2 Mt Pd^3 )/(k π^2 γ Np) => k"
eq2 = σ == (2 Mt P^3 ) / (kp π^2 γ Np);
```

```
kps = Solve[eq2, kp];
k = kp /. kps[[1]];
Print["k = ", k];

p = N[π / P];
Print["circular pitch p = π/Pd = ", p];
B = k p;
Print["face width B = k  p = ", B, " in"];
a = 1. / P;
Print["addendum a = 1/Pd = ", a, " in"];
b = 1.157 / P;
Print["min. dedendum b = 1.157/Pd = ", b, " in"];
rp = Np / (2. P);
Print["radius of pitch diameter for pinion: rp = Np/(2 Pd) = ", rp, " in"];
rg = Ng / (2. P);
Print["radius of pitch diameter for gear: rg = Ng/(2 Pd) = ", rg, " in"];
rbp = rp Cos[ϕ];
rbg = rg Cos[ϕ];
Print["radius of base diameter for pinion: rbp = rp Cos[ϕ] = ", rbp, " in"];
Print["radius of base diameter for gear: rbg = rg Cos[ϕ] = ", rbg, " in"];
c = rp + rg;
Print["center distance c=rp+rg= ", c, " in"];
"radius of maximum possible addendum circle ra(max)=(rb^2+(c Sin[ϕ])^2)^.5"
ramp = (rbp^2 + (c Sin[ϕ])^2)^.5;
ramg = (rbg^2 + (c Sin[ϕ])^2)^.5;
Print["ra(max)p = (rbp^2+(c Sin[ϕ])^2)^.5 = ", ramp, " in"];
Print["ra(max)g = (rbg^2+(c Sin[ϕ])^2)^.5 = ", ramg, " in"];
"radius of addendum circle ra = r + a"
rap = rp + a;
rag = rg + a;
Print["rap = rp + a = ", rap, " in"];
Print["rag = rg + a = ", rag, " in"];
If[ramp > rap && ramg > rag,
  Print[" ra(max)>ra  => no interference "], Print[" interference "]];

pb = p Cos[ϕ];
Print["base pitch pb = p Cos[ϕ] =  ", pb, " in"];
CR = ((rap^2 - rbp^2)^.5 + (rag^2 - rbg^2)^.5 - c Sin[ϕ]) / pb;
Print[
  "contact ratio CR = ((rap^2-rbp^2)^.5+(rag^2-rbg^2)^.5-c Sin[ϕ])/pb = ", CR ];
"contact ratio CR > 1.2 "
```

endurance strength for pinion - σ0p = 20000 psi

endurance strength for gear - σ0g = 8000 psi

transmission ratio i = -3.5

pressure angle ϕ = 0.253073 rad = 14.5 deg

speed of the pinion n = 1500 rpm

power trasmitted by the pinion H = 35. hp

select Np = 16 teeth

Ng = −i Np = 56. teeth

form factor γp = 0.081

form factor γg = 0.111

load carrying capacity pinion: Fp = σ0p γp = 1620. psi

load carrying capacity gear: Fg = σ0g γg = 888. psi

Fp>Fg => gear is weaker

moment trasmitted Mt=63000 H/n = 1470. lb−in

face width factor k = 4

assume allowable stress σ = σ0/2 = 4000. psi

σ=(2 Mt Pd^3)/(k π^2 γ N) =>

$4000. == 11.9805\,Pd^3$

Pd = 6.93736

Pd = 6

pitch diameter dp = Np/Pd = 9.33333 in

pitch line velocity V = dp π n/12 = 3665.19 ft/min

allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = 1973.2 psi

induced stress σi=(2 Mt Pd^3)/(k π^2 γ Np) = 2587.8 psi

σi>σ => weak because the induced stress is greater than the allowable stress

Pd = 7

pitch diameter pinion: dp = Np/Pd = 8. in

pitch line velocity V = dp π n/12 = 3141.59 ft/min

allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = 2211.17 psi

induced stress σi=(2 Mt Pd^3)/(k π^2 γ Np) = 4109.33 psi

σi>σ => weak because the induced stress is greater than the allowable stress

Pd = 5

pitch diameter pinion: dp = Np/Pd = 11.2 in

pitch line velocity V = dp π n/12 = 4398.23 ft/min

allowable stress for V>4000 ft/min is σ = 78 σ0/(78+V^0.5) = 4323.75 psi

induced stress σi=(2 Mt Pd^3)/(k π^2 γ Np) = 1497.57 psi

σi<σ => strong because the induced stress is less than the allowable stress

k is reduced from the maximum value k=4

σ=(2 Mt Pd^3)/(k π^2 γ Np) => k

k = 1.38543

circular pitch p = π/Pd = 0.628319

face width B = k p = 0.870494 in

addendum a = 1/Pd = 0.2 in

min. dedendum b = 1.157/Pd = 0.2314 in

radius of pitch diameter for pinion: rp = Np/(2 Pd) = 5.6 in

radius of pitch diameter for gear: rg = Ng/(2 Pd) = 5.6 in

radius of base diameter for pinion: rbp = rp Cos[ϕ] = 5.42163 in

radius of base diameter for gear: rbg = rg Cos[ϕ] = 5.42163 in

center distance c=rp+rg= 11.2 in

radius of maximum possible addendum circle ra(max)=(rb^2+(c Sin[ϕ])^2)^.5

ra(max)p = (rbp^2+(c Sin[ϕ])^2)^.5 = 6.10392 in

ra(max)g = (rbg^2+(c Sin[ϕ])^2)^.5 = 6.10392 in

radius of addendum circle ra = r + a

rap = rp + a = 5.8 in

rag = rg + a = 5.8 in

ra(max)>ra => no interference

base pitch pb = p Cos[ϕ] = 0.608305 in

contact ratio CR = ((rap^2-rbp^2)^.5+(rag^2-rbg^2)^.5-c Sin[ϕ])/pb = 2.16485

contact ratio CR > 1.2

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

(*Input data*)
(*pressure angle ϕ=20 stub involute*)

σ0p = 15000; (*endurance strength cast steel psi*)
σ0g = 12000; (*endurance strength bronze psi*)
i = -3.;(*transmission ratio*)
ϕ = 20 π / 180;
n = 900; (*rpm*)
H = 10.; (*hp*);

Print["endurance strength for pinion -  σ0p = ", σ0p, " psi"];
Print["endurance strength for gear - σ0g = ", σ0g, " psi"];
Print["transmission ratio i = ", i];
Print["pressure angle ϕ = ", ϕ, " rad = ", ϕ 180 / π, " deg"];
Print["speed of the pinion n = ", n, " rpm"];
Print["power trasmitted by the pinion H = ", H, " hp"];

Np = 16;
Print["select Np = ", Np, " teeth" ];
Ng = -i Np;
Print["Ng = -i Np = ", Ng, " teeth" ];

γp = 0.115;
Print["form factor γp = ", γp ];
γg = 0.150;
Print["form factor γg = ", γg ];

Fp = σ0p γp;
Print["load carrying capacity pinion: Fp = σ0p  γp = ", Fp, " psi"];
Fg = σ0g γg;
Print["load carrying capacity gear: Fg = σ0g  γg = ", Fg, " psi"];
If[Fp < Fg, Print["Fp<Fg => pinion is weaker"];
  γ = γp; σ0  = σ0p ,
  Print["Fp>Fg => gear is weaker"];
  Np = Ng; γ = γg; σ0  = σ0g ];

Mt = 63000 H / n;
Print["moment trasmitted Mt=63000 H/n = ", Mt, " lb-in"];

k = 4;
Print["face width factor k = ", k]
σ = σ0 / 2.;
Print["assume allowable stress σ = σ0/2 = ", σ, " psi"];
"σ=(2 Mt Pd^3 )/(k π^2 γ N) =>"
eq1 = σ == (2 Mt Pd^3 ) / (k π^2 γ Np)
Pds = Solve[eq1, Pd];
```

```
Print["Pd = ", Pd /. Pds[[3]]];
P = Input["Select diametral pitch Pd"];
Print["Pd = ", P];

dp = N[Np / P];
Print["pitch diameter dp = Np/Pd = ", dp, " in"];
V = dp π n / 12.;
Print["pitch line velocity V = dp π n/12 = ", V, " ft/min"];
If[V < 2000, σ = 600 σ0 / (600 + V);
  Print["allowable stress for V<2000 ft/min is σ = 600 σ0/(600+V) = ", σ, " psi"]
 ];
If[2000 < V < 4000, σ = 1200 σ0 / (1200 + V);
  Print[
   "allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = ", σ, " psi"]
 ];
If[V > 4000, σ = 78 σ0 / (78 + V^0.5);
  Print["allowable stress for V>4000 ft/min is σ = 78 σ0/(78+V^0.5)  = ", σ, " psi"]
 ];

σi = (2 Mt P^3 ) / (k π^2 γ Np);
Print["induced stress σi=(2 Mt Pd^3 )/(k π^2 γ Np) = ", σi, " psi"];
While[σi > σ,
  Print[
   "σi>σ => weak because the induced stress is greater than the allowable stress"];
  P = Input["Select a stronger diametral pitch Pd"];
  Print["Pd = ", P];

  dp = N[Np / P];
  Print["pitch diameter pinion: dp = Np/Pd = ", dp , " in"];
  V = dp π n / 12.;
  Print["pitch line velocity V = dp π n/12 = ", V, " ft/min"];
  If[V < 2000, σ = 600 σ0 / (600 + V);
   Print["allowable stress for V<2000 ft/min is σ = 600 σ0/(600+V) = ", σ, " psi"]
  ];
  If[2000 < V < 4000, σ = 1200 σ0 / (1200 + V);
   Print["allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = ",
    σ, " psi"]
  ];
  If[V > 4000, σ = 78 σ0 / (78 + V^0.5);
   Print[
    "allowable stress for V>4000 ft/min is σ = 78 σ0/(78+V^0.5)  = ", σ, " psi"]
  ];

  σi = (2 Mt P^3 ) / (k π^2 γ Np);
  Print["induced stress σi=(2 Mt Pd^3 )/(k π^2 γ Np) = ", σi, " psi"]
 ];
Print["σi<σ => strong because the induced stress is less than the allowable stress"]

"k is reduced from the maximum value k=4"
"σ=(2 Mt Pd^3 )/(k π^2 γ Np) => k"
eq2 = σ == (2 Mt P^3 ) / (kp π^2 γ Np);
```

```
kps = Solve[eq2, kp];
k = kp /. kps[[1]];
Print["k = ", k];

p = N[π / P];
Print["circular pitch p = π/Pd = ", p];
B = k p;
Print["face width B = k  p = ", B, " in"];
```

endurance strength for pinion – $\sigma 0p$ = 15000 psi

endurance strength for gear – $\sigma 0g$ = 12000 psi

transmission ratio i = –3.

pressure angle $\phi = \frac{\pi}{9}$ rad = 20 deg

speed of the pinion n = 900 rpm

power trasmitted by the pinion H = 10. hp

select Np = 16 teeth

Ng = –i Np = 48. teeth

form factor γp = 0.115

form factor γg = 0.15

load carrying capacity pinion: Fp = $\sigma 0p$ γp = 1725. psi

load carrying capacity gear: Fg = $\sigma 0g$ γg = 1800. psi

Fp<Fg => pinion is weaker

moment trasmitted Mt=63000 H/n = 700. lb–in

face width factor k = 4

assume allowable stress σ = $\sigma 0$/2 = 7500. psi

σ=(2 Mt Pd^3)/(k π^2 γ N) =>

$7500. == 19.2731\, Pd^3$

Pd = 7.3008

Pd = 7

pitch diameter dp = Np/Pd = 2.28571 in

pitch line velocity V = dp π n/12 = 538.559 ft/min

allowable stress for V<2000 ft/min is σ = 600 $\sigma 0$/(600+V) = 7904.73 psi

induced stress σi=(2 Mt Pd^3)/(k π^2 γ Np) = 6610.66 psi

σi<σ => strong because the induced stress is less than the allowable stress

k is reduced from the maximum value k=4

```
σ=(2 Mt Pd^3 )/(k π^2 γ Np) => k
```

```
k = 3.34516
```

```
circular pitch p = π/Pd = 0.448799
```

```
face width B = k  p = 1.50131 in
```

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

(*Input data*)
(*pressure angle ϕ=20 stub involute*)

σ0p = 30000; (*endurance strength psi*)
σ0g = 20000; (*endurance strength psi*)
i = -3.; (*transmission ratio*)
ϕ = 20 π / 180;
n = 600; (*rpm*)
H = 15.; (*hp*);

Print["endurance strength for pinion -  σ0p = ", σ0p, " psi"];
Print["endurance strength for gear - σ0g = ", σ0g, " psi"];
Print["transmission ratio i = ", i];
Print["pressure angle ϕ = ", ϕ, " rad = ", ϕ 180 / π, " deg"];
Print["speed of the pinion n = ", n, " rpm"];
Print["power trasmitted by the pinion H = ", H, " hp"];

Np = 16;
Print["select Np = ", Np, " teeth" ];
Ng = -i Np;
Print["Ng = -i Np = ", Ng, " teeth" ];

γp = 0.115;
Print["form factor γp = ", γp ];
γg = 0.150;
Print["form factor γg = ", γg ];

Fp = σ0p γp;
Print["load carrying capacity pinion: Fp = σ0p  γp = ", Fp, " psi"];
Fg = σ0g γg;
Print["load carrying capacity gear: Fg = σ0g  γg = ", Fg, " psi"];
If[Fp < Fg, Print["Fp<Fg => pinion is weaker"];
  γ = γp; σ0  = σ0p ,
  Print["Fp>Fg => gear is weaker"];
  Np = Ng; γ = γg; σ0  = σ0g ];

Mt = 63000 H / n;
Print["moment trasmitted Mt=63000 H/n = ", Mt, " lb-in"];

k = 4;
Print["face width factor k = ", k]
σ = σ0 / 2.;
Print["assume allowable stress σ = σ0/2 = ", σ, " psi"];
"σ=(2 Mt Pd^3 )/(k π^2 γ N) =>"
eq1 = σ == (2 Mt Pd^3 ) / (k π^2 γ Np)
Pds = Solve[eq1, Pd];
```

```
Print["Pd = ", Pd /. Pds[[3]]];
P = Input["Select diametral pitch Pd"];
Print["Pd = ", P];

dp = N[Np / P];
Print["pitch diameter dp = Np/Pd = ", dp, " in"];
V = dp π n / 12.;
Print["pitch line velocity V = dp π n/12 = ", V, " ft/min"];
If[V < 2000, σ = 600 σ0 / (600 + V);
  Print["allowable stress for V<2000 ft/min is σ = 600 σ0/(600+V) = ", σ, " psi"]
 ];
If[2000 < V < 4000, σ = 1200 σ0 / (1200 + V);
  Print[
   "allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = ", σ, " psi"]
 ];
If[V > 4000, σ = 78 σ0 / (78 + V^0.5);
  Print["allowable stress for V>4000 ft/min is σ = 78 σ0/(78+V^0.5)  = ", σ, " psi"]
 ];

σi = (2 Mt P^3 ) / (k π^2 γ Np);
Print["induced stress σi=(2 Mt Pd^3 )/(k π^2 γ Np) = ", σi, " psi"];
While[σi > σ,
  Print[
   "σi>σ => weak because the induced stress is greater than the allowable stress"];
  P = Input["Select a stronger diametral pitch Pd"];
  Print["Pd = ", P];

  dp = N[Np / P];
  Print["pitch diameter pinion: dp = Np/Pd = ", dp , " in"];
  V = dp π n / 12.;
  Print["pitch line velocity V = dp π n/12 = ", V, " ft/min"];
  If[V < 2000, σ = 600 σ0 / (600 + V);
   Print["allowable stress for V<2000 ft/min is σ = 600 σ0/(600+V) = ", σ, " psi"]
  ];
  If[2000 < V < 4000, σ = 1200 σ0 / (1200 + V);
   Print["allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = ",
    σ, " psi"]
  ];
  If[V > 4000, σ = 78 σ0 / (78 + V^0.5);
   Print[
    "allowable stress for V>4000 ft/min is σ = 78 σ0/(78+V^0.5)  = ", σ, " psi"]
  ];

  σi = (2 Mt P^3 ) / (k π^2 γ Np);
  Print["induced stress σi=(2 Mt Pd^3 )/(k π^2 γ Np) = ", σi, " psi"]
 ];
Print["σi<σ => strong because the induced stress is less than the allowable stress"]

"k is reduced from the maximum value k=4"
"σ=(2 Mt Pd^3 )/(k π^2 γ Np) => k"
eq2 = σ == (2 Mt P^3 ) / (kp π^2 γ Np);
```

```
kps = Solve[eq2, kp];
k = kp /. kps[[1]];
Print["k = ", k];

p = N[π / P];
Print["circular pitch p = π/Pd = ", p];
B = k p;
Print["face width B = k  p = ", B, " in"];
```

endurance strength for pinion – $\sigma 0p$ = 30000 psi

endurance strength for gear – $\sigma 0g$ = 20000 psi

transmission ratio i = –3.

pressure angle $\phi = \frac{\pi}{9}$ rad = 20 deg

speed of the pinion n = 600 rpm

power trasmitted by the pinion H = 15. hp

select Np = 16 teeth

Ng = –i Np = 48. teeth

form factor γp = 0.115

form factor γg = 0.15

load carrying capacity pinion: Fp = $\sigma 0p$ γp = 3450. psi

load carrying capacity gear: Fg = $\sigma 0g$ γg = 3000. psi

Fp>Fg => gear is weaker

moment trasmitted Mt=63000 H/n = 1575. lb–in

face width factor k = 4

assume allowable stress σ = $\sigma 0$/2 = 10000. psi

σ=(2 Mt Pd^3)/(k π^2 γ N) =>

$10000. == 11.082\, Pd^3$

Pd = 9.66334

Pd = 9

pitch diameter dp = Np/Pd = 5.33333 in

pitch line velocity V = dp π n/12 = 837.758 ft/min

allowable stress for V<2000 ft/min is σ = 600 $\sigma 0$/(600+V) = 8346.33 psi

induced stress σi=(2 Mt Pd^3)/(k π^2 γ Np) = 8078.78 psi

σi<σ => strong because the induced stress is less than the allowable stress

k is reduced from the maximum value k=4

```
σ=(2 Mt Pd^3 )/(k π^2 γ Np) => k
```

```
k = 3.87178
```

```
circular pitch p = π/Pd = 0.349066
```

```
face width B = k  p = 1.35151 in
```

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];

(*Input data*)
(*pressure angle ϕ=20 deg full-depth involute*)

σ0p = 15000; (*endurance strength mild steel psi*)
σ0g = 12000; (*endurance strength bronze psi*)
i = -3.5; (*transmission ratio*)
ϕ = 20. π / 180;
n = 1750; (*rpm*)
H = 6.; (*hp*);

Print["endurance strength for pinion -  σ0p = ", σ0p, " psi"];
Print["endurance strength for gear - σ0g = ", σ0g, " psi"];
Print["transmission ratio i = ", i];
Print["pressure angle ϕ = ", ϕ, " rad = ", ϕ 180 / π, " deg"];
Print["speed of the pinion n = ", n, " rpm"];
Print["power trasmitted by the pinion H = ", H, " hp"];

Np = 16;
Print["select Np = ", Np, " teeth" ];
Ng = -i Np;
Print["Ng = -i Np = ", Ng, " teeth" ];
γp = 0.081;
Print["form factor γp = ", γp ];
γg = 0.132;
Print["form factor γg = ", γg ];
Fp = σ0p γp;
Print["load carrying capacity pinion: Fp = σ0p  γp = ", Fp, " psi"];
Fg = σ0g γg;
Print["load carrying capacity gear: Fg = σ0g  γg = ", Fg, " psi"];
If[Fp < Fg, Print["Fp<Fg => pinion is weaker"];
  γ = γp; σ0 = σ0p ,
  Print["Fp>Fg => gear is weaker"];
  Np = Ng; γ = γg; σ0 = σ0g ];
Mt = 63000 H / n;
Print["moment trasmitted Mt=63000 H/n = ", Mt, " lb-in"]
k = 4;
Print["face width factor k = ", k]
σ = σ0 / 2.;
Print["assume allowable stress σ = σ0/2 = ", σ, " psi"];
"σ=(2 Mt Pd^3 )/(k π^2 γ N) =>"
eq1 = σ == (2 Mt Pd^3 ) / (k π^2 γ Np)
Pds = Solve[eq1, Pd];
Print["Pd = ", Pd /. Pds[[3]]];
P = Input["Select diametral pitch Pd"];
Print["Pd = ", P];
```

```
dp = N[Np / P];
Print["pitch diameter dp = Np/Pd = ", dp, " in"];
V = dp π n / 12.;
Print["pitch line velocity V = dp π n/12 = ", V, " ft/min" ];
If[V < 2000, σ = 600 σ0 / (600 + V);
  Print["allowable stress for V<2000 ft/min is σ = 600 σ0/(600+V) = ", σ, " psi"]
 ];
If[2000 < V < 4000, σ = 1200 σ0 / (1200 + V);
  Print[
   "allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = ", σ, " psi"]
 ];
If[V > 4000, σ = 78 σ0 / (78 + V^0.5);
  Print["allowable stress for V>4000 ft/min is σ = 78 σ0/(78+V^0.5)  = ", σ, " psi"]
 ];

σi = (2 Mt P^3 ) / (k π^2 γ Np);
Print["induced stress σi=(2 Mt Pd^3 )/(k π^2 γ Np) = ", σi, " psi"];
While[σi > σ,
  Print[
   "σi>σ => weak because the induced stress is greater than the allowable stress"];
  P = Input["Select a stronger diametral pitch Pd"];
  Print["Pd = ", P];

  dp = N[Np / P];
  Print["pitch diameter pinion: dp = Np/Pd = ", dp , " in"];
  V = dp π n / 12.;
  Print["pitch line velocity V = dp π n/12 = ", V, " ft/min" ];
  If[V < 2000, σ = 600 σ0 / (600 + V);
   Print["allowable stress for V<2000 ft/min is σ = 600 σ0/(600+V) = ", σ, " psi"]
  ];
  If[2000 < V < 4000, σ = 1200 σ0 / (1200 + V);
   Print["allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = ",
    σ, " psi"]
  ];
  If[V > 4000, σ = 78 σ0 / (78 + V^0.5);
   Print[
    "allowable stress for V>4000 ft/min is σ = 78 σ0/(78+V^0.5)  = ", σ, " psi"]
  ];

  σi = (2 Mt P^3 ) / (k π^2 γ Np);
  Print["induced stress σi=(2 Mt Pd^3 )/(k π^2 γ Np) = ", σi, " psi"]
 ];
Print["σi<σ => strong because the induced stress is less than the allowable stress"]

"k is reduced from the maximum value k=4"
"σ=(2 Mt Pd^3 )/(k π^2 γ Np) => k"
eq2 = σ == (2 Mt P^3 ) / (kp π^2 γ Np);
kps = Solve[eq2, kp];
k = kp /. kps[[1]];
Print["k = ", k];
p = N[π / P];
```

```
Print["circular pitch p = π/Pd = ", p];
B = k p;
Print["face width B = k  p = ", B, " in"];
a = 1. / P;
Print["addendum a = 1/Pd = ", a, " in"];
b = 1.157 / P;
Print["min. dedendum b = 1.157/Pd = ", b, " in"];
rp = Np / (2. P);
Print["radius of pitch diameter for pinion: rp = Np/(2 Pd) = ", rp, " in"];
rg = Ng / (2. P);
Print["radius of pitch diameter for gear: rg = Ng/(2 Pd) = ", rg, " in"];
rbp = rp Cos[ϕ];
rbg = rg Cos[ϕ];
Print["radius of base diameter for pinion: rbp = rp Cos[ϕ] = ", rbp, " in"];
Print["radius of base diameter for gear: rbg = rg Cos[ϕ] = ", rbg, " in"];
c = rp + rg;
Print["center distance c=rp+rg= ", c, " in"];
"radius of maximum possible addendum circle ra(max)=(rb^2+(c Sin[ϕ])^2)^.5"
ramp = (rbp^2 + (c Sin[ϕ])^2)^.5;
ramg = (rbg^2 + (c Sin[ϕ])^2)^.5;
Print["ra(max)p = (rbp^2+(c Sin[ϕ])^2)^.5 = ", ramp, " in"];
Print["ra(max)g = (rbg^2+(c Sin[ϕ])^2)^.5 = ", ramg, " in"];
"radius of addendum circle ra = r + a"
rap = rp + a;
rag = rg + a;
Print["rap = rp + a = ", rap, " in"];
Print["rag = rg + a = ", rag, " in"];
If[ramp > rap && ramg > rag,
  Print[" ra(max)>ra  => no interference "], Print[" interference "]];

pb = p Cos[ϕ];
Print["base pitch pb = p Cos[ϕ] =  ", pb, " in"];
CR = ((rap^2 - rbp^2)^.5 + (rag^2 - rbg^2)^.5 - c Sin[ϕ]) / pb;
Print[
  "contact ratio CR = ((rap^2-rbp^2)^.5+(rag^2-rbg^2)^.5-c Sin[ϕ])/pb = ", CR ];
"contact ratio CR > 1.2 "
```

endurance strength for pinion - σ0p = 15000 psi

endurance strength for gear - σ0g = 12000 psi

transmission ratio i = -3.5

pressure angle ϕ = 0.349066 rad = 20. deg

speed of the pinion n = 1750 rpm

power trasmitted by the pinion H = 6. hp

select Np = 16 teeth

Ng = -i Np = 56. teeth

form factor $\gamma p = 0.081$

form factor $\gamma g = 0.132$

load carrying capacity pinion: Fp = σ0p γp = 1215. psi

load carrying capacity gear: Fg = σ0g γg = 1584. psi

Fp<Fg => pinion is weaker

moment trasmitted Mt=63000 H/n = 216. lb-in

face width factor k = 4

assume allowable stress $\sigma = \sigma 0/2 = 7500.$ psi

σ=(2 Mt Pd^3)/(k π^2 γ N) =>

$7500. == 8.44343\, Pd^3$

Pd = 9.61274

Pd = 10

pitch diameter dp = Np/Pd = 1.6 in

pitch line velocity V = dp π n/12 = 733.038 ft/min

allowable stress for V<2000 ft/min is $\sigma = 600\ \sigma 0/(600+V) = 6751.49$ psi

induced stress σi=(2 Mt Pd^3)/(k π^2 γ Np) = 8443.43 psi

σi>σ => weak because the induced stress is greater than the allowable stress

Pd = 9

pitch diameter pinion: dp = Np/Pd = 1.77778 in

pitch line velocity V = dp π n/12 = 814.487 ft/min

allowable stress for V<2000 ft/min is $\sigma = 600\ \sigma 0/(600+V) = 6362.73$ psi

induced stress σi=(2 Mt Pd^3)/(k π^2 γ Np) = 6155.26 psi

σi<σ => strong because the induced stress is less than the allowable stress

k is reduced from the maximum value k=4

σ=(2 Mt Pd^3)/(k π^2 γ Np) => k

k = 3.86957

circular pitch p = π/Pd = 0.349066

face width B = k p = 1.35074 in

addendum a = 1/Pd = 0.111111 in

min. dedendum b = 1.157/Pd = 0.128556 in

radius of pitch diameter for pinion: rp = Np/(2 Pd) = 0.888889 in

radius of pitch diameter for gear: rg = Ng/(2 Pd) = 3.11111 in

radius of base diameter for pinion: rbp = rp Cos[ϕ] = 0.835282 in

radius of base diameter for gear: rbg = rg Cos[ϕ] = 2.92349 in

center distance c=rp+rg= 4. in

radius of maximum possible addendum circle ra(max)=(rb^2+(c Sin[ϕ])^2)^.5

ra(max)p = (rbp^2+(c Sin[ϕ])^2)^.5 = 1.60292 in

ra(max)g = (rbg^2+(c Sin[ϕ])^2)^.5 = 3.22776 in

radius of addendum circle ra = r + a

rap = rp + a = 1. in

rag = rg + a = 3.22222 in

ra(max)>ra => no interference

base pitch pb = p Cos[ϕ] = 0.328015 in

contact ratio CR = ((rap^2-rbp^2)^.5+(rag^2-rbg^2)^.5-c Sin[ϕ])/pb = 1.63623

contact ratio CR > 1.2

```
Apply[Clear, Names["Global`*"]];
Off[General::spell];
Off[General::spell1];
(*Input data*)
"full depth involute profile"
(*pressure angle ϕ=20 deg stub involute*)
σ0p = 20000; (*endurance strength steel psi*)
σ0g = 8000; (*endurance strength cast iron psi*)
ϕ = 20. π / 180;
dp = 4. ; (*in.*)
np = 900.; (*rpm*)
i = -7 / 3.; (*transmission ratio*)
H = 30.; (*hp*);

Print["endurance strength for pinion: σ0p = ", σ0p, " psi"];
Print["endurance strength for gear: σ0g = ", σ0g, " psi"];
Print["transmission ratio i = ", i];
Print["pressure angle ϕ = ", ϕ, " rad = ", ϕ 180 / π, " deg"];
Print["speed of the pinion np = ", np, " rpm"];
Print["diameter of the pinion dp = ", dp, " in."];
Print["power trasmitted H = ", H, " hp"];
ng = -i np;
Print["speed of the pinion ng = -i np = ", ng, " rpm"];
Np = 15;
Print["select Np = ", Np, " teeth" ];
Ng = -i Np;
Print["Ng = -i Np = ", Ng, " teeth" ];
γp = 0.092;
Print["table 1, Np = ", Np, " => form factor γp = ", γp ];
x1 = 60.; y1 = 0.154;
x2 = 75; y2 = 0.158;
m1 = (y2 - y1) / (x2 - x1);
b1 = y2 - m1 x2;
γg = m1 Ng + b1;
γg = 0.119;
Print["table 1, Ng = ", Ng, " => form factor γg = ", γg ];
Fp = σ0p γp;
Print["load carrying capacity pinion: Fp = σ0p  γp = ", Fp, " psi"];
Fg = σ0g γg;
Print["load carrying capacity gear: Fg = σ0g  γg = ", Fg, " psi"];
If[Fp < Fg,
  Print["Fp<Fg => pinion is weaker  => design will be based on the pinion"],
  Print["Fp>Fg => gear is weaker => design will be based on the gear"]];
Mt = 63000 H / np;
Print["moment trasmitted by pinion: Mt=63000 H/np = ", Mt, " lb-in"];
rp = dp / 2; rg = -i rp; dg = 2 rg;
Print["radius of pitch diameter for pinion: rp = dp/2 = ", rp, " in."];
Print["radius of pitch diameter for gear: rg = -i rp = ", rg, " in."];
F = Mt / rp;
Print["force trasmitted by pinion F = Mt/rp = ", F, " psi"];
```

```
V = dp π np / 12.;
Print["pitch line velocity V = dp π np/12 = ", V, " ft/min"];
σ0 = σ0g;
Print["stress σ0 = σ0g = ", σ0, " psi"];

If[V < 2000, σ = 600 σ0 / (600 + V);
  Print["allowable stress for V<2000 ft/min is σ = 600 σ0/(600+V) = ", σ, " psi"]
 ];
If[2000 < V < 4000, σ = 1200 σ0 / (1200 + V);
  Print[
   "allowable stress for 2000<V<4000 ft/min is σ = 1200 σ0/(1200+V) = ", σ, " psi"]
 ];
If[V > 4000, σ = 78 σ0 / (78 + V^0.5);
  Print["allowable stress for V>4000 ft/min is σ = 78 σ0/(78+V^0.5)  = ", σ, " psi"]
 ];

k = 4;
Print["face width factor k = ", k]
Print["Pd^2/γ = σ k π^2/F  = ", σ k π^2 / F];
γ = 0.1;
Print["assume  γ = ", γ];
Pd = Sqrt[γ σ k π^2 / F];
Print["Pd = Sqrt[γ σ k π^2/F] = ", Pd, " teeth per inch"];
P = Input["Select diametral pitch Pd"];
Print["try Pd = ", P, " teeth per inch"];
Ng = dg P;
Np = dp P;
Print["Ng = dg Pd = ", Ng, " teeth"];
Print["Np = dp Pd = ", Np, " teeth"];
γg = 0.112;
Print["table 1, Ng = ", Ng, " => form factor γg = ", γg];
Print["Pd^2/γg = ", P^2 / γg];
If[P^2 / γg < σ,
 Print["the gear is strong \(\*GridBox[{{\(Pd^2 / γg\), <}}]\)σ allowable"],
 Print["the gear is weak"]];
"k is reduced from the maximum value k=4"
"Pd^2/γ = σ k π^2/F  => k"
k = F P^2 / (γg σ π^2);
Print["reduce k to k = F Pd^2/(γg σ π^2) = ", k];
p = N[π / P];
Print["circular pitch p = π/Pd = ", p, " in."];
B = k p;
Print["face width B = k  p = ", B, " in."];
a = .8 / P;
Print["addendum a = 1/Pd = ", a, " in."];
rbp = rp Cos[ϕ];
rbg = rg Cos[ϕ];
Print["radius of base diameter for pinion: rbp = rp Cos[ϕ] = ", rbp, " in."];
Print["radius of base diameter for gear: rbg = rg Cos[ϕ] = ", rbg, " in."];
c = rp + rg;
```

```
Print["center distance c=rp+rg= ", c, " in"];
"radius of maximum possible addendum circle ra(max)=(rb^2+(c Sin[ϕ])^2)^.5"
ramp = (rbp^2 + (c Sin[ϕ])^2)^.5;
ramg = (rbg^2 + (c Sin[ϕ])^2)^.5;
Print["ra(max)p = (rbp^2+(c Sin[ϕ])^2)^.5 = ", ramp, " in."];
Print["ra(max)g = (rbg^2+(c Sin[ϕ])^2)^.5 = ", ramg, " in."];
"radius of addendum circle ra = r + a"
rap = rp + a;
rag = rg + a;
Print["rap = rp + a = ", rap, " in."];
Print["rag = rg + a = ", rag, " in."];
If[ramp > rap && ramg > rag,
  Print["ra(max)>ra  => no interference "], Print["interference "]];

pb = p Cos[ϕ];
Print["base pitch pb = p Cos[ϕ] =  ", pb, " in."];
CR = ((rap^2 - rbp^2)^.5 + (rag^2 - rbg^2)^.5 - c Sin[ϕ]) / pb;
Print[
  "contact ratio CR = ((rap^2-rbp^2)^.5+(rag^2-rbg^2)^.5-c Sin[ϕ])/pb = ", CR ];
"contact ratio CR > 1.2 "

Null
```

full depth involute profile

endurance strength for pinion: σ0p = 20000 psi

endurance strength for gear: σ0g = 8000 psi

transmission ratio i = −2.33333

pressure angle ϕ = 0.349066 rad = 20. deg

speed of the pinion np = 900. rpm

diameter of the pinion dp = 4. in.

power trasmitted H = 30. hp

speed of the pinion ng = −i np = 2100. rpm

select Np = 15 teeth

Ng = −i Np = 35. teeth

table 1, Np = 15 => form factor γp = 0.092

table 1, Ng = 35. => form factor γg = 0.119

load carrying capacity pinion: Fp = σ0p γp = 1840. psi

load carrying capacity gear: Fg = σ0g γg = 952. psi

Fp>Fg => gear is weaker => design will be based on the gear

moment trasmitted by pinion: Mt=63000 H/np = 2100. lb-in

radius of pitch diameter for pinion: rp = dp/2 = 2. in.

radius of pitch diameter for gear: rg = -i rp = 4.66667 in.

force trasmitted by pinion F = Mt/rp = 1050. psi

pitch line velocity V = dp π np/12 = 942.478 ft/min

stress σ0 = σ0g = 8000 psi

allowable stress for V<2000 ft/min is σ = 600 σ0/(600+V) = 3111.88 psi

face width factor k = 4

Pd^2/γ = σ k π^2/F = 117.002

assume γ = 0.1

Pd = Sqrt[γ σ k π^2/F] = 3.42055 teeth per inch

try Pd = 3 teeth per inch

Ng = dg Pd = 28. teeth

Np = dp Pd = 12. teeth

table 1, Ng = 28. => form factor γg = 0.112

Pd^2/γg = 80.3571

the gear is strong \(*GridBox[{{\(Pd^2/γg\), <}}]\)σ allowable

k is reduced from the maximum value k=4

Pd^2/γ = σ k π^2/F => k

reduce k to k = F Pd^2/(γg σ π^2) = 2.74721

circular pitch p = π/Pd = 1.0472 in.

face width B = k p = 2.87687 in.

addendum a = 1/Pd = 0.266667 in.

radius of base diameter for pinion: rbp = rp Cos[ϕ] = 1.87939 in.

radius of base diameter for gear: rbg = rg Cos[ϕ] = 4.38523 in.

center distance c=rp+rg= 6.66667 in

radius of maximum possible addendum circle ra(max)=(rb^2+(c Sin[ϕ])^2)^.5

ra(max)p = (rbp^2+(c Sin[ϕ])^2)^.5 = 2.95484 in.

ra(max)g = (rbg^2+(c Sin[ϕ])^2)^.5 = 4.9426 in.

radius of addendum circle ra = r + a

rap = rp + a = 2.26667 in.

rag = rg + a = 4.93333 in.

ra(max)>ra => no interference

base pitch pb = p Cos[ϕ] = 0.984044 in.

```
contact ratio CR = ((rap^2-rbp^2)^.5+(rag^2-rbg^2)^.5-c Sin[ϕ])/pb = 1.26723
```

```
contact ratio CR > 1.2
```