Contents


```
clear
clc
resloution = 0.001;
```

Inputs

```
%All in standard SI units unless noted
OperatingVoltage = 40                                                   %V
TorqueConstant = 8.474E-3                                               %N.m/A
VoltageConstant = 1125                                                  %RPM/V
ArmatureResistance = 0.072                                              %Ohms
reqOutputSpeed = 575                                                    %RPM
reqOutputTorque = 55                                                    %N.m
Efficiency = 90/100
Duty = 2000                                                             %Hours

%Gear Specs
PressureAngle = 20*pi/180                                               %Rad
FaceWidth = [1.5, 1.25, 1, 0.75, 0.5, 0.25, 0.188, 0.125]               %inch
DiametralPitch = [8, 10, 12, 16, 20, 24, 32, 48]                        %teeth/inch
DiametralPitchSelected = 20;
k = 1                                                                   %Teeth Depth (1 = full)

%Number of teeth variables:
P1 = 16
N1 = 70
P2 = 16
N2 = 70
```

```
OperatingVoltage =

    40

TorqueConstant =

    0.0085

VoltageConstant =

        1125

ArmatureResistance =

    0.0720

reqOutputSpeed =

   575

reqOutputTorque =

    55

Efficiency =

    0.9000

Duty =

        2000

PressureAngle =

    0.3491

FaceWidth =
```

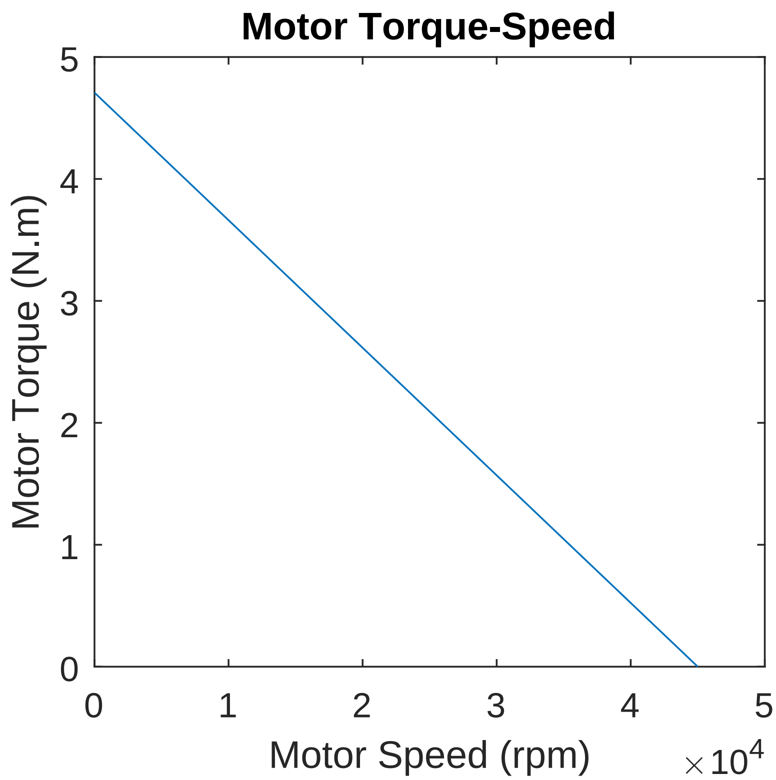
```
  Columns 1 through 7

    1.5000    1.2500    1.0000    0.7500    0.5000    0.2500    0.1880

  Column 8

    0.1250


DiametralPitch =

     8    10    12    16    20    24    32    48


k =

     1


P1 =

    16


N1 =

    70


P2 =

    16


N2 =

    70
```

Motor Torque-Speed

```
%point 1:
NoLoadSpeed = VoltageConstant*OperatingVoltage;
NoLoadTorque = 0;
```

```
%point 2:
StallTorque = TorqueConstant*OperatingVoltage/ArmatureResistance;
StallSpeed = 0;

%determine Torque-speed graph
points = [StallSpeed, StallTorque;
          NoLoadSpeed, NoLoadTorque];
polynomialDegree = length(points)-1;

%fit a polynomial to the two data points
MotorLine = polyfit(points(:,1),points(:,2),polynomialDegree);

%generate figure
f1 = figure('Renderer', 'painters', 'Position', [10 10 1200 300])
subplot(1,3,1)
plot([StallSpeed:NoLoadSpeed], polyval(MotorLine,[StallSpeed:NoLoadSpeed]))
hold on
title("Motor Torque-Speed")
xlabel("Motor Speed (rpm)")
ylabel("Motor Torque (N.m)")
hold off
```

```
f1 =

  Figure (1) with properties:

      Number: 1
        Name: ''
       Color: [0.9400 0.9400 0.9400]
    Position: [10 10 1200 300]
       Units: 'pixels'

  Use GET to show all properties
```

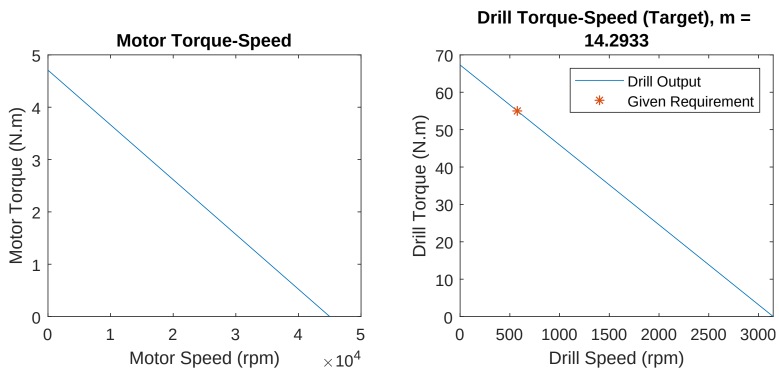


Gear Ratio Target (minimization)

```
%setup equation to determine optimal ratio
syms r
eqn = MotorLine(1)*reqOutputSpeed*r^2 + MotorLine(2)*r == reqOutputTorque;
soln = double(solve(eqn,r))

%solve equation for tearget ratio
ratioTarget = soln(1);

%determine line for the target ratio
TargetLine = [MotorLine(1)*ratioTarget^2, MotorLine(2)*ratioTarget];

%generate figure
subplot(1,3,2)
plot([StallSpeed/ratioTarget: NoLoadSpeed/ratioTarget], polyval(TargetLine,[StallSpeed/ratio
hold on
plot(reqOutputSpeed, reqOutputTorque,'*')
title(["Drill Torque-Speed (Target), m = ", ratioTarget])
xlabel("Drill Speed (rpm)")
```

```
ylabel("Drill Torque (N.m)")
legend("Drill Output", "Given Requirement")
hold off
```

```
soln =

   14.2933
   63.9676
```



Gears

```
m1actual = N1/P1;
m2actual = N2/P2;
ratio = m1actual*m2actual;

%limits:
%pinions
P1l = ceil((2*k*(m1actual+(m1actual^2+(1-2*m1actual)*(sin(PressureAngle))^2)^0.5))/((1+2*m1a
P2l = ceil((2*k*(m2actual+(m2actual^2+(1-2*m2actual)*(sin(PressureAngle))^2)^0.5))/((1+2*m2a

%gear Limits
N1l = floor(((P1l^2)*(sin(PressureAngle)^2)-4*k^2)/(4*k-2*P1l*sin(PressureAngle)^2));
N2l = floor(((P1l^2)*(sin(PressureAngle)^2)-4*k^2)/(4*k-2*P2l*sin(PressureAngle)^2));

%generate ratio table
TRatio = table(P1, P1l, N1, N1l, m1actual, P2, P2l, N2, N2l, m2actual, ratio)

%old ratio determiner
%{
if(m1*P1l > N1l)
    N1 = N1l;   %Gear Ratio m is too large
    disp("Ratio m1 Too Large, increasing P1")
```

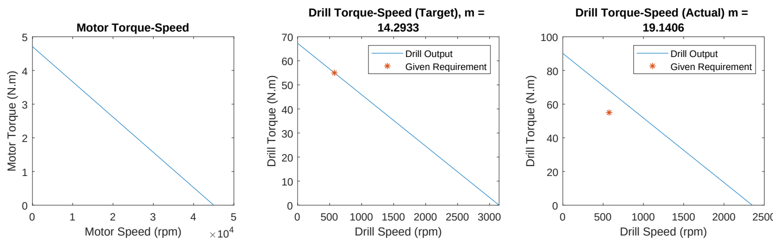
```
    P1l = P1l+1;
    N1 = floor(m1*P1l);
else
    N1 = floor(m1*P1l);
end

if(m2*P2 > N2l);
    N2 = N2l;    %Gear Ratio m is too large
    disp("Ratio m2 Too Large, increasing P2")
    P2 = P2+1;
    N2 = floor(m2*P2);
else
    N2 = floor(m2*P2);
end

%}
```

```
TRatio =

  1x11 table

    P1    P1l    N1    N1l    m1actual    P2    P2l    N2    N2l    m2actual    ratio 
    --    ---    --    ---    --------    --    ---    --    ---    --------    ------

    16    16     70    101     4.375      16    16     70    101     4.375      19.141
```

Gear Ratio (Overall)

```
outputTorque = [0];
outputSpeed = [0];

%Adjust line with ratio
RealLine = [MotorLine(1)*ratio^2, MotorLine(2)*ratio];

for x = [StallSpeed:NoLoadSpeed]
   outputSpeed = [outputSpeed, x/ratio];
   outputTorque = [outputTorque, polyval(RealLine,x/ratio)];
end
outputSpeed = outputSpeed(2:end);
outputTorque = outputTorque(2:end);

%generate figure
subplot(1,3,3)
plot(outputSpeed, outputTorque)
```

```
hold on
plot(reqOutputSpeed,reqOutputTorque,'*')
title(["Drill Torque-Speed (Actual) m = ", ratio])
xlabel("Drill Speed (rpm)")
ylabel("Drill Torque (N.m)")
legend("Drill Output", "Given Requirement")
hold off
```



Shaft Torque and Speed Estimation

```
%{
Motor - P1  : Shaft A
N1 - P2     : Shaft B
N2 - Chuck  : Shaft C
%}

outputPower = reqOutputSpeed*reqOutputTorque*pi/30 ;
intermediatePower = outputPower/Efficiency^0.5;
inputPower = intermediatePower/Efficiency^0.5;
efficiency = outputPower/inputPower;

%Shaft C
SpeedC = reqOutputSpeed;
TorqueC = reqOutputTorque;
%Shaft B
SpeedB = SpeedC*m2actual;
TorqueB = intermediatePower/(SpeedB*pi/30);
%Shaft A
SpeedA = SpeedB*m1actual;
TorqueA = inputPower/(SpeedA*pi/30);

%Table for torque and speed estimations
TTorqueSpeedEstimation = table(TorqueA, SpeedA, TorqueB, SpeedB, TorqueC, SpeedC)

%table for power estimations
TPower = table(inputPower, intermediatePower, outputPower, efficiency)
```

```
TTorqueSpeedEstimation =

  1×7 table

    TorqueA    SpeedA    TorqueB    SpeedB    TorqueC    SpeedC
    _______    ______    _______    ______    _______    ______

    3.1927     11006     13.251     2515.6      55        575


TPower =

  1×7 table

    inputPower    intermediatePower    outputPower    efficiency
    __________    _________________    ___________    __________

      3679.7           3490.9             3311.8          0.9
```

Operating Gear Forces, Torques and Diameters

```
%initialize arrays
Force1t = [0];
Force1r = [0];
Force2t = [0];
Force2r = [0];
P1diameter = [0];
N1diameter = [0];
P2diameter = [0];
N2diameter = [0];

for x = DiametralPitch
    x = x/0.0254;  %Teeth/inch -> teeth/meter
    P1dia = P1/x; %Teeth / (Teeth/meter) = meter
    N1dia = N1/x;
    P2dia = P2/x;
    N2dia = N2/x;

    %record diameter
    P1diameter = [P1diameter, P1dia];
    N1diameter = [N1diameter, N1dia];
    P2diameter = [P2diameter, P2dia];
    N2diameter = [N2diameter, N2dia];
```

```
    %Transmitted Load: Pinion 1 -> Gear 1 EQN 13-36
    Wt1 = (60000*inputPower*10^-3)/(pi*(P1dia*1000)*SpeedA);
    %Radial Load: Pinion 1 -> Gear 1
    Wr1 = tan(PressureAngle)*Wt1;

    %Transmitted Load: Pinion 2 -> Gear 2
    Wt2 = (60000*outputPower*10^-3)/(pi*(N2dia*1000)*SpeedC);
    %Radial Load: Pinion 2 -> Gear 2
    Wr2 = tan(PressureAngle)*Wt2;

    %Record Forces
    Force1t = [Force1t, Wt1*1000]; %kN -> N
    Force1r = [Force1r, Wr1*1000];
    Force2t = [Force2t, Wt2*1000];
    Force2r = [Force2r, Wr2*1000];
end

%Prepare arrays for table
Force1t = transpose(Force1t(2:end));
Force2t = transpose(Force2t(2:end));
Force1r = transpose(Force1r(2:end));
Force2r = transpose(Force2r(2:end));
P1diameter = transpose(P1diameter(2:end)).*100; %meters -> centimeters;
N1diameter = transpose(N1diameter(2:end)).*100; %meters -> centimeters;
P2diameter = transpose(P2diameter(2:end)).*100; %meters -> centimeters;
N2diameter = transpose(N2diameter(2:end)).*100; %meters -> centimeters;

%Table with Forces and Diameters
TForceDiameter = table(transpose(DiametralPitch), Force1t, Force1r, P1diameter, N1diameter,

%{

Not confident that this is correct

%Wt, Tangential Forces
Force1t = [0];
Force2t = [0];
%Wr, Radial Forces
Force1r = [0];
Force2r = [0];
%Gear Diameters
P1diameter = [0];
N1diameter = [0];
P2diameter = [0];
N2diameter = [0];
%Shaft Torques
```

```
AT = [0];
BT = [0];
CT = [0];

for x = DiametralPitch
DiametralPitch1 = x/0.0254;
DiametralPitch2 = x/0.0254;  %Teeth/inch -> teeth/meter

P1dia = P1/DiametralPitch1; %Teeth / (Teeth/meter) = meter
N1dia= N1/DiametralPitch1;
P2dia= P2/DiametralPitch2;
N2dia= N2/DiametralPitch2;

%Logging diameters for the table below
P1diameter = [P1diameter, P1dia];
N1diameter = [N1diameter, N1dia];
P2diameter = [P2diameter, P2dia];
N2diameter = [N2diameter, N2dia];

%Tangential Forces
Ctorque = CopTorque;
Wt2 = Ctorque/(cos(PressureAngle2)*N2dia/2);
Btorque = (Wt2*P2dia/2)/cos(PressureAngle2);
Wt1 = Btorque/(cos(PressureAngle1)*N1dia/2);
Atorque = (Wt1*P1dia/2)/cos(PressureAngle1);
Force2t = [Force2t, Wt2];
Force1t = [Force1t, Wt1];
%Radial Forces
Force1r = [Force1r, tan(PressureAngle1)*Wt1];
Force2r = [Force2r, tan(PressureAngle2)*Wt2];
%Shaft Torques
AT = [AT, Atorque];
BT = [BT, Btorque];
CT = [CT, Ctorque];

end

Force1t = Force1t(2:end);
Force2t = Force2t(2:end);
Force1r = Force1r(2:end);
Force2r = Force2r(2:end);

P1diameter = P1diameter(2:end);
N1diameter = N1diameter(2:end);
P2diameter = P2diameter(2:end);
N2diameter = N2diameter(2:end);
```

```
AT = AT(2:end);
BT = BT(2:end);
CT = CT(2:end);

DiametralPitch = transpose(DiametralPitch);
Force1t = transpose(Force1t);
Force2t = transpose(Force2t);
Force1r = transpose(Force1r);
Force2r = transpose(Force2r)
P1diameter = transpose(P1diameter).*100; %meters -> centimeters
N1diameter = transpose(N1diameter).*100;
P2diameter = transpose(P2diameter).*100;
N2diameter = transpose(N2diameter).*100;
AT = transpose(AT);
BT = transpose(BT);
CT = transpose(CT);

ForceTorqueTable = table(DiametralPitch, AT, Force1t, Force1r, BT,  Force2t, Force2r, CT)

DiameterTable = table(DiametralPitch, P1diameter, N1diameter, P2diameter, N2diameter)

%}
```

```
TForceDiameter =

  817table

    Var1    Force1t    Force1r    P1diameter    N1diameter    Force2t    Force2r    P2diamet
    ----    -------    -------    ----------    ----------    -------    -------    --------

      8      125.7     45.751          5.08        22.225     494.94     180.14          5.08
     10     157.12     57.188         4.064         17.78     618.67     225.18         4.064
     12     188.55     68.626        3.3867        14.817     742.41     270.21        3.3867
     16      251.4     91.501          2.54        11.113     989.88     360.29          2.54
     20     314.25     114.38         2.032          8.89     1237.3     450.36         2.032
     24      377.1     137.25        1.6933        7.4083     1484.8     540.43        1.6933
     32     502.79        183          1.27        5.5563     1979.8     720.57          1.27
     48     754.19      274.5       0.84667        3.7042     2969.6     1080.9       0.84667
```

Stresses

(Calculated in USCS then converted to metric)

```
%Init Arrays
ContactPinion1 = [0];
BendingPinion1 = [0];
ContactGear1 = [0];
BendingGear1 = [0];
ContactPinion2 = [0];
BendingPinion2 = [0];
ContactGear2 = [0];
BendingGear2 = [0];

Pinion1 = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];
Gear1 = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];
Pinion2 = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];
Gear2 = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];

for x = [1:length(DiametralPitch)]

    p1 = stresses(DiametralPitch(x), P1, SpeedA, FaceWidth(x), Force1t(x), m1actual, Pressur
    g1 = stresses(DiametralPitch(x), N1, SpeedB, FaceWidth(x), Force1t(x), m1actual, Pressur
    p2 = stresses(DiametralPitch(x), P2, SpeedB, FaceWidth(x), Force2t(x), m2actual, Pressur
    g2 = stresses(DiametralPitch(x), N2, SpeedC, FaceWidth(x), Force2t(x), m2actual, Pressur

    Pinion1 = [Pinion1; p1];
    Gear1 = [Gear1; g1];
    Pinion2 = [Pinion2; p2];
    Gear2 = [Gear2; g2];

    if DiametralPitch(x) == DiametralPitchSelected
       PINION1 =  p1;
       GEAR1 =  g1;
       PINION2 =  p2;
       GEAR2 =  g2;
    end

end

Pinion1 = Pinion1(2:end,:);
Gear1 = Gear1(2:end,:);
Pinion2 = Pinion2(2:end,:);
Gear2 = Gear2(2:end,:);

%Appendix tables, DP varying
names = ["DP","ContactStress", "BendingStress", "ContactFOS", "BendingFOS", "Ko", "Kv", "Ks'
Tpinion1 = array2table(Pinion1, 'VariableNames', names)
Tgear1 = array2table(Gear1, 'VariableNames', names)
Tpinion2 = array2table(Pinion2, 'VariableNames', names)
```

```
Tgear2 = array2table(Gear2, 'VariableNames', names)

%Prepare arrays for table
PINION1 = transpose(PINION1);
GEAR1 = transpose(GEAR1);
PINION2 = transpose(PINION2);
GEAR2 = transpose(GEAR2);

%Table for selected DP
Tselected = table(transpose(names), PINION1, GEAR1, PINION2, GEAR2)
```

```
Tpinion1 =

  817 table

    DP    ContactStress    BendingStress    ContactFOS    BendingFOS     Ko       Kv
    --    -------------    -------------    ----------    ----------    ----    ------    --

     8       198.31           8.3576          7.2734        52.846      1.25    1.4293     1
    10       264.79             14.9          5.4473        29.642      1.25    1.3898     1
    12       346.72           25.547          4.1601        17.288      1.25      1.36     1
    16       516.52           56.698          2.7925        7.7897      1.25     1.317     1
    20          764           124.05          1.8879        3.5605      1.25     1.287    0.
    24       1241.9           327.75          1.1614        1.3475      1.25    1.2644    0.
    32       1855.6            731.7         0.77733       0.60361      1.25     1.232    0.
    48       3284.6           2292.7         0.43913       0.19263      1.25    1.1926    0.


Tgear1 =

  817 table

    DP    ContactStress    BendingStress    ContactFOS    BendingFOS     Ko       Kv
    --    -------------    -------------    ----------    ----------    ----    ------    --

     8        92.82           5.2751          16.879        87.814      1.25    1.4293     1
    10       123.82           9.3871          12.653        49.347      1.25    1.3898     1
    12       162.26           16.121          9.6551        28.735      1.25      1.36     1
    16       241.71           35.772          6.4815        12.949      1.25     1.317     1
    20       358.75           78.799           4.367        5.8785      1.25     1.287    0.
    24       587.26           211.16          2.6677        2.1937      1.25    1.2644    0.
    32       877.42           471.37          1.7855       0.98272      1.25     1.232    0.
    48       1553.2           1477.1          1.0087       0.31361      1.25    1.1926    0.


Tpinion2 =
```

817 table

DP	ContactStress	BendingStress	ContactFOS	BendingFOS	Ko	Kv	
8	363.97	28.152	4.3044	16.454	1.25	1.2227	1
10	488.44	50.7	3.2075	9.1367	1.25	1.201	1
12	642.16	87.633	2.4397	5.286	1.25	1.1848	1
16	962.55	196.9	1.6276	2.3526	1.25	1.1616	1
20	1430.3	434.74	1.0954	1.0655	1.25	1.1455	0.
24	2333.3	1157	0.67144	0.40038	1.25	1.1335	0.
32	3505.1	2610.9	0.44696	0.17742	1.25	1.1165	0.
48	6248.1	8296.4	0.25074	0.055835	1.25	1.096	0.

Tgear2 =

817 table

DP	ContactStress	BendingStress	ContactFOS	BendingFOS	Ko	Kv	
8	170.36	17.769	9.9888	27.342	1.25	1.2227	1
10	228.4	31.941	7.4502	15.21	1.25	1.201	1
12	300.52	55.297	5.6623	8.786	1.25	1.1848	1
16	450.44	124.23	3.7778	3.9109	1.25	1.1616	1
20	671.6	276.17	2.5337	1.7592	1.25	1.1455	0.
24	1103.4	745.38	1.5422	0.65181	1.25	1.1335	0.
32	1657.4	1682	1.0267	0.28885	1.25	1.1165	0.
48	2954.6	5344.8	0.57594	0.0909	1.25	1.096	0.

Tselected =

1517table

Var1	PINION1	GEAR1	PINION2	GEAR2
"DP"	20	20	20	20
"ContactStress"	764	358.75	1430.3	671.6
"BendingStress"	124.05	78.799	434.74	276.17
"ContactFOS"	1.8879	4.367	1.0954	2.5337
"BendingFOS"	3.5605	5.8785	1.0655	1.7592
"Ko"	1.25	1.25	1.25	1.25

```
"Kv"                1.287       1.287      1.1455      1.1455
"Ks"              0.97972     0.97972     0.97972     0.97972
"Km"               1.0907      1.0521      1.0907      1.0521
"Kb"                    1           1           1           1
"Kt"                    1           1           1           1
"Kr"                    1           1           1           1
"Cf"                    1           1           1           1
"J"                  0.27        0.41        0.27        0.41
"I"                0.1308      0.1308      0.1308      0.1308
```

Torque Calculation

```
Torque = zeros(3,1); %index 1 = Torque A, %index 2 = Torque B, %index 3 = Torque C,
Wt = zeros(4,1); %index 1 = P1, %index 2 = N1, %index 3 = P2, index 4 = N2
Wr = zeros(4,1);

Torque(3) = TorqueC;
Wt(4) = Torque(3)/(0.5*0.0254*N2/DiametralPitchSelected); %F = T/d, meters/inch* teeth / (te
Wr(4) = tan(PressureAngle)*Wt(4);

Torque(2) = TorqueB;
Wt(3) = Torque(2)/(0.5*0.0254*P2/DiametralPitchSelected); %F = T/d, meters/inch* teeth / (te
Wr(3) = tan(PressureAngle)*Wt(3);
Wt(2) = Torque(2)/(0.5*0.0254*N1/DiametralPitchSelected); %F = T/d, meters/inch* teeth / (te
Wr(2) = tan(PressureAngle)*Wt(2);

Torque(1) = TorqueA;
Wt(1) = Torque(1)/(0.5*0.0254*P1/DiametralPitchSelected); %F = T/d, meters/inch* teeth / (te
Wr(1) = tan(PressureAngle)*Wt(1);


TTorqueCalc = table(["Shaft A";"Shaft B";"Shaft C"], Torque)
TForceCalc = table(["Pinion 1";"Gear 1";"Pinion 2";"Gear 2"], Wt, Wr)
```

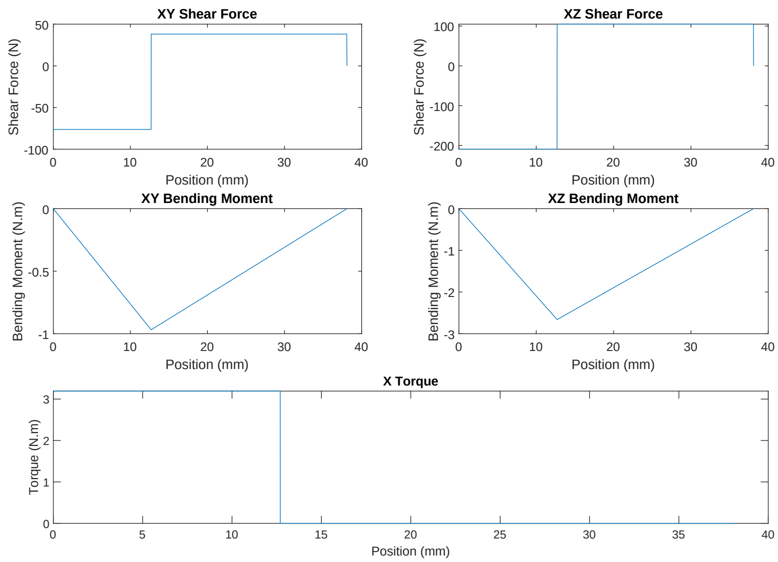
```
TTorqueCalc =

  317table

      Var1       Torque
    ---------    ------

    "Shaft A"    3.1927
    "Shaft B"    13.251
    "Shaft C"        55
```

```
TForceCalc =

  4×3 table

       Var1          Wt        Wr
    __________    ______    ______

    "Pinion 1"    314.25    114.38
    "Gear 1"      298.12    108.51
    "Pinion 2"    1304.3    474.72
    "Gear 2"      1237.3    450.36
```

Shaft A BMD

```
%define Shaft A length and positions, units: meters
LengthA = 1.5*0.0254; %inch -> meter
BearingA2pos = 1.5*0.0254;
BearingA1pos = 0; %bearing supports shaft
Motor1pos = 0; %motor generates torque
Pinion1pos = 0.5*0.0254; %inch -> meter;

pinion = [Wr(1), Wt(1), Pinion1pos, P1, 1];
gear = [0, 0, 0, 0, 0];
moment = [Torque(1), Motor1pos];
bearing = [BearingA1pos, BearingA2pos];

[OUT] = BMDGenerator(pinion, gear, bearing)
FxyA = OUT(1,:);
FxyposA = OUT(2,:);
FxzA = OUT(3,:);
FxzposA = OUT(4,:);

%Shear Force and Bending Moment Diagrams
padding = 0.2
f4 = figure('Renderer', 'painters', 'Position', [10 10 900 600])
hold on
title("Shaft A")
hold off
subplot(3,2,1)
ShearXY = Shear(LengthA, FxyposA, FxyA);
plot(ShearXY(:,1)*1000, ShearXY(:,2))
hold on
```

```
title("XY Shear Force")
xlabel("Position (mm)")
ylabel("Shear Force (N)")
hold off
subplot(3,2,2)
ShearXZ = Shear(LengthA, FxzposA, FxzA);
plot(ShearXZ(:,1)*1000, ShearXZ(:,2))
hold on
title("XZ Shear Force")
xlabel("Position (mm)")
ylabel("Shear Force (N)")
hold off
subplot(3,2,3)
BendingMomentXY = Moment(LengthA, FxyposA, FxyA);
plot(BendingMomentXY(:,1)*1000, BendingMomentXY(:,2))
hold on
title("XY Bending Moment")
xlabel("Position (mm)")
ylabel("Bending Moment (N.m)")
hold off
subplot(3,2,4)
BendingMomentXZ = Moment(LengthA, FxzposA, FxzA);
plot(BendingMomentXZ(:,1)*1000, BendingMomentXZ(:,2))
hold on
title("XZ Bending Moment")
xlabel("Position (mm)")
ylabel("Bending Moment (N.m)")
hold off
subplot(3,2,5:6)
TorqueX = TorquePlotter(LengthA, pinion, gear, moment);
plot(TorqueX(:,1)*1000, TorqueX(:,2))
hold on
title("X Torque")
xlabel("Position (mm)")
ylabel("Torque (N.m)")
hold off
```



Shaft B BMD

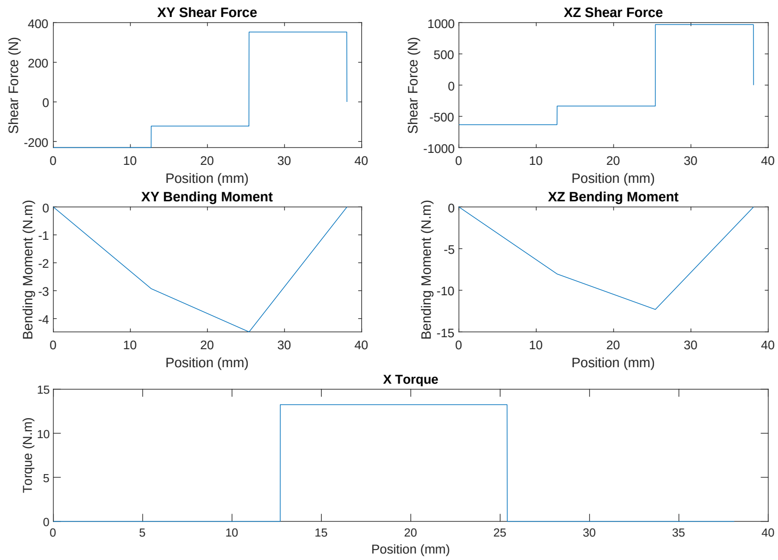
```
%define Shaft B length and positions, units: meters
LengthB = 1.5*0.0254; %inch -> meter
BearingB2pos = 1.5*0.0254;
BearingB1pos = 0; %bearing supports shaft
Gear1pos = 0.5*0.0254; %motor generates torque
Pinion2pos = 1*0.0254; %inch -> meter;

pinion = [Wr(3), Wt(3), Pinion2pos, P2, 1];
gear = [ Wr(2), Wt(2), Gear1pos, N1, 0];
moment = [0, 0];
bearing = [BearingB1pos, BearingB2pos];

[OUT] = BMDGenerator(pinion, gear, bearing)
FxyB = OUT(1,:);
FxyposB = OUT(2,:);
FxzB = OUT(3,:);
FxzposB = OUT(4,:);

%Shear Force and Bending Moment Diagrams
padding = 0.2
f5 = figure('Renderer', 'painters', 'Position', [10 10 900 600])
hold on
title("Shaft B")
hold off
subplot(3,2,1)
```

```
ShearXY = Shear(LengthB, FxyposB, FxyB);
plot(ShearXY(:,1)*1000, ShearXY(:,2))
hold on
title("XY Shear Force")
xlabel("Position (mm)")
ylabel("Shear Force (N)")
hold off
subplot(3,2,2)
ShearXZ = Shear(LengthB, FxzposB, FxzB);
plot(ShearXZ(:,1)*1000, ShearXZ(:,2))
hold on
title("XZ Shear Force")
xlabel("Position (mm)")
ylabel("Shear Force (N)")
hold off
subplot(3,2,3)
BendingMomentXY = Moment(LengthB, FxyposB, FxyB);
plot(BendingMomentXY(:,1)*1000, BendingMomentXY(:,2))
hold on
title("XY Bending Moment")
xlabel("Position (mm)")
ylabel("Bending Moment (N.m)")
hold off
subplot(3,2,4)
BendingMomentXZ = Moment(LengthB, FxzposB, FxzB);
plot(BendingMomentXZ(:,1)*1000, BendingMomentXZ(:,2))
hold on
title("XZ Bending Moment")
xlabel("Position (mm)")
ylabel("Bending Moment (N.m)")
hold off
subplot(3,2,5:6)
TorqueX = TorquePlotter(LengthB, pinion, gear, moment);
plot(TorqueX(:,1)*1000, TorqueX(:,2))
hold on
title("X Torque")
xlabel("Position (mm)")
ylabel("Torque (N.m)")
hold off
```

```
SigmaFxy =

B1xy + B2xy + 2565049596265321/4398046511104 == 0
```

```
SigmaMxy =

(381*B2xy)/10000 + 60509782446090171/4503599627370496 == 0


SigmaFxz =

B1xz + B2xz + 7047415845520165/4398046511104 == 0


SigmaMxz =

(381*B2xz)/10000 + 41562315231686103/1125899906842624 == 0


eqns =

          B1xy + B2xy + 2565049596265321/4398046511104 == 0
 (381*B2xy)/10000 + 60509782446090171/4503599627370496 == 0
          B1xz + B2xz + 7047415845520165/4398046511104 == 0
 (381*B2xz)/10000 + 41562315231686103/1125899906842624 == 0


soln =

  struct with fields:

    B1xy: [1x1 sym]
    B1xz: [1x1 sym]
    B2xy: [1x1 sym]
    B2xz: [1x1 sym]


soln =

 -230.5772
 -633.5057
 -352.6475
 -968.8911


OUT =

   1.0e+03 *

   -0.2306    0.4747    0.1085   -0.3526
```

```
         0    0.0000    0.0000    0.0000
   -0.6335    1.3043    0.2981   -0.9689
         0    0.0000    0.0000    0.0000


padding =

    0.2000


f5 =

  Figure (3) with properties:

      Number: 3
        Name: ''
       Color: [0.9400 0.9400 0.9400]
    Position: [10 10 900 600]
       Units: 'pixels'

  Use GET to show all properties


t =

     0


t =

   13.2514


t =

  -13.2514
```



Shaft C BMD

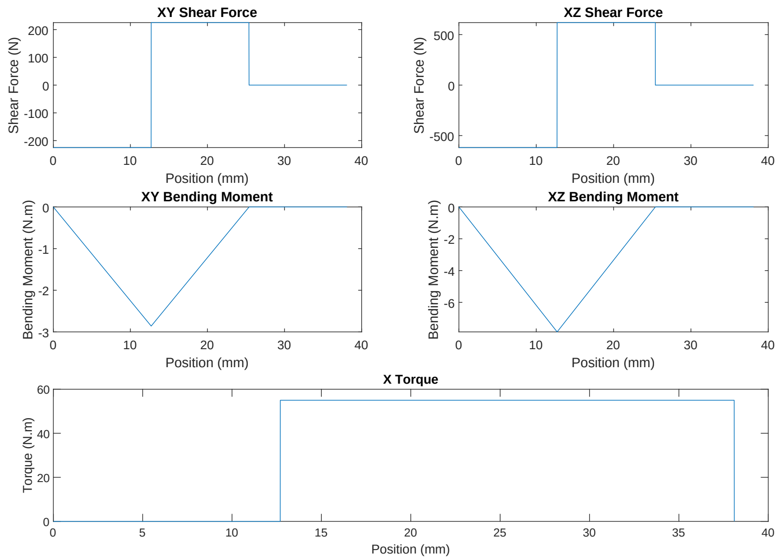
```
%define Shaft B length and positions, units: meters
LengthC = 1.5*0.0254; %inch -> meter
BearingC2pos = 1*0.0254;
BearingC1pos = 0; %bearing supports shaft
Gear2pos = 0.5*0.0254; %motor generates torque
Chuckpos = 1.5*0.0254; %inch -> meter;

pinion = [0,0,0,0,0];
gear = [Wr(4), Wt(4), Gear2pos, N2, 0];
moment = [-1*Torque(3), Chuckpos];
bearing = [BearingC1pos, BearingC2pos];

[OUT] = BMDGenerator(pinion, gear, bearing)
FxyC = OUT(1,:);
FxyposC = OUT(2,:);
FxzC = OUT(3,:);
FxzposC = OUT(4,:);

%Shear Force and Bending Moment Diagrams
padding = 0.2
f6 = figure('Renderer', 'painters', 'Position', [10 10 900 600])
hold on
title("Shaft C")
hold off
subplot(3,2,1)
```

```
ShearXY = Shear(LengthC, FxyposC, FxyC);
plot(ShearXY(:,1)*1000, ShearXY(:,2))
hold on
title("XY Shear Force")
xlabel("Position (mm)")
ylabel("Shear Force (N)")
hold off
subplot(3,2,2)
ShearXZ = Shear(LengthC, FxzposC, FxzC);
plot(ShearXZ(:,1)*1000, ShearXZ(:,2))
hold on
title("XZ Shear Force")
xlabel("Position (mm)")
ylabel("Shear Force (N)")
hold off
subplot(3,2,3)
BendingMomentXY = Moment(LengthC, FxyposC, FxyC);
plot(BendingMomentXY(:,1)*1000, BendingMomentXY(:,2))
hold on
title("XY Bending Moment")
xlabel("Position (mm)")
ylabel("Bending Moment (N.m)")
hold off
subplot(3,2,4)
BendingMomentXZ = Moment(LengthC, FxzposC, FxzC);
plot(BendingMomentXZ(:,1)*1000, BendingMomentXZ(:,2))
hold on
title("XZ Bending Moment")
xlabel("Position (mm)")
ylabel("Bending Moment (N.m)")
hold off
subplot(3,2,5:6)
TorqueX = TorquePlotter(LengthC, pinion, gear, moment);
plot(TorqueX(:,1)*1000, TorqueX(:,2))
hold on
title("X Torque")
xlabel("Position (mm)")
ylabel("Torque (N.m)")
hold off
```

```
SigmaFxy =

B1xy + B2xy + 7922761848621797/17592186044416 == 0
```

```
SigmaMxy =

(127*B2xy)/5000 + 1609905207639949/281474976710656 == 0


SigmaFxz =

B1xz + B2xz + 5441902319701237/4398046511104 == 0


SigmaMxz =

(127*B2xz)/5000 + 110/7 == 0


eqns =

      B1xy + B2xy + 7922761848621797/17592186044416 == 0
 (127*B2xy)/5000 + 1609905207639949/281474976710656 == 0
       B1xz + B2xz + 5441902319701237/4398046511104 == 0
                            (127*B2xz)/5000 + 110/7 == 0


soln =

  struct with fields:

    B1xy: [1x1 sym]
    B1xz: [1x1 sym]
    B2xy: [1x1 sym]
    B2xz: [1x1 sym]


soln =

 -225.1784
 -618.6727
 -225.1784
 -618.6727


OUT =

   1.0e+03 *

   -0.2252         0    0.4504   -0.2252
```

```
         0         0    0.0000    0.0000
   -0.6187         0    1.2373   -0.6187
         0         0    0.0000    0.0000


padding =

    0.2000


f6 =

  Figure (4) with properties:

      Number: 4
        Name: ''
       Color: [0.9400 0.9400 0.9400]
    Position: [10 10 900 600]
       Units: 'pixels'

  Use GET to show all properties


t =

     0


t =

    55


t =

   -55
```



BMD Tables

Endurance Limits

```
%Shaft Daimeters (meters) 1 = A, 2 = B...
Diameters = [5*10^-3; 5*10^-3; 5*10^-3];

%Shaft Material Properties
%Ultimate Tensile Stress (MPa)
UltimateTensile = [800; 800; 800]; %assumed material from CES

%Endurance Limits (MPa)
EA = enduranceLimit(Diameters(1), UltimateTensile(1));
EB = enduranceLimit(Diameters(2), UltimateTensile(2));
EC = enduranceLimit(Diameters(3), UltimateTensile(3));
EnduranceLimit = [EA(1); EB(1); EC(1)];
MarinFactors = [EA; EB; EC];

TEnduranceLimit = table(Diameters, UltimateTensile, EnduranceLimit)
TMarinFactors = array2table([["A";"B";"C"],Diameters, UltimateTensile, MarinFactors], 'Varia
```

```
kb =

    1.0461


kc =
```

```
     1


kb =

    1.0461


kc =

     1


kb =

    1.0461


kc =

     1


TEnduranceLimit =

  317table

    Diameters    UltimateTensile    EnduranceLimit
    _________    _______________    ______________

      0.005            800              261.79
      0.005            800              261.79
      0.005            800              261.79


TMarinFactors =

  317 table

    Shaft    Diameters    UltimateTensile    EnduranceLimit        Ka              Kb
    _____    _________    _______________    ______________    ___________    __________

     "A"      "0.005"          "800"           "261.7855"      "0.7671101"    "1.046115"
     "B"      "0.005"          "800"           "261.7855"      "0.7671101"    "1.046115"
     "C"      "0.005"          "800"           "261.7855"      "0.7671101"    "1.046115"
```

Test

```
%{
L = 61
Fpos = [0 14 34 49 61]
F = [82.24 -80 -110 142.76 -35]
figure()
subplot(2,1,1)
plot(Shear(L, Fpos, F))
subplot(2,1,2)
plot(Moment(L, Fpos, F))
%}

function [OUTPUT] = BMDGenerator(pinion, gear, bearing)

Pxy = pinion(1);
Pxz = pinion(2);
PPos = pinion(3);
P = pinion(4);

Gxy = gear(1);
Gxz = gear(2);
GPos = gear(3);
N = gear(4);

B1Pos = bearing(1);
B2Pos = bearing(2);

DiametralPitchSelected = 20;
%generate system of equations for the shaft
% Variable naming convention: B1xy
% B = Bearing, P = Pinion, G = Gear, M = motor or chuck
% 1 = first bearing from the origin, 2 = second from origin...
% xy, xz, yz = reference plane
% Prad = pinion radius, Grad = gear radius
syms B1xy B1xz B2xy B2xz

Prad = 0.5*0.0254*P/DiametralPitchSelected;
Grad = 0.5*0.0254*N/DiametralPitchSelected;

% xy equations
SigmaFxy = B1xy + B2xy + Pxy + Gxy == 0
SigmaMxy = B1xy*B1Pos + B2xy*B2Pos + Pxy*PPos + Gxy*GPos == 0
```

```
% xz equations
SigmaFxz = B1xz + B2xz + Pxz + Gxz == 0
SigmaMxz = B1xz*B1Pos + B2xz*B2Pos + Pxz*PPos + Gxz*GPos == 0

%Solve system of equations
eqns = [SigmaFxy; SigmaMxy; SigmaFxz; SigmaMxz]
soln = solve(eqns)
soln = structfun(@double,soln)

%define bearing values
B1xy = soln(1);
B1xz = soln(2);
B2xy = soln(3);
B2xz = soln(4);

Fxypos = [B1Pos, PPos, GPos, B2Pos];
Fxzpos = [B1Pos, PPos, GPos, B2Pos];
Fxy = [B1xy, Pxy, Gxy, B2xy];
Fxz = [B1xz, Pxz, Gxz, B2xz];

OUTPUT = [Fxy; Fxypos; Fxz; Fxzpos];
end

%Shear Force Diagram Plotter: Tlength = length of shaft, Fpos = array of force
%positions (3 decimal places or fewer), F = array for force vectors (Transverse Direction On
function V = Shear(Tlength, FPos, F)
    RES = 10^-6; %
    size = ceil(Tlength/RES + 1);
    V = zeros(size, 2); %array which shear is plotted
    k = 0;
    for i = 1:length(FPos)
        k = k+1;
        v = F(k);
        for pos = 0:RES:Tlength
            index = int64((pos/RES)+1);
            V(index, 1) = pos;
            if(pos >= FPos(i))
                V(index, 2) = V(index, 2) + v;
            end
        end
    end
end

%Bending Moment Plotter: Tlength = length of shaft, Fpos = array of force
%positions (3 decimal places or fewer), F = array for force vectors (Transverse Direction On
```

```
function M = Moment(Tlength, FPos, F)
    RES = 10^-6;
    size = ceil(Tlength/RES + 1);
    M = zeros(size, 2);
    k = 0;
    for i = 1:length(FPos)
        k = k+1;
        mx = F(k);
        for pos = 0:RES:Tlength
            index = int64((pos/RES)+1);
            M(index, 1) = pos;
            if(pos >= FPos(i))
                M(index, 2) = M(index, 2) + mx*(pos - FPos(i));
            end
        end
    end
end

%Bending Moment Plotter: Tlength = length of shaft, Fpos = array of force
%positions (3 decimal places or fewer), F = array for force vectors (Transverse Direction Or
function T = TorquePlotter(Tlength, pinion, gear, moment)
    DiametralPitchSelected = 20;
    RES = 10^-6;
    size = ceil(Tlength/RES + 1);
    T = zeros(size, 2);

    Pxz = pinion(2);
    PPos = pinion(3);
    P = pinion(4);
    Prad = 0.5*0.0254*P/DiametralPitchSelected;
    Pdir = pinion(5);
    if Pdir == 1
        Pxz = Pxz*-1;
    end


    Gxz = gear(2);
    GPos = gear(3);
    N = gear(4);
    Grad = 0.5*0.0254*N/DiametralPitchSelected;
    Gdir = gear(5);
    if Gdir == 1
        Gxz = Gxz*-1;
    end

    Myz = moment(1);
```

```
    Mpos = moment(2);

    ActingTorques = [Myz, Mpos; Gxz*Grad, GPos; Pxz*Prad, PPos];
    ActingTorques = sortrows(ActingTorques, 2); %sort by position

    k = 0;
    for i = 1:length(ActingTorques)
        k = k+1;
        t = ActingTorques(k,1)
        for pos = 0:RES:Tlength
            index = int64((pos/RES)+1);
            T(index, 1) = pos;
            if(pos >= ActingTorques(i,2))
                T(index, 2) = T(index, 2) + t;
            end
        end
    end
end

%{
Pd = Diametral Pitch (teeth/inch)
N = Number of Teeth
n = Angular Velocity (rpm)
F = Face Width (inches)
WtM = Tangetntial load (Newtons)
m = gear Ratio
phi = pressure angle (Rad)
duty = number of revs
%}
function [OUTPUT] = enduranceLimit(shaftDiameter, Sut)
    %SI Units

    if Sut <= 1400 %Eq. 6-8
        Se_ = 0.5*Sut;
    else
        Se_ = 700;
    end

    %Ka - surface condition factor
    a = 4.51; %Machined/CD, T6-2
    b = -0.265; %T6-2
    ka = a*Sut^b; %Eq. 6-19

    %Kb - size modification factor
    d = shaftDiameter*10^3; %mm
    if d <= 51 %Eq. 6-20
```

```
        kb = (d/7.62)^-0.107
    else
        kb = 1.51*d^-0.157
    end

    %Kc - load mofification factor
    kc = 1% Eq. 6-26, Bending

    %Kd - temperature modification factor
    Tf = 77; % room temp in degF, 25 degC
    kd = 0.975 + Tf*0.432*10^-3 - Tf^2*0.115*10^-5 + Tf^3*0.104*10^-8 - Tf^4*0.595*10^-12; %

    %Ke - reliability factir
    ke = 0.814; %T6-5, 99% reliability

    %Kf - misc effects modification factor
    kf = 1;

    Se = ka*kb*kc*kd*ke*kf*Se_;

    OUTPUT = [Se, ka, kb, kc, kd, ke, kf];
end


%{
Pd = Diametral Pitch (teeth/inch)
N = Number of Teeth
n = Angular Velocity (rpm)
F = Face Width (inches)
WtM = Tangetntial load (Newtons)
m = gear Ratio
phi = pressure angle (Rad)
duty = number of revs
%}
function [OUTPUT] = stresses(Pd, N, n, F, WtM, m, phi, duty)
    dp = N/Pd;             %Diameter inches
    V = pi*dp*n/12;        %Linear Velocity
    Wt = 0.224809*WtM ;     % Newtons -> lbf


    %Ko - Overload Factor
    Ko = 1.25; %uniform - MODERATE SHOCK

    %Kv - Dynamic Factor
    Qv = 9; %Low end of precision quality gears, Catalog: pg. 48, AGMA class: 9
    B = 0.25*(12 - Qv)^(2/3);
```

```
A = 50 + 56*(1 - B);
Kv = ((A + V^0.5)/A)^B;

%Ks - Size Factor
x = 1.5708/Pd; %Tooth Width, equation from boston
Y = 2*x*Pd/3;
Ks = 1.192*((F*Y^0.5)/Pd)^0.0535;

%Km - Load Distribution Factor
Cmc = 0.8; %Crowned
Cpf = F/(10*dp) - 0.025;
Cpm = 1;
A = 0.0675; %PRECISION, enclosed, Table 14-9
B = 0.0167;
C = -0.926E-4;
Cma = A + B*F + C*F^2;
Ce = 1;
Km = 1 + Cmc*(Cpf*Cpm + Cma*Ce);

%Kb - Rim Thickness Factor
Kb = 1; %Assumption given by professor
%{
if Pd < 20 %Whole Depth Equation from Boston
    ht = 2.157/Pd;
else
    ht = 2.2/Pd + 0.002;
end

tr = %Cannot find equation or values specifying rim thickness

mb = tr/ht;
if mb < 1.2
    Kb = 1.6*log(2.242/mb);
else
    Kb = 1;
end
%}

%J - Bending Strength Geometry Factor Fig. 14-6, Very bad lookup table
%for selected gears
if N == 16
    J = 0.27;
else
    J = 0.41;
end
```

```
%Kt - Temperature Factor
Kt = 1; %Less than 250F

%Kr - Reliability Factor
Kr = 1; %0.99 - Eq. 14-38

%Cp - Elastic Coefficient
Cp = 2300; %Table 14-8 steel-steel

%I - Pitting Resistance Geometry Factor
mn = 1; %Load sharing ratio: 1 for spur gears
I = ((cos(phi)*sin(phi))/(2*mn))*(m/(m+1));

%Cf - surface condition factor
Cf = 1;

%Contact Stress
CS = (Cp*sqrt(Wt*Ko*Kv*Ks*(Km/(dp*F))*(Cf/I))); %Contact stress in psi

%Bending Stress
BS = (Wt*Ko*Kv*Ks*(Pd/F)*((Km*Kb)/J)); %Contact stress in psi

%Factor of Safety

%Table 14-6, Grade 3 steel, carburized and hardened
St = 75000;
Sc = 275000; %psi

if duty > 10^4 %Fig 14-15
    Zn = 2.466*duty^-0.056;
else
    Zn = 1.5;
end

Ch = 1;

if duty > 10^6 %Fig 14-14
    Yn = 1.6831*duty^-0.0323;
else
    Yn = 6.1514*duty^-0.1192;
end

%Contact FOS
CFOS = ((Sc*Zn*Ch)/(Kt*Kr))/CS;

%Bending FOS
```

```
    BFOS = ((St*Yn)/(Kt*Kr))/BS;

    CS = CS*0.00689476; %psi -> MPa
    BS = BS*0.00689476;

    OUTPUT = [Pd, CS, BS, CFOS, BFOS, Ko, Kv, Ks, Km, Kb, Kt, Kr, Cf, J, I];
end
```

```
SigmaFxy =

B1xy + B2xy + 8048519973203097/70368744177664 == 0


SigmaMxy =

(381*B2xy)/10000 + 6541837034219477/4503599627370496 == 0


SigmaFxz =

B1xz + B2xz + 2764140860800629/8796093022208 == 0


SigmaMxz =

(381*B2xz)/10000 + 1760/441 == 0


eqns =

        B1xy + B2xy + 8048519973203097/70368744177664 == 0
 (381*B2xy)/10000 + 6541837034219477/4503599627370496 == 0
         B1xz + B2xz + 2764140860800629/8796093022208 == 0
                          (381*B2xz)/10000 + 1760/441 == 0


soln =

  struct with fields:

    B1xy: [117sym]
    B1xz: [117sym]
    B2xy: [117sym]
    B2xz: [117sym]
```

```
soln =

  -76.2509
 -209.4976
  -38.1254
 -104.7488


OUT =

  -76.2509  114.3763         0  -38.1254
         0    0.0127         0    0.0381
 -209.4976  314.2464         0 -104.7488
         0    0.0127         0    0.0381


padding =

    0.2000


f4 =

  Figure (2) with properties:

      Number: 2
        Name: ''
       Color: [0.9400 0.9400 0.9400]
    Position: [10 10 900 600]
       Units: 'pixels'

  Use GET to show all properties


t =

    3.1927


t =

     0


t =
```

```
-3.1927
```