

# Machine Design Homework 5

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```
[1]: # Notebook Preamble
import matplotlib.pyplot as plt
import sympy as sp

plt.style.use('maroon_ipynb.mplstyle')

def von_mises(sx_, sy_, sz_, txy_, tyz_, tzx_):
    return(1/sp.sqrt(2)*sp.sqrt((sx_ - sy_)**2 + (sy_ - sz_)**2 + (sz_ - sx_)**2 +
    ↪ 6*(txy_**2 + tyz_**2 + tzx_**2))).n()
```

# Contents

<b>1</b>	<b>Problem 8-1</b>	<b>3</b>
1.1	Given . . . . .	3
1.2	Find . . . . .	3
1.3	Solution . . . . .	3
1.3.1	Part A . . . . .	3
1.3.2	Part B . . . . .	4
<b>2</b>	<b>Problem 8-7</b>	<b>6</b>
2.1	Given . . . . .	6
2.2	Find . . . . .	6
2.3	Solution . . . . .	7
2.3.1	Part A . . . . .	7
2.3.2	Part B . . . . .	7
2.3.3	Part C . . . . .	8
2.3.4	Part D . . . . .	8
<b>3</b>	<b>Problem 8-9</b>	<b>10</b>
3.1	Given . . . . .	10
3.2	Find . . . . .	10
3.3	Solution . . . . .	10
<b>4</b>	<b>Problem 8-11</b>	<b>12</b>
4.1	Given . . . . .	12
4.2	Find . . . . .	12
4.3	Solution . . . . .	12
4.3.1	Part A . . . . .	12
4.3.2	Part B . . . . .	12
4.3.3	Part C . . . . .	13
<b>5</b>	<b>Problem 8-19</b>	<b>14</b>
5.1	Given . . . . .	14
5.2	Find . . . . .	14
5.3	Solution . . . . .	14
5.3.1	Part A . . . . .	14
5.3.2	Part B . . . . .	14
5.3.3	Part C . . . . .	14

## 1 Problem 8-1

### 1.1 Given

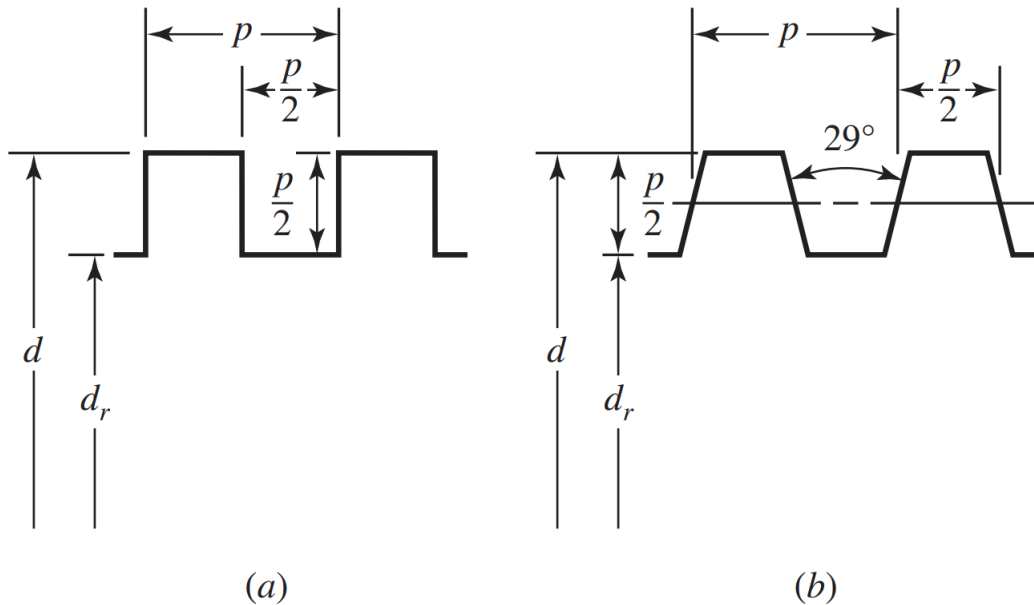
A power screw is 25 mm in diameter and has a thread pitch of 5 mm.

```
[2]: d = sp.S(25)
     p = sp.S(5)
```

### 1.2 Find

- Find the thread depth, the thread width, the mean and root diameters, and the lead, provided square threads are used.
- Repeat part (a) for Acme threads.

### 1.3 Solution



#### 1.3.1 Part A

##### Thread Depth

From (a) in the figure above, the thread depth is half the pitch.

```
[3]: # Thread depth
     thread_depth = (p/2).n()
     thread_depth # mm
```

```
[3]: 2.5
```

### Thread Width

The thread width is the same as the thread depth.

```
[4]: thread_width = thread_depth  
     thread_width # mm
```

```
[4]: 2.5
```

### Mean and Root Diameters

```
[5]: # Root diameter is the same as minor diameter  
     dr = d - 2*thread_depth  
     dr # mm
```

```
[5]: 20.0
```

```
[6]: # Mean diameter  
     dm = (d + dr)/2  
     dm # mm
```

```
[6]: 22.5
```

### Lead

```
[7]: # The lead is the same as the pitch because it's single threaded  
     l = p  
     l # mm
```

```
[7]: 5
```

### 1.3.2 Part B

The same procedure is done in Part B, but now we look at (b) in the above figure.

### Thread Depth and Thread Width

```
[8]: # The thread depth and thread width is still the same  
     thread_depth # mm
```

```
[8]: 2.5
```

```
[9]: thread_width # mm
```

```
[9]: 2.5
```

Because the thread depth is the same, so will the minor and mean diameter. The lead also remains unchanged.

### Mean Diameter, Root Diameter, and Lead

```
[10]: dm # mm
```

```
[10]: 22.5
```

```
[11]: dr # mm
```

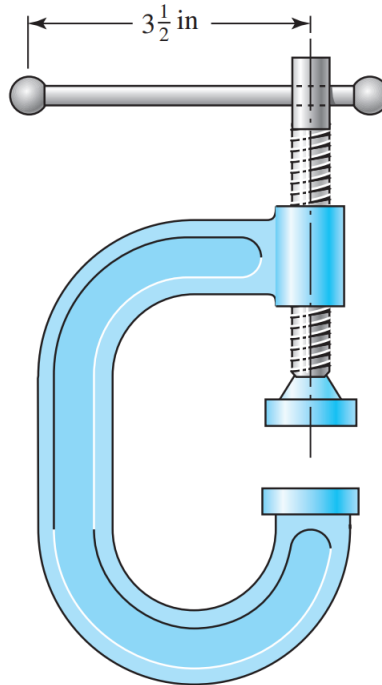
```
[11]: 20.0
```

```
[12]: 1 # mm
```

```
[12]: 5
```

## 2 Problem 8-7

### 2.1 Given



For the C clamp shown, a force is applied at the end of the  $\frac{3}{8}$  in diameter handle. The screw is a  $\frac{3}{4}$  in – 6 Acme thread, and is 10 inches long overall, with a maximum of 8 inches possible in the clamping region. The handle and screw are both made from cold-drawn AISI 1006 steel. The coefficients of friction for the screw and the collar are 0.15. The collar, which in this case is the anvil striker's swivel joint, has a friction diameter of 1 inch. It is desired that the handle will yield before the screw will fail.

```
[13]: # Cold Drawn Steel  
Sy = sp.S(41) # ksi
```

### 2.2 Find

Check this by the following steps:

- Determine the maximum force that can be applied to the end of the handle to reach the point of yielding of the handle.
- Using the force from part (a), determine the clamping force.
- Using the force from part (a), determine the factor of safety for yielding at the interface of the screw body and the base of the first engaged thread, assuming the first thread carries 38% of the total clamping force.
- Determine the factor of safety for buckling of the screw.

## 2.3 Solution

### 2.3.1 Part A

The handle is a cantilever beam.

```
[14]: # Getting the maximum force
F = sp.Symbol('F')
M = (sp.S('3.5') - sp.S('0.375'))*F
d_handle = sp.Rational(3, 8)
I = sp.pi*d_handle**4/64
eq1 = sp.Eq((M*(d_handle/2)/I).nsimplify(), Sy) # Force in kips
eq1
```

```
[14]: 51200F
      27π = 41
```

```
[15]: F_ = (sp.solve(eq1)[0]*1000).n()
      F_ # lbf
```

```
[15]: 67.9246692875762
```

### 2.3.2 Part B

For a  $\frac{3}{4}$  in – 6 thread,

```
[16]: p = 1 = sp.Rational(1, 6).n()
      d = sp.S('0.75')
      dm = d - p/2
      dm # inches
```

```
[16]: 0.6666666666666667
```

Equations 8-5 and 8-6 may be used to compute the force,

$$T_R = \frac{F d_m}{2} \left( \frac{l + \pi f d_m \sec \alpha}{\pi d_m - f l \sec \alpha} \right)$$
$$T_c = \frac{F f_c d_c}{2}$$

```
[17]: fc = sp.S('0.15')
      dc = 1
      alpha = sp.rad(sp.S('14.5')) # see Figure 8-7 (a)
      sec_a = (1/sp.cos(alpha)).n()
      T_ = sp.S('3.5')*F_
      T = F*dm/2*((1 + sp.pi*fc*dm*sec_a)/(sp.pi*dm - fc*l*sec_a)) + F*fc*dc/2
      eq2 = sp.Eq(T, T_)
      eq2
```

```
[17]: 0.075F + \frac{0.333333333333333F(0.166666666666667 + 0.103290031219769\pi)}{-0.0258225078049421 + 0.666666666666667\pi} = 237.736342506517
```

```
[18]: F_clamp = sp.solve(eq2)[0]
      F_clamp # lbf
```

```
[18]: 1542.27366292139
```

### 2.3.3 Part C

Use Eq. 8-8, 8-11, 8-7, and 8-12.

```
[19]: # Finding the axial stress
      dr = d - p
      sig_y = ((-4*F_clamp/(sp.pi*dr**2))/1000).n()
      sig_y # ksi
```

```
[19]: -5.77082590952346
```

```
[20]: # Find the bending stress
      sig_x = ((6*sp.S('0.38')*F_clamp/(sp.pi*dr*1*p))/1000).n()
      sig_x # ksi
```

```
[20]: 11.5127976894993
```

```
[21]: tau_yz = ((16*T_/(sp.pi*dr**3))/1000).n()
      tau_yz # ksi
```

```
[21]: 6.09979591836735
```

```
[22]: tau_zx = ((-4*sp.S('0.38')*T_/(sp.pi*dr**2*1*p))/1000).n()
      tau_zx # ksi
```

```
[22]: -2.02818214285714
```

Now the von mises stress may be calculated.

```
[23]: sig_prime = von_mises(sig_x, sig_y, 0, 0, tau_yz, tau_zx)
      sig_prime # ksi
```

```
[23]: 18.874543508812
```

```
[24]: # Get the factor of safety
      ny = Sy/sig_prime
      ny
```

```
[24]: 2.17223796595972
```

### 2.3.4 Part D

The critical force,  $P_{cr}$ , may be found from Eq. 4-48,

$$\frac{P_{cr}}{A} = S_y - \left( \frac{S_y l}{2\pi k} \right)^2 \frac{1}{CE}$$



$C = 1.2$  from Table 4-2

```
[25]: C = sp.S('1.2')
      E = sp.S(30_000) # ksi (steel)
      k = dr/4
      A = sp.pi/4*dr**2
      P_cr = (A*(Sy - (Sy*8/(2*sp.pi*k))**2*1/(C*E))).n()
      P_cr
```

```
[25]: 10.0061437991992
```

```
[26]: # Factor of safety
      P_cr*1000/F_clamp
```

```
[26]: 6.48791718341702
```

### 3 Problem 8-9

#### 3.1 Given

A 1.5 inch power screw has double square threads with a pitch of  $\frac{1}{4}$  in. The nut is to move at a velocity of 2 in/s and move a load of  $F = 2.2$  kips. The frictional coefficients are 0.1 for the threads and 0.15 for the collar. The frictional diameter of the collar is 2.25 inches.

```
[27]: p = sp.S('0.25') # inches
d = sp.S('1.5') # inches
f, fc = sp.S('0.1'), sp.S('0.15')
V = 2 # in/s
F = sp.S('2200') # lbf
dc = sp.S('2.25') # inches

l = 2*p # lead in inches
dm = d - p/2 # mean diameter in inches
dr = d - p # minor diameter in inches
```

#### 3.2 Find

Find the power required to drive the power screw.

#### 3.3 Solution

Power is  $P = T\omega$  and the torque for square threads when raising a load is (Eq. 8-1),

$$T_R = \frac{F d_m}{2} \left( \frac{l + \pi f d_m}{\pi d_m - f l} \right)$$

The total torque also encompasses Eq. 8-6.

```
[28]: TR = (F*dm/2*(1 + sp.pi*f*dm)/(sp.pi*dm - f*l)).n()
TC = F*fc*dc/2
T = TR + TC
T # in*lbf
```

```
[28]: 701.39179732586
```

The angular velocity may be acquired by using the lead because in 1 revolution, the nut has travelled the distance of the lead.

```
[29]: # getting rev/s
w = V/l
w
```

```
[29]: 4.0
```

```
[30]: # Getting power
      hp = 1/(550*12) # 1 hp = 550*12 in*lb/s
      P = T*w*2*sp.pi*hp
      P.n() # hp
```

```
[30]: 2.67089371850553
```

## 4 Problem 8-11

### 4.1 Given

An M14  $\times$  2 hex-head bolt with a nut is used to clamp together two 15 mm steel plates.

### 4.2 Find

- Determine a suitable length for the bolt, rounded up to the nearest 5 mm.
- Determine the bolt stiffness.
- Determine the stiffness of the members.

### 4.3 Solution

#### 4.3.1 Part A

Bolt dimensions may be found from Table A-31.

```
[31]: l, H = sp.S(15), sp.S('12.8')  
L = 2*l + H  
L
```

```
[31]: 42.8
```

The bolt length must be greater than 42.8 mm to the nearest 5 mm. The final value is  $L = 45$  mm.

#### 4.3.2 Part B

The fastener stiffness along with more relationships come from Table 8-7.

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$$

```
[32]: # Getting stiffness  
d = sp.S(14) # mm  
E = sp.S('207') # Pa  
L = 45 # mm  
  
Ad = sp.pi*d**2/4  
At = sp.S(115)  
Lt = 2*d + 6  
ld = L - Lt  
lt = 2*l - ld  
kb = Ad*At*E/(Ad*lt + At*ld)  
kb.n() # MN/m
```

```
[32]: 874.618152674828
```

### 4.3.3 Part C

```
[33]: # Eq. 8-22
      x = sp.S('0.5774')
      km = (x*sp.pi*d)/(2*sp.log(5*(x**2 + sp.S('0.5')*d)/(x**2 + sp.S('2.5')*d)))
      km.n() # MN/m
```

```
[33]: 3116.45077847628
```

## 5 Problem 8-19

### 5.1 Given

A 30 mm thick AISI 1020 steel plate is sandwiched between two 10 mm thick 2024-T3 aluminum plates and compressed with a bolt and nut with no washers. The bolt is an  $M10 \times 1.5$ , property class 5.8.

### 5.2 Find

- Determine a suitable length for the bolt, rounded up to the nearest 5 mm.
- Determine the bolt stiffness.
- Determine the stiffness of the members.

### 5.3 Solution

#### 5.3.1 Part A

Use a similar procedure from 8-11.

```
[34]: l, H = sp.S(50), sp.S('8.4')
      L_min = l + H
      L_min # mm
```

```
[34]: 58.4
```

Rounding up to the nearest 5 mm, the length of the bolt is  $L = 60 \text{ mm}$ .

#### 5.3.2 Part B

```
[35]: # From Table 8-7
      L = sp.S(60)
      d = sp.S(10)
      E = sp.S(207)

      LT = 2*d + 6
      ld = L - LT
      lt = l - ld
      Ad = sp.pi*d**2/4
      At = 58
      kb = Ad*At*E/(Ad*lt + At*ld)
      kb.n() # MN/m
```

```
[35]: 292.057923214078
```

#### 5.3.3 Part C

Use Eq. 8-20 and then acquire the equivalent stiffness.

```
[36]: def get_k(E_, d_, t_, D_):
        return ((sp.S('0.5774')*sp.pi*E_*d_)/sp.log(((sp.S('1.155')*t_ + D_ -
        ↪ d_)*(D_ + d_))/((sp.S('1.155')*t_ + D_ + d_)*(D_ - d_))))).n()

        # The upper and lower plates have the same stiffness
        k1 = get_k(71, 10, 10, 15)
        k1 # MN/m
```

[36]: 1576.11182584228

```
[37]: # splitting the top half
        D2 = 15 + 20*sp.tan(30*sp.pi/180)
        k2 = get_k(207, 10, 15, D2)
        k2 # MN/m
```

[37]: 11434.8600387284

```
[38]: k_half = 1/(1/k1 + 1/k2)
        k_half
```

[38]: 1385.18615838124

```
[39]: k_total = (1/k_half + 1/k_half)**-1
        k_total # MN/m
```

[39]: 692.593079190621