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

1 Problem 8-1

1.1 Given

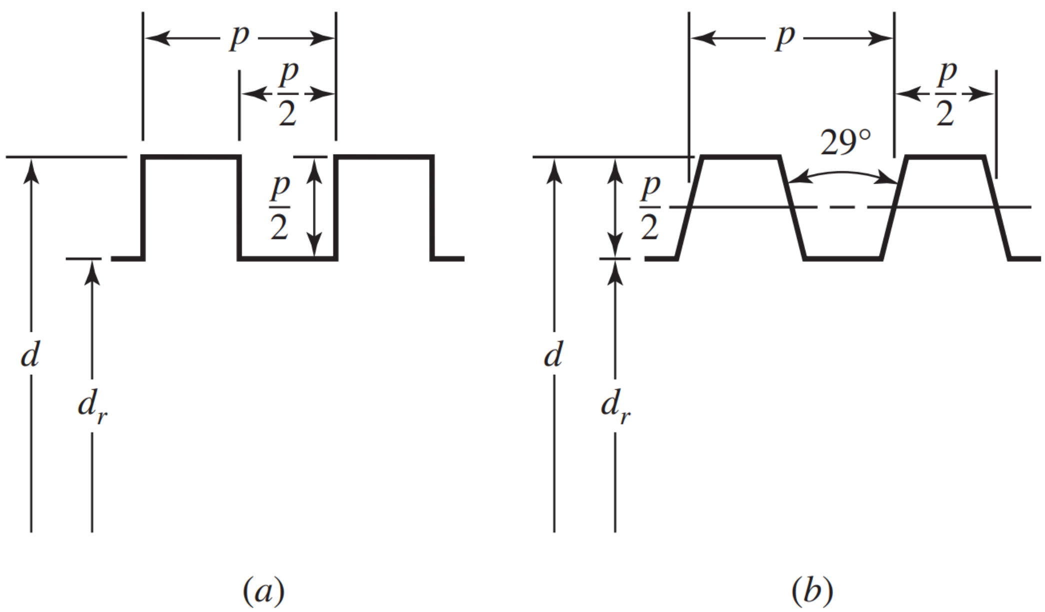
A power screw is 25 mm in diameter and has a thread pitch of 5 mm.

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

1.2 Find

a. Find the thread depth, the thread width, the mean and root diameters, and the lead, provided square threads are used.
b. 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]:
```python
thread_width = thread_depth
thread_width  # mm
```

[4]: 2.5

Mean and Root Diameters

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

[5]: 20.0

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

[6]: 22.5

Lead

[7]:
```python
# 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]:
```python
# The thread depth and thread width is still the same
thread_depth  # mm
```

[8]: 2.5

[9]:
```python
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]:
```python
dm  # mm
```

[10]: 22.5

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

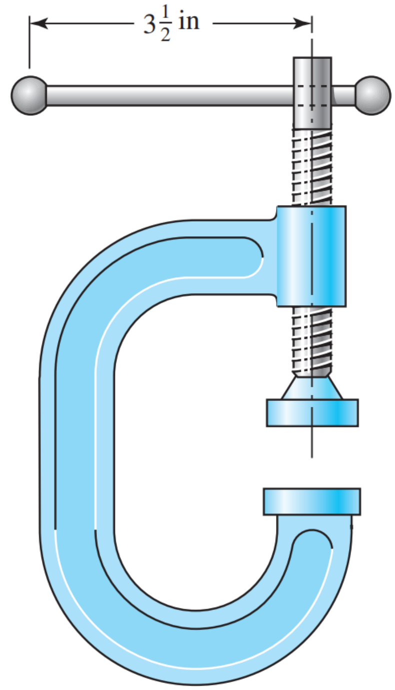
[11]: 20.0

[12]:
```
l  # 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:

a. Determine the maximum force that can be applied to the end of the handle to reach the point of yielding of the handle.
b. Using the force from part (a), determine the clamping force.
c. 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.
d. 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]:

$$\frac{51200F}{27\pi} = 41$$

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

[16]:

0.666666666666667

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

$$T_R = \frac{Fd_m}{2}\left(\frac{l + \pi f d_m \sec\alpha}{\pi d_m - fl\sec\alpha}\right)$$

$$T_c = \frac{Ff_c d_c}{2}$$

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

[21]: 6.09979591836735

[22]:
```python
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]:
```python
sig_prime = von_mises(sig_x, sig_y, 0, 0, tau_yz, tau_zx)
sig_prime  # ksi
```

[23]: 18.874543508812

[24]:
```python
# 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,

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

$C = 1.2$ 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),

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

The total torque also encompasses Eq. 8-6.

[28]:
```
TR = (F*dm/2*(l + 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*lbf/s
P = T*w*2*sp.pi*hp
P.n()  # hp
```

[30]: 2.67089371850553

4 Problem 8-11

4.1 Given

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

4.2 Find

a. Determine a suitable length for the bolt, rounded up to the nearest 5 mm.
b. Determine the bolt stiffness.
c. 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*E*d)/(2*sp.log(5*(x*2*l + sp.S('0.5')*d)/(x*2*l + 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 place 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

a. Determine a suitable length for the bolt, rounded up to the nearest 5 mm.
b. Determine the bolt stiffness.
c. 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 $L = 60\,mm$.

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]:
```python
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]:
```python
# 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]:
```python
k_half = 1/(1/k1 + 1/k2)
k_half
```

[38]:

1385.18615838124

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

[39]:

692.593079190621

6 Problem 8-29

6.1 Given

For a bolted assembly with 6 bolts, the stiffness of each bolt is $k_b = 3\, M\, lbf/in$ and the stiffness of the members is $k_m = 12\, M\, lbf/in$ per bolt. An external load of 80 $kips$ is applied to the entire joint. Assume the load is equally distributed to all the bolts. It has been determined to use $\frac{1}{2} in - 13$ UNC grade 8 bolts with rolled threads. Assume the bolts are preloaded to 75 percent of the proof load.

6.2 Find

a. Determine the yielding factor of safety.
b. Determine the overload factor of safety.
c. Determine the factor of safety based on joint separation.

6.3 Solution

6.3.1 Part A

The yielding factor of safety is,

$$n_p = \frac{S_p A_t}{CP + F_i}$$

[40]:
```
kb = sp.S(3_000)  # kips per in
km = sp.S(12_000)  # kips per in
P_total = sp.S(80)  # kips

Sp = 120  # ksi from Table 8-9
At = sp.S('0.1419') # in from Table 8-2
C = kb/(kb + km)  # p. 448
P = P_total/6
Fi = sp.S('0.75')*At*Sp  # Eq. 8-31 and 8-32

np = Sp*At/(C*P + Fi)
np
```

[40]: 1.10301643167145

6.3.2 Part B

[41]:
```
# Eq. 8-29
nL = (Sp*At - Fi)/(C*P)
nL
```

[41]: 1.596375

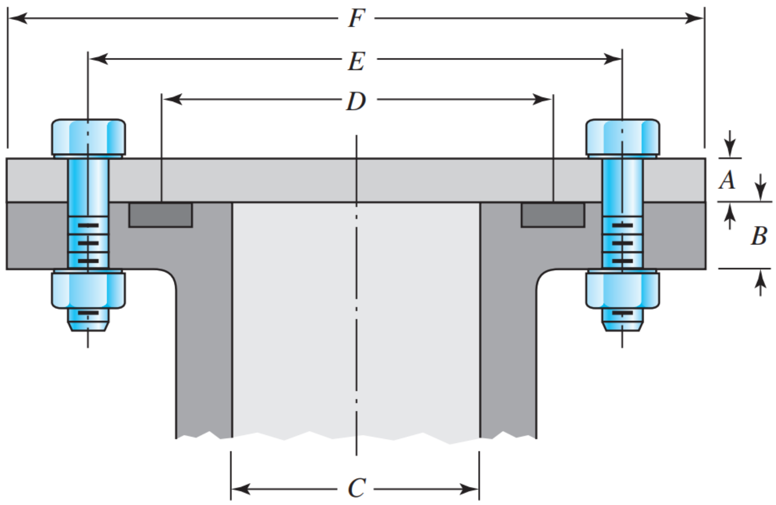
6.3.3 Part C

[42]:
```
# Eq. 8-30
n0 = Fi/(P*(1 - C))
n0
```

[42]: 1.19728125

7 Problem 8-34

7.1 Given



The figure illustrates the non-permanent connection of a steel cylinder head to a grade 30 cast-iron pressure vessel using N bolts. A confined gasket seal has an effective sealing diameter D. The cylinder stores has at a maximum pressure p_g.

$A = \frac{1}{2}\,in$, $B = \frac{5}{8}\,in$, $C = 2.75\,in$, $D = 3.5\,in$, $E = 6\,in$, $F = 8\,in$, $N = 10$, $p_g = 1500\,psi$

[43]:
```
A, B, C, D, E, F = [sp.S(i) for i in ('0.5', '0.625', '2.75', '3.5', 6, 8)]
N = sp.S(10)
pg = sp.S('1.5')  # ksi
```

The bolt grade is SAE 5 and the specification is $\frac{1}{2}\,in - 13$.

7.2 Find

a. Select a suitable bolt length, assuming the bolts are available in $\frac{1}{4}\,in$ increments.
b. Determine the yielding factor of safety n_p.
c. Determine the load factor n_L.
d. Determine the separation factor n_0.

7.3 Solution

7.3.1 Part A

[44]:
```
l = A + B
H = sp.Rational(7, 16).n()
L_min = l + H
L_min  # in
```

[44]:

1.5625

The next $\frac{1}{4}\,in$ increment is $L = 1.75\,in$.

7.3.2 Part B

Start off by finding the bolt and member stiffness.

[45]:
```
# From Table 8-7
L = sp.S('1.75')
d = sp.S('0.5')
E_mod = sp.S(30_000)  # ksi

LT = 2*d + sp.S('0.25')
ld = L - LT
lt = l - ld
Ad = sp.pi*d**2/4
At = sp.S('0.1419')
kb = Ad*At*E_mod/(Ad*lt + At*ld)
kb.n()  # kips/in
```

[45]:

4315.9324048675

For the member stiffness,

[46]:
```
# There are no washers
# D comes from the diameter of the hex head, which is usually around 1.5*d
k_steel = get_k(E_mod, d, A, sp.S('0.75'))
k_steel  # kips/in
```

[46]:

33298.1371656819

The cast iron has two frustums because the plates have different thicknesses.

[47]:
```
k_cast1 = get_k(sp.S('14_500'), d, l/2 - A, 1.5*d + 2*A*sp.tan(sp.rad(30)))
k_cast1  # kips/in
```

[47]:

292838.671366163

[48]:
```
k_cast2 = get_k(sp.S('14_500'), d, l/2, 1.5*d)
k_cast2  # kips/in
```

[48]:

15255.8665193505

[49]:
```
# Now we can grab km
km = (1/k_steel + 1/k_cast1 + 1/k_cast2)**-1
km  # kips/in
```

[49]:

10101.5086260364

The load that the bolts experience is based on the area of the seal.

$$P_{total} = p_g \cdot \frac{\pi}{4} D^2$$

[50]:
```
P_total = (pg*sp.pi/4*D**2).n()
P_total  # kips
```

[50]: 14.4316912524281

Now the factor of safety for yielding may be found using the same process as before.

[51]:
```
Sp = 85  # ksi from Table 8-9
At = sp.S('0.1419') # in from Table 8-2
C_val = kb/(kb + km)  # p. 448
P = P_total/N
Fi = sp.S('0.75')*At*Sp  # Eq. 8-31 and 8-32

np = Sp*At/(C_val*P + Fi)
np.n()
```

[51]: 1.27255915782795

7.3.3 Part C

[52]:
```
# Eq. 8-29
nL = (Sp*At - Fi)/(C_val*P)
nL.n()
```

[52]: 6.97971436741409

7.3.4 Part D

[53]:
```
# Eq. 8-30
n0 = Fi/(P*(1 - C_val))
n0.n()
```

[53]: 8.94637915887079