Contents

Detailed Calculation Worksheet

Mechanical Design Project | Power Gears

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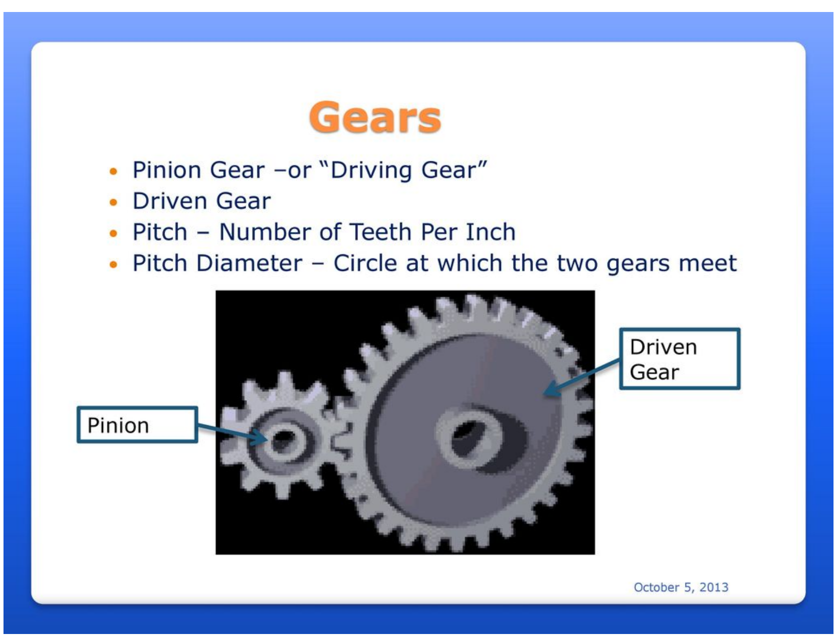
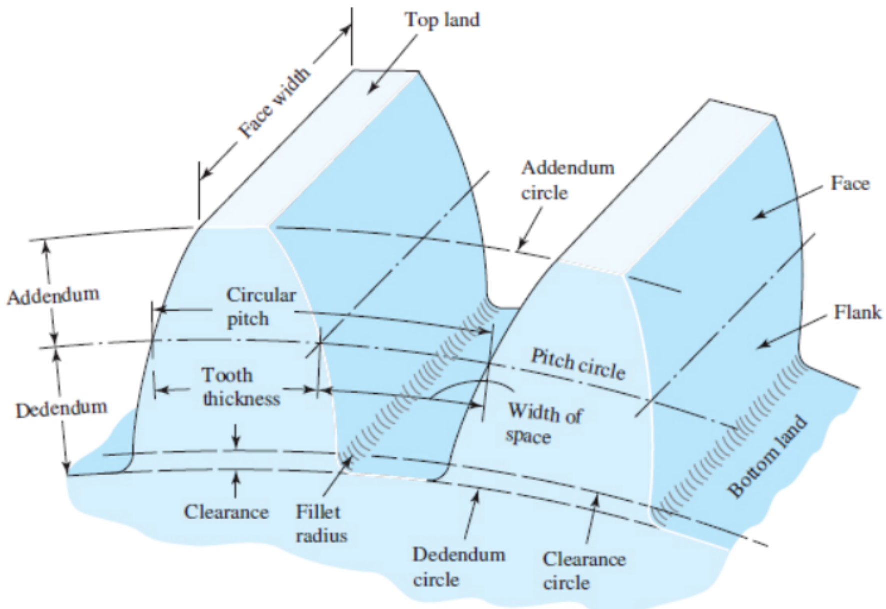
```
clc; clear; format SHORTENG
```





Circular pitch p is the distance, measured on the pitch circle, from a point on one tooth to a corresponding point on an adjacent tooth. Thus the circular pitch is equal to the sum of the *tooth thickness* and the *width of space*.

Module m is the ratio of the pitch diameter to the number of teeth. The customary unit of length used is the millimeter. The module is the index of tooth size in SI.

Diametral pitch P is the ratio of the number of teeth on the gear to the pitch. diameter. Thus, it is the reciprocal of the module. Since diametral pitch is used only with U.S. units, it is expressed as teeth per inch.

Addendum a is the radial distance between the *top land* and the pitch circle.

Dedendum b is the radial distance from the *bottom land* to the pitch circle.

Whole depth h_t is the sum of the addendum and the dedendum.

Clearance circle is a circle that is tangent to the addendum circle of the mating gear.

Clearance c is the amount by which the dedendum in a given gear exceeds the addendum of its mating gear.

Backlash is the amount by which the width of a tooth space exceeds the thickness of the engaging tooth measured on the pitch circles.

You should prove for yourself the validity of the following useful relations:

Wanted Values

```
goal_ratio = 20; % 20:1 is the wanted ratio
```

Given Values

```
% Gear Specifications
k = 1; % normal tooth length
phi = 20; % press. angle
phi = phi/180*pi;
m = sqrt(20); % gear ratio
% P = [12 16 18]' % unsilence if you want to compare P's
P = 16; % diametral pitch
Face_width = [0.37464]'; % width of the gearface
n = 1.5; % safety factor

% Power and rates
```

```
Power_in_W = 250; % [W] the power transmitted into gear train
Power_in_hp = Power_in_W/745.69987158227; % [hp] the power transmitted into gear train
H = Power_in_hp;
rpm_in = 2000; % [rpm] the input rpm
omega_in = rpm_in*2*pi/60; % [rad/s] the input angular velocity

% Gear Material Specs
Gear_material = 'S45C Steel';
S_y = 71100; % [psi] tensile yield strength
S_ut = 99600; % [psi] tensile ultimate strength
E = 29700; % [ksi] Modulus of Elasticity
```

Pinion

Number Pinion Gear Teeth

The smallest number of teeth on a spur gear is N_p , the teeth count of the pinion gear, and is defined by this equation (13-11)

$$N_p = \frac{2k}{(1+2m)\sin^2\phi}(m + \sqrt{(m)^2 + (1+2m)\sin^2\phi})$$

where k is equal to 1 because we are using a spur gear and m is the modulus, P is the diametral pitch and ϕ is the diametral pitch (from section 13-3 textbook).

```
N_p = ceil(2*k./( (1+2*m) .* (sin(phi)^2) ) .* (m + sqrt((m).^2 ...
    + (1+2*m).*(sin(phi)^2)))); % pinion teeth gear min number
fprintf('the minimum number teeth on pinion N_p: %.0f\n',N_p)
```

```
the minimum number teeth on pinion N_p: 16
```

The pitch diameter of the pinion can be found using equation (13-1)

$P = \frac{N}{d}$ | $N/P = d$

Pinion Gear Dimensioning

```
N_p; % found earlier
d_p = N_p./P; % pitch diameter of pinion
p_c_p = pi*d_p./N_p; % circular pitch of pinion

adendum_p = 1./P;
adendum_d_p= d_p + 2*adendum_p; % diameter of adendum circle (max diameter)
dedendum_p = 1.35./P;
dedendum_d_p = d_p - 2*dedendum_p; % diameter of dedendum circle
```

Pinion Table Summary

```
pinion_summary = table(P,d_p,N_p,adendum_p,adendum_d_p,dedendum_p,dedendum_d_p)
```

pinion_summary = 1×7 table

	P	d_p	N_p	adendum_p	adendum_d_p	...
1	16.0000e+000	1.0000e+000	16.0000e+000	62.5000e-003	1.1250e+000	

Gear

```
N_g = [floor(N_p*m) ceil(N_p*m)]; % low to high Gear teeth number
N_g = N_g(2); % choose 72 teeth on gear
d_g = N_g(1,1)./P; % pitch diameter (p_c)
% d_g = [N_g(1,1)./P, N_g(1,2)./P]; % pitch diameter (p_c)\ -- unsilence if
% multiple P's
p_c_g = pi*d_g./N_g; % circular pitch of gear

adendum_g = 1./P;
adendum_d_g= d_g + 2*adendum_g; % diameter of adendum circle (max diameter)
dedendum_g = 1.35./P;
dedendum_d_g = d_g - 2*dedendum_g; % diameter of dedendum circle
```

Gear Table Summary

```
 % d_g=d_g(2); N_g=N_g(2);
gearmesh_ratio=gearmesh_ratio(2);output_ratio=output_ratio(2);dedendum=dedendum;
 gear_summary = table(P,d_g,N_g,adendum_g,adendum_d_g,dedendum_g,dedendum_d_g)
```

gear_summary = 1×7 table

	P	d_g	N_g	adendum_g	adendum_d_g	...
1	16.0000e+000	4.5000e+000	72.0000e+000	62.5000e-003	4.6250e+000	

Gear Mesh Ratio

```
gearmesh_ratio = N_g./N_p; % mesh ratio
output_ratio = gearmesh_ratio.^2; % output ratio
percent_offset = 100*(abs(output_ratio-goal_ratio)/goal_ratio);
```

Gear Mesh Ratio Summary

```
format shortg
ratio_summary = table(m,gearmesh_ratio,output_ratio,percent_offset)
```

ratio_summary = 1×4 table

	m	gearmesh_ratio	output_ratio	percent_offset
1	4.4721	4.5	20.25	1.25

Force Analysis

To calculate W_t, which is the tangential force, use this equation and V is caluculated using equation 13-34 from shigley

$$W_t = 33\,000\frac{H}{V} \qquad (13\text{-}35)$$

where W_t = transmitted load, lbf
H = power, hp
V = pitch-line velocity, ft/min

The radial force force can be calculated using this equation

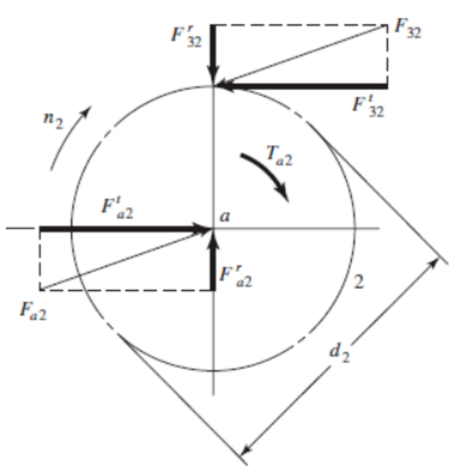
$$F_{23} = \frac{F_{23}^t}{\cos 20°}$$

where $F_{23}^t = W_t$, 20° is the pressure angle and F_{23}^r is the radial force and the pressure line force can be calculated using this equation

$$F_{23}^r = F_{23}^t \tan 20°$$

```
format SHORTENG
rpms = [rpm_in, rpm_in/gearmesh_ratio]; % the gear ratio decreases
V = pi.*d_p.*rpms/12; % [ft/min] pitch-line velocity
W_t = 33000*(H./V); % [lbf] transmitted load
F_t = W_t; % [lbf]
F_pres = F_t./cos(phi); % [lbf] pressure line force
F_r = F_t*tan(phi); % [lbf] radial force line
```

Shaft Reaction Forces



$$F_{b3}^x = -(F_{23}^t + F_{43}^r)$$
$$F_{b3}^y = -(F_{23}^r + F_{43}^t)$$

and then the resultant force on the shaft can be found. The direction of the x force on gear mesh changes

```
F_x = -(-F_t+F_r).*[1 -1] % [lbf]
```

```
F_x = 1×2
   13.4391   -60.4757
```

```
F_y = -(F_r-F_t) % [lbf]
```

```
F_y = 1×2
   13.4391    60.4757
```

```
F_react = sqrt(F_x.^2+F_y.^2);
```

Curve Fit Parameters

Furface Finish Factor k_a

Table 6-2 for equation 6-18

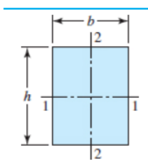
$$k_a = aS_{ut}^b \tag{6-18}$$

```
a = 2;
b = -0.217;
k_a = a*(S_ut/1000).^b
```

```
k_a =
   736.8986e-003
```

Size Factor k_b

Find the equilvalent diameter from table 6-3, d_e can be found and then the k_b can be found using equation 6-19 from Shigley. For diameters less than 0.3, it is reccomended to use a k_b = 1.



$$A_{0.95\sigma} = 0.05hb$$
$$d_e = 0.808\sqrt{hb}$$

$$k_b = \begin{cases} (d/0.3)^{-0.107} = 0.879d^{-0.107} & 0.3 \le d \le 2 \text{ in} \\ 0.91d^{-0.157} & 2 < d \le 10 \text{ in} \\ (d/7.62)^{-0.107} = 1.24d^{-0.107} & 7.62 \le d \le 51 \text{ mm} \\ 1.51d^{-0.157} & 51 < d \le 254 \text{ mm} \end{cases}$$

```
h = (adendum_p+dedendum_p).*2; % the height of tooth × 2
b = Face_width;
d_e = 0.808*sqrt(h.*b)
```

```
d_e =
   268.0448e-003
```

```
k_b = 0.879*d_e.^(-0.107)
```

```
k_b =
```

```
    1.0120e+000
```

```
% k_b = [1 1 1 1 1 1 1 k_b(end)]' % ignore values more than 1
```

Loading Factor k_c

$$k_c = \begin{cases} 1 & \text{bending} \\ 0.85 & \text{axial} \\ 0.59 & \text{torsion} \end{cases} \qquad (6\text{-}25)$$

Assume bending for gear teeth

```
k_c = 1
```

```
k_c = 1
    1.0000e+000
```

Temperature Factor k_d

$$S_T/S_{RT} = 0.98 + 3.5(10^{-4})T_F - 6.3(10^{-7})T_F^2 \qquad (6\text{-}26)$$

```
T_F = 130; % degrees Fahrenheit
S_temp_ratio = 0.98+3.5*(10^-4)*T_F-6.3e-7*T_F^2
```

```
S_temp_ratio =
    1.0149e+000
```

```
k_d = 1.00 % temp factor found to be negligible
```

```
k_d =
    1.0000e+000
```

Reliability factor

Assume a 95% reliability factor. From table 6-4

```
k_e = 0.868
```

```
k_e =
  868.0000e-003
```

Stress Analysis

Measured values for later use

```
tooth_width = 0.10202; % tooth width
```

$$\sigma = \frac{M}{I/c} = \frac{6W^t l}{Ft^2}$$

from section 14-1 applying Lewis Equations

```
% sigma = 6*W_t*
Y = 0.296; % Lewis number
S_e_prime = 0.5*S_ut % Endurance limit from equation 6-10 from Shigley
```

```
S_e_prime =
   49.8000e+003
```

```
format shortG
S_e = k_a.*k_b.*k_c.*k_d.*k_e.*S_e_prime
```

```
S_e =
       32235
```

```
% S_e = k_b.*k_c.*k_d.*k_e.*S_e_prime % yield stress with safety factors applied

F = 6  .*W_t(2)  .*(adendum_p+dedendum_p)   ./(S_e.*tooth_width^2) % face width
```

```
F =
     0.24975
```

```
F*n
```

```
ans =
     0.37462
```

```
n_s = S_y./S_e % factor of safety on yield stress
```

```
n_s =
      2.2057
```

Meeting Record

Power Gears | Meeting 1 04/07/22 | 10:40-11:20am for 40 min.

Present: Qier A, Pavel N, Ryan S, Tayber M

Proposed worm gear reduction but was denied because gear output needs to be parallel. We are currently deciding on gear reduction which will be done with 4 gears with 4:1 and 5:1 for a total reduction of 20:1.

It was proposed we would print the gear and shaft combined but if you print it together the mass production of it would be done the same way. The assembly which we are creating is a prototype for mass production so we must take into account the manufacturing process.

We decided that our team name would be Power Gears.

Last edited: 04/7/22 11:40:17 AM

Power Gears | Meeting 2 04/14/22 | 10:30-12:08pm for 98 min.

Present: Pavel N, Tayber M

Ryan and Archer are not present as they do not feel well.

Beginning our design, we first began to examine our constraints of the project, aka the box of the project. We first began our design on paper to allow us to throw a few ideas around for the project.

We decided to make everything imperial. The gears which we are going to use will be imperial and thus will be chosen on diametral pitch. We have not decided on the diametral pitch yet.

We asked the professor if we could have the box bigger than 5” cubed. The box assembly can be bigger than 5” cubed but the parts of the assembled (or whole part) must be smaller than 5” cubed.

The housing can be smaller for easier use of it and will work as another selling point. The wanted gear reduction is 20:1 and we began to look at gear options for us. The gear reduction can be exactly 20:1 or close to it within a few percentage points. We need to look at gear diameters.

We will use spur gears (regular gears) with a defined diametral pitch P. The gears intersect at the pitch circle (see Figure 13-8) the addendum circle will have a max diameter of 5”.

We are going to use full-depth teeth thus the k=1 (from page 13 of lecture slide).

We will probably choose the max pitch diameter to be around 4” since that is not the max diameter.

We might use metric gears. We might need to look for better places for better selections of imperial (US customary standard) and metric gears. McMastr-Carr has a small selection but we need to explore it more.

Last edited: 04/14/22 12:09:09 PM

Power Gears | Meeting with professor 04/14/22 | 12:08-12:36 for 27 min.

Present: Pavel N, Tayber M

Asked how we are going to model the teeth. Does Solidworks have teeth profiles to choose from. Should the gear teeth follow an involute or should they be square? There is a method to draw involute teeth profile.

Teeth number and size is related by module and diameter pitch. There is not one method in finding the correct pair of gear teeth. You will have to test. The pairing.

Large P, hard to manufacture, tolerance is close, fine teeth engagement is more smooth while a less number of teeth is easier to manufacture but is less smooth in operation.

For reliability, it seems like there is negligible difference between fine teeth and coarse teeth.

Pavel came up with an idea to have a 4-gear assembly where 2 are the same (around 4.47 ratio at contact points of gear pairs) which will have to be approximated. The benefit of having two same gears is decreased manufacturing cost.

Will have to find bearings for the shafts. If we want to find the bearings in the wall of the housing? You can measure the bearing, and then make a half wall, you can use a little friend such as a screw, you can use a brace with screws to tighten the brace down.

We have to make the box open for demonstration purposes.

Last edited: 04/14/22 12:36:50 PM

Power Gears | Meeting 3 4/28/2022 | 10:21-12:00 for 99 min.

Present: Pavel N, Tayber M, Ryan S

Pavel has started the assembly box in solidworks. I am starting to make a live script. We need the gear ratios to be around sqrt(20) = 4.47. We found all of the gear meshing specifics and output ratio. We still need to find the specifics for the method of assembly the gear dimensions to a body housing.

We need to specify more gear dimensions such as the width and the hole cut-out for the shaft. I/we made a matlab script to find the gear specifications for meshing specifics, gear anatomy, teeth count and ratios of the gears accomplished. We decided to settle for an output ratio of 20.25:1 the diametral pitch.

Last edited: 05/5/22 10:41:30 PM

Power Gears | Meeting 5 4/28/2022 | 10:03 for approx 120 min.

Present: Pavel N, Ryan S, Tayber M

Pavel is working on the design of the box assembly with the accompaniment with . Ryan is working on the pinion and gear profile on SolidWorks using this website to make it up to conventional standards. Tayber is working on the torque and force analysis. Pavel is working on shaft/casing design.
Noted that we need to use plastic bearings.

Lower the assembled shaft into the bottom part of the gearbox and then clamp everything together. Use maybe 3 screws to hold everything in place. Yet to decide how the gears and bearing are going to be held in place. Is there a type of bearing that combines the benefits of conventional and thrush bearings.

Since we are loading the shafts from the top, the bearings can be cradled in.

Last edited: 06/2/22 12:26:30 AM

Power Gears | Meeting 4 5/12/2022 | 10:15-1:23pm for 193 min.

Present: Pavel N, Ryan S, Tayber M, Archer A

Bearing research is being done by Pavel and Archer. Pavel is making the body of the assembly. Ryan and Tayber are doing the force analysis of the forces and finding gear width. We found that we need to have a gear face width to be ⅜ inches. We still need to make sure the axles are not too small and to find the correct bearing size to the axles.

Last edited: 5/12/22 2:42:30 PM

Power Gears | Meating 5/19/2022 | 10:15-5:45pm for 450 min.

Present: Pavel N, Ryan S, Tayber M

We made solidworks model of every part and began printing one batch of prints. We decided on using a ½-inch axle and using a bearing with a ½-inch inner diameter and a 1-⅛ inch outer diameter. We made the axles/shafts and the body. We made a handle/crank which will be used to move the gear assembly. The issues that need to be addressed is the presently printing shaft is not sized correctly (an updated part file is on the google drive) and the handle being too small in the square hole.

Last edited: 5/12/22 2:42:30 PM

Power Gears | Meeting 5/26/2022 | 10:40-12:40pm for 120 min.

Present: Pavel N, Ryan S, Tayber M, Archer A

We put together the gearbox with our received bearings. We found that our gearbox had some spacing issues between the gears and the body. Also, we found the axle to be too short, so we are extending the axle length. To solve this issue, we are reprinting axle b and also printing some washers.

Last edited: 5/26/22 12:38:30 PM

Drawings, part and presentation file links and specifications

Presentation given 6/2/2022:

https://docs.google.com/presentation/d/1sGpd5PyKU9zEq_U2a3y-62qa9WhFopPq/edit?usp=sharing&ouid=103468396526148159177&rtpof=true&sd=true

Compiled pdfs of drawings:

https://drive.google.com/file/d/1KybdnGVEauxgqbxx6jo5IQX3rdu1R0VN/view?usp=sharing

Part and drawing files:

https://drive.google.com/drive/folders/1LRuiffJAPAQG9Zm4W9B8j2Z6BGo57Ap4?usp=sharing

Bearing Specifications from Amazon.com:

In our assembly, we used 6 - Mlxkell R8-2RS Ball Bearings (1/2" x1-1/8" x5/16") sourced from Amazon.
https://www.amazon.com/Mlxkell-Bearings-Bearing-Miniature-Household-appliances/dp/B092VRBDZX/ref=pd_di_sccai_cn_sccl_2_1/132-8966007-2756911?pd_rd_w=nbLiR&pf_rd_p=1ed8df3a-0df8-4988-98b9-252e4c99c568&pf_rd_r=TW02TZ5DSHH8JXTAY4TJ&pd_rd_r=2c294ce7-41d3-47c2-b4da-e51715aa71ee&pd_rd_wg=wT7aw&pd_rd_i=B092VRBDZX&psc=1

Specifications for this item

Bearing Type	Ball Bearing
Brand Name	Mlxkell
Compatible Lubricant Type	Grease
Ean	0760385793743
Material	Carbon Steel , Alloy Steel
Measurement System	Inch
Number of Items	16
Part Number	MO21041901
UNSPSC Code	31171500
UPC	760385793743