A9: Pulley System Design

- Center Distance 4-6 in
- Pulley Diam = 3 in
- Rotational Speed = 1,000 - 2,000 rpm
- Belt Tension (Static) = 4 - 6 lbf
- Mat'l = Al, ABS, or Steel Pulleys
- Safety Factor = minimum 3
- belt = polyurethane rubber
  $\llcorner S_y = 3.25$ MPa (471 psi) at 20% strain

Belt Selection

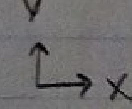
① Calculate forces on both tight and loose side of belt with no slippage.
Calculate ∅ using normal stress eq. + yield strength
Calculate belt's outer circumference then select a suitable belt

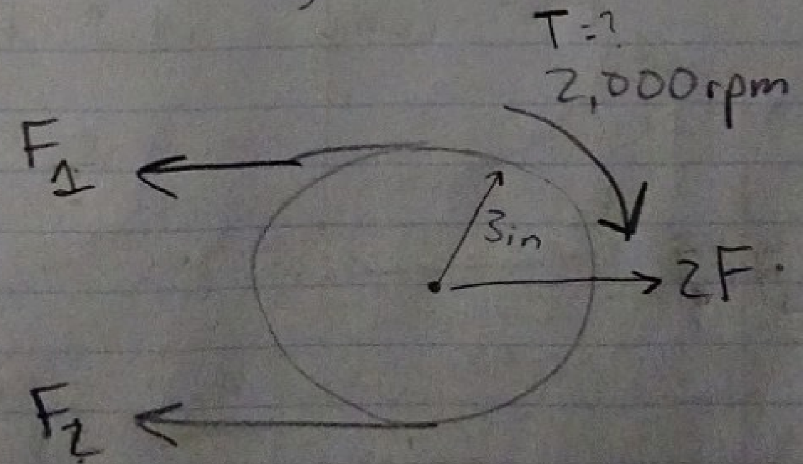
known

pulley ∅ = 3 in
tension = 6 lbf
rpm = 2,000 rpm
max values
S_y = 471 psi @ 20% strain
SF = 3
no slippage
$\theta = \pi$

unknown

belt ∅ = $\varnothing_B$
F_1
F_2
μ = ?





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$$\frac{S_y}{SF} = \frac{F}{A}$$

<u>Statically</u>, $F_1 = F_2$ = belt tension = 6 lbf

$$A_{\text{belt section}} = \frac{F(SF)}{S_y} = \frac{6\,\text{lbf}\,(3)}{471\,\text{psi}}$$

$$A_{\text{belt}} = 0.0382\ \text{in}^2$$

$$A = \pi \frac{d^2}{4} \qquad d = \phi_B = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(0.0382)}{\pi}}$$

$$\phi_B = 0.221\ \text{in} \approx 1/4\ \text{in}$$

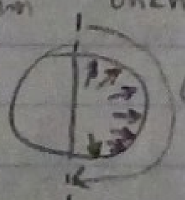
<u>Dynamically</u>, $F_{\text{Tight}} > F_{\text{loose}}$

$$P = T\omega = r\omega\underbrace{(F_{\text{Tight}} - F_{\text{loose}})}_{\text{unknown}}$$

unknown ... known known

y x

$$\frac{F_1}{F_2} = e^{\mu\Theta}$$



$\Theta = 180° = \pi$

$$F_1 + F_2 = 2F = 2(6\,\text{lbf}) = 12\,\text{lbf}$$

www.engineersedge.com/coefficients-of-friction.htm

"rubber (60 A belt) — stainless steel 316 → $\mu_s = 0.64$

<u>Assumption</u>: Mat'l pulley = "Steel"

$\mu_s \approx 0.64$

$$F_1 + F_2 = 2F$$

$$\frac{F_1}{F_2} = e^{\mu\theta}$$

$$F_1 = F_2 e^{\mu\theta}$$

$$F_2\left(e^{\mu\theta} + 1\right) = 2F$$

$$F_2 = \frac{2F}{e^{\mu\theta} + 1} \qquad F_1 = 2F - F_2$$

$$F_2 = \frac{2(6\,lb_f)}{e^{(0.64)(\pi)} + 1} = 1.417\ lb_f$$

$$F_1 = 2(6\,lb_f) - (1.417\,lb_f) = 10.58\ lb_f$$

$$F_{tight} = 10.58\,lb_f\ (max)$$
$$F_{loose} = 1.417\ lb_f\ (min)$$

$$\frac{S_y}{SF} = \frac{F_{tight}}{A} \rightarrow A = \frac{F_T(SF)}{S_y} = \pi\frac{d^2}{4}$$

$$\phi_B = \sqrt{\frac{4F_T(SF)}{\pi S_y}} = \sqrt{\frac{4(10.58\,lb_f)(3)}{\pi(471\,psi)}}$$

$$\phi_B = 0.293\,in$$

$$\boxed{5/16''} = 0.3125\,in$$

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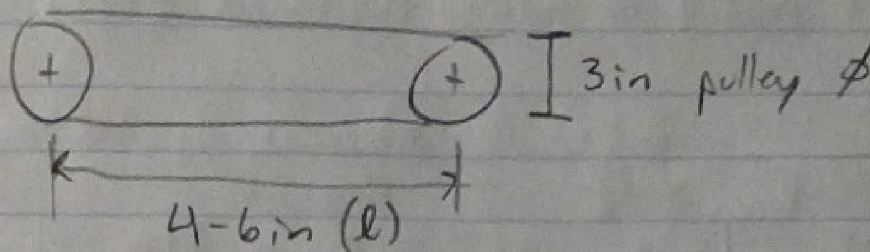
Belt Circumference



using max → 6in

Belt circumference = $2\ell + \pi\,\phi_{pulley}$

$$C_B = 2(6in) + \pi(3in) = 21.4\ in$$

$$\boxed{\text{Circumference of Belt} = 21.4\ in}$$

Belt selection McMaster-Carr

$$\phi_B = 0.293in \approx 5/16''$$
$$\phi_B = 0.293in\left(\frac{1cm}{2.54in}\right) = 0.1154cm = 1.154mm \approx 2mm$$

$$C_B = 21.4in$$
$$C_B = 21.4in\left(\frac{1cm}{2.54in}\right)\left(\frac{10mm}{1cm}\right) = 84.25mm$$

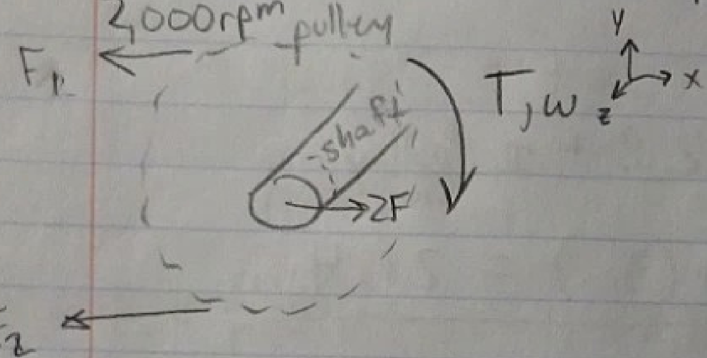
$$\phi_{pulley} = 3in$$
$$\phi_{pulley} = 3in\left(\frac{10mm}{2.54in}\right) = 11.81mm$$

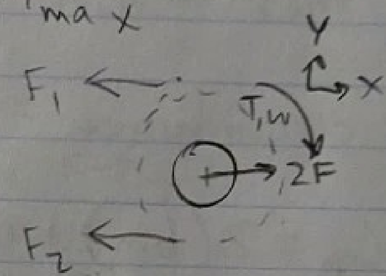
Round Belting, 5/16" 59725K733
+ connector 6180K15

Shaft Diameter (minimum)

Shaft mat'l = 1060 hardened steel

<u>known</u>	<u>unknown</u>
$\max T = F_{Tight} \times \frac{\phi_p}{2}$	ϕ_{shaft}
$F_R = 2F$ $SF = 3$	pulley width
2,000 rpm	T_{max}





Matweb → 1060 Steel, oil quenched 845°C, 480°C temper, . . .

~~Shear Modulus = 11600 ksi~~

tensile S_y = 98200 psi = 98.2 ksi

Research → von Mises criterion → $\tau_y \approx 0.577\,\sigma_y$

$$\tau_y = 0.577(98.2\text{ ksi}) = 56.7\text{ ksi}$$

$$\tau_y = 56{,}700\text{ psi}$$

~~$\frac{\tau_y}{SF} = \frac{V}{A} = \frac{2F}{A_{surface}}$ A_s = pulley width × circumference shaft~~

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Diameter from Torque

$$\text{Torque} = F_{TIGHT}\,\frac{\phi_p}{2} = 10.58\,lb_f\left(\frac{3in}{2}\right)$$

$$\text{Torque} = 15.87\ \text{in-lb}_f$$

$$\tau = \frac{Tr}{J} = \frac{T\,\frac{\phi}{2}}{\frac{\pi\,\phi^4}{32}} = \frac{16T}{\pi\,\phi^3}$$

$$\phi^3 = \frac{16T}{\pi\,\tau}$$

$$\phi = \sqrt[3]{\frac{16\,T}{\pi\,\tau}}$$

$$\phi = \sqrt[3]{\frac{16\,(10.58\ \text{in-lb}_f)}{\pi\,(56{,}700\,psi)}} = 0.0983\ in$$

$$\boxed{\begin{array}{l}\phi_{shaft} \approx 0.0983\,in \\ \text{options likely } 1/8'' = 0.125\ in\end{array}}$$

Journal Bearing Design

mat'l = sintered metal or non-metallic

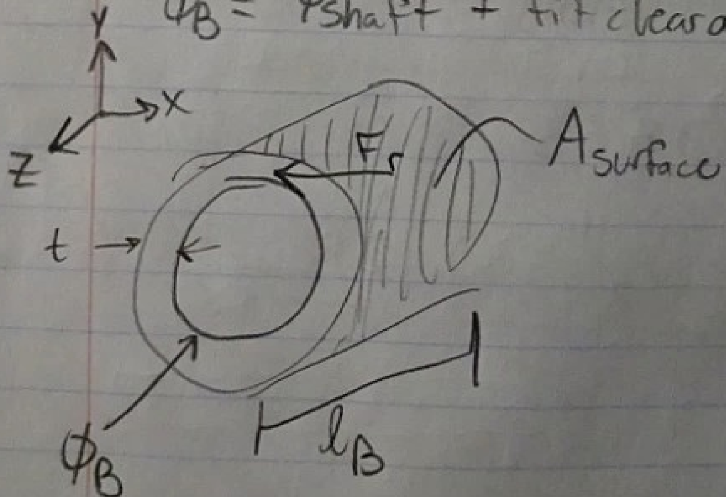
2442
Table 4 (pg 2440) Machinery's Handbook

Determine P, V, PV, select suitable material

Known	Unknown	
2000 rpm	P	Bearing depth (l_B)
T = 15.87 in-lbf	V	$\phi_{Bearing}$
ϕ_{shaft} = 1/8" = 0.125	PV	F_r

Assumption: RC5 fit and $l_B = 1$ in
hole +0.7 thou

$\phi_B = \phi_{shaft}$ + fit clearance



ϕ_B = 1/8" + 0.0007 in
ϕ_B = 0.1257 in

$$P = \frac{F}{A} = \frac{F_r}{A} = \frac{2T/\phi_B}{l_b \times \pi \phi_B} = \frac{2T}{l_b \pi \phi_B^2}$$

$$P = \frac{2(15.87\,\text{in-lbf})}{(1\,\text{in})\pi(0.1257\,\text{in})^2} = 639\ \text{psi}$$

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$$V = (rpm)\left(\frac{\pi \phi_B}{1\,rev}\right)\left(\frac{1\,ft}{12\,in}\right) \qquad \phi_B - in$$

$$V = (2{,}000)\left(\pi\,(0.1257\,in)\right)\left(\frac{1\,ft}{12\,in}\right) = 65.8\ ft/min$$

$P = 639$ psi
$V = 65.8$ ft/min

$PV = 42{,}046.2$ psi-ft/min

Options

Porous Bronze
Porous iron
Porous metals

Porous Bronze $P \leq 4500$ psi ✓
$V \leq 1500$ ft/min ✓
$PV \leq 50{,}000$ psi-ft/min ✓

Assumption: Porous Bronze uses a sintered process

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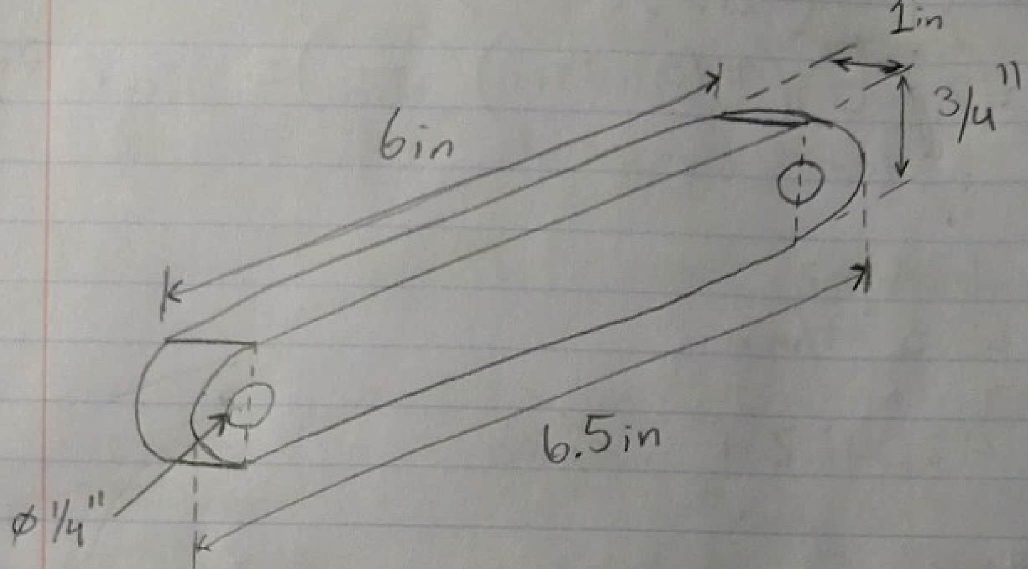
Design a Frame



journal bearings + shaft ~ 1/4" diameter hole