

Answer Key

Flywheels and Bearings

$$\Delta KE = \frac{1}{2} \frac{m}{g_c} (v_2^2 - v_1^2)$$

$$v_2 = \pi D N_2 = \pi (1m) \left(\frac{280 \text{ rpm}}{60} \right) = 14.6608 \text{ m/s}$$

$$v_1 = \pi D N_1 = \pi (1m) \left(\frac{220 \text{ rpm}}{60} \right) = 11.5192 \text{ m/s}$$

subst;

$$260 \text{ kJ} = \frac{1}{2} \left(\frac{m}{1000 \frac{\text{kg} \cdot \text{m}}{\text{kJ} \cdot \text{s}^2}} \right) (14.6608^2 - 11.5192^2) \text{ m}^2/\text{s}^2$$

$$m = 6322.41229 \text{ kg}$$

for the width;

$$m_w = m + m_h + m_a$$

$$6322.41229 \text{ kg} = m + 0.12 \text{ m}$$

$$m = 5645.0109 \text{ kgs}$$

Hence;

$$\rho_{\text{rim}} = \frac{m}{V_{\text{rim}}} = \frac{m}{b t L} = \frac{m}{b t \pi D m}$$

$$0.020 \frac{\text{kg}}{\text{cm}^3} = \frac{5645.0109 \text{ Kgs}}{b (10 \text{ cm}) (\pi) (100 \text{ cm})}$$

$$b = 89.8431 \text{ cm}$$

$$E = \frac{1}{2} S_u A t$$

$$A = \pi d t = \pi (2.5 \text{ in}) (0.5 \text{ in}) \left(\frac{1 \text{ ft}^2}{144 \text{ in}^2} \right) \left(\frac{1 \text{ m}}{3.28 \text{ ft}} \right)^2$$

$$A = 2.5348 \times 10^{-3} \text{ m}^2$$

Substj:

$$E = \frac{1}{2} (260000 \text{ kPa}) (2.5348 \times 10^{-3} \text{ m}^2) (0.5 \text{ in}) \left(\frac{1 \text{ ft}}{12 \text{ in}} \right) \left(\frac{1 \text{ m}}{3.28 \text{ ft}} \right)$$

$$E = 4.1860 \text{ kJ}$$

Hence, the power required;

$$P = (4.1860 \text{ kJ}) \left(\frac{18 \text{ holes}}{\text{min}} \right) \left(\frac{1 \text{ min}}{60 \text{ s}} \right)$$

$$P = 1.2558 \text{ kW}$$

$$\Delta KE = \frac{1}{2} \frac{m}{g_c} (v_2^2 - v_1^2)$$

$$v_2 = \pi D N_2 = \pi (0.650 \text{ m}) \left(\frac{200 \text{ rpm}}{60} \right) = 6.8068 \text{ m/s}$$

$$v_1 = \pi D N_1 = \pi (0.650 \text{ m}) \left(\frac{170 \text{ rpm}}{60} \right) = 5.7857 \text{ m/s}$$

subst:

$$\Delta KE = \frac{1}{2} \frac{(800 \text{ kg})}{\left(\frac{1000 \text{ kg} \cdot \text{m}}{\text{KJ} \cdot \text{s}^2} \right)} (6.8068^2 - 5.7857^2) \text{ m}^2/\text{s}^2$$

$$\Delta KE = 5.1433 \text{ KJ}$$

$$P = 80 \text{ dt}$$
$$= 80(3.5 \sin)(1.5 \sin)$$

$$P = 420 \text{ tons}$$

$$\Delta KE = \frac{1}{2} \frac{m}{g_c} (v_2^2 - v_1^2)$$

$$C_f = \frac{v_2 - v_1}{v_a} \quad ; \quad v_a = \frac{v_2 + v_1}{2}$$

$$0.10 = \frac{v_2 - v_1}{90 \text{ ft/sec}} \quad ; \quad 90 \text{ ft/sec} = \frac{v_2 + v_1}{2}$$

$$v_2 - v_1 = 9 \text{ ft/sec} \quad ; \quad v_2 + v_1 = 180 \text{ ft/sec}$$

Subst to solve for v_1 & v_2

$$v_2 + (v_2 - 9 \text{ ft/sec}) = 180 \text{ ft/sec}$$

$$v_2 = 94.5 \text{ ft/sec}$$

$$v_1 = 85.5 \text{ ft/sec}$$

Hence;

$$3800 \text{ ft-lb} = \frac{1}{2} \frac{m}{\left(32.2 \frac{\text{lbm-ft}}{\text{lb-f-sec}^2}\right)} (94.5^2 - 85.5^2) \text{ ft/sec}^2$$

$$m = 151.0617 \text{ lbs}$$

$$\Delta KE = \frac{1}{2} \frac{m}{g_c} (v_2^2 - v_1^2)$$

$$v_a = 2\pi R_m N_a = 2\pi (1.80 \text{ m}) \left(\frac{180 \text{ rpm}}{60} \right) = 33.9292 \frac{\text{m}}{\text{s}}$$

$$C_f = \frac{v_2 - v_1}{v_a} \quad ; \quad v_a = \frac{v_2 + v_1}{2}$$

$$0.08 = \frac{v_2 - v_1}{33.9292 \text{ m/s}} \quad ; \quad 33.9292 \text{ m/s} = \frac{v_2 + v_1}{2}$$

$$v_2 - v_1 = 2.7143 \text{ m/s} \quad ; \quad v_2 + v_1 = 67.8584 \text{ m/s}$$

subst to solve for v_1 & v_2 ;

$$v_2 + (v_2 - 2.7143 \text{ m/s}) = 67.8584 \text{ m/s}$$

$$v_2 = 35.2864 \text{ m/s}$$

$$v_1 = 32.572 \text{ m/s}$$

Subst;

$$\Delta KE = \frac{1}{2} \frac{(1200 \text{ Fg})}{\left(\frac{1000 \text{ kg} \cdot \text{m}}{\text{KN} \cdot \text{s}^2} \right)} (35.2864^2 - 32.572^2) \text{ m}^2/\text{s}^2$$

$$\Delta KE = 110.5169 \text{ KJ}$$

$$\Delta KE = \frac{1}{2} \frac{m}{g_c} (v_2^2 - v_1^2)$$

$$v_a = \pi D N_a = \pi (50 \text{ in}) \left(\frac{1 \text{ ft}}{12 \text{ in}} \right) \left(\frac{190 \text{ rpm}}{60} \right) = 41.4516 \frac{\text{ft}}{\text{sec}}$$

$$C_p = \frac{v_2 - v_1}{v_a} \quad ; \quad v_a = \frac{v_2 + v_1}{2}$$

$$0.09 = \frac{v_2 - v_1}{41.4516 \text{ ft/sec}} \quad ; \quad 41.4516 \text{ ft/sec} = \frac{v_2 + v_1}{2}$$

$$v_2 - v_1 = 3.7306 \text{ ft/sec} \quad ; \quad v_2 + v_1 = 82.9032 \text{ ft/sec}$$

Subst to solve for v_1 & v_2 ;

$$v_2 + (v_2 - 3.7306 \text{ ft/sec}) = 82.9032 \text{ ft/sec}$$

$$v_2 = 43.3169 \text{ ft/sec}$$

$$v_1 = 39.5863 \text{ ft/sec}$$

Hence;

$$\Delta KE = \frac{1}{2} \left(\frac{830 \text{ lbs}}{32.2 \frac{\text{lbm-ft}}{\text{lb-sec}^2}} \right) (43.3169^2 - 39.5863^2) \frac{\text{ft}^2}{\text{sec}^2}$$

$$\Delta KE = 3986.0451 \text{ lb-ft}$$

$$\Delta KE = \frac{1}{2} \frac{m}{g_c} (v_2^2 - v_1^2)$$

$$\rho = \frac{m}{\pi b t}$$

$$7200 \text{ kg/m}^3 = \frac{m}{\pi (0.920 \text{ m}) (0.380 \text{ m}) (0.080 \text{ m})}$$

$$m = 632.6213 \text{ kg}$$

$$v_1 = \pi D N_1 = \pi (0.920 \text{ m}) \left(\frac{240}{60} \text{ rpm} \right) = 11.5611 \text{ m/s}$$

$$v_2 = \pi D N_2 = \pi (0.920 \text{ m}) \left(\frac{290}{60} \text{ rpm} \right) = 13.9696 \text{ m/s}$$

subst:

$$\Delta KE = \frac{1}{2} \frac{(632.6213 \text{ kg})}{\left(\frac{1000 \text{ kg-m}}{\text{kJ-s}^2} \right)} (13.9696^2 - 11.5611^2) \text{ m}^2/\text{s}^2$$

$$\Delta KE = 19.4502 \text{ kJ}$$

$$E = \frac{1}{2} S_{su} A t$$

$$\left(8 \frac{\text{kJ}}{\text{sec}}\right) (12 \text{ sec}) = \frac{1}{2} (450\,000 \text{ kPa}) A (0.060 \text{ m})$$

$$A = 7.1111 \times 10^{-3} \text{ m}^2$$

Hence;

$$A = b t$$

$$7.1111 \times 10^{-3} \text{ m}^2 = b (0.060 \text{ m})$$

$$b = 0.1185 \text{ m}$$

$$b = 118.50 \text{ mm}$$

$$\rho = \frac{m}{bt\pi Dm} ; b = 6t$$

$$7300 \frac{\text{kg}}{\text{m}^3} = \frac{480 \text{ kg}}{6t^2 \pi 2(0.480 \text{ m})}$$

$$t = 0.06028 \text{ m}$$

$$t = 60.28 \text{ mm}$$

Hence;

$$b = 6(60.28 \text{ mm})$$

$$b = 361.6798 \text{ mm}$$

$$\rho = \frac{m}{bt\pi D_m} \quad ; \quad m_w = m + m_n + m_a$$
$$600 \text{ kg} = m + (0.10)(600 \text{ kg})$$
$$m = 540 \text{ kg}$$

Substi

$$7100 \frac{\text{kg}}{\text{m}^3} = \frac{540 \text{ kg}}{(0.310 \text{ m})t\pi(1.2 \text{ m})}$$

$$t = 0.06508 \text{ m}$$

$$t = 65.08 \text{ mm}$$

Considering Flywheel Effect:

$$KE = \frac{1}{2} \frac{m_w}{g_c} (v_2^2 - v_1^2)$$

$$v_2 = \pi D N_2 = \pi (0.850 \text{ m}) (3.5 \text{ rps}) = 9.3462 \text{ m/s}$$

$$v_1 = \pi D N_1 = \pi (0.850 \text{ m}) (2.8 \text{ rps}) = 7.4769 \text{ m/s}$$

$$3.20 \text{ kJ} = \frac{1}{2} \frac{m_w}{\left(1000 \frac{\text{kg} \cdot \text{m}}{\text{N} \cdot \text{s}^2}\right)} (9.3462^2 - 7.4769^2) \text{ m}^2/\text{s}^2$$

$$m_w = 203.5143 \text{ kg} \quad (\text{total mass of flywheel})$$

From;

$$m_w = m + m_n + m_a$$

$$203.5143 \text{ kg} = m + (0.09)m$$

$$m = 186.7104 \text{ kg} \quad (\text{mass of the rim})$$

$$KE = \frac{1}{2} \frac{m}{g_c} (v_2^2 - v_1^2)$$

$$v_2 = \frac{\pi D N_2}{60} = \frac{\pi (1.30 \text{ m}) (230 \text{ rpm})}{60} = 15.6556 \text{ m/s}$$

$$v_1 = \frac{\pi D N_1}{60} = \frac{\pi (1.30 \text{ m}) (210 \text{ rpm})}{60} = 14.2942 \text{ m/s}$$

Substi

$$KE = \frac{1}{2} \frac{480 \text{ kg}}{\left(\frac{1000 \text{ kg-m}}{\text{kN-s}^2} \right)} (15.6556^2 - 14.2942^2) \text{ m}^2/\text{s}^2$$

$$KE = 9.7857 \text{ kJ}$$

Hence; Energy required to punch a hole

$$E = \frac{1}{2} F t$$

$$9.7857 \text{ kJ} = \frac{1}{2} F (0.028 \text{ m})$$

$$F = 698.9786 \text{ kN}$$

$$KE = \frac{1}{2} \frac{m}{g_c} (v_2^2 - v_1^2)$$

$$\text{from; } v_2 = \frac{\pi D N_2}{60} = \frac{\pi (0.90 \text{ m})(220 \text{ rpm})}{60} = 10.3673 \text{ m/s}$$

$$v_1 = \frac{\pi D N_1}{60} = \frac{\pi (0.90 \text{ m})(190 \text{ rpm})}{60} = 8.9535 \text{ m/s}$$

$$\text{from; } S_{su} = \frac{F}{bt}$$

$$420000 \frac{\text{KN}}{\text{m}^2} = \frac{F}{(0.180 \text{ m})(0.025 \text{ m})}$$

$$F = 1890 \text{ KN}$$

$$\text{From; } E = \frac{1}{2} Ft = \frac{1}{2} (1890 \text{ KN})(0.025 \text{ m}) = 23.625 \text{ KJ}$$

Hence; substit;

$$23.6250 \text{ KJ} = \frac{1}{2} \frac{m}{\left(\frac{1000 \text{ kg-m}}{\text{KN-s}^2} \right)} (10.3673^2 - 8.9535^2) \text{ m}^2/\text{s}^2$$

$$m = 1729.7715 \text{ Kg}$$

$$KE = \frac{1}{2} \frac{m}{g_c} (v_2^2 - v_1^2)$$

$$v_2 = \frac{\pi D N_2}{60} = \frac{\pi (1.20 \text{ m}) (200 \text{ rpm})}{60} = 12.5663 \text{ m/s}$$

$$v_1 = \frac{\pi D N_1}{60} = \frac{\pi (1.20 \text{ m}) (170 \text{ rpm})}{60} = 10.6814 \text{ m/s}$$

Subst;

$$KE = \frac{1}{2} \frac{(400 \text{ kg})}{\left(\frac{1000 \text{ kg} \cdot \text{m}}{\text{N} \cdot \text{s}^2} \right)} (12.5663^2 - 10.6814^2) \frac{\text{m}^2}{\text{s}^2}$$

$$KE = 8.7639 \text{ kJ}$$

$$F = \frac{1}{2} F t ; \quad s_{cu} = \frac{F}{\pi d t}$$

$$F = \frac{1}{2} s_{cu} \pi d t^2$$

$$8 \text{ kN} = \frac{1}{2} (450\,000 \text{ kPa}) \pi (0.030 \text{ m}) t^2$$

$$t = 0.01942 \text{ m}$$

$$t = 19.42 \text{ mm}$$

$$S_{su} = \frac{F}{\pi d t}$$

$$420000 \text{ KPa} = \frac{F}{\pi (0.028 \text{ m}) (0.025 \text{ m})}$$

$$F = 923.6282 \text{ kN}$$

Hence;

$$E = \frac{1}{2} F t = \frac{1}{2} (923.6282 \text{ kN}) (0.025 \text{ m}) \left(\frac{10 \text{ holes}}{\text{min}} \right)$$

$$E = \left(115.4535 \frac{\text{kJ}}{\text{min}} \right) \left(\frac{1 \text{ min}}{60 \text{ sec}} \right)$$

$$E = 1.9242 \text{ kW}$$

19 to 20

UNIT load or Bearing pressure

$$P = \frac{F}{LD} = \frac{1420 \text{ lbs}}{(1.8 \text{ in})(2.0 \text{ in})}$$

$$P = 394.4444 \text{ psi}$$

$$\text{BEARING modulus} = BM = \frac{MN}{P}$$

$$16.50 = \frac{M(1500 \text{ rpm})}{394.444 \text{ psi}}$$

$$M = 4.3389$$

$$\frac{N_1}{P_1} = \frac{N_2}{P_2}$$

$$\frac{520 \text{ rpm}}{12 \text{ Kg/cm}^2} = \frac{600 \text{ rpm}}{P_2}$$

$$P_2 = 13.8462 \text{ Kg/cm}^2$$

$$T_f = \frac{4\mu\pi^2 r^3 L N}{C_r}$$

$$= \frac{4(2.8 \times 10^{-6} \text{ reyns}) \pi^2 \left(\frac{3.5 \text{ in}}{2}\right)^3 (4.5 \text{ in}) N}{0.009 \text{ in}}$$

$$T_f = 0.2962 \text{ N} ; \quad T = \text{in-lb}$$

$$N = \text{rps}$$

then;

$$P = 2\pi T_f N$$

$$(0.95 \text{ hp}) \left(\frac{550 \frac{\text{ft-lb}}{\text{sec}}}{1 \text{ hp}} \right) \left(\frac{12 \text{ in}}{1 \text{ ft}} \right) = 2\pi (0.2962) N^2$$

$$N = \left(38.0431 \frac{\text{rev}}{\text{sec}} \right) \left(\frac{60 \text{ sec}}{1 \text{ min}} \right)$$

$$N = 3482.5917 \text{ rpm}$$

$$P = 2\pi T_f N$$

$$20 \text{ kW} = \frac{2\pi T_f (550 \text{ rpm})}{60}$$

$$T_f = 0.3472 \text{ kN-m}$$

and from;

$$T = \frac{F f D}{2}$$

$$0.3472 \text{ kN-m} = \frac{(35 \text{ kN})(0.15) D}{2}$$

$$D = (0.1323 \text{ m}) \left(\frac{1000 \text{ mm}}{1 \text{ m}} \right)$$

$$D = 132,2846 \text{ mm}$$

$$\frac{C_d}{D} = 0.0015$$

$$\frac{0.120 \text{ mm}}{D} = 0.0015$$

$$D = 80 \text{ mm}$$

from;

$$p = \frac{F}{LD}$$

$$600 \text{ kPa} = \frac{25 \text{ kN}}{L(0.080 \text{ m})}$$

$$L = (0.5208 \text{ m}) \left(\frac{1000 \text{ mm}}{1 \text{ m}} \right)$$

$$L = 520.8 \text{ mm}$$

$$P = 2\pi T_f N ; T_f = \frac{F f D}{2} = \frac{60 \text{ kN} (0.13) (0.25 \text{ m})}{2} = 0.975 \text{ kN-m}$$

Subst;

$$P = 2\pi (0.975 \text{ kN-m}) \left(\frac{480 \text{ RPM}}{60} \right)$$

$$P = 49.00 \text{ kW}$$

$$P = 24.50 \text{ kW} \quad (\text{per bearing})$$

$$T = \frac{F f D}{2} = (6000 \text{ kg}) \left(\frac{9.81 \text{ m/s}^2}{1 \frac{\text{kg} \cdot \text{m}}{\text{N} \cdot \text{s}^2}} \right) (0.19) \left(\frac{0.160 \text{ m}}{2} \right)$$

$$T = 894.6 \text{ N} \cdot \text{m}$$

$$P = \frac{F}{LD}$$

$$= \frac{(4500 \text{ kg}) \left(\frac{9.81 \text{ m/s}^2}{1000 \frac{\text{kg} \cdot \text{m}}{\text{KN} \cdot \text{s}^2}} \right)}{(0.290 \text{ m})(0.150 \text{ m})}$$

$$P = 1014.0276 \frac{\text{KN}}{\text{m}^2}$$

$$P = 507.4138 \frac{\text{KN}}{\text{m}^2} \quad (\text{per bearing})$$

$$T_f = \frac{F_f D}{2} = 5800 \text{ kg} \left(\frac{9.81 \frac{\text{m}}{\text{s}^2}}{1 \frac{\text{kg} \cdot \text{m}}{\text{N} \cdot \text{s}^2}} \right) (0.18) \left(\frac{0.160 \text{ m}}{2} \right)$$

$$T_f = 864.8496 \text{ kN} \cdot \text{m}$$

$$P = \frac{F}{LD} = \frac{4200 \text{ kg} \left(\frac{9.81 \frac{\text{m}}{\text{s}^2}}{1000 \frac{\text{kg} \cdot \text{m}}{\text{kN} \cdot \text{s}^2}} \right)}{(0.290 \text{ m})(0.150 \text{ m})}$$

$$P = 947.1724 \text{ kPa}$$

$$\begin{aligned}
 P &= f F v \\
 &= (0.05)(5800 \text{ lbs})(600 \frac{\text{ft}}{\text{min}})(4 \text{ wheels}) \\
 P &= (696000 \frac{\text{lb-ft}}{\text{min}}) \left(\frac{1 \text{ min}}{60 \text{ sec}} \right) \left(\frac{1 \text{ hp}}{550 \frac{\text{lb-ft}}{\text{sec}}} \right)
 \end{aligned}$$

$$P = 21.0909 \text{ hp}$$

$$\text{Desired Life} = (10 \text{ yrs}) \left(365 \frac{\text{days}}{\text{yr}} \right) \left(20 \frac{\text{hrs}}{\text{day}} \right)$$

$$\text{Desired Life} = 73000 \text{ hrs}$$

$$F = f W = 0.007 (6000 \text{ lbs})$$

$$F = 42 \text{ lbs}$$