Answer Key

Flywheels and Bearings

$$\Delta KE = \frac{1}{2}\frac{m}{g_c}\left(V_2^2 - V_1^2\right)$$

$$V_2 = \pi D N_2 = \pi(1m)\left(\frac{280 rpm}{60}\right) = 14.6608\ m/s$$

$$V_1 = \pi D N_1 = \pi(1m)\left(\frac{220 rpm}{60}\right) = 11.5192\ m/s$$

subst;

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

$$m = 6322.41229\ kg$$

for the width;

$$m_w = m + m_n + m_a$$

$$6322.41229\ kg = m + 0.12m$$

$$m = 5645.0109\ kgs$$

Hence;

$$\rho_{rim} = \frac{m}{V_{rim}} = \frac{m}{btL} = \frac{m}{bt\pi Dm}$$

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

$$b = 89.8431\ cm$$

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

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

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

Substi;

$$E = \frac{1}{2}(260\,000\,kPa)(2.5348 \times 10^{-3}\,m^2)(0.5\,in)\left(\frac{1\,ft}{12\,in}\right)\left(\frac{1\,m}{3.28\,ft}\right)$$

$$E = 4.1860\,kJ$$

Hence, the power required;

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

$$P = 1.2558\,kW$$

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

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

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

Substituting:

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

$$\Delta KE = 5.1433\ KJ$$

$$P = 80dt$$

$$= 80(3.5\text{in})(1.5\text{in})$$

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

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

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

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

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

Subst to solve for v_1 & v_2

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

$$v_2 = 94.5\ ft/sec$$

$$v_1 = 85.5\ ft/sec$$

Hence;

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

$$m = 151.0617\ lbs$$

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

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

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

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

$$v_2 - v_1 = 2.7143\,m/s \quad ; \quad v_2 + v_1 = 67.8584\,m/s$$

subst to solve for v_1 & v_2 ;

$$v_2 + (v_2 - 2.7143\,m/s) = 67.8584\,m/s$$

$$v_2 = 35.2864\,m/s$$

$$v_1 = 32.572\,m/s$$

Subst;

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

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

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

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

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

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

$$v_2 - v_1 = 3.7306\,ft/sec \quad ; \quad v_2 + v_1 = 82.9032\,ft/sec$$

Subst to solve for v_1 & v_2;

$$v_2 + (v_2 - 3.7306\,ft/sec) = 82.9032\,ft/sec$$

$$v_2 = 43.3169\,ft/sec$$

$$v_1 = 39.5863\,ft/sec$$

Hence;

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

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

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

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

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

$$m = 632.6213\ kg$$

$$v_1 = \pi D N_1 = \pi(0.920\,m)\left(\frac{290}{60}\,rpm\right) = 11.5611\ m/s$$

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

subst:

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

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

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

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

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

Hence;

$$A = bt$$

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

$$b = 0.1185\ m$$

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

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

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

$$t = 0.06028\ m$$

$$t = 60.28\ mm$$

Hence;

$$b = 6(60.28mm)$$

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

$$\rho = \frac{m}{6t\pi D_m} \quad ; \quad m_w = m + m_n + m_a$$

$$600\,kg = m + (0.10)(600\,kg)$$

$$m = 540\,kg$$

Substi

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

$$t = 0.06508\,m$$

$$\boxed{t = 65.08\,mm}$$

Considering Flywheel Effect:

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

$$v_2 = \pi D_m N_2 = \pi(0.850\,m)(3.5\,rps) = 9.3462\ m/s$$

$$v_1 = \pi D_m N_1 = \pi(0.850\,m)(2.8\,rps) = 7.4769\ m/s$$

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

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

From;

$$m_w = m + m_h + m_a$$

$$203.5143\ kg = m + (0.09)m$$

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

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

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

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

Substi

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

$$KE = 9.7857\,kJ$$

Hence; Energy required to punch a hole

$$E = \frac{1}{2}Ft$$

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

$$F = 698.9786\,kN$$

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

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

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

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

$420000\,\frac{kN}{m^2} = \frac{F}{(0.180\,m)(0.025\,m)}$

$F = 1890\,kN$

From; $E = \frac{1}{2}Ft = \frac{1}{2}(1890\,kN)(0.025\,m) = 23.625\,kJ$

Hence; substi;

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

$m = 1729.7715\,kg$

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

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

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

Substi

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

$$KE = 8.7639\ kJ$$

$$E = \frac{1}{2} F t \; ; \quad S_{su} = \frac{F}{\pi d t}$$

$$E = \frac{1}{2} S_{su} \pi d t^2$$

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

$$t = 0.01942\ m$$

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

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

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

$$F = 923.6282\ kN$$

Hence;

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

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

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

19 to 20

Unit load or Bearing pressure

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

$$P = 394.4444\ psi$$

Bearing modulus $= BM = \frac{N}{P}$

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

$$N = 4.3389$$

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

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

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

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

$$= \frac{4(2.8\times10^{-6}\ \text{reyns})\,\pi^2\left(\frac{3.5\,in}{2}\right)^3(4.5\,in)\,N}{0.009\,in}$$

$T_f = 0.2962\,N$; T = in-lb, N = rps

then;

$$P = 2\pi T_f N$$

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

$$N = \left(58.0431\,\frac{rev}{sec}\right)\left(\frac{60\,sec}{1\,min}\right)$$

$$N = 3482.5917\ rpm$$

$$P = 2\pi T_f N$$

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

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

and from;

$$T = \frac{F_f D}{2}$$

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

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

$$D = 132.2846\ mm$$

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

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

$$D = 80\,mm$$

from;

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

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

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

$$L = 520.8\,mm$$

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

Substj

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

$$P = 49.00\,kW$$

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

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

$$\boxed{T = 894.6\ \text{N-m}}$$

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

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

$$P = 1014.8276\ \frac{kN}{m^2}$$

$$P = 507.4138\ \frac{kN}{m^2}$$ (per bearing)

$$T_f = \frac{F_f D}{2} = 5800\,kg\left(\frac{9.81\ m/s^2}{1\ \frac{kg-m}{N-s^2}}\right)(0.19)\left(\frac{0.160m}{2}\right)$$

$$T_f = 864.8496\ kN-m$$

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

$$P = 947.1724\ kPa$$

$$P = f F v$$

$$= (0.05)(5800\ \text{lbs})\left(600\ \frac{\text{ft}}{\text{min}}\right)(4\ \text{wheels})$$

$$P = \left(696000\ \frac{\text{lb-ft}}{\text{min}}\right)\left(\frac{1\ \text{min}}{60\ \text{sec}}\right)\left(\frac{1\ \text{hp}}{550\ \frac{\text{lb-ft}}{\text{sec}}}\right)$$

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

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

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

$$F = fW = 0.007\,(6000\,lbs)$$

$$\boxed{F = 42\,lbs}$$