Hammer Calculations

For these calculations it is assumed that the main air tank is equipped with a high-delivery regulator and that the hammer cycle consists of applying the output of this regulator to the air cylinder for a preset fraction of the cylinder's stroke.

The force exerted on the piston is constant for the fraction f of the stroke. Then the force on the piston declines according to the laws of thermodynamics for an adiabatic expansion.

The drives system is a cylinder with a piston attached to chain wrapped around a sprocket on the hammer axle.

Cylinder

$$A_{throw} := \pi \cdot \left(\left(\frac{d_{throw}}{2} \right)^2 - \left(\frac{d_{rod}}{2} \right)^2 \right) = 26.507 \ \boldsymbol{in}^2 \qquad Vol_{throw} := A_{throw} \cdot stroke$$

Mechanism

$$J_{hammer} := m_{head} \cdot {len_{arm}}^2 + m_{arm} \cdot \left(\frac{len_{arm}}{2} \right)^2$$ rotational inertia of the arm+hammer

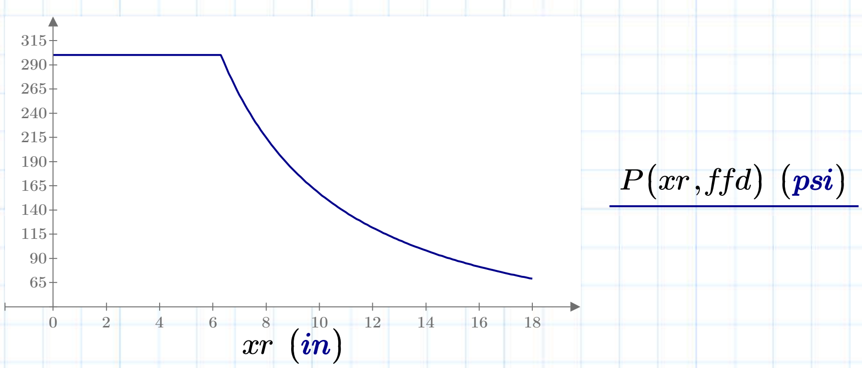
Thermodynamics

$$const(ff) := P_0 \cdot \left(ff \cdot Vol_{throw} \right)^{1.4}$$ this is the constant required for the adiabatic expansion calc, as a function of fill fraction ff

$$V_{stroke}(x) := A_{throw} \cdot x$$ volume expression for the stroke

$$P(x, ff) := \text{if} \left(\left(\frac{V_{stroke}(x)}{Vol_{throw}} \le ff \right), P_0, \frac{const(ff)}{V_{stroke}(x)^{1.4}} \right)$$ the complete expression for the pressure

$$xr := 0 \cdot \boldsymbol{in}, .1 \cdot \boldsymbol{in} .. stroke$$



Motion

$$r_{sprocket} := \frac{stroke}{\theta_{max}} = 3.82\ in$$

$$x_{cyl}(\theta) := \theta \cdot r_{sprocket} \qquad x_{cyl}(180 \cdot deg) = 12\ in$$

$$\theta_{hammer}(x) := \frac{x}{r_{sprocket}} \qquad \theta_{stroke} := \theta_{hammer}(stroke) = 270\ deg$$

$$T_{axle}(\theta, ff) := P(x_{cyl}(\theta), ff) \cdot A_{throw} \cdot r_{sprocket}$$ torque applied by cylinder on crank

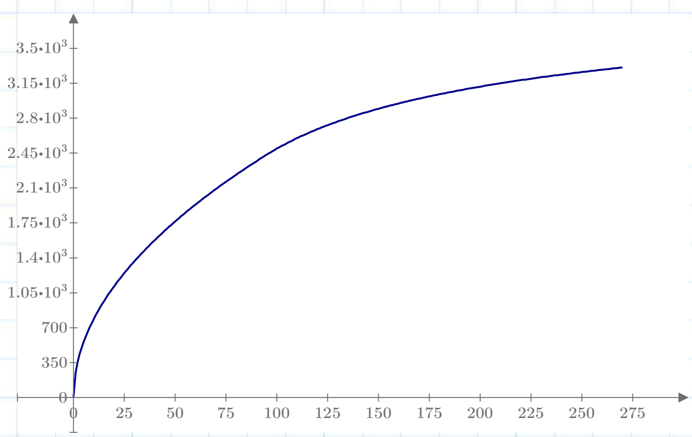
$$\alpha_{hammer}(\theta, ff) := \frac{T_{axle}(\theta, ff)}{J_{hammer}}$$ acceleration of hammer

$$E_{hammer}(\theta, ff) := \int_0^\theta T_{axle}(\theta, ff)\, \mathrm{d}\theta \qquad E_{hammer}(\theta_{max}, ffd) = (1.051 \cdot 10^4)\ J$$

$$\omega_{hammer}(\theta, ff) := \sqrt{2 \cdot \int_0^\theta \alpha_{hammer}(\theta, ff)\, \mathrm{d}\theta}$$ angular velocity of hammer

$$t(\theta, ff) := \int_0^\theta \frac{2}{\omega_{hammer}(\theta, ff)}\, \mathrm{d}\theta$$ time to get to an angle

$$\theta r := 0 \cdot deg, 1 \cdot deg .. \theta_{max}$$

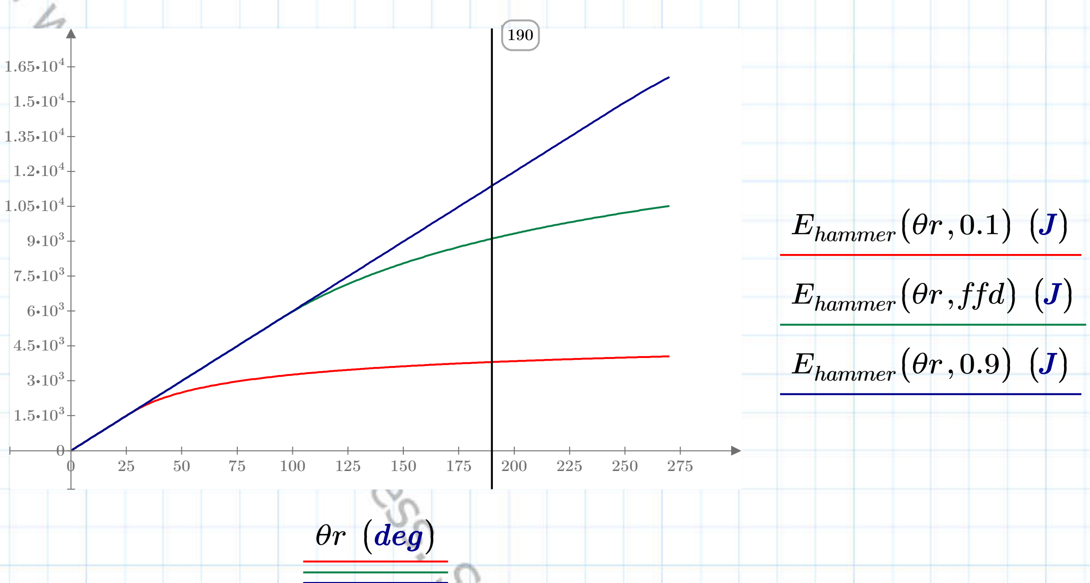


$$\omega_{hammer}(\theta r, ffd) \left(\frac{deg}{s}\right)$$

$$\theta r\ (deg)$$

System

$$V_{shot} := Vol_{throw} \cdot ffd \cdot \frac{P_0}{1 \cdot atm}$$ volume of air at STP consumed per shot



Parameters

$$V_{tank} := 87 \cdot ft^3$$

$P_0 \equiv 300 \cdot psi$ hammer cylinder pressure

$ffd \equiv 35\%$ default fill fraction

$\theta_{max} \equiv 270 \cdot deg$ maximum hammer angle

$\theta_{hit} := 190 \cdot deg$ hammer angle at impact

$d_{throw} \equiv 6 \cdot in$ hammer cylinder diameter

$d_{rod} \equiv 1.5\ in$ hammer rod diameter

$stroke \equiv 18 \cdot in$ hammer cylinder stroke

$m_{head} \equiv 26 \cdot lb$ hammer head mass

$m_{arm} \equiv 6 \cdot lb$ hammer arm mass

$len_{arm} \equiv 28 \cdot in$ hammer arm length

Results

$r_{sprocket} = 3.82 \ in$

$t(\theta_{hit}, ffd) = 0.224 \ s$ swing time

$E_{hammer}(\theta_{hit}, ffd) = 9109.5 \ J$ terminal swing energy

$t_{chain} := A_{throw} \cdot P_0 = (7.952 \cdot 10^3) \ lbf$

$w_{max} := \omega_{hammer}(180 \cdot deg, ffd) = 506.516 \ rpm$

$n_{shots} := \dfrac{V_{tank}}{V_{shot}} = 44.1$

$F_{max} := P_0 \cdot A_{throw} = (7.952 \cdot 10^3) \ lbf$ peak force from fire cylinder

$F_{hammer} := \dfrac{T_{axle}(0, ffd)}{len_{arm}} = (1.085 \cdot 10^3) \ lbf$ force at hammer head

$T_{max} := T_{axle}(0, ffd) = (2.531 \cdot 10^3) \ ft \cdot lbf$ peak torque on hammer axle

Retract pulse considerations

$d_{retract} \equiv 4 \ in$ $d_{retract.rod} \equiv 0.75 \ in$

$A_{retract} := \pi \cdot \left(\left(\dfrac{d_{retract}}{2} \right)^2 - \left(\dfrac{d_{rod}}{2} \right)^2 \right) = 10.799 \ in^2$

$Ve_{retract} := A_{retract} \cdot \dfrac{stroke}{3}$ volume of retract side at 180 degrees

$T_{retract}(P) := A_{retract} \cdot P \cdot r_{sprocket}$

$A_{retract} := \pi \cdot \left(\left(\dfrac{d_{retract}}{2} \right)^2 - \left(\dfrac{d_{retract.rod}}{2} \right)^2 \right) = 12.125 \ in^2$

$Fmax_{retract} := P_0 \cdot A_{retract} = (3.637 \cdot 10^3) \ lbf$

$Fmin_{retract} := \dfrac{T_{retract}(40 \cdot psi)}{len_{arm}} = 58.929 \ lbf$

$Q_{retract} := 14 \cdot cfm$ flow rate of tiny valve from McMaster at 3000psi

$t(P) := \frac{P \cdot Ve_{retract}}{1 \cdot bar \cdot Q_{retract}}$ time to fill to a given pressure

$t(100 \cdot psi) = 1.108\ s$

Hammer axle and bearing

$F_{perBearing} := \frac{F_{max}}{2} = \left(3.976 \cdot 10^{3}\right)\ lbf$

$d_{axle} := 55\ mm = 2.165\ in$

$l_{axle} := 120\ mm = 4.724\ in$

$A_{effAxle} := d_{axle} \cdot l_{axle} = 10.23\ in^{2}$

$P_{effAxle} := \frac{F_{perBearing}}{A_{effAxle}} = 388.668\ psi$

$v_{surf} := \omega_{hammer}(180 \cdot deg, ffd) \cdot \frac{d_{axle}}{2} = 1.459\ \frac{m}{s}$

$\omega_{hammer}(180 \cdot deg, ffd) = 506.516\ rpm$

$PV := P_{effAxle} \cdot v_{surf} = \left(1.116 \cdot 10^{5}\right)\ \frac{ft}{min} \cdot psi$

hat s too small a diameter for an aluminum axle

$\tau_{y2\_6061} := 30 \cdot ksi$

$\tau_{y1\_6061} := 27\ ksi$

$A_{double} := 2 \cdot \pi \cdot \left(\frac{d_{axle}}{2}\right)^{2} = 7.365\ in^{2}$

$P_{swing} := \frac{F_{max}}{A_{double}} = 1.08\ ksi$ ow totally fine.

orce on chain idlers support structure

$\theta_{idler} := 159.2 \cdot deg$

$F_{halfIdler} := F_{max} \cdot \cos\left(\dfrac{\theta_{idler}}{2}\right) = \left(1.436 \cdot 10^{3}\right)\ lbf$

$F_{idler} := 2 \cdot F_{halfIdler} = \left(2.871 \cdot 10^{3}\right)\ lbf$

$\sigma_{y1\_4\_20bolt} := 5730 \cdot lbf$ per bolt area

according to ikipedia it s approxmiately true that

$\tau_{y1\_4\_20bolt} := 0.58 \cdot \sigma_{y1\_4\_20bolt} = \left(3.323 \cdot 10^{3}\right)\ lbf$

$SF_{idlerbolt} := \dfrac{\tau_{y1\_4\_20bolt}}{F_{halfIdler}} = 2.315$

$\sigma_{y6061} := 42 \cdot ksi$

$\tau_{y6061} := 0.55 \cdot \sigma_{y6061} = 23.1\ ksi$

$e_{dist} := 1.492 \cdot in$

$F_{tearout} := \tau_{y6061} \cdot e_{dist} \cdot 0.25\ in = \left(8.616 \cdot 10^{3}\right)\ lbf$

$SF_{tearout} := \dfrac{F_{tearout}}{F_{halfIdler}} = 6.002$

rive dog shear and bearing loads

$A_{shear.sprocket} := 1.3\ in^{2}$ $A_{shear.shaft} := 1.286\ in^{2}$

$n_{dog.sprocket} := 6$ $r_{dog.shaft} := 1.286\ in$

$r_{dog.sprocket} := 1.8\ in$

$F_{dog.sprocket} := \dfrac{T_{axle}(0, ffd)}{r_{dog.sprocket}} = \left(1.688 \cdot 10^{4}\right)\ lbf$

$P_{shear.sprocket} := \dfrac{F_{dog.sprocket}}{n_{dog.sprocket} \cdot A_{shear.sprocket}} = 2.163\ ksi$

$F_{dog.shaft} := \dfrac{T_{axle}(0, ffd)}{r_{dog.shaft}} = \left(2.362 \cdot 10^{4}\right)\ lbf$

$$P_{shear.shaft} := \frac{F_{dog.shaft}}{n_{dog.sprocket} \cdot A_{shear.shaft}} = 3.061\ ksi$$

$$r_{bearing.shaft} := 1.5\ in$$

$$t_{shaft} := 0.7\ in \qquad l_{shaft} := 0.54\ in$$

$$F_{bearing.shaft} := \frac{T_{axle}(0, ffd)}{r_{bearing.shaft}} = \left(2.025 \cdot 10^4\right)\ lbf$$

$$P_{bearing.shaft} := \frac{F_{bearing.shaft}}{n_{dog.sprocket} \cdot t_{shaft} \cdot l_{shaft}} = 8.929\ ksi$$

Shear Stress on asteners Sprocket and Hammer

$$r_{bolt.sprocket} := \frac{2.5}{2}\ in = 1.25\ in$$ olt radius

$$F_{bolt.sprocket} := \frac{T_{axle}(0, ffd)}{r_{bolt.sprocket}} = \left(2.43 \cdot 10^4\right)\ lbf$$ orce per bolt

$$d_{bolt.sprocket} := 0.25\ in$$ iameter of bolt

$$A_{bolt.sprocket} := \pi \cdot \left(\frac{d_{bolt.sprocket}}{2}\right)^2 = 0.049\ in^2$$ rea per bolt

$$n_{bolt} := 12$$ of bolts

$$\tau_{Gr.8.bolt} := 150\ ksi$$ rade 8 bolt yield

$$P_{bolt.sprocket} := \frac{F_{bolt.sprocket}}{n_{bolt} \cdot A_{bolt.sprocket}} = 41.253\ ksi$$ Stress per bolt

$$FoS := \frac{\tau_{Gr.8.bolt}}{P_{bolt.sprocket}} = 3.636$$ actor of Safety

$$r_{bolt.hammer} := \frac{4.5}{2}\ in = 2.25\ in$$

$$F_{bolt.hammer} := \frac{T_{axle}(0, ffd)}{r_{bolt.hammer}} = \left(1.35 \cdot 10^4\right)\ lbf$$

$n_{bolt.hammer} := 12$

$$P_{bolt.hammer} := \frac{F_{bolt.hammer}}{n_{bolt.hammer} \cdot A_{bolt.sprocket}} = 22.918\ ksi$$

Hammer xle Torsional Stress and Stiffness

$r_{axle.o} := 1.8\ in$ xle outside radius

$r_{axle.i} := \frac{2.9}{2}\ in = 1.45\ in$ xle inside radius

$l_{axle.hollow} := 3.3\ in$ ength of axle that s hollow

$J_{axle} := 2 \cdot \pi \cdot \left(r_{axle.o}{}^4 - r_{axle.i}{}^4\right)$ Polar moment of inertia

$\tau_{shear.mod.7075} := 3900\ ksi$ Shear modulus of 0

$$\tau_{shear.axle} := \frac{r_{axle.o} \cdot T_{axle}(0, ffd)}{J_{axle}} = 1.432\ ksi$$ Shear stress

$$\theta_{axle} := \frac{T_{axle}(0, ffd) \cdot l_{axle.hollow}}{J_{axle} \cdot \tau_{shear.mod.7075}} = 0.039\ deg$$ Torsional deflection