Hammer operation

The pneumatic hammer makes efficient use of air by allowing an initial charge of air to expand during the throw phase. The initial charge is metered by opening the fill valve on command and closing it once the hammer has passed a specified angle, or by leaving the valve open for a maximum time.

** Hammer throw energy calculations here **

Braking

During the retract phase, the same techniques is used in the retract cylinder. To prevent the hammer from colliding with its stop, the hammer is decelerated by compressing air in the throw cylinder.

The energy that can be absorbed by the throw cylinder to brake the retract motion between the angle of initial braking $\bar{\theta}$ and final stopping angle of θ_s is

$$E_{brake} = -\int_{\bar{\theta}}^{\theta_s} P(\theta)dV(\theta)$$

Making a simplifying (and incorrect) assumption that the process is isothermal

$$P(\theta) = \frac{P_{atm}V(\bar{\theta})}{V(\theta)}$$

The volume of the throw cylinder is linear in throw angle as the throw chain wraps around its sprocket at p_r.

$$V(\theta) = \pi r_{throw}^2 p_r \theta$$

Solving

$$E_{brake} = -\int_{\bar{\theta}}^{\theta_s} \frac{P_{atm}\pi r_{throw}^2 p_r \bar{\theta}}{\pi r_{throw}^2 p_r \theta} \pi r_{throw}^2 p_r d\theta$$

$$E_{brake} = -P_{atm}\pi r_{throw}^2 p_r \bar{\theta} \int_{\bar{\theta}}^{\theta_s} \frac{d\theta}{\theta}$$

$$E_{brake} = -P_{atm}\pi r_{throw}^2 p_r \bar{\theta}(\ln \theta_s - \ln \bar{\theta})$$

$$E_{brake} = P_{atm}\pi r_{throw}^2 p_r \bar{\theta} \ln \frac{\bar{\theta}}{\theta_s}$$

Close the vent valve when the hammer energy becomes greater than the braking energy with a suitable stopping angle θ_s.

$$\frac{1}{2} I \omega^2 \geq E_{brake}$$

$$\frac{1}{2} I \omega^2 \geq P_{atm} \pi r_{throw}^2 p_r \theta \ln \frac{\theta}{\theta_s}$$

Description	Parameter	Value	Units
Atmospheric Pressure	P_{atm}	101325	Pa
Hammer Moment of Inertia	I	1.818	$kg\, m^2$
Throw Cylinder Radius	r_{throw}	0.0762	m
Throw Sprocket Pitch Radius	p_r	0.0964	m
Hammer Angle	θ		rad
Hammer Brake Angle	$\bar{\theta}$		rad
Hammer Stop Angle	θ_s	0.0873	rad

I think the efficient way to evaluate the braking condition is

$$\frac{\frac{1}{2} I}{P_{atm} \pi r_{throw}^2 p_r} \omega^2 \geq \theta \ln \frac{\theta}{\theta_s}$$

Checking units.

$$\frac{[kg][m]^2}{[kg][m]^{-1}[s]^{-2}[m]^2[m]} = [s]^2$$

Numerically

$$5.102e - 3\omega^2 \geq \theta \ln \frac{\theta}{\theta_s}$$

Sensor calibration.

ADC Converter

The ADC uses a $V_{ref} 5V$ reference and makes a $n = 10$ bit conversion. This means an ADC code of c gives

$$V(c) = \frac{c * V_{ref}}{2^n} = \frac{c * 5}{1024}$$

A convenient scale for representing voltage in a 16bit signed value is mV, calculated as

$$V(c) = c * 4 + c * \frac{22}{25}$$

Hammer Angle

The voltage from the hammer angle sensor should always be $0.5V \leq v \leq 4.5V$, voltages outside this range indicate a disconnected or damaged sensor.

The hammer angle sensor reads $v_{min} = 4.004V$ at $\theta = 0$ and $v_{max} = 1.941V$ at $\theta = \pi$.

Symbolically

$$\theta(v) = \frac{v - v_{min}}{v_{max} - v_{min}} \pi$$

With the values measured from our current assembly

$$\theta(v) = (4.004 - v) * 6.481$$

When stored as a 16-bit signed value as scaled from ADC counts, this can be scaled to miliradians

$$\theta(c) = (820 - c) * 37/5 + (820 - c) * 2/100$$

Pressure Sensors

The pressure sensor on both cylinders is an SSI Technologies P51-500-A-B-I36-4.5V.

The pressure sensor voltages should always be $0.5V \leq v \leq 4.5V$, voltages outside this range indicate a disconnected or damaged sensor.

This sensor has a $P_{max} = 500PSIA = 3.447e6Pa$ full-scale reading at $v_{max} = 4.5V$ and a voltage of $v_{min} = 0.5V$ at $P_{min} = 0$ absolute pressure.

The absolute pressure is

$$P(v) = \frac{(v - v_{min})(P_{max} - P_{min})}{v_{max} - v_{min}} + P_{min}$$

In Pa,

$$P(v) = (v - 0.5) * 8.618e5$$

When stored in a 16 bit signed value, this can be scaled to kPa as scaled from ADC counts

$$P(c) = (c - 102) * 24/5$$