Ecoflex: 400 mL = 1 lb

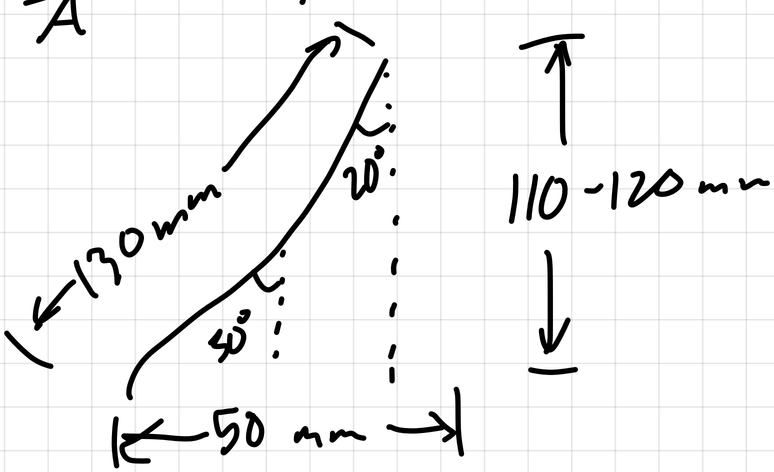
Required size for sensor: $6 \times 6 \times 6\ mm^3 = 0.216\ mL$

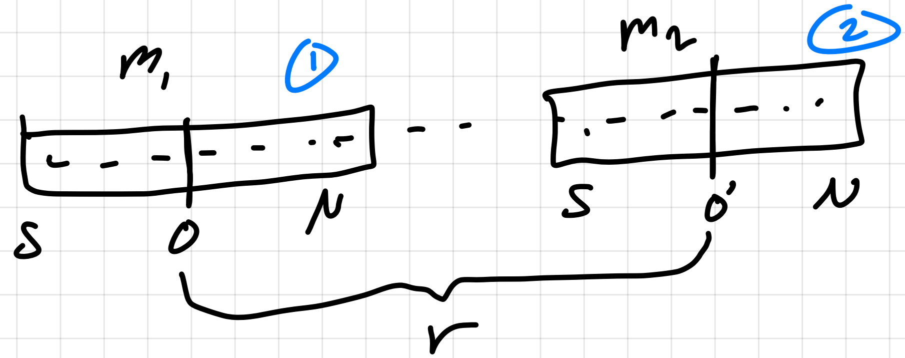
$$\frac{\$42.99}{2\ lb} \cdot \frac{1\ lb}{400\ mL} \cdot \frac{0.216\ mL}{1\ sensor} = \$0.012$$

$$7\ kPa = 7\ \frac{kN}{m^2}$$

$$A = 36\ mm^2 = 36 \times 0.001^2\ m^2 = 36 \times 10^{-6}\ m^2$$

$$P = \frac{F}{A} \rightarrow F = P \cdot A = 7\ \frac{kN}{m^2} \cdot 36 \times 10^{-6}\ m^2 = 0.252\ N$$





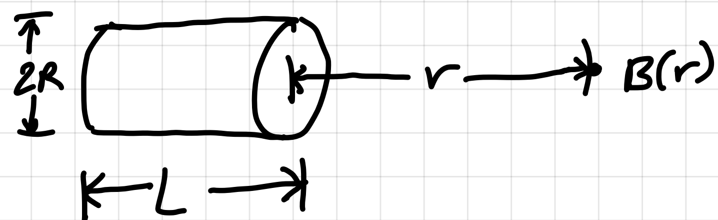
$$\tau = mB\sin\theta$$

$$U = -mB\cos\theta$$

$$F = -\frac{dU}{dr}$$

magnetic field due to 1 on 2

$$B_1 = \frac{\mu_0}{4\pi}\cdot\frac{2m_1}{r^3}$$ (from south to North of 1)



$$B(r) = \frac{B_{residual}}{2}\left[\frac{L+r}{\sqrt{R^2+(L+r)^2}} - \frac{r}{\sqrt{R^2+r^2}}\right]$$

$$U_2 = -m_2 B_1 \cos\theta \,, \quad \theta = 0^\circ$$

$$U_2 = -m_2 B_1 = -\frac{m_2 B_{res}}{2}\left[\frac{L+r}{\sqrt{R^2+(L+r)^2}} - \frac{r}{\sqrt{R^2+r^2}}\right]$$

$$F_2 = -\frac{dU_2}{dr} = -\frac{d}{dr}\left[\frac{m_2 B_{res}}{2}\left(\frac{L+r}{\sqrt{R^2+(L+r)^2}} - \frac{r}{\sqrt{R^2+r^2}}\right)\right]$$

$$-\frac{m_2 B_{res}}{2}$$

$$\frac{d}{dr}\left[\frac{L+r}{\sqrt{R^2+(L+r)^2}}\right] = \frac{\left(\sqrt{R^2+(L+r)^2}\right)(1) - (L+r)\frac{d}{dr}\left[\sqrt{R^2+(L+r)^2}\right]}{R^2+(L+r)^2}$$

$$= \frac{\sqrt{R^2+(L+r)^2} - (L+r)\frac{L+r}{\sqrt{R^2+(L+r)^2}}}{R^2+(L+r)^2}$$

$$\frac{d}{dr}\left[\frac{-r}{\sqrt{R^2+r^2}}\right] = -\left(\frac{\sqrt{R^2+r^2} - r\left(\frac{L+r}{R^2+(L+r)^2}\right)}{R^2+r^2}\right)$$

$$F_2 = -\frac{dU_2}{dr} = -\frac{m_2 Bres}{2}\left(\frac{\sqrt{R^2+(L+r)^2} - (L+r)\frac{L+r}{\sqrt{R^2+(L+r)^2}}}{R^2+(L+r)^2} + \frac{\frac{rL+r^2}{R^2+(L+r)^2} - \sqrt{R^2+r^2}}{R^2+r^2}\right)$$

$$F(r) = \frac{-0.65r^2 m_2}{\sqrt{(256+r^2)^3}} + \frac{0.65m_2}{\sqrt{256+r^2}} + \frac{2.6\, m_2}{\sqrt{(256+(2+r)^2)^3}} + \frac{2.6r\, m_2}{\sqrt{(256+(2+r)^2)^3}}$$

$$+ \frac{0.65r^2 m_2}{\sqrt{(256+(2+r^2))^3}} - \frac{0.65\, m_2}{\sqrt{256+(2+r)^2}}$$

$$\boxed{F(r) = \frac{-0.65r^2 m_2}{\sqrt{(256+r^2)^3}} + \frac{0.65m_2}{\sqrt{256+r^2}} + \frac{2.6\, m_2}{\sqrt{(256+(2+r)^2)^3}} + \frac{2.6r\, m_2}{\sqrt{(256+(2+r)^2)^3}} + \frac{0.65r^2 m_2}{\sqrt{(256+(2+r^2))^3}} - \frac{0.65\, m_2}{\sqrt{256+(2+r)^2}}}$$

$$m_2 = 5.5\,g/cm^3 \cdot \frac{1\,cm^3}{10^3\,mm^3} \cdot \pi \left(\frac{5}{2}\right)^2 \cdot 2\,mm^3 = 0.216\,g$$

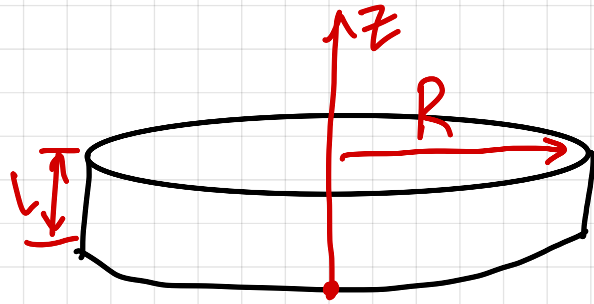
To log Arduino::Serial.print to .txt:

1) cd into directory of desired .txt path
2) script -a -t0 filename.txt
3) screen /dev/$\underbrace{\text{cu.usbmodem11301}}_{\text{serial port of Arduino}}$ $\underbrace{115200}_{\text{baud rate}}$

To stop logging:

1) ctrl+A then ctrl+K
2) ctrl+D

$$B(z) = \frac{\mu_0 M}{2}\left(\frac{z}{\sqrt{z^2+R^2}} - \frac{z-L}{\sqrt{(z-L)^2+R^2}}\right)$$



$$T = \frac{N}{A\cdot m}$$

$$\mu_0 = \frac{N}{A^2}$$

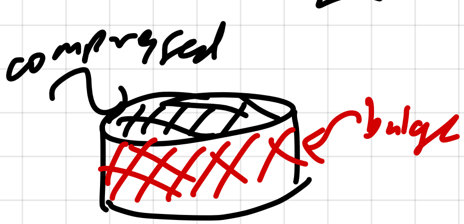
$$\left[\frac{N}{A^2}\right][M] = \left[\frac{N}{A\cdot m}\right]$$

$$[M] = \frac{A}{m}$$

$$B(z) = \alpha\left(\frac{z}{\sqrt{z^2+5^2\,\mathrm{mm}^2}} - \frac{z-2\,\mathrm{mm}}{\sqrt{(z-2\,\mathrm{mm})^2+5^2\,\mathrm{mm}^2}}\right)$$

$$\Delta = \frac{P}{\gamma(1+2f^2)} = \frac{\frac{mg}{A}}{\gamma(1+2f^2)} = \frac{mg}{\gamma A(1+2f^2)}$$

% of original thickness



$$f = \frac{\pi R^2}{2\pi R L} = \frac{25\pi\,\mathrm{mm}^2}{20\pi\,\mathrm{mm}^2} = \frac{5}{4} = 1.25$$

$$Z = \tau_i - \Delta\tau_i - \tau_m$$

$$z = \tau_e\left(1 - \frac{\beta m}{\pi R_e^2}\right) - \tau_m$$

$$B_z = \alpha\left(\frac{z+\tau_m}{\sqrt{(z+\tau_m)^2 + R_m^2}} - \frac{z}{\sqrt{z^2 + R_m^2}}\right)$$

$$B_z = \alpha\left(\frac{\tau_e\left(1 - \frac{\beta m}{\pi R_e^2}\right) \cancel{- \tau_m} + \cancel{\tau_m}}{\sqrt{\left(\tau_e\left(1 - \frac{\beta m}{\pi R_e^2}\right) \cancel{- \tau_m} + \cancel{\tau_m}\right)^2 + R_m^2}} - \frac{\tau_e\left(1 - \frac{\beta m}{\pi R_e^2}\right) - \tau_m}{\sqrt{\left(\tau_e\left(1 - \frac{\beta m}{\pi R_e^2}\right) - \tau_m\right)^2 + R_m^2}}\right)$$

$$B_z = \frac{\alpha \tau_e\left(1 - \frac{\beta M}{\pi R_e^2}\right)}{\sqrt{\left(\tau_e\left(1 - \frac{\beta M}{\pi R_e^2}\right)\right)^2 + R_m^2}} - \frac{\alpha \tau_e\left(1 - \frac{\beta M}{\pi R_e^2}\right) - \alpha \tau_m}{\sqrt{\left(\tau_e\left(1 - \frac{\beta M}{\pi R_e^2}\right) - \tau_m\right)^2 + R_m^2}}$$

$$B_z = \frac{d\tau_e - d\tau_e \frac{\beta}{\pi R_e^2} M}{\sqrt{\tau_e^2 - 2\tau_e^2 \frac{\beta M}{\pi R_e^2} + \tau_e^2 \frac{\beta^2 M^2}{\pi^2 R_e^4} + R_m^2}} - \frac{d\tau_e + d\frac{\tau_e \beta M}{\pi R_e^2} - d\tau_m}{\sqrt{\tau_e^2 \frac{\beta^2 M^2}{\pi^2 R_e^4} + 2\tau_e\tau_m \frac{\beta M}{\pi R_e^2} + \tau_m^2 - 2\tau_e\tau_m - \tau_e^2 \frac{\beta M}{\pi R_e^2} + R_m^2}}$$

$$\left(\tau_e - \tau_e \frac{\beta M}{\pi R_e^2}\right)\left(\tau_e - \tau_e \frac{\beta M}{\pi R_e^2}\right) = \tau_e^2 - 2\tau_e^2 \frac{\beta M}{\pi R_e^2} + \tau_e^2 \frac{\beta^2 M^2}{\pi^2 R_e^4}$$

$$\left(\tau_e - \tau_e \frac{\beta M}{\pi R_e^2} - \tau_m\right)\left(\tau_e - \tau_e \frac{\beta M}{\pi R_e^2} - \tau_m\right)$$

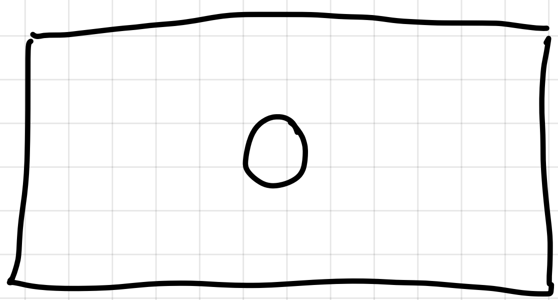
$$= \cancel{\tau_e^2} - \tau_e^2 \frac{\beta M}{\pi R_e^2} \underline{- \tau_e\tau_m} - \cancel{\tau_e^2} + \tau_e^2 \frac{\beta^2 M^2}{\pi^2 R_e^4} + \underline{\tau_e\tau_m \frac{\beta M}{\pi R_e^2}} \underline{- \tau_e\tau_m} + \underline{\tau_e\tau_m \frac{\beta M}{\pi R_e^2}} + \tau_m^2 = \tau_e^2 \frac{\beta^2 M^2}{\pi^2 R_e^4} + 2\tau_e\tau_m \frac{\beta M}{\pi R_e^2} + \tau_m^2 - 2\tau_e\tau_m - \tau_e^2 \frac{\beta M}{\pi R_e^2}$$

Time (s)	Mass (g)
38	1.07
68	2.46
109	3.93
135	6.73
158	8.46
185	12.75
209	14.17
227	15.95
261	16.96

Experimental Design:

30 data points →

1kg @ 10s/sample = 0.5g/sample for 5 minutes



1kg/L = 1g/mL = 1g/cc

$50\ cm^3 = 50 \times 10^3 = 50{,}000\ mm^3$

$50 \times 50 \times ? = 50{,}000\ mm^3$

2500

$$2{,}500 \overline{)\,50{,}000} \quad 20$$

Test #2:

Jump	Mass (g)
Ø	Ø
1	0.44
2	1.10
3	2.02
4	3.37
5	4.18
6	5.36
7	6.69
8	8.13
9	9.32
10	11.12
11	12.15
12	12.99

Test 3

Sample	Mass (g)
1	0
2	0.90
3	1.96
4	2.92
5	3.79
6	4.75
7	5.80
8	6.73
9	7.62
10	8.58
11	9.56
12	10.58
13	11.54
14	12.49
15	13.55
16	14.56
17	15.68
18	16.84
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	

Sample	Mass (g)

Sample	Mass (g)

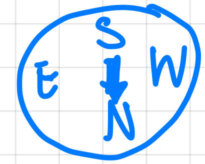
Sample	Mass (g)

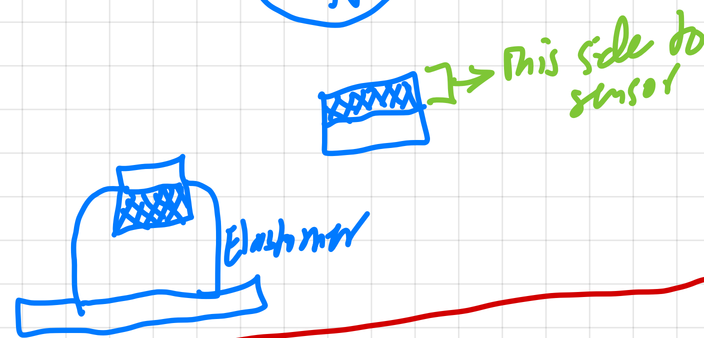
Sample	Mass (g)

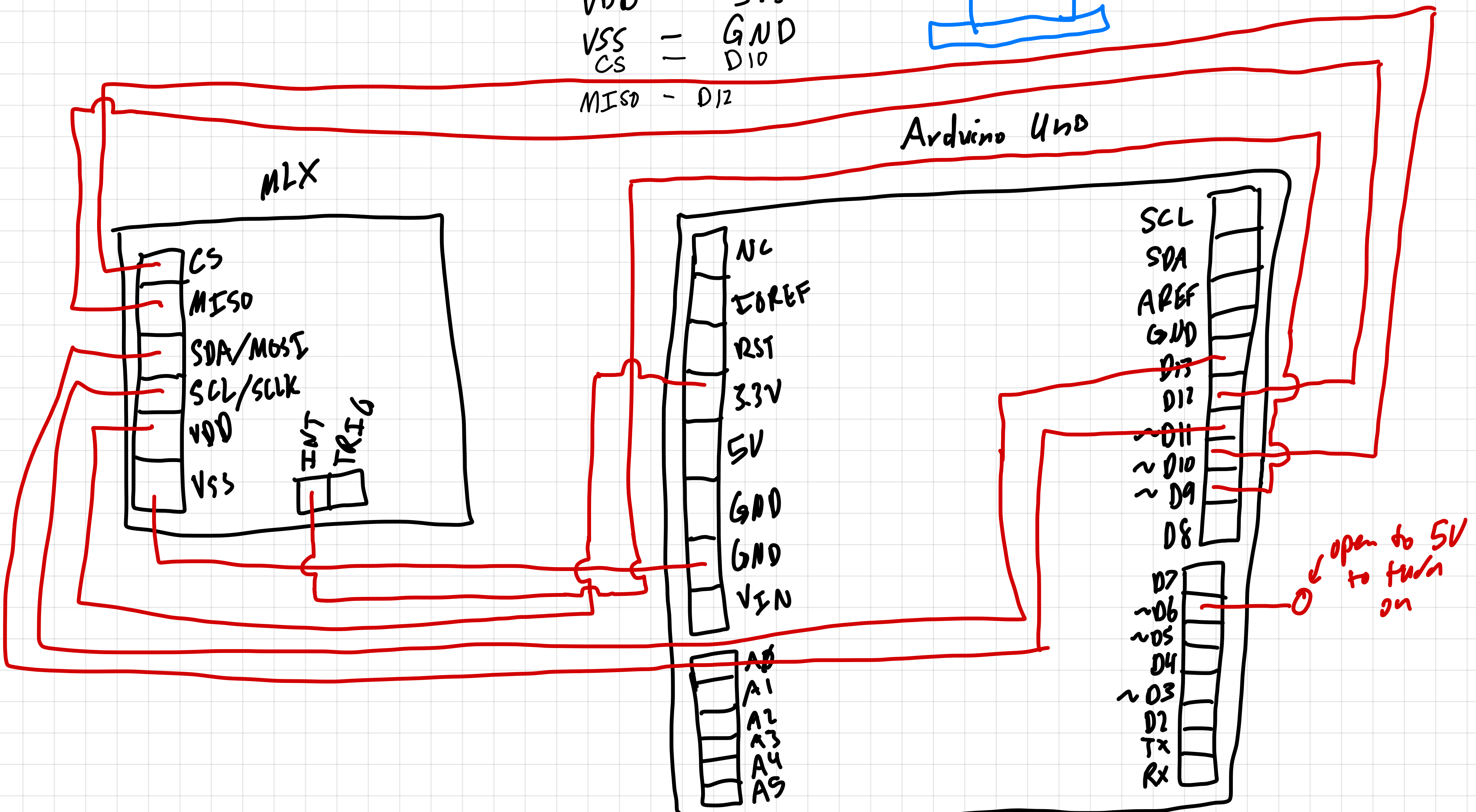
* North of magnet is facing the sensor

Connections

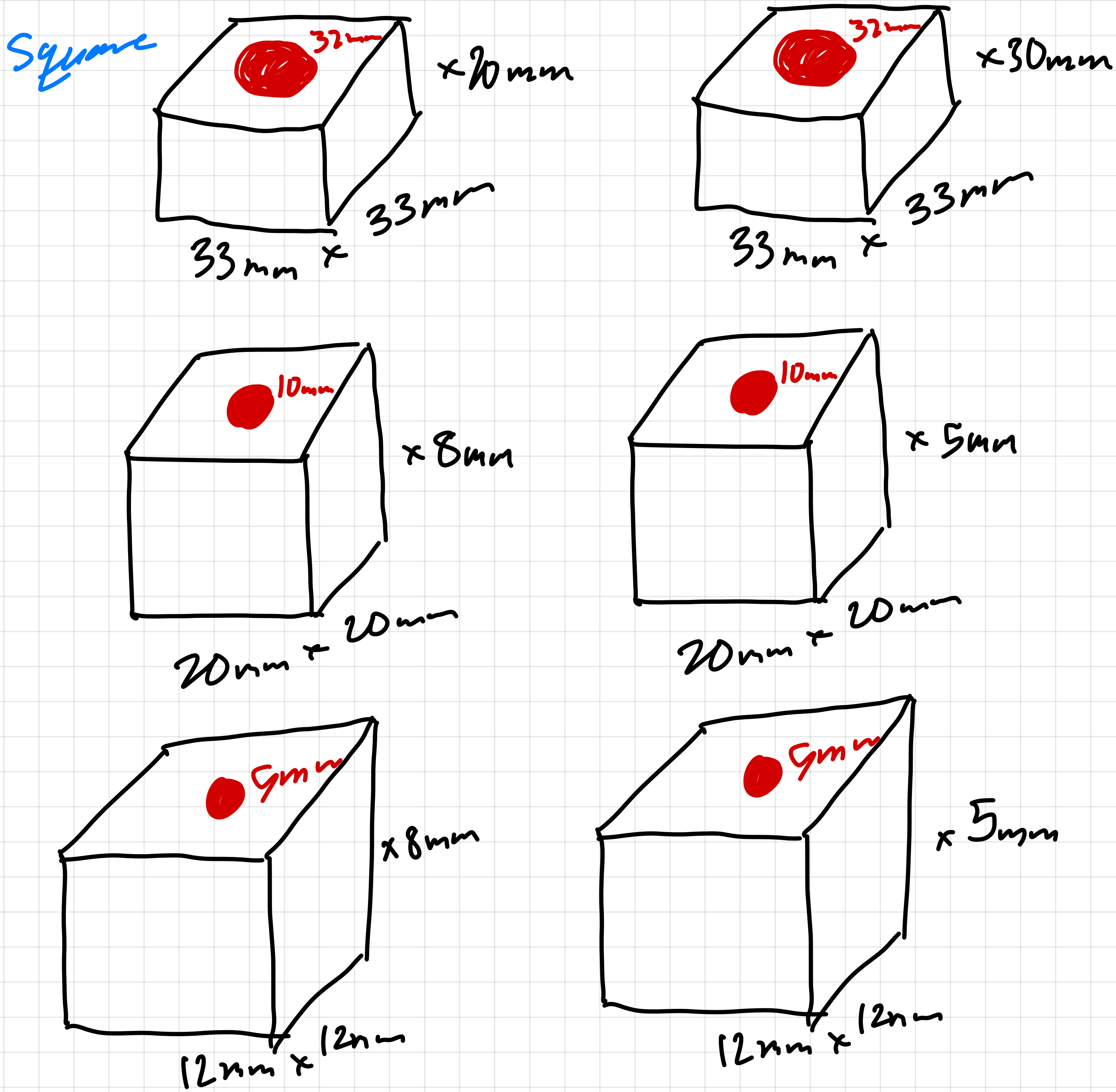
MLX		Arduino Uno
SDA	—	D6/A4/D11
SCL	—	D7/A5/D13
(DRDY) INT	—	D9
VDD	—	3.3V
VSS	—	GND
CS	—	D10
MISO	—	D12







Elastomer Designs



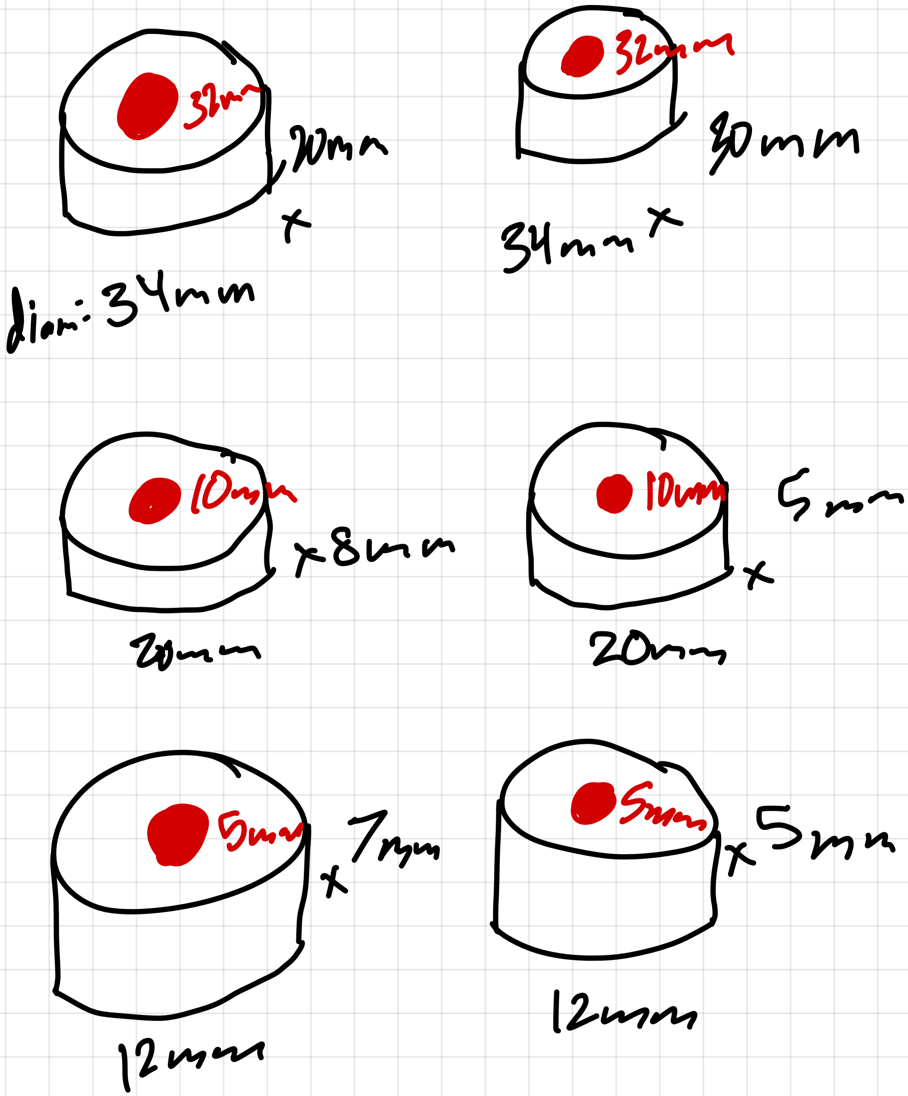
Material:

- ☐ VytaFlex 20
- ☐ EcoFlex 00-50
- ☐ EcoFlex 00-20
- ☐ EcoFlex 00-10

Gains:

- ☐ 1x
- ☐ 2x
- ☐ 2.5x
- ☐ 3x
- ☐ 4x
- ☐ 5x

Circle

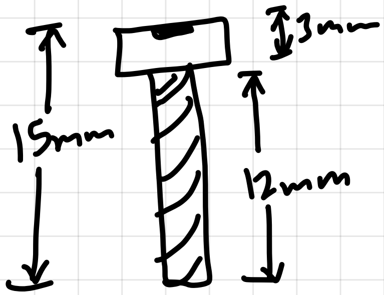


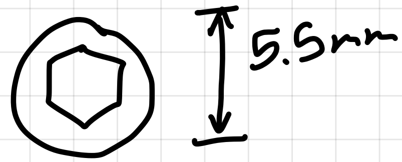
Material:

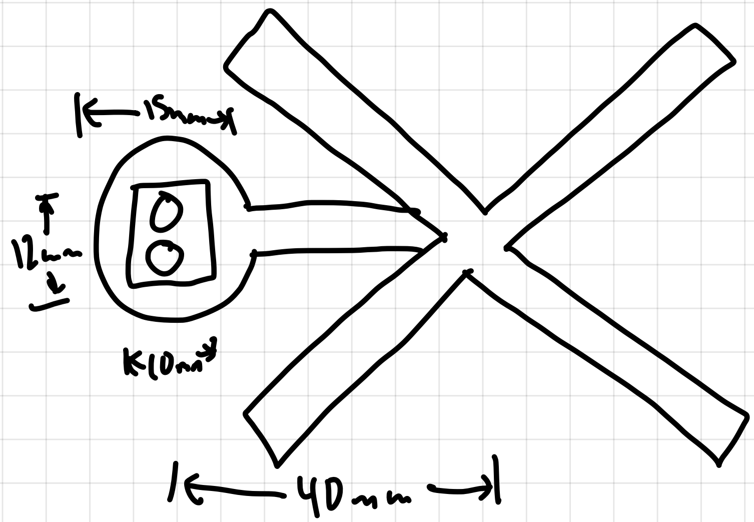
- ☐ VytaFlex 20
- ☐ EcoFlex 00-50
- ☐ EcoFlex 00-20
- ☐ EcoFlex 00-10

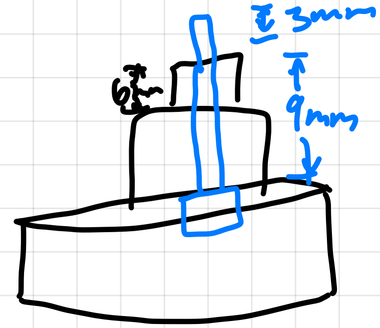
Gain:

- ☐ 1x
- ☐ 2x
- ☐ 2.5x
- ☐ 3x
- ☐ 4x
- ☐ 5x





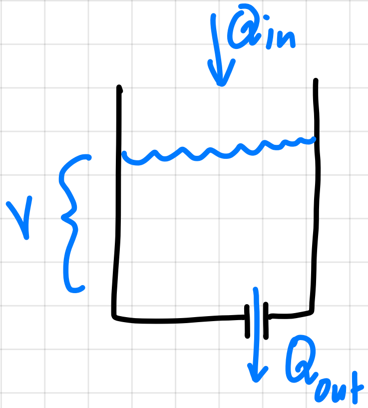




Print Times/Volumes:

Load Cell Bottom → 6hr / 36.24 mL
Load Cell Top → 7hr / 110.33 mL
Anchor Magnetic Section → 7.5hr / 107.15 mL
Anchor Filleted Section → 7.5hr / 230.04 mL

Dynamic Testing



$$\boxed{\frac{dV}{dt} = Q_{in} - Q_{out}}$$

$$Q_{in} = Q_{out} + \frac{dV}{dt} = v A_e C_d + \frac{dV}{dt}$$

$$\boxed{v = \sqrt{2gh}}$$

$g = 9.81\,m/s^2$

h = height of fluid

A_e = exit cross-sectional area

v = velocity V = volume

C_d = discharge coefficient (found experimentally)

$$Q_{in} = \frac{dV}{dt} + \sqrt{2gh}\, A_e C_d$$

$$\rho = \frac{m}{V}$$

h is derived from magnetometer reading:

$$h = \frac{m}{\rho A_c}\ ,$$

m = mass from magnetometer [kg]
ρ = density of water [kg/m³]
A_c = chamber cross-sectional area [m²]

$$Q_{in} = \frac{dV}{dt} + \sqrt{2g\frac{m}{\rho A_c}}\, A_e C_d$$

$$\frac{dV}{dt} = \frac{V_f - V_i}{\Delta t} = \frac{C_v\left(\sqrt{2g\frac{m_f}{\rho A_c}}A_e - \sqrt{2g\frac{m_i}{\rho A_c}}A_e\right)}{\Delta t} = \frac{A_e\sqrt{\frac{2g}{\rho A_c}}\left(\sqrt{m_f} - \sqrt{m_i}\right)C_v}{\Delta t}$$

$$\boxed{Q_{in} = \frac{C_v A_e\sqrt{\frac{2g}{\rho A_c}}\left(\sqrt{m_f} - \sqrt{m_i}\right)}{\Delta t} + \sqrt{2g\frac{m_f}{\rho A_c}}A_e C_d}$$

C_v = coefficient of velocity (experimentally determined)

$$m = \alpha x + \beta$$

m = mass (g)
α, β = constants given by calibration
x = B-field measurement (μT)

$$\boxed{Q_{in} = \frac{C_v A_e\sqrt{\frac{2g}{\rho A_c}}\left(\sqrt{\alpha x_f + \beta} - \sqrt{\alpha x_i + \beta}\right)}{\Delta t} + \sqrt{2g\frac{\alpha x_f + \beta}{\rho A_c}}A_e C_d}$$

$$\frac{C_v A_e \sqrt{\frac{2g}{\rho A_c}(\alpha x_f+\beta-\alpha x_i+\beta)}}{\Delta t} + \sqrt{\frac{2g}{\rho A_c}(\alpha x_f+\beta)}\, A_e C_d$$

$$\downarrow$$

$$Q_{in} = \frac{C_v A_e \sqrt{\frac{2g\alpha}{\rho A_c}(x_f-x_i)}}{\Delta t} + \sqrt{\frac{2g}{\rho A_c}(\alpha x_f+\beta)}\, A_e C_d$$

$$= \frac{C_v A_e \sqrt{\frac{2g}{\rho A_c}}\sqrt{(x_f-x_i)}}{\Delta t} + \sqrt{\frac{2g}{\rho A_c}}\sqrt{\alpha x_f+\beta}\, A_e C_d$$

$$= A_e \sqrt{\frac{2g}{\rho A_c}} \left(\frac{C_v\sqrt{x_f-x_i}}{\Delta t} + C_d\sqrt{\alpha x_f+\beta} \right)$$

$$\frac{\sqrt{2}\, A_e \left(\Delta t\, C_d \sqrt{\frac{g(\alpha x_f+\beta)}{\rho A_c}} + C_v\left(\sqrt{\frac{g(\beta+\alpha x_f)}{\rho A_c}} - \sqrt{\frac{g(\beta+\alpha x_i)}{\rho A_c}}\right)\right)}{\Delta t}$$

$$\frac{\sqrt{2}\, A_e \left(\Delta t\, C_d \sqrt{\frac{g(\alpha x_f + \beta)}{\rho A_c}} + C_v \left(\sqrt{\frac{g(\beta + \alpha x_f)}{\rho A_c}} - \sqrt{\frac{g(\beta + \alpha x_i)}{\rho A_c}} \right) \right)}{\Delta t}$$

$$Q_{in} = \frac{C_v A_e \sqrt{\frac{2g\alpha}{\rho A_c}} \left(\sqrt{x_f - x_i} \right)}{\Delta t} + \sqrt{2g \frac{\alpha x_f + \beta}{\rho A_c}}\, A_e C_d$$

C_v = coefficient of velocity for fluid (unitless/experimentally determined)

A_e = exhaust cross-sectional area (m^2)

g = gravitational acceleration (9.81 m/s^2)

α = calibrated slope for B-field → mass conversion (kg/μT)

β = calibrated y-int for B-field → mass conversion (kg)

x_f = final measured B-field (μT)

x_i = initial measured B-field (μT)

ρ = density of fluid (kg/m^3)

A_c = chamber cross-sectional area (m^2)

C_d = coefficient of discharge for fluid (unitless/experimentally determined)

Δt = increment of measurement (s)

Dimensional Analysis:

$$Q_{in} = \frac{C_v A_e \sqrt{\frac{2g\alpha}{\rho A_c}}\left(\sqrt{x_f - x_i}\right)}{\Delta t} + \sqrt{2g\frac{\alpha x_f + \beta}{\rho A_c}}\; A_e C_d$$

$$= \frac{[\text{unitless}][m^2]\sqrt{\frac{[m/s^2]\,\cancel{[kg/\mu T]}}{\cancel{[kg}/m^3][m^2]}}\left(\sqrt{\cancel{[\mu T]}}\right)}{[s]} + \sqrt{\frac{[m/s^2]\left([kg/\mu T][\mu T] + [kg]\right)}{[kg/m^3][m^2]}}\;[m^2][\text{unitless}]$$

$$\frac{m^2 \cdot \sqrt{\frac{m \cdot m^3}{m^2 \cdot s^2}}}{s} = \frac{m^2 \cdot \sqrt{\frac{m^2}{s^2}}}{s}$$

$$= \frac{m^2 \cdot \frac{m}{s}}{s} = \frac{m^3}{s^2}$$

$$\frac{dV}{dt} = Q_{in} - Q_{out} \rightarrow \quad Q_{in} = \frac{dV}{dt} + Q_{out}$$

$$Q_{out} = C_d A_e \sqrt{2g\frac{m}{\rho A_c}}$$

$$Q_{in} = \frac{dV}{dt} + C_d A_c \sqrt{2g \frac{m}{\rho A_c}}$$

$$\frac{dV}{dt} = \frac{V_f - V_i}{\Delta t}$$

$$V = Ah = \frac{m}{\rho}$$

$$Q_{in} = \frac{\frac{m_f}{\rho} - \frac{m_i}{\rho}}{\Delta t} + C_d A_c \sqrt{2g \frac{m_f}{\rho A_c}}$$

$$= \frac{m_f - m_i}{\rho \Delta t} + C_d A_c \sqrt{2g \frac{m_f}{\rho A_c}}$$

$$= \frac{(\alpha x_f + \cancel{\beta}) - (\alpha x_i + \cancel{\beta})}{\rho \Delta t} + C_d A_c \sqrt{2g \frac{\alpha x_f + \beta}{\rho A_c}}$$

$$Q_{in} = \frac{\alpha (x_f - x_i)}{\rho \Delta t} + C_d A_c \sqrt{2g \frac{\alpha x_f + \beta}{\rho A_c}}$$

Final Derivation ($O(h)$ FFD)

$$\boxed{Q_{in} = \frac{\alpha}{\rho \Delta t}(x_f - x_i) + C_d A_e \sqrt{2g \frac{\alpha x_f + \beta}{\rho A_c}}}$$

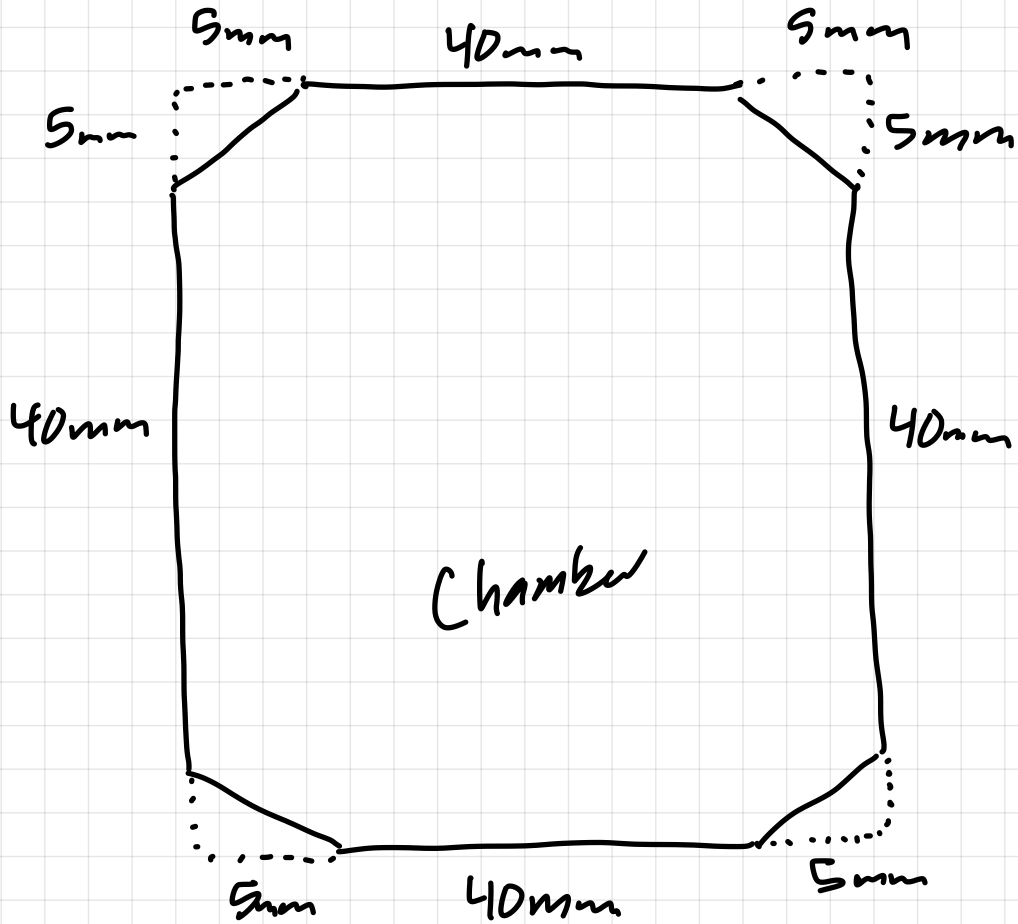
α = calibrated slope from B-field → mass conversion (kg/μT)
β = calibrated y-int from B-field → mass conversion (kg)
x_f = final B-field value (μT)
x_i = initial B-field value (μT)
ρ = density of fluid (kg/m³)
Δt = time increment (s)
C_d = coefficient of discharge of fluid (unitless/experimentally determined)
A_e = exhaust cross-sectional area (m²)
A_c = chamber cross-sectional area (m²)

Dimensional Analysis:

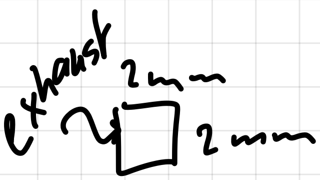
$[Q_{in}] = m^3/s$ ✓

$$\frac{[\cancel{kg}/\cancel{\mu T}]}{[\cancel{kg}/m^3][s]}[\cancel{\mu T}] + [\varnothing][m^2]\sqrt{[m/s^2]\frac{[\cancel{kg}/\cancel{\mu T}][\cancel{\mu T}] + [\cancel{kg}]}{[\cancel{kg}/m^3][m^2]}}$$

$$\frac{m^3}{s} + m^2\sqrt{\frac{m^2}{s^2}} = \frac{m^3}{s} + \frac{m^3}{s} \checkmark \quad \frac{m^3}{s}$$



$$A_c = 2460\,mm^2$$



$$A_e = 4\,mm^2$$

$$h_{max} = 60mm$$

$$m_{max} = \rho_{water} \cdot A_c h_{max} = 0.00000997 \frac{kg}{mm^3} \cdot 2460\,mm^2 \cdot 60\,mm = 147.157g$$

$$Q_{in} = \frac{dV}{dt} + C_d A_e \sqrt{2g \frac{\alpha x_\xi + \beta}{\rho A_c}}$$

$$V(t) = \frac{m_t}{\rho} = \frac{\alpha x_t + \beta}{\rho}$$

FFD:

$$\frac{dV}{dt} = \frac{V_{i+1} - V_i}{\Delta t} + O(h)$$

$$\frac{dV}{dt} = \frac{-V_{i+2} + 4V_{i+1} - 3V_i}{2\Delta t} + O(h^2)$$

BFD:

$$\frac{dV}{dt} = \frac{V_i - V_{i-1}}{\Delta t} + O(h)$$

$$\frac{dV}{dt} = \frac{3V_i - 4V_{i-1} + V_{i-2}}{2\Delta t} + O(h^2)$$

CFD:

$$\frac{dV}{dt} = \frac{V_{i+1} - V_{i-1}}{2\Delta t} + O(h^2)$$

$$\frac{dV}{dt} = \frac{-V_{i+2} + 8V_{i+1} - 8V_{i-1} + V_{i-2}}{12\Delta t} + O(h^3)$$

$$\frac{dV}{dt} = \frac{-V_{i+2} + 4V_{i+1} - 3V_i}{2\Delta t} + O(h^2)$$

$$\frac{dV}{dt} = \frac{-\frac{\alpha x_{i+2} + \beta}{\rho} + 4\,\frac{\alpha x_{i+1} + \beta}{\rho} - 3\,\frac{\alpha x_i + \beta}{\rho}}{2\Delta t} = \frac{-(\alpha x_{i+2} + \beta) + 4(\alpha x_{i+1} + \beta) - 3(\alpha x_i + \beta)}{2\rho\Delta t}$$

$$= \frac{-\alpha x_{i+2} \cancel{-\beta} + 4\alpha x_{i+1} \cancel{+4\beta} - 3\alpha x_i \cancel{-3\beta}}{2\rho\Delta t}$$

$$= \frac{-\alpha x_{i+2} + 4\alpha x_{i+1} - 3\alpha x_i}{2\rho\Delta t} = \frac{\alpha}{2\rho\Delta t}\left(4x_{i+1} - x_{i+2} - 3x_i\right)$$

FFD $O(h^2)$

$$\boxed{Q_{in} = \frac{\alpha}{2\rho\Delta t}\left(4x_{i+1} - x_{i+2} - 3x_i\right) + C_d A_e \sqrt{2g\,\frac{\alpha x_{i+2} + \beta}{\rho A_c}}}$$

$$\frac{dV}{dt} = \frac{V_i - V_{i-1}}{\Delta t}$$

$$\frac{dV}{dt} = \frac{\frac{\alpha x_i + \beta}{\rho} - \frac{\alpha x_{i-1} + \beta}{\rho}}{\Delta t} = \frac{\alpha x_i \cancel{+\beta} - \alpha x_{i-1} \cancel{+\beta}}{\rho \Delta t} = \frac{\alpha}{\rho \Delta t}(x_i - x_{i-1})$$

BFD $O(h)$:

$$\boxed{Q_{in} = \frac{\alpha}{\rho \Delta t}(x_i - x_{i-1}) + C_d A_e \sqrt{2g \frac{\alpha x_i + \beta}{\rho A_c}}}$$

$$\frac{dV}{dt} = \frac{3V_i - 4V_{i-1} + V_{i-2}}{2\Delta t}$$

$$\frac{dV}{dt} = \frac{3\frac{\alpha x_i \cancel{+\beta}}{\rho} - 4\frac{\alpha x_{i-1} \cancel{+\beta}}{\rho} + \frac{\alpha x_{i-2} \cancel{+\beta}}{\rho}}{2\Delta t} = \frac{\alpha}{2\rho \Delta t}(3x_i - 4x_{i-1} + x_{i-2})$$

BFD $O(h^2)$:

$$\boxed{Q_{in} = \frac{\alpha}{2\rho \Delta t}(3x_i - 4x_{i-1} + x_{i-2}) + C_d A_e \sqrt{2g \frac{\alpha x_i + \beta}{\rho A_c}}}$$

$$\frac{dV}{dt} = \frac{V_{i+1} - V_{i-1}}{2\Delta t}$$

$$\frac{\frac{\alpha x_{i+1} + \beta}{\rho} - \frac{\alpha x_{i-1} + \beta}{\rho}}{2\Delta t} = \frac{\alpha}{2\rho\Delta t}\left(x_{i+1} - x_{i-1}\right)$$

CFD $O(h^2)$:

$$\boxed{Q_{in} = \frac{\alpha}{2\rho\Delta t}\left(x_{i+1} - x_{i-1}\right) + C_d A_e \sqrt{2g \frac{\alpha x_{i+1} + \beta}{\rho A_c}}}$$

$$\frac{dV}{dt} = \frac{-V_{i+2} + 8V_{i+1} - 8V_{i-1} + V_{i-2}}{12\Delta t}$$

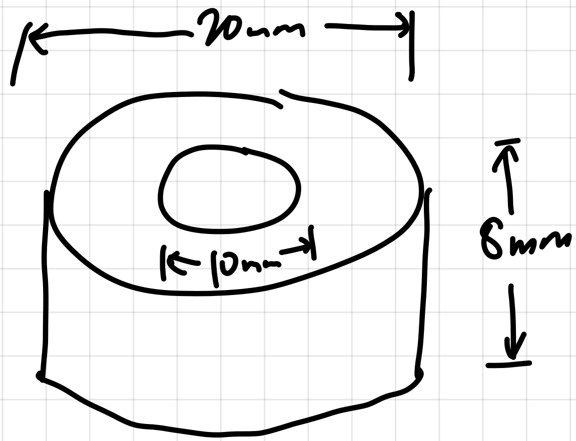
$$\frac{dV}{dt} = \frac{-\frac{\alpha x_{i+2} \cancel{+\beta}}{\rho} + 8\frac{\alpha x_{i+1} \cancel{+\beta}}{\rho} - 8\frac{\alpha x_{i-1} \cancel{+\beta}}{\rho} + \frac{\alpha x_{i-2} \cancel{+\beta}}{\rho}}{12\Delta t}$$

$$= \frac{\alpha}{12\rho\Delta t}\left(x_{i-2} + 8x_{i+1} - 8x_{i-1} - x_{i+2}\right)$$

CFD $O(h^4)$:

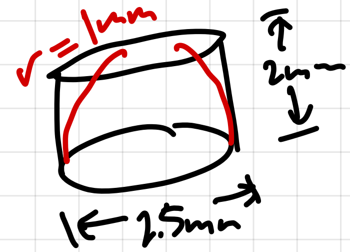
$$\boxed{Q_{in} = \frac{\alpha}{12\rho\Delta t}\left(x_{i-2} + 8x_{i+1} - 8x_{i-1} - x_{i+2}\right) + C_d A_e \sqrt{2g \frac{\alpha x_{i+2} + \beta}{\rho A_c}}}$$

C-10m-8t

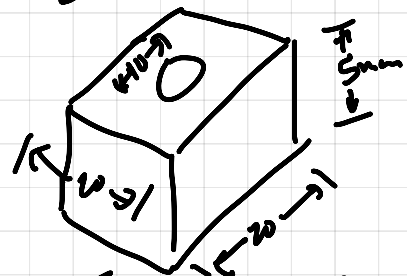


Magnet Thickness: 2.5mm

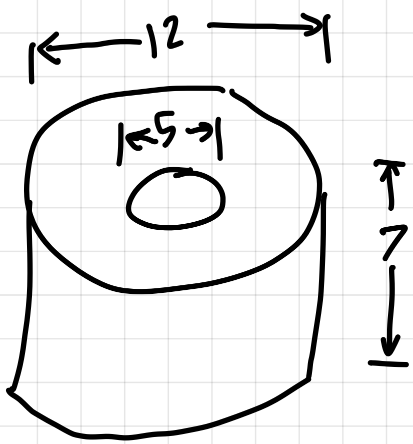
Anus Dimensions:



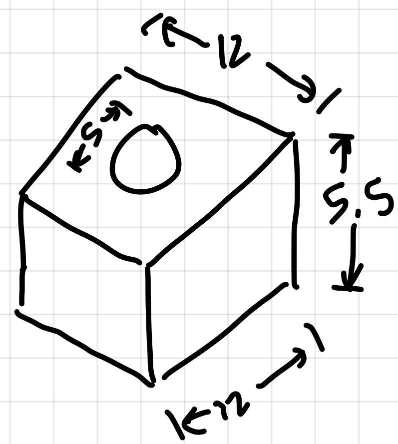
S-10m-5t



C-5m-7t



S-5m-5t



$$B(z) = \alpha\left(\frac{z+2\,mm}{\sqrt{(z+2\,mm)^2+S^2\,mm^2}} - \frac{z}{\sqrt{z^2+S^2\,mm^2}}\right)$$

$$z(m) = \frac{P}{\gamma(1+2f^2)} = \frac{\frac{mg}{A}}{\gamma(1+2f^2)} = \frac{mg}{\gamma A(1+2f^2)}$$

$$f = \frac{\pi R^2}{2\pi R L} = \frac{25\pi\,mm^2}{20\pi\,mm^2} = \frac{5}{4} = 1.25$$

$$\gamma = 12\,psi \cdot \frac{6894.76\,Pa}{1\,psi} = 82737.12\,Pa$$

$$\gamma = 82737.12\,\frac{N}{m^2} \cdot \frac{1\,m^2}{(1000)^2\,mm^2} = 0.08273712\,\frac{N}{mm^2}$$

$$A = \pi R^2 = 25\pi \qquad g = 9.81\,m/s^2 \cdot \frac{1000\,mm}{1\,m} = 9810\,\frac{mm}{s^2}$$

$$z(m) = \frac{9810\,m}{(0.08273712)(25\pi)(1+2(1.25)^2)}$$

$$B(m) = \alpha\left(\frac{\frac{9810\,m}{(0.08273712)(25\pi)(1+2(1.25)^2)}+2}{\sqrt{\left(\frac{9810\,m}{(0.08273712)(25\pi)(1+2(1.25)^2)}+2\right)^2+25}} - \frac{\frac{9810\,m}{(0.08273712)(25\pi)(1+2(1.25)^2)}}{\sqrt{\left(\frac{9810\,m}{(0.08273712)(25\pi)(1+2(1.25)^2)}\right)^2+25}}\right)$$

$$\beta = \frac{9810}{25\pi\gamma(1+2f^2)}$$

$$B = \alpha\left(\frac{\beta m+2}{\sqrt{(\beta m+2)^2+25}} - \frac{\beta m}{\sqrt{(\beta m)^2+25}}\right)$$

$$B\sqrt{(\beta m+2)^2+25} = \alpha\left(\beta m+2 - \frac{\sqrt{(\beta m+2)^2+25}}{\sqrt{(\beta m)^2+25}}\beta m\right)$$

$$(\beta m+2)(\beta m+2)$$

$$\beta^2m^2+2\beta m+2\beta m+4 = \beta^2m^2+4\beta m+4$$

$$B\sqrt{\beta^2 m^2 + 4\beta m + 29} = \alpha\beta m + 2\alpha - \frac{\sqrt{\beta^2 m^2 + 4\beta m + 29}}{\sqrt{\beta^2 m^2 + 25}}\alpha\beta m$$

$$\frac{B\frac{\cancel{\sqrt{\beta^2 m^2 + 4\beta m + 29}}}{\alpha} - 2}{1 - \frac{\cancel{\sqrt{\beta^2 m^2 + 4\beta m + 29}}}{\sqrt{\beta^2 m^2 + 25}}} = \frac{\beta m\left(1 - \frac{\sqrt{\beta^2 m^2 + 4\beta m + 29}}{\sqrt{\beta^2 m^2 + 25}}\right)}{1 - \frac{\sqrt{\beta^2 m^2 + 4\beta m + 29}}{\sqrt{\beta^2 m^2 + 25}}}$$

$$\frac{\frac{B}{\alpha} - 2}{1 - \frac{1}{\sqrt{\beta^2 m^2 + 25}}} = \beta m$$

$$F = \frac{mg}{A} = \frac{0.001 \cdot 9.81}{25\pi}$$

$$\frac{B}{\alpha} - 2 = \beta m - \frac{\beta m}{\sqrt{\beta^2 m^2 + 25}}$$

$$S_r = \sum_i (y_{true} - y_{pred})^2$$

$$S_{y/x} = \sqrt{\frac{S_r}{n - DOF}}$$

DOF = degrees of freedom (# of fitted variables)

Example: If a_0, a_1, and a_2 are the variables fit, then DOF = 3. In linear regression DOF = 2 since slope a_0 and intercept a_1 are 2 fitted variables.

$$\tau = \frac{mg}{\gamma A(1+2f^2)} = \frac{L}{\gamma(1+2f^2)}$$

$$B(z) = \alpha\left(\frac{z+2\,mm}{\sqrt{(z+2\,mm)^2+S^2\,mm^2}} - \frac{z}{\sqrt{z^2+S^2\,mm^2}}\right)$$

τ = thickness of magnet

$$B(m) = \alpha\left(\frac{\frac{mg}{\gamma A(1+2f^2)}+\tau}{\sqrt{\left(\frac{mg}{\gamma A(1+2f^2)}+\tau\right)^2+R^2}} - \frac{\frac{mg}{\gamma A(1+2f^2)}}{\sqrt{\left(\frac{mg}{\gamma A(1+2f^2)}\right)^2+R^2}}\right)$$

$$B(m) = \alpha \left(\frac{\frac{mg}{\gamma A(1+2f^2)} + \tau}{\sqrt{\left(\frac{mg}{\gamma A(1+2f)^2} + \tau\right)^2 + R^2}} - \frac{\frac{mg}{\gamma A(1+2f^2)}}{\sqrt{\left(\frac{mg}{\gamma A(1+2f^2)}\right)^2 + R^2}} \right)$$

$$h = \frac{m}{\rho A}$$

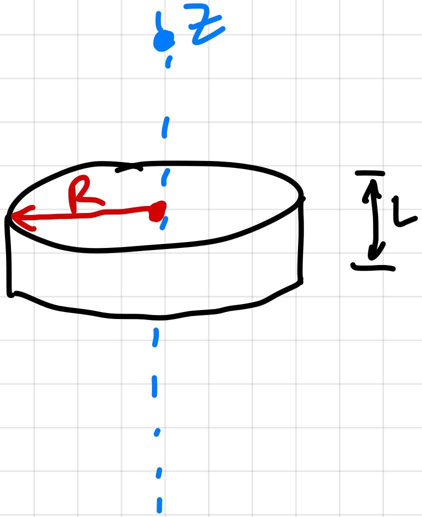
or

$$B(m) = \alpha \left(\frac{\frac{\rho g h}{\gamma(1+2f^2)} + \tau}{\sqrt{\left(\frac{\rho g h}{\gamma(1+2f^2)} + \tau\right)^2 + R^2}} - \frac{\frac{\rho g h}{\gamma(1+2f^2)}}{\sqrt{\left(\frac{\rho g h}{\gamma(1+2f^2)}\right)^2 + R^2}} \right)$$

$$B(m) = \frac{\mu_0 M}{2} \left(\frac{Z + \tau}{\sqrt{(Z+\tau)^2 + R^2}} - \frac{Z}{\sqrt{Z^2 + R^2}} \right)$$

$$\left[\frac{A}{m}\right] \left(\frac{m}{m} - \frac{m}{m} \right) \rightarrow \frac{A}{m} \cdot \frac{m}{m} = \frac{A}{m}$$

$$B(z) = \frac{\mu_0 M}{2}\left(\frac{z}{\sqrt{z^2+R^2}} - \frac{z-L}{\sqrt{(z-L)^2+R^2}}\right)$$



$$B(z) = \frac{\mu_0 M}{2}\left(\frac{z+H_m}{\sqrt{(z+H_m)^2+R^2}} - \frac{z}{\sqrt{z^2+R^2}}\right)$$

$$\downarrow$$

$$B(z) = \frac{\mu_0 M}{2}\left(\frac{z+L}{\sqrt{(z+L)^2+R^2}} - \frac{z}{\sqrt{z^2+R^2}}\right)$$

z = thickness - deflection

$$B - \frac{\mu_0 M}{2}\left(\frac{z+L}{\sqrt{(z+L)^2+R^2}} - \frac{z}{\sqrt{z^2+R^2}}\right) = 0$$

$$P = \rho g h$$

$$\frac{F}{A} = \rho g h$$

$$F = \rho g h A \rightarrow 1000\,\mathrm{kg}/m^3 \cdot 9.81\,m/s^2 \cdot 50\times10^{-3}\,m \cdot (50\times10^{-3})^2\,m^2$$

Read Measurement z, y, x : 0100 1110 = 0x4E

Single Measurement z, y, x: 0011 1110 = 0x3E

Read Measurement z, x, y, t: 0100 1111 = 0x4F

Single Measurement z, x, y, t: 0011 1111 = 0x3F clear

15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

0000 0000 0000 0000

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

X Y Z OSR

shift

To Clear X:

data &= ~0b0000 0110 0000 0000

or

data &= ~0x0600

Then set Resolution:

data |= resolution << 5

Enable Temp compensation

clear

5 4 3 2 1 0

TCMP_EN

0000 0000 0000 0000

0 1 2 3 4 5 6 7 8 9 10 15

shift

~0b0101 or ~0x5 and 1 << 10

0 1 2 3 4 5

0x0400 = 0b 0000 0100 0000 0000

Clear

Z-series :

8 7 6 5 4 3 2 1 0

15 Z BIST ANA

0000 0000 | 0 | 0 | 0 00 0000

0 1 2 3 4 5 6 7 15

0000 0001 0000 0000

0x0100