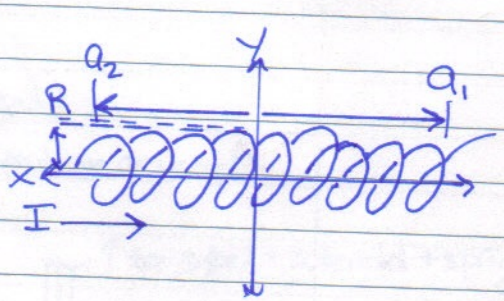
Seng 466 1
Solenoid Design
Logbook
March 10 2013

Mag field

$B = \frac{\mu_0 N I}{2R}$ (in center of loops)



$B(x) = \frac{\mu_0 N I}{2}\left(\frac{x-a_1}{\sqrt{(x-a_1)^2+R^2}} - \frac{x-a_2}{\sqrt{(x-a_2)^2+R^2}}\right)$ (Tot field along x)

*if ~~L =>~~ $L >= 10R \rightarrow B = \mu_0 N I$

$\int E \cdot dA = \frac{Q}{\varepsilon_0}$

$\int B \cdot dA = \emptyset$

Force

$F = \frac{(Fm)^2 \mu_0 A}{(2g^2)} = \frac{(NI)^2 \mu_0 A}{(2g^2)}$

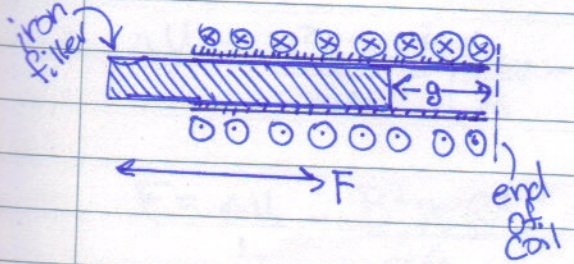
$A = ~~2\pi R~~ \pi R^2$

g = gap from end of iron filler to end of coil

F = Newtons

N = turns

I = Amps

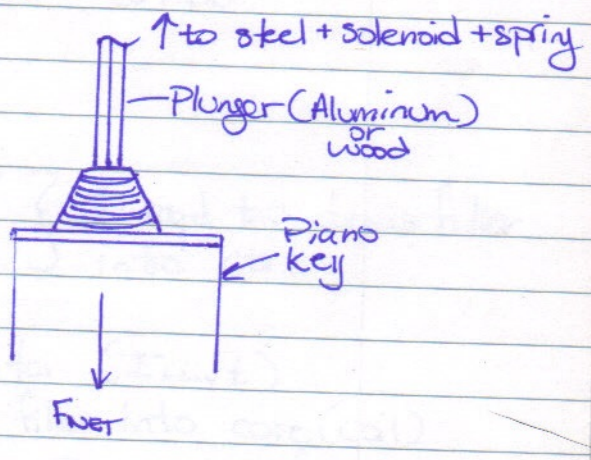


March 11 2013

Solenoid Design

mass plunger = ~5-10g = (steel)
mass attachment = (Aluminum or wood)
Force to depress key = 0.65N

$\mu_{steel} = 8.75 \times 10^{-4}$
$\mu_{iron} = 4\pi \times 10^{-3}$?
$\mu_{copper} = 1.2566 \times 10^{-6}$



$F_{NET} = F_{key} + F_{spring} - F_{mass}$
$F_{NET} = 0.65N$ ...

data from website: spiff.rit.edu....sol

$U(filled) = (Volume)\frac{B^2}{2\mu_0}\left(\frac{\mu_m}{\mu_0}\right)$ $\quad Volume = L\pi R^2$

$\Delta U = \frac{B^2 L\pi R^2}{2\mu_0}\left(\frac{\mu_m}{\mu_0} - 1\right)$ $\quad B = \mu_0 NI$

$F = \frac{\Delta U}{L} = \frac{B^2 \pi R^2}{2\mu_0}\left(\frac{\mu_m}{\mu_0} - 1\right)$

Test Dsgn March 18 2013

Solenoid Length = 5cm
Rad = 0.35cm (straw-plastic)
N = ~100 turns
~~filler~~

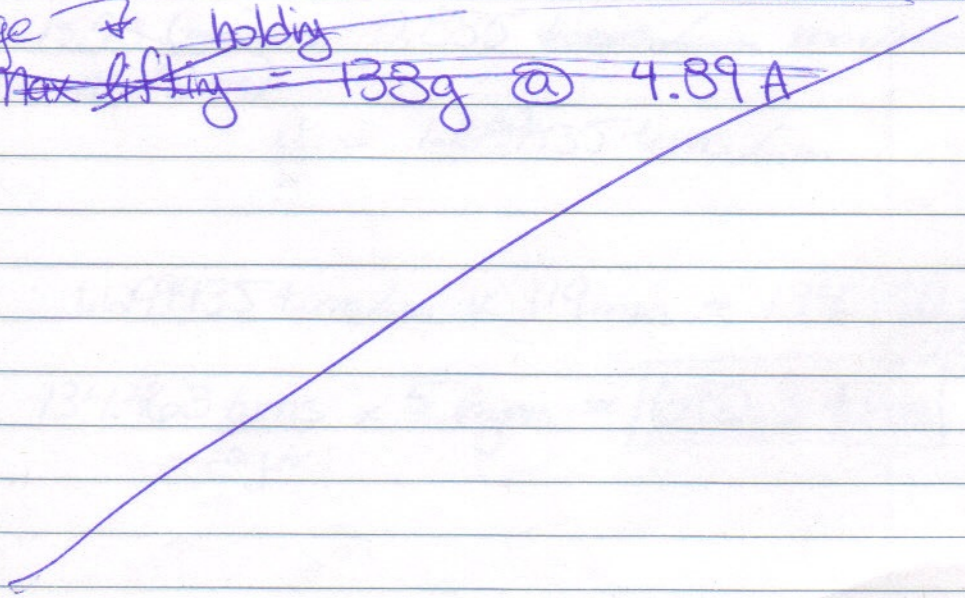
filler length = doesn't mtr (steel)
mass = 5g
Dia. =

@ 30V → ~~0.2~~ A ? } I reqd to draw filler into coil
5V → ~0.88A }

↳ 5V/0.88 w/o limiter (I_{Limit})
↳ Effect: pulls steel filler into core (coil) and centers @ C.O.M. of steel

~~March 19 2013~~

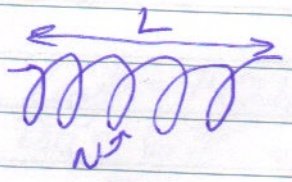
wrong page ~~holding~~
~~Max lifting = 138g @ 4.89A~~



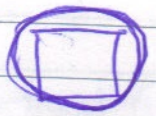
Test Solenoid

March 20 2013

20 Ga wire



18 turns in 15.93 mm



L = 119 mm

wound on square stock - Plastic

ID - 7.1 × 7.1 mm (square)

OD - 9.59 mm × 9.59 mm (square)

Layers = 5

~~$\frac{18N}{15.93mm} = 1.1299435$~~

$\frac{15.93\ (mm)}{18\ (turns)} = 0.885$ ~~turns/mm~~ mm/turn

$\frac{N}{L} = 1.1299435$ turns/mm

$1.1299435 \frac{turns}{mm} \times 119mm = 134.463$ turns

$134.463 \frac{turns}{layer} \times 5\ layers = \boxed{672.3\ turns}$

test solenoid March 20 2013

mass steel = 34g Length = 140.1mm
Dia = 6.35mm (round)

max testing Current I_{max} = 5A

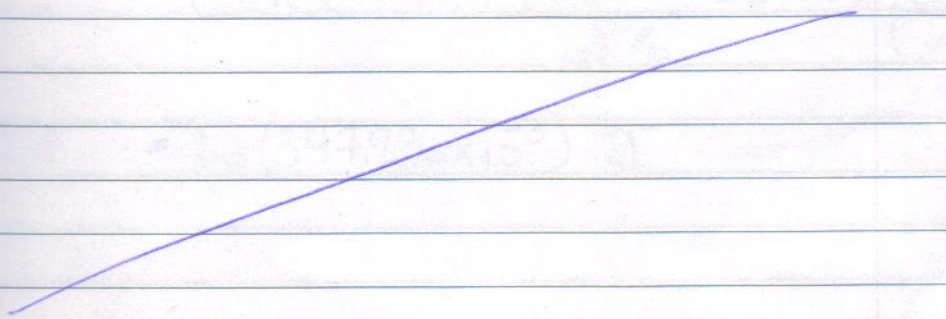
Ability to lift mass steel from vertical (app g)
@ 18.90 mm protruding into coil @ 5.2A (I_{max})

(34g)
Lift mass inserted ½ length (70.05mm) into coil @ I = ~2A (1.9→2.2) (friction)

V_{max} = 5.37Vdc

March 21 2013

Max holding mass = 138g @ 4.88A (5.37Vdc)

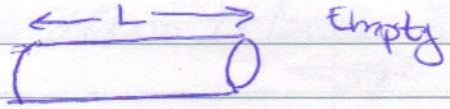


Solenoid energy + Force

March 25 2013

$U_{empty} = \frac{(L\pi R^2) B^2}{2\mu_0}$ $\quad U$ = Energy (J)

$U_{filled} = \frac{(L\pi R^2) B^2}{2\mu_0} \left(\frac{\mu_m}{\mu_0}\right)$



$F = \frac{\Delta U}{L}$

Coil

$U_{empty} = \frac{(1\text{Pmm}\,\pi)\left(\frac{9.59\text{mm}}{2}\right)^2 B^2}{2\mu_0}$

$L = 1\text{Pmm}$

$B = \mu_0 n I$

$R = 9.59\text{mm}/2$

$n = 680$

$I = 4.88$

$U_{empty} = \cancel{\text{Ho}349 \times 10^{3}\ \text{J}}$ $\quad 59.47 \times 10^{-6}\ \text{J}$

L part filled?

$V = \cancel{8.59555 \times 10^{-6}\ \text{m}^3}$

$U_{partfilled} = \frac{V B^2}{2\mu_0} \left(\frac{\mu_m}{\mu_0}\right)$

$= (L_2 \pi (9.59\text{mm}/2)^2) \frac{(680 \cdot 4.88 \cdot \mu_0)^2}{2\mu_0} \left(\frac{8.75 \times 10^{-4}}{\mu_0}\right)$

$U_{pf} = L_2 (347.986 \times 10^{-3})\ \text{J}$

$U_{remain} = L_3\left(\pi \frac{9.59mm}{2}^2\right)\frac{(680 \cdot 4.88\mu)^2}{2\mu_0}$ March 25 2013

$U_{remain} = L_3(499.763 \times 10^{-6})\ J$

~~$U_{empty} = (U_{pf} + U_{remain}) =$~~

$(U_{pf} + U_{remain}) - U_{empty} = \left(L_2(348 \times 10^{-3}) + L_3(500 \times 10^{-6})\right) = 59.47 \times 10^{-6}$

$=$

$U_{filled} = L\left(\pi\left(\frac{9.59mm}{2}\right)^2\right)\frac{(680 \cdot 4.88\mu_0)^2}{2\mu_0}\left(\frac{1Pmm}{\mu_0}\right)$

$U_{filled} = 41.41 \times 10^{-3}\ J$

$U_{filled} - (U_{pf} + U_{remain}) = [L_2 = L_3 = \tfrac{1}{2}L]$

$\Delta U = 20.674 \times 10^{-3}\ J$ [from bar ½L inserted]

$F = \frac{\Delta U}{L} = \frac{20.7 \times 10^{-3} J}{119mm/2} = 0.348\ N$

[L/2 because ½ filled]

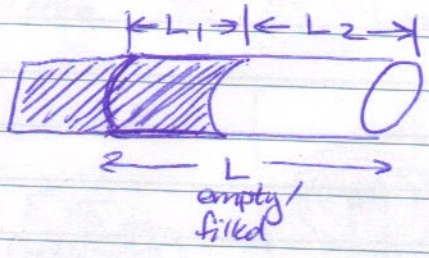
Actual test from 34g mass @ L/2 = 0.335 N

March 25 2013

Equation for Solenoid dsgn

$U_{filled} - (U_{partfilled} + U_{remain}) = \Delta U$

$\frac{\Delta U}{L_{remain}} = F$



$U_{filled} = (Volume)\frac{(B^2)}{2\mu_0}\left(\frac{\mu_m}{\mu_0}\right)$ $\quad B = \mu_0 N I$

$Vol = L_{eff}\pi R^2$

$U_{partfilled} = \frac{B^2}{2\mu_0}\left(\frac{\mu_m}{\mu_0}\right)(L_1 \pi R^2)$

$U_{remain} = \frac{L_2 \pi R^2 B^2}{2\mu_0}$

March 27 2013

Freq (to push piano key) = 0.65 N

Fspring (holding mass up) =

Fmass (plunger) =

μ_m ( ) =

L (coil) = 88.5 mm

L_1 (part fill) =

L_2 (remainempty) =

Radius (coil) = $\frac{14.29\,mm}{2} = 7.145\,mm$

F_{NET} = (key + spring − mass)

mass =

to be completed

~~Finished~~
final design

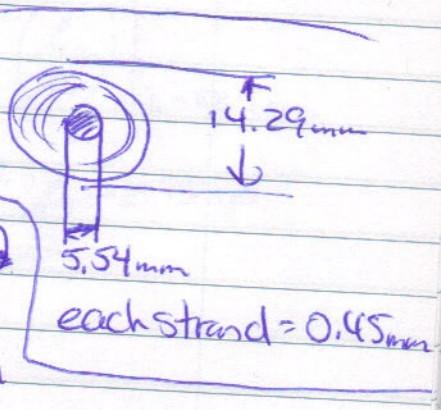
March 27 2013

#turns:

compensated for play (-4mm)

~15 turns / 7.85mm for 84.44mm (length)

~# Layers =



$(14.29 - 5.54)\,mm = 8.75\,mm$ (both sides)

$\frac{8.75}{2} = 4.375\,mm$ (one side coil)

$\frac{4.375}{0.45mm} = 9.722$ strands high

Since packing is staggered (off max dia)
round up turns layers

∴ # Layers = 10 layers

$\frac{15\,t}{7.85mm} = 1.910828\,\frac{t}{mm}$

$1.9108\,\frac{t}{mm} \times 84.44\,mm = 161.3503\,\frac{turns}{Layer}$

$161.35\,\frac{turns}{Layer} \times 10\,Layers = 1613.5\,turns$

∴ 1614 turns

March 28 2013

$$F = \frac{U_{fill} - (U_{pf} + U_{rem})}{\Delta L}\Bigg|_{\substack{L= \\ L, x, L-x}}$$

① $U_{fill} = \dfrac{L(\pi(7.145mm)^2)(\mu_0 1600 I)^2}{2\mu_0}\left(\dfrac{\mu_m}{\mu_0}\right)\Bigg|_{L=88.5mm}$

$= (88.5mm)(160.38\times10^{-6})(1600^2)I^2 \dfrac{\mu m}{2} 8.75\times10^{-4}$

$\rightarrow \boxed{U_{fill} = 15.897\times10^{-3}(I)^2 \ J}$

② $U_{pf} = X(160.38\times10^{-6})(1600^2)I^2 \dfrac{8.75\times10^{-4}}{2}$

$\rightarrow \boxed{U_{pf} = 179.627\times10^{-3}(x)(I^2) \ J}$

③ $U_{remain} = (L-x)(160.38\times10^{-6})(1600^2)I^2 \dfrac{8.75\times10^{-4}}{2}$

$\rightarrow U_{rem} = 179.627\times10^{-3}(L-x)(I^2) \ J\Big|_{L=88.5mm}$

$\boxed{U_{rem} = (15.897\times10^{-3} - 179.627\times10^{-3}x)I^2 \ J}$

$F = \dfrac{\Delta U}{(L-X)}$