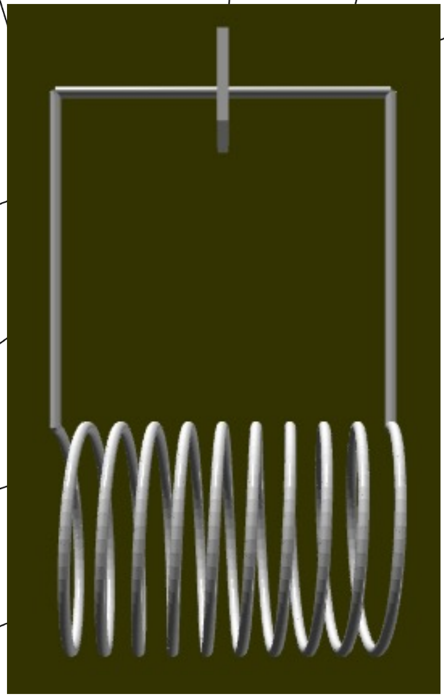
Vpython 電磁砲模擬



電路元件渲染

```python
'''---------------------circuit rendering---------------------'''
inductor_length = 3E-2
inductor_radius = 1E-2
wire_length = 3E-2
R = 10
L = 1.2E-4
C = 220E-6
V0 = 75
N = 146

scene = canvas(width=800, height=800,
               background=vector(0.2, 0.2, 0), align='left')

inductor = helix(canvas=scene, pos=vector(-inductor_length/2, 0, 0),
                 axis=vector(inductor_length, 0, 0,), radius=inductor_radius, coils=10)
capacitor = box(pos=vector(0, 0, inductor_radius + wire_length),
                size=vector(1E-3, 8E-3, 8E-3))
wire1 = cylinder(pos=vector(-inductor_length/2, 0, inductor_radius),
                 axis=vector(0, 0, wire_length), radius=inductor_radius/20)
wire2 = cylinder(pos=vector(inductor_length/2, 0, inductor_radius),
                 axis=vector(0, 0, wire_length), radius=inductor_radius/20)
wire3 = cylinder(pos=vector(-inductor_length/2, 0, inductor_radius+wire_length),
                 axis=vector(inductor_length, 0, 0), radius=inductor_radius/20)
```

RLC 電路

$$L\frac{d^2 i}{dt^2} + R\frac{di}{dt} + \frac{1}{C} i = 0$$

$$i = k_1 e^{\lambda_1 t} + k_2 e^{\lambda_2 t}$$

$$\lambda = \frac{-R \pm \sqrt{R^2 - 4\frac{L}{C}}}{2L}$$

$$k_1 = \frac{V_C(0)}{L(\lambda_2 - \lambda_1)}, k_2 = \frac{V_C(0)}{L(\lambda_1 - \lambda_2)}$$

```
'''---------------------i(t)---------------------'''
lambda_1 = (-R+sqrt(R**2-4*L/C))/(2*L)
lambda_2 = (-R-sqrt(R**2-4*L/C))/(2*L)

k_1 = V0/(L*(lambda_2-lambda_1))
k_2 = V0/(L*(lambda_1-lambda_2))
```

$$\mathbf{m} = \frac{1}{\mu_0}\mathbf{B}_r V,$$

where:

- $\mathbf{B}_r$ is the residual flux density, expressed in teslas.
- V is the volume of the magnet (in m^3).
- μ_0 is the permeability of vacuum ($4\pi \times 10^{-7}$ H/m).[7]

```
'''---------------------bullet rendering---------------------'''
miu0 = 4*pi*10**(-7)
magnet_mass = 3.7E-3
magnet_length = 1E-2
magnet_radius = 5E-3
magnet_volume = magnet_length * pi * (magnet_radius)**2
magnet_magnetic_moment = 4500/10000*magnet_volume/miu0

bullet = cylinder(pos=vector(-inductor_length/2, 0, 0),
                  axis=vector(magnet_length, 0, 0), radius=magnet_radius)
bullet.v = vector(0, 0, 0)
```

子彈特性—小磁鐵

Source :https://en.wikipedia.org/wiki/Magnetic_moment

$$\vec{F} = \nabla(\vec{m}\cdot\vec{B}) \quad \frac{dB}{dx} = \frac{\mu_0(ni)}{2}\cdot r^2\cdot\left(\frac{1}{[(\frac{l}{2}+x)^2+r^2]^{\frac{3}{2}}} + \frac{1}{[(\frac{l}{2}-x)^2+r^2]^{\frac{3}{2}}}\right)$$

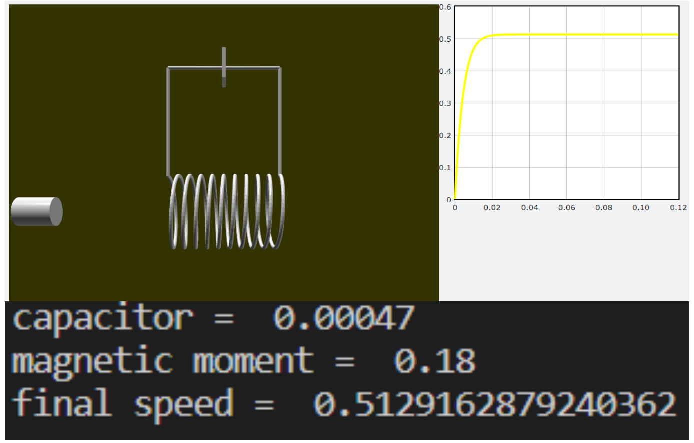
$$F = m\frac{dB}{dx}$$

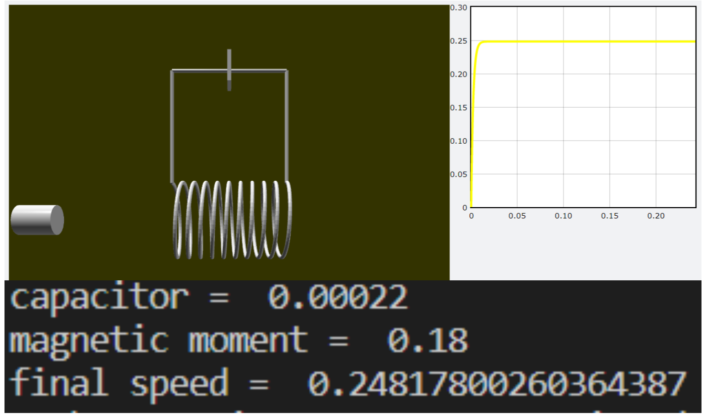
```
while bullet.pos.x <= inductor_length/2*3:
    rate(2000)
    i = abs(k_1*exp(lambda_1*t)+k_2*exp(lambda_2*t))
    # B = magnetic_field(bullet.pos.x,i)
    grad_B = miu0 * (N/inductor_length) * i / 2 * inductor_radius**2 * (1/((inductor_length/2+bullet.pos.x)**2+inductor_radius**2)**(3/2) +
                                                                         1/((inductor_length/2-bullet.pos.x)**2+inductor_radius**2)**(3/2))
    F = magnet_magnetic_moment * grad_B
    a = F/magnet_mass
    bullet.v.x += a*dt
    bullet.pos.x += bullet.v.x*dt
    final_v = bullet.v.x
    # print("i=", i)
    # print("v=", bullet.v.x)
    Vt.plot(t, bullet.v.x)
    t += dt
```

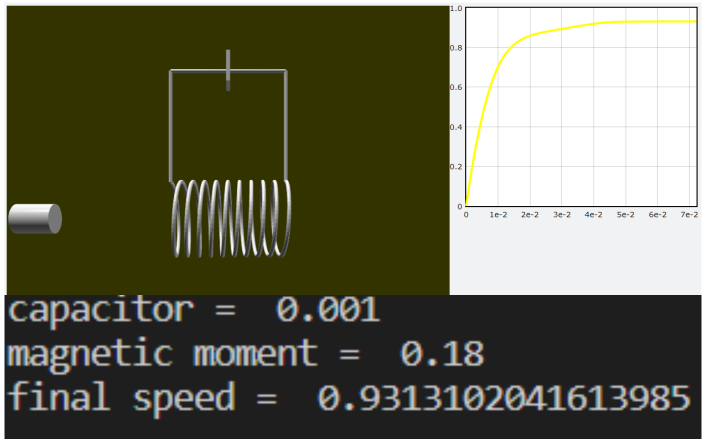
子彈受力分析—小磁鐵

Source :https://en.wikipedia.org/wiki/Magnetic_moment

實驗結果—小磁鐵


capacitor = 0.00047
magnetic moment = 0.18
final speed = 0.5129162879240362


capacitor = 0.00022
magnetic moment = 0.18
final speed = 0.24817800260364387


capacitor = 0.001
magnetic moment = 0.18
final speed = 0.9313102041613985

```python
'''---------------------bullet rendering---------------------'''
miu0 = 4*pi*10**(-7)
bullet_mass = 3E-4
bullet_length = 2E-3
bullet_radius = 1E-3
bullet_volume = bullet_length * pi * (bullet_radius)**2
bullet_magnetic_susceptibility = 700


bullet = cylinder(pos=vector(-inductor_length/2, 0, 0),
                  axis=vector(bullet_length, 0, 0), radius=bullet_radius)
bullet.v = vector(0, 0, 0)
```

子彈特性—螺絲

Source :https://zh.wikipedia.org/zh-tw/%E7%A3%81%E5%AF%BC%E7%8E%87

$$B = \frac{\mu_0 i R^2}{2(z^2 + R^2)^{\frac{3}{2}}}$$

$$B = \frac{\mu_0 n i}{2} \cdot \left(\frac{\frac{l}{2} + x}{\sqrt{(\frac{l}{2} + x)^2 + r^2}} + \frac{\frac{l}{2} - x}{\sqrt{(\frac{l}{2} - x)^2 + r^2}} \right)$$

```
def magnetic_field(pos_x, current):
    cos1 = (inductor_length/2 + pos_x) / sqrt((inductor_length/2 + pos_x)**2+inductor_radius**2)
    cos2 = (inductor_length/2 - pos_x) / sqrt((inductor_length/2 - pos_x)**2+inductor_radius**2)
    return miu0*N/inductor_length*current/2*(cos1+cos2)
```

磁場生成—螺絲

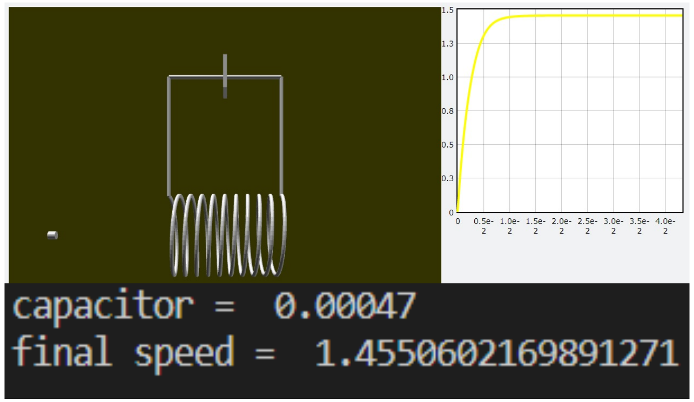
$$F \square \frac{V\chi}{\square_0} B \frac{dB}{dx} \qquad \frac{dB}{dx} \square \frac{\square_0 (ni)}{2} \cdot r^2 \cdot \left(\frac{1}{[(\frac{l}{2} \square x)^2 \square r^2]^{\frac{3}{2}}} \square \frac{1}{[(\frac{l}{2} - x)^2 \square r^2]^{\frac{3}{2}}} \right)$$

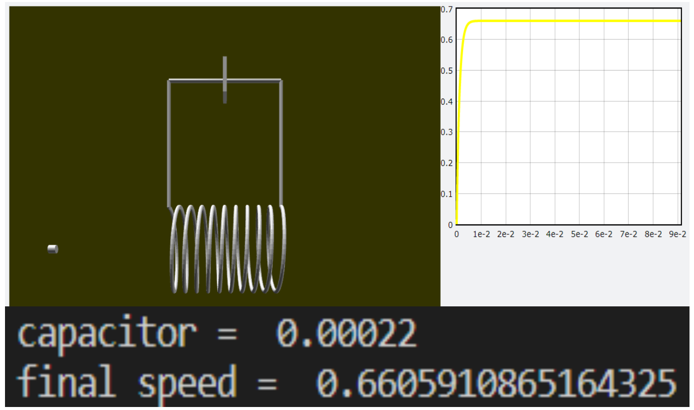
```python
while bullet.pos.x <= inductor_length/2*3:
    rate(2000)
    i = abs(k_1*exp(lambda_1*t)+k_2*exp(lambda_2*t))
    B = magnetic_field(bullet.pos.x, i)
    grad_B = miu0 * (N/inductor_length) * i / 2 * inductor_radius**2 * (1/((inductor_length/2+bullet.pos.x)**2+inductor_radius**2)**(3/2) +
                                                                         1/((inductor_length/2-bullet.pos.x)**2+inductor_radius**2)**(3/2))
    F = bullet_volume*bullet_magnetic_susceptibility*grad_B*B/miu0
    a = F/bullet_mass
    bullet.v.x += a*dt
    bullet.pos.x += bullet.v.x*dt
    final_v = bullet.v.x
    # print("i=", i)
    # print("v=", bullet.v.x)
    Vt.plot(t, bullet.v.x)
    t += dt
```

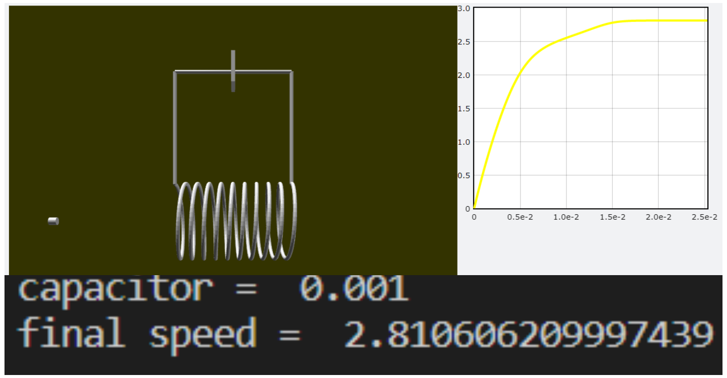
子彈受力分析—螺絲

Source : https://www.kjmagnetics.com/blog.asp?p=magnetic-grates

實驗結果—螺絲

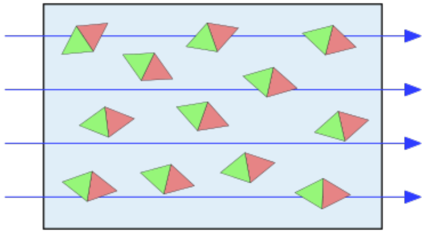

capacitor = 0.00047
final speed = 1.4550602169891271


capacitor = 0.00022
final speed = 0.6605910865164325


capacitor = 0.001
final speed = 2.810606209997439

速度比較比較

	220uF	470uF	1000uF
磁鐵(0.45T ,3.7g)	0.25 m/s	0.51 m/s	0.93 m/s
螺絲(0T ,0.3g)	0.66 m/s	1.46 m/s	2.81m/s



誤差討論—磁場與磁化率

The magnetic field can be found using the vector potential, which for a finite solenoid with radius R and length l in cylindrical coordinates (ρ, ϕ, z) is[5][6]

$$A_\phi = \frac{\mu_0 I}{2\pi}\frac{1}{l}\sqrt{\frac{R}{\rho}}\left[\zeta k\left(\frac{k^2+h^2-h^2k^2}{h^2k^2}K(k^2)-\frac{1}{k^2}E(k^2)+\frac{h^2-1}{h^2}\Pi(h^2,k^2)\right)\right]_{\zeta_-}^{\zeta_+},$$

Where:

- $\zeta_\pm = z \pm \frac{l}{2},$
- $h^2 = \frac{4R\rho}{(R+\rho)^2},$
- $k^2 = \frac{4R\rho}{(R+\rho)^2+\zeta^2},$
- $K(m) = \int_0^{\frac{\pi}{2}} \frac{d\theta}{\sqrt{1-m\sin^2\theta}},$
- $E(m) = \int_0^{\frac{\pi}{2}} \sqrt{1-m\sin^2\theta}\,d\theta,$
- $\Pi(n,m) = \int_0^{\frac{\pi}{2}} \frac{d\theta}{(1-n\sin^2\theta)\sqrt{1-m\sin^2\theta}}.$

Here, $K(m)$, $E(m)$, and $\Pi(n,m)$ are complete elliptic integrals of the first, second, and third kind.

Using:

$$\vec{B} = \nabla \times \vec{A},$$

The magnetic flux density is obtained as[7][8][9]

$$B_\rho = \frac{\mu_0 I}{4\pi}\frac{2}{l}\sqrt{\frac{R}{\rho}}\left[\frac{k^2-2}{k}K(k^2)+\frac{2}{k}E(k^2)\right]_{\zeta_-}^{\zeta_+},$$

$$B_z = \frac{\mu_0 I}{4\pi}\frac{1}{l}\frac{1}{\sqrt{R\rho}}\left[\zeta k\left(K(k^2)+\frac{R-\rho}{R+\rho}\Pi(h^2,k^2)\right)\right]_{\zeta_-}^{\zeta_+}.$$