DRIPVOLTS

CALCULATIONS OF THE DIMENSIONS OF THE COMPONENTS OF THE CELL

21.07.2025

1. PLA Structural Failure (Compressive, Tensile, Shear, Bending)

PLA components under analysis: Beating head, support layers, and inner shafts.

<u>Forces acting on the PLA components</u>

- 450g water drop adds dynamic load on the beating head.
- Spring force provides a restoring force on the beating head, and the solenoid support layer is subjected to reaction forces from the springs.

Force due to water impact:

F_{impact} = mg

= 0.45 kg x 9.81

= 4.41 N

Dynamic force from spring compression:

F_{spring} = kx ; where k is the spring constant and x is the displacement.

= k ($4x10^{-2}$)

To avoid failure,

$F_{impact} \leq F_{spring}$

$4.41N \leq k \times 4 \times 10^{-2} \times 4$

$k \geq 27.56\ Nm^{-1}$

Assume that k = 30 Nm^{-1}.

Stress Calculations:

<u>Compressive stress</u>:

Since the angle of the beating head is very small, it is assumed to be circular in shape.

Maximum radius $= \frac{200}{2}$ mm

= 100mm

$A_{max} = \pi r^2$

$= \pi \times 100 \times 100\ mm^2$

$= 0.0314\ m^2$

$$\sigma_{c,max} = \frac{F_{impact}}{A}$$

$$= \frac{4.41\ \text{N}}{\pi \text{ x } (100 \text{ x } 10^{-3})^2}$$

$= 140.37\ \text{Nm}^{-2}$

PLA material compressive strength,

$\sigma_{c,mat} = 60\ \text{MPa}$

A factor of safety of 5 is assumed.

$\sigma_{allow} = \frac{60MPa}{5}$

$= 12\ \text{MPa}$

To prevent from compressive strength,

$\sigma_{allow} \geq \sigma_{c,max}$

Therefore, our beating head does not fail due to compressive stress.

<u>Shear stress</u>:

$A_S = \pi r^2$

$= \pi \text{ x } 100 \text{ x } 100\ \text{mm}^2$

$= 0.0314\ \text{m}^2$

$\tau_{max} = \frac{F}{A_S}$

$$= \frac{4.41\ \text{N}}{\pi \text{ x } (100 \text{ x } 10^{-3})^2}$$

$= 140.37\ \text{Nm}^{-2}$

PLA material 3D printed,

$\tau_{mat} = 30\text{MPa}$

A factor of safety of 5 is assumed.

$\tau_{allow} = \frac{30}{5}$

$= 6\ \text{MPa}$

To prevent failure due to shear stress,

$\tau_{allow} \geq \tau_{max}$

$$6 \text{ MPa} \geq 140.37 \text{ Pa}$$

Therefore, the beating head is not expected to fail under shear stress.

2. Spring Compression and Deflection

Spring made of stainless steel. Ensure that the springs do not fail due to excessive deformation.

Deflection calculation:

δ = F / k, where F is the force applied (due to water impact and magnet interaction), and k is the spring constant.

$$\rho_{PLA} = 1250 \text{kgm}^{-3}$$

$$\begin{aligned} F_{PLA} &= mg \\ &= v\rho g \\ &= \pi r^2 h \times \rho g \\ &= \pi \times (10 \times 10^{-2})^2 \times 4 \times 10^{-2} \times 1250 \times 9.81 \\ &= 15.40 \text{ N} \end{aligned}$$

$$\begin{aligned} \delta &= \frac{F + F_{PLA}}{k} \\ &= \frac{4.41+15.40}{30} \\ &= 0.660 \text{m} \end{aligned}$$

$$\begin{aligned} \text{Deflection of 1 spring} &= \frac{0.660}{4} \\ &= 0.165 \text{ m} \end{aligned}$$

Maximum deflection calculation

Shear yield strength of stainless steel = 250 MPa

$$\delta = \frac{F_{max}}{k}$$

$$\begin{aligned} \text{Wire diameter} &= 1.00 \text{mm} \\ &= 1.0 \times 10^{-3} \text{m} \end{aligned}$$

Coil diameter $= 15$ mm

$k = 30Nm^{-1}$

$\tau = 250MPa$

Find maximum safe force.

$$\tau = \frac{8FD}{\pi d^3}$$

$$F = \frac{8\tau D}{\pi d^3}$$

$$= \frac{250 \times 10^6 \times \pi \times (1 \times 10^{-3})^3}{8 \times 15 \times 10^{-3}}$$

$= 6.545$ N

Safe deflection,

$$\delta_{max} = \frac{F_{max}}{k}$$

$$= \frac{6.55N}{30N/m}$$

$= 0.22$m

$$\delta_{max} > \delta$$

The deflection remains within the allowable elastic range; therefore, the spring will not fail due to excessive deflection.

3. Magnetic Field Cutting Failure (Inductive Load)

$N = 80$ turns

Assumed that,

$B = 0.3T$

Coil diameter(d) $= 3.5$cm

Velocity $= 0.1$m/s

<u>LED Requirements</u>

A red LED bulb was selected for the system.

Forward voltage(V_f) = 2V (Red)

Operating current(I_{LED}) = 5mA

To light the LED coil must generate,

$$\delta \geq V_f \text{ ---------------->(1)}$$

$$I \geq I_{LED} \text{ --------------->(2)}$$

Induced EMF of coil,

N = 80 turns
B = 0.3 T

Coil diameter = 350mm

$A = \pi r^2$
$= \pi(350 \times 10^{-3})^2$
$= 0.384\ m^{-3}$

Velocity = 0.1m/s

ε = N.B.A.U
= 80 x 0.3 x 0.384 x0.1
= 0.9216 V

Requirement (1);

$\delta \geq V_f$
$0.9216 \geq 2V$
No failure occurs.

Current output

From ohm's law,

$$I = \frac{\varepsilon}{R_{total}} \text{ ----------------->(3)}$$

$R_{total} = R_{coil} + R_{LED}$

Find copper coil resistance

Cross sectional area,

$$A = \frac{\pi d^2}{4}$$

$$= \frac{\pi d(0.35 \times 10^{-3})^2}{4}$$

$$= 9.621 \text{ x } 10^{-8} \text{ m}^2$$

$$R = \frac{\rho l}{A}$$

Where;

ρ – Resistivity of copper

L – Length of wire

A – Cross sectional area

ρ = 1.68 x $10^{-8} \Omega$m

L = 30 cm

$$R_{coil} = \frac{1.68 \times 10^{-8} \times 30 \times 10^{-2}}{9.621 \times 10^{-8}}$$

$$= 0.052\ \Omega$$

$$R_{red} = \frac{V_f}{I_f}$$

$$= \frac{2.0\ V}{15 \times 10^{-3}}$$

$$= 133.33\ \Omega$$

$$R_{total} = 133.33 + 0.052$$

$$= 133.385\ \Omega$$

From (3),

$$I = \frac{0.9216}{133.385\ \Omega}$$

$$= 6.909 \text{ mA}$$

$I > I_{LED}$

No failure occurs.

All components operate within safe limits, and no failures are expected.

4. Buckling of Vertical PLA Rods (Spring Support Layers)

To calculate the Euler Buckling Load for the vertical PLA rods that support the upper casing, we need to apply the following formula:

$$F_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

Where;

E - Young's modulus of PLA (which is 3.5×10^9 Pa).
I - moment of inertia of the rod's cross-section.
L - length of the rod.
K is the effective length factor (For fixed support K=0.7)

Diameter of rod (d) = 45mm
Length of rod (L) = 40mm

$$I = \frac{\pi\left(45\times10^{-3}\right)^4}{64}$$
$$= 2.013 \times 10^{-7}$$

$$F_{cr} = \frac{\pi^2\left(3.5\times10^9\right)\times\left(2.013\times10^{-7}\right)}{(0.7\times40\times10^{-3})^2}$$
$$= 8.8 \text{ mN}$$

Spring system applied force = (4.41 + 15.40)N
= 19.81N

$19.81\text{N} < 8.8 \text{ mN}$

Since the applied force is less than 8.8 mN, the rod is not expected to buckle.

5. Wooden Base and Upper Casing Failure

$$\sigma_{wood} = \frac{F_{total}}{A_{contact}}$$

Where;

σ_{wood} - Compressive stress in the wood
F_{total} - Total force acting on the base
$A_{contact}$ - Contact area between the spring and the wood

M = 625.44g

F = mg
= 625.44 x 10^{-3} x 9.81
= 6.14N

D = 13cm

A = πr^2
= $\pi(\frac{13}{2} \times 10^{-2})^2$
= $0.0133m^2$

$$\sigma_{wood} = \frac{6.14N}{0.0133m^2}$$

= 461.65 N/m^2

Wood compressive strength,

σ_{mat} = 40 MPa

Assumed that factor of safety is 5.

$$\sigma_{allow} = \frac{40}{5}$$

= 8 MPa

To prevent failure,

$$\sigma_{allow} \geq \sigma_{wood}$$
$$8 \text{ MPa} \geq 461.65 \text{ Pa}$$

Therefore, the wooden base does not experience failure under compressive loading.

6. Fatigue Failure of PLA Components (Repetitive Load)

<u>Material properties of PLA</u>

Ultimate tensile strength = 60MPa
Fatigue strength limit = 15MPa

<u>Estimate the stress from each load cycle</u>

For impact load,

F_{impact} = 4.41N (previously calculated)
A = 0.0314m^2 (previously calculated)

$$\sigma_{impact} = \frac{F}{A} = \frac{4.41}{0.0314} = 140.37 \text{ Pa} \quad \text{------->}(4)$$

For spring,

F_{spring} = 19.81N (previously calculated)
A = 0.0314m^2 (previously calculated)

$$\sigma_{spring} = \frac{19.81}{0.0314} = 630.89 \text{ Pa} \quad \text{------->}(5)$$

Allowable fatigue strength,

Assumed that factor of safety is 5.

$$\sigma_{allow} = \frac{\sigma_{fatigue}}{5}$$

$= \frac{15}{5}$ MPa

= 3 Mpa

From (4); $\sigma_{allow} \geq \sigma_{impact}$

From (5); $\sigma_{allow} \geq \sigma_{spring}$

Since both impact and spring-induced stresses are below the fatigue limit of PLA, fatigue failure is not expected.

7. Solenoid Coil Overheating (Electrical Failure)

Overheating failure due to continuous electrical generation.

Power dissipation

LED Current(I) = 5mA

R_{total} = 133.385 Ω

Power,

$P = I^2R$

$= (5 \times 10^{-3})^2 \times 133.385$

$= 3.33\text{mW}$

Since 3.33 mW is a very low power value, overheating of the solenoid is not expected.