1. IJS: C-088 (ob vhodu z Jadranske)

   Tel: 01-477-35-35

   e-mail: Tomaz.Podobnik@ijs.si

   FMF: 416, 4. nadstropje, Jadranska 19 (OF)

   e-mail: Tomaz.Podobnik@fmf.uni-lj.si

2. Gregor Skačej

3. Snov:
   - Nihanje in valovanje
   - Elektrika in magnetizem
   - Optika
   - Izbrana poglavja iz Moderne fizike

4. Literatura: J. Strnad, Fizika I (Nihanje in valovanje)

   Fizika II (EM in Optika)

   Fizika III, IV (Izbrana poglavja iz Moderne fizike)

5. Urnik predavanj

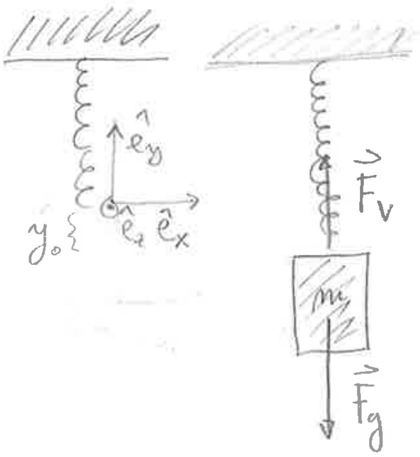
   Sreda: 10^h-12^h

   Petek: 8^h-10^h (od tega 1 h seminarja)

$\boxed{\text{I. NIHANJE IN VALOVANJE}}$

1 Enostavna nihala - enačba nihanja

Nihalo na vijačni vzmeti



Hook

$$\vec{F}_g = \begin{bmatrix} 0 \\ -mg_0 \\ 0 \end{bmatrix}, \quad \vec{F}_v = \begin{bmatrix} 0 \\ -ky_0 \\ 0 \end{bmatrix}$$

$y_0 < 0 \Rightarrow \vec{F}_v$ navzgor ✓

$g_0 \approx 10 m/s^2$

1. Newtonov zakon: $\boxed{\Sigma \vec{F} = 0}$

$$\Rightarrow -mg_0 - ky_0 = 0 \Rightarrow \boxed{mg_0 = -ky_0} \Leftrightarrow \boxed{y_0 = -\frac{mg_0}{k}}$$

Utež v smeri y izmaknemo iz ravnovesne lege: $y_0 \to y$

2. Newtonov zakon: $\boxed{\vec{F} = m\vec{a} = m\frac{d\vec{v}}{dt} = m\frac{d^2\vec{r}}{dt^2} = m\ddot{\vec{r}}}$

$$\vec{F} = \vec{F}_g + \vec{F}_v; \quad \vec{F}_g = \begin{bmatrix} 0 \\ -mg_0 \\ 0 \end{bmatrix}, \quad F_v = \begin{bmatrix} 0 \\ -ky \\ 0 \end{bmatrix} \Rightarrow \vec{F} = \begin{bmatrix} 0 \\ -mg_0 - ky \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ -k(y - y_0) \\ 0 \end{bmatrix}$$

$$\vec{r} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \Rightarrow \ddot{\vec{r}} = \begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix}$$

$$\Rightarrow \boxed{\begin{aligned} m\ddot{x} &= 0 \\ m\ddot{y} &= -k(y - y_0) \\ m\ddot{z} &= 0 \end{aligned}}$$

Enostavni (trivialni) rešitvi:

a) $m\ddot{x} = 0 \Rightarrow \dot{x} = \text{konst.}$; začetni pogoj $v_x(t=0) = 0 \Rightarrow \dot{x} = 0 \Rightarrow x = \text{konst.}$

začetni pogoj $x(t=0) \Rightarrow x = 0$

b) $m\ddot{z} = 0 \Rightarrow \ldots \Rightarrow v_z = 0,\ z = 0$

$\Rightarrow$ gibanje samo v navpični smeri (v)

c) V navpični smeri:

$$m\ddot{y} = -k(y - y_0) \Rightarrow \boxed{\ddot{y} + \omega_0^2 (y - y_0) = 0}\ ; \boxed{\omega_0^2 \equiv \frac{k}{m}} = \text{konst.}$$

Poenostavitev: $y' \equiv y - y_0 \Rightarrow y = y' + y_0 \Rightarrow \ddot{y} = \ddot{y}'$

$$\Rightarrow \boxed{\ddot{y}' + \omega_0^2 y' = 0}$$ Enačba (nedušenega, nevsiljenega) nihanja

Mat: homogena linearna diferencialna enačba 2. reda s konstantnimi koeficienti

Reševanje z nastavkom: $y' = Ce^{\lambda t}$; $\lambda, C = \text{konst.}$

$$\Rightarrow \ddot{y}' = \lambda^2 C e^{\lambda t} = \lambda^2 y'$$

$$\Rightarrow (\lambda^2 + \omega_0^2) y' = 0 \quad \forall y' \Rightarrow \boxed{\lambda^2 + \omega_0^2 = 0}$$ (karakteristični polinom)

$$\Rightarrow \lambda^2 = -\omega_0^2 \Rightarrow \lambda_{1,2} = \pm i\omega_0$$

$$\Rightarrow y_1' = C_1 e^{i\omega_0 t},\ y_2' = C_2 e^{-i\omega_0 t}$$ rešitvi

$\Rightarrow y_1' + y_2'$ tudi rešitev

Res: $(\ddot{y}_1' + \ddot{y}_2') + \omega_0^2 (y_1' + y_2') =$

$\ddot{y}_1' + \ddot{y}_2' + \omega_0^2 y_1' + \omega_0^2 y_2'$

$= \ddot{y}_1' + \omega_0^2 y_1' + \ddot{y}_2' + \omega_0^2 y_2'$

$= 0$

$$\Rightarrow \boxed{y' = C_1 e^{i\omega_0 t} + C_2 e^{-i\omega_0 t}}$$

Eulerjeva enačba: $e^{i\omega_0 t} = \cos(\omega_0 t) + i \sin(\omega_0 t)$

$e^{-i\omega_0 t} = \cos(\omega_0 t) - i \sin(\omega_0 t)$

$\Rightarrow \boxed{y'} = (C_1 + C_2)\cos(\omega_0 t) + i(C_1 - C_2)\sin(\omega_0 t)$

$= \boxed{B_1 \cos(\omega_0 t) + B_2 \sin(\omega_0 t)}$; $B_1 \equiv C_1 + C_2$, $B_2 = i(C_1 - C_2)$

Še tretja oblika:

$\boxed{y' = y'_{max} \sin(\omega_0 t + \delta)}$, y'_{max} = amplituda , δ = fazni zamik

$y'_{max}[\sin(\omega_0 t)\cos\delta + \cos(\omega_0 t)\sin\delta]$

$y'_{max}\sin\delta\cos(\omega_0 t) + y'_{max}\cos\delta\sin(\omega_0 t)$ $\Rightarrow y'_{max}\sin\delta = B_1$

$y'_{max}\cos\delta = B_2$

$\Rightarrow y'_{max} = \sqrt{B_1^2 + B_2^2}$

$\Rightarrow \delta = \operatorname{arc\,tg}\left(\frac{B_1}{B_2}\right)$

$\omega_0 = \sqrt{\frac{k}{m}} = 2\pi\nu_0$; $\nu_0 = \frac{1}{t_0}$ = (lastna) frekvenca

Preveri!

$\Rightarrow \boxed{\nu_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}}} \Rightarrow \boxed{t_0 = 2\pi\sqrt{\frac{m}{k}} \text{ (lastni) nihajni čas}}$

y'_{max} in δ iz začetnih pogojev: $y'(t=0)$ in $\dot{y}'(t=0)$

$$y'(t=0) = y'_{max}\sin\delta \quad \Rightarrow \quad \omega_0 y'(t=0) = y'_{max}\omega_0 \sin\delta$$

$$\dot{y}' = y'_{max}\omega_0\cos(\omega_0 t+\delta) \quad \Rightarrow \quad \dot{y}'(t=0) = y'_{max}\omega_0\cos\delta$$

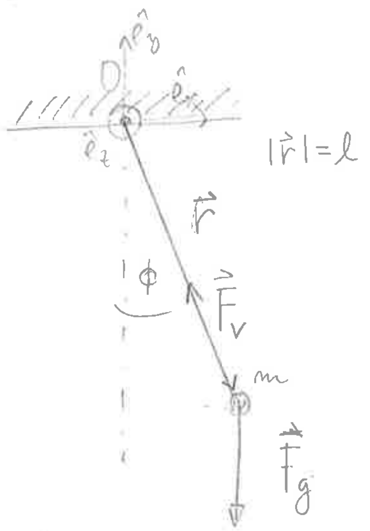
$$\Rightarrow \boxed{\delta = \mathrm{arctg}\left(\frac{\omega_0 y'(t=0)}{\dot{y}'(t=0)}\right)}$$

$$\Rightarrow \boxed{y'_{max} = \frac{1}{\omega_0}\sqrt{[\omega_0 y'(t=0)]^2 + \dot{y}'(t=0)^2}}$$

$$\Rightarrow \boxed{y} = y' + y_0 = \boxed{y_0 + y'_{max}\sin(\omega_0 t+\delta)}$$

$$[y'_{max}] = \mathrm{m}$$

Nitno (matematično) nihalo



$|\vec{r}| = l$

$$\vec{M} = \vec{r}\times\vec{F} = \vec{r}\times(\vec{F}_g + \vec{F}_v) = \vec{r}\times\vec{F}_g + \vec{r}\times\vec{F}_v = \vec{r}\times\vec{F}_g$$

$$\vec{F}_g = \begin{bmatrix} 0 \\ -mg_0 \\ 0 \end{bmatrix}, \quad \vec{r} = \begin{bmatrix} l\sin\phi \\ -l\cos\phi \\ 0 \end{bmatrix}$$

$$\Rightarrow \boxed{\vec{M} = \vec{r}\times\vec{F}_g = \begin{bmatrix} 0 \\ 0 \\ -mgl\sin\phi \end{bmatrix}}$$ (D.n.: preveri!)

M_z

$$\boxed{M_z = J_z\alpha = J_z\ddot{\phi}}$$ "Newtonov zakon" za vrtenje okoli fiksne osi $\hat{e}_z$

$$J_z = ml^2 \Rightarrow -mgl\sin\phi = ml^2\ddot{\phi}$$

$$\Rightarrow \boxed{\ddot{\phi} + \frac{g}{l}\sin\phi = 0}$$ V splošnem ni enačba sinusnega nihanja.

Taylorjev razvoj: $\sin\phi = \phi + O(\phi^3) \Rightarrow \phi \ll 1$ $([\phi] = rd)$: $\sin\phi \simeq \phi$

$\Rightarrow \phi \ll 1$: $\boxed{\ddot{\phi} + \omega_0^2 \phi = 0}$; $\boxed{\omega_0^2 = \frac{g}{l}}$ (enačba sinusnega nihanja)

$\Rightarrow \boxed{t_0 = 2\pi\sqrt{\frac{l}{g}}}$ Preveri! (Neodvisno od amplitude!)

$\Rightarrow$ Rešitev: $\boxed{\phi = \phi_{max} \sin(\omega_0 t + \delta)}$; $[\phi_{max}] = /$ (rd)

Fizično nihalo

$M_z = -mgl^* \sin\phi$; l^*: razdalja med osjo in težiščem

$\boxed{M_z = J_z \alpha} \Rightarrow -mgl^* \sin\phi = J_z \ddot{\phi}$

$\Rightarrow \phi \ll 1$: $\boxed{\ddot{\phi} + \frac{mgl^*}{J_z}\phi = 0}$

$\Rightarrow \boxed{\omega_0^2 = \frac{mgl^*}{J_z}}$ in $\boxed{t_0 = 2\pi \frac{1}{\omega_0}}$

J_z: vztrajnostni moment za vrtenje (razsežnega togega) telesa okoli dane osi.

Primer: homogena palica z osjo v enem izmed krajišč

$J = J^* + ml^{*2}$ (Steinerjev izrek)

$= \frac{1}{12} ml^2 + m\left(\frac{l}{2}\right)^2$

$= \frac{1}{12} ml^2 + \frac{1}{4} ml^2$

$= \frac{1}{3} ml^2$