1.1 **Kinematik eines Massenpunktes**

1.1.1 Grundbegriffe

Geschwindigkeit: $\boxed{\vec{v} = \lim_{\Delta t\to 0}\frac{\Delta \mathbf{r}}{\Delta t} = \frac{d\mathbf{r}}{dt} = \dot{\mathbf{r}}}$

Beschleunigung: $\boxed{\vec{a} = \lim_{\Delta t\to 0}\frac{\Delta \mathbf{v}}{\Delta t} = \frac{d\mathbf{v}}{dt} = \dot{\mathbf{v}} = \ddot{\mathbf{r}}}$

1.1.2 Geradlinige Bewegung

kinematische Grundaufgaben:

1) a=0 $\rightarrow$ $\boxed{x(t) = x_0 + v_0(t-t_0)}$ $\boxed{x(t) = x_0 + v_0 t + \frac{1}{2}a_0 t^2}$

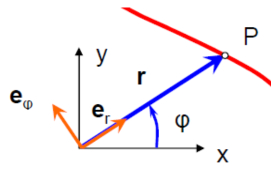
2) $a=a_0 \rightarrow$ $\boxed{v(t) = v_0 + a_0 t}$

3) a=a(t) $\rightarrow$ $\boxed{v(t) = v_0 + \int_{t_0}^{t} a(\bar{t})d\bar{t}}$ $\boxed{x(t) = x_0 + \int_{t_0}^{t} v(\bar{t})d\bar{t}}$

4) a=a(v) $\rightarrow$ $\boxed{t = t_0 + \int_{v_0}^{v}\frac{d\bar{v}}{a(\bar{v})} = f(v)}$ $\boxed{x(t) = x_0 + \int_{t_0}^{t} F(\bar{t})d\bar{t}}$ $\boxed{x(v) = x_0 + \int_{v_0}^{v}\frac{\bar{v}}{a(\bar{v})}d\bar{v}}$

5) a=a(x) $\rightarrow$ $\boxed{\frac{1}{2}v^2 = \frac{1}{2}v_0^2 + \int_{x_0}^{x} a(\bar{x})d\bar{x} = f(x)}$ $\boxed{v(x) = \sqrt{2f(x)}}$ $\boxed{t(x) = t_0 + \int_{x_0}^{x}\frac{d\bar{x}}{\sqrt{2f(\bar{x})}} = g(x)}$

1.1.3 ebene Bewegung, Polarkoordinaten



Geschwindigkeit: $\boxed{\vec{v} = \dot{\mathbf{r}} = \dot{r}\vec{e}_r + r\dot{\varphi}\,\vec{e}_\varphi}$; $\boxed{v_r = \dot{r} \;,\; v_\varphi = r\dot{\varphi}}$

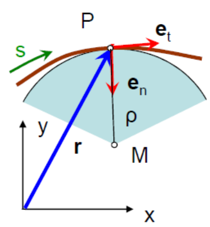
Beschleunigung: $\boxed{\vec{a} = (\ddot{r} - r\dot{\varphi}^2)\vec{e}_r + (r\ddot{\varphi} + 2\dot{r}\dot{\varphi})\vec{e}_\varphi}$; $\boxed{a_r = \ddot{r} - r\dot{\varphi}^2 \;,\; a_\varphi = r\ddot{\varphi} + 2\dot{r}\dot{\varphi}}$

Sonderfall – Kreisbewegung: $\boxed{\vec{r} = r\vec{e}_r \;,\; \vec{v} = r\omega\,\vec{e}_\varphi \;,\; \vec{a} = -r\omega^2\vec{e}_r + r\dot{\omega}\vec{e}_\varphi}$

$\boxed{v = v_\varphi = r\omega \,,\; a_\varphi = r\dot{\omega} \,,\; a_r = -r\omega^2}$

Spezialfall ω=const : $\boxed{v = r\omega \;,\; a_\varphi = 0 \;,\; \text{aber} \quad a_r = -r\omega^2 = -\frac{v^2}{r}}$

1.1.4 räumliche Bewegung, natürliche Koordinaten



Geschwindigkeit: $\boxed{\mathbf{v} = v\vec{e}_t}$

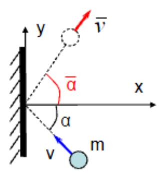
Beschleunigung: $\boxed{\mathbf{a} = \dot{v}\vec{e}_t + \frac{v^2}{\rho}\vec{e}_n}$

Kreisbewegung: $\boxed{v = \dot{s} = r\omega}$, $\boxed{a_t = \dot{v} = r\dot{\omega} = r\ddot{\varphi}}$, $\boxed{a_n = \frac{v^2}{r} = r\omega^2}$

1.2 Kinematik eines Massenpunktes

Impulssatz, Stoß: $\boxed{m\mathbf{v} - m\mathbf{v}_0 = \int_{t_0}^{t}\mathbf{F}d\bar{t}}$

$\rightarrow: m\bar{v}_x - mv_x = \hat{F}_x$ $\quad\uparrow: m\bar{v}_y - mv_y = \hat{F}_y$



Momentensatz: $\boxed{\Theta^{(O)} = mr^2}$ $\boxed{\Theta^{(O)}\ddot{\varphi} = M^{(O)}}$

Arbeitssatz: $\boxed{E_{k1} - E_{k0} = W}$ **Leistung/Wirkungsgrad:** $\boxed{P = \frac{dW}{dt} = \frac{\mathbf{F}.d\mathbf{r}}{dt} = \mathbf{F}.\mathbf{v}}$ $\boxed{\eta = \frac{W_N}{W_A}}$

Energiesatz: $\boxed{E_{k1} + E_{p1} = E_{k0} + E_{p0} = const}$

Bewegungsgleichung: Kräfte-/Momentensatz

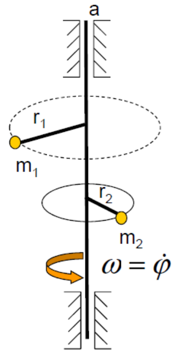
1. n Koordinaten wählen, positive allgemeine Lage
2. Beschleunigung in gewählten Koordinaten
3. Freischnitt in allgemeiner Lage, Kräfte/Momente eintragen
4. Entgegengesetzt der positiven Beschleunigungsrichtungen alle Scheinkräfte eintragen
5. Skalare Auswertung des Kräfte-/Momentengleichgewichts
6. Anzahl der Freiheitsgrade f
7. (n-f) kinematische Beziehungen zwischen den Koordinaten
8. Elimination der Zwangskräfte → Bewegungsgleichung

2.1 **Kinetik eines Systems von Massenpunkten**

Schwerpunktsatz: $\boxed{m\mathbf{a}_S = \mathbf{F}}$ Der Schwerpunkt bewegt sich so, als ob die Gesamtmasse in ihm vereinigt wäre und alle äußeren Kräfte an ihm angreifen.

Impulssatz: $\boxed{\mathbf{p} = \sum_i \mathbf{p}_i = \sum_i m_i \mathbf{v}_i = m\mathbf{v}_S}$, $\boxed{\mathbf{p} - \mathbf{p}_0 = \int_{t_0}^{t} \mathbf{F} d\bar{t} = \hat{\mathbf{F}}}$

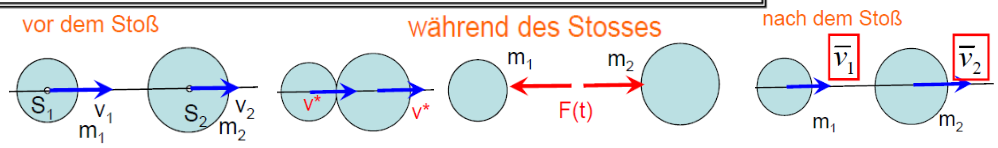
Momentensatz um feste Achse: $\boxed{\Theta_a \ddot{\varphi} = M_a}$ **Richtung M und φ gleich!!!** →



Arbeitssatz: $\boxed{E_k - E_{k0} = W^{(a)} + W^{(i)} = W}$

Energiesatz: $\boxed{E_k + E_p^{(a)} + E_p^{(i)} = E_{k0} + E_{p0}^{(a)} + E_{p0}^{(i)} = const}$

gerader, zentrischer Stoß:



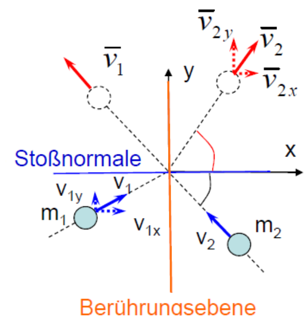
e=1 →elast.
e=0 →plast.

$$\boxed{e = -\frac{\bar{v}_1 - \bar{v}_2}{v_1 - v_2}} \quad \boxed{\bar{v}_1 = \frac{m_1 v_1 + m_2 v_2 - e m_2 (v_1 - v_2)}{m_1 + m_2}, \ \bar{v}_2 = \frac{m_1 v_1 + m_2 v_2 + e m_1 (v_1 - v_2)}{m_1 + m_2}}$$

Beispiel:

$$\begin{aligned} m_1(v^* - v_1) &= -\hat{F}_K \\ m_2(v^* - v_2) &= +\hat{F}_K \end{aligned} \qquad \begin{aligned} m_1(\bar{v}_1 - v^*) &= -\hat{F}_R \\ m_2(\bar{v}_2 - v^*) &= +\hat{F}_R \end{aligned} \qquad \boxed{\hat{F}_R = e\hat{F}_K}$$

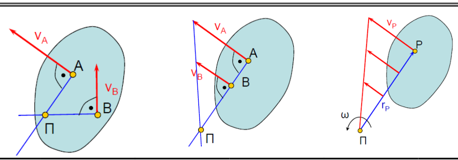
schiefer, zentrischer Stoß: $\boxed{e = -\frac{\bar{v}_{1x} - \bar{v}_{2x}}{v_{1x} - v_{2x}}}$ $\boxed{\begin{aligned} \bar{v}_{1y} &= v_{1y} \\ \bar{v}_{2y} &= v_{2y} \end{aligned}}$ **-Massen sind glatt**
-in x wie gerade.



3. Kinematik und Kinetik des starren Körpers

3.1 Kinematik $\boxed{\text{• allgemeine Bewegung = Translation + Rotation}}$

Momentanpol:

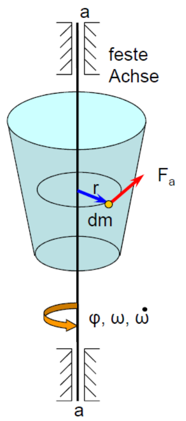


3.2 Kinetik der Rotation um eine feste Achse, Momentensatz:

$$\boxed{\Theta_a \dot{\omega} = M_a} \qquad \boxed{\Theta_a = \int r^2 dm}$$

Drehimpulssatz: $\boxed{L_a = \Theta_a \omega}$ $\boxed{\dot{L}_a = M_a}$ $\boxed{\Theta_a(\omega - \omega_0) = \int_{t_0}^{t} M_a d\bar{t}}$ wenn M=0, Drehimpuls bleibt const.

Satz von Steiner: $\boxed{\Theta_a = \Theta_s + r_s^2 m}$



Arbeitssatz: $\boxed{E_k - E_{k0} = W}$, $\boxed{E_k = \frac{1}{2}\Theta_a \omega^2}$, $\boxed{W = \int_{\varphi_0}^{\varphi} M_a d\bar{\varphi}}$

Energiesatz: $\boxed{E_k + E_p = E_{k0} + E_{p0} = const}$ **Leistung:** $\boxed{P = \frac{dW}{dt} = M_a \omega}$

3.3 Kinetik der ebenen Bewegung – Kräfte- und Momentensatz:

Schwerpunktsatz/Kräftesatz : $\boxed{m\ddot{x}_S = F_x \, , \; m\ddot{y}_S = F_y}$

Drallsatz/Momentensatz: $\boxed{\Theta_S \ddot{\varphi} = M_S}$ $\boxed{\Theta_A \ddot{\varphi} = M_A}$ — Sonderfall: reine Rotation um festen Punkt A (z.B. Lager)

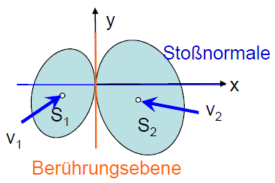
Impulssatz: $\boxed{\begin{array}{l} m\dot{x}_S - m\dot{x}_{S0} = \hat{F}_x \, , \; m\dot{y}_S - m\dot{y}_{S0} = \hat{F}_y \\ \Theta_S \dot{\varphi} - \Theta_S \dot{\varphi}_0 = \hat{M}_S \end{array}}$ — bezügl. Schwerpkt. $\boxed{\begin{array}{l} \dot{x}_A = 0 \, , \; \dot{y}_A = 0 \\ \Theta_A \dot{\varphi} - \Theta_A \dot{\varphi}_0 = \hat{M}_A \end{array}}$ — bezügl. festen Punkt A

kinetische Energie: $\boxed{E_k = \frac{1}{2} m v_S^2 + \frac{1}{2}\Theta_S \omega^2}$ $\boxed{\begin{array}{l} E_k = \frac{1}{2}\Theta_A \omega^2 \\ \text{A} - \text{fest} \end{array}}$

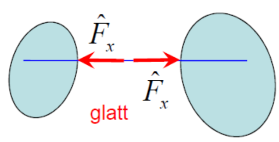
Energiesatz

Arbeitssatz,Energiesatz: $\boxed{E_k - E_{k0} = W}$ - Arbeitssatz $\boxed{E_k + E_p = E_{k0} + E_{p0} = const}$

exzentrischer, schiefer Stoß, zwei glatte Körper:



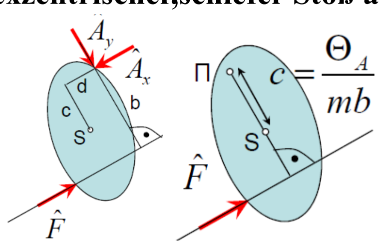
$$\boxed{\begin{array}{l} \rightarrow: m_1(\bar{v}_{1x} - v_{1x}) = -\hat{F}_x \\ \uparrow: m_1(\bar{v}_{1y} - v_{1y}) = 0 \\ \curvearrowleft S_1 : \Theta_{S1}(\bar{\omega}_1 - \omega_1) = a_1 \hat{F}_x \end{array}} \qquad \boxed{\begin{array}{l} \rightarrow: m_2(\bar{v}_{2x} - v_{2x}) = \hat{F}_x \\ \uparrow: m_2(\bar{v}_{2y} - v_{2y}) = 0 \\ \curvearrowleft S_2 : \Theta_{S2}(\bar{\omega}_2 - \omega_2) = -a_2 \hat{F}_x \end{array}}$$



$$\boxed{\begin{array}{l} \bar{v}_{1x} = v_{1x} - \frac{\hat{F}_x}{m_1}, \; \bar{v}_{1y} = v_{1y} \, , \; \bar{\omega}_1 = \omega_1 + \frac{a_1 \hat{F}_x}{\Theta_{S_1}}, \\ \bar{v}_{2x} = v_{2x} + \frac{\hat{F}_x}{m_2}, \; \bar{v}_{2y} = v_{2y} \, , \; \bar{\omega}_2 = \omega_2 - \frac{a_2 \hat{F}_x}{\Theta_{S_2}} \end{array}}$$

— Schwerpunkts- und Winkelgeschwindigkeiten vor/ nach dem Stoß

exzentrischer,schiefer Stoß auf einen gelagerten Körper:



$\boxed{c = \frac{\Theta_A}{mb}, \; d = 0}$ — Lagerreaktionen verschwinden, wenn d = 0

$\boxed{\hat{A}_x = \hat{F}\left(1 - \frac{mcb}{\Theta_A}\right), \; \hat{A}_y = \hat{F}\frac{mdb}{\Theta_A}}$ — Lagerreaktionen

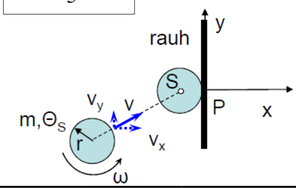
schiefer Stoß bei rauhem Körper:

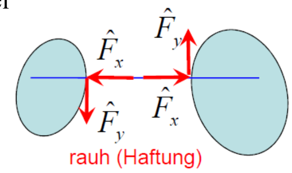
$$\uparrow: m(\bar{v}_y - v_y) = -\hat{F}_y$$
$$\rightarrow: m(\bar{v}_x - v_x) = -\hat{F}_x$$
$$\curvearrowleft S: \Theta_S(\bar{\omega} - \omega) = -r\hat{F}_y$$

während des Stoßes haftet die Kugel in P:

$$\bar{v}_y^P = 0 = \bar{v}_y + r\bar{\omega}$$

$\Theta_S = \frac{2}{5}mr^2$ homogene Kugel





3.4 Kinetik der räumlichen Bewegung:

Kräftesatz: $\boxed{m\mathbf{v}_S = \mathbf{p}}$ $\boxed{m\ddot{\mathbf{r}}_S = \mathbf{F}}$

Momentensatz: $\boxed{\dot{\mathbf{L}}^{(A)} - (\boldsymbol{\omega}\times\mathbf{r}_{AS})\times\mathbf{v}_A m = \mathbf{M}^{(A)}}$ $\boxed{\dot{\mathbf{L}}^{(S)} = \mathbf{M}^{(S)}}$ $\boxed{\dot{\mathbf{L}}^{(A)} = \mathbf{M}^{(A)},\ A - \text{fest}}$

Drehimpuls, Trägheitstensor:

$$\mathbf{L}^{(A)} = \begin{bmatrix} \mathbf{L}_x^{(A)} \\ \mathbf{L}_y^{(A)} \\ \mathbf{L}_z^{(A)} \end{bmatrix} = \begin{bmatrix} \Theta_x\omega_x + \Theta_{xy}\omega_y + \Theta_{xz}\omega_z \\ \Theta_{yx}\omega_x + \Theta_y\omega_y + \Theta_{yz}\omega_z \\ \Theta_{zx}\omega_x + \Theta_{zy}\omega_y + \Theta_z\omega_z \end{bmatrix} = \boldsymbol{\Theta}^{(A)}.\boldsymbol{\omega}$$

axiale Massenträgheitsmomente: $\Theta_x = \int(y^2+z^2)dm$, $\Theta_y = \int(z^2+x^2)dm$, $\Theta_z = \int(x^2+y^2)dm$

Deviations- bzw. Zentrifugalmomente: $\Theta_{xy} = \Theta_{yx} = -\int xydm$, $\Theta_{yz} = \Theta_{zy} = -\int yzdm$, $\Theta_{zx} = \Theta_{xz} = -\int zxdm$

Eulersche Gleichungen:

$$\boldsymbol{\Theta}^{(A)}.\dot{\omega} + \omega\times(\boldsymbol{\Theta}^{(A)}\cdot\omega) = \mathbf{M}^{(A)}$$

$$\Theta_1\dot{\omega}_1 - (\Theta_2 - \Theta_3)\omega_2\omega_3 = M_1$$
$$\Theta_2\dot{\omega}_2 - (\Theta_3 - \Theta_1)\omega_3\omega_1 = M_2$$
$$\Theta_3\dot{\omega}_3 - (\Theta_1 - \Theta_2)\omega_1\omega_2 = M_3$$

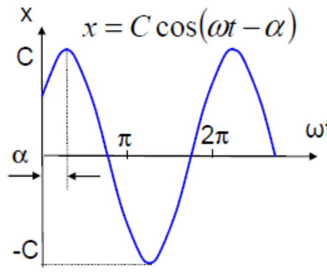
4. Schwingungen

4.1 Grundbegriffe:

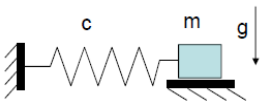
$$\omega = \frac{2\pi}{T} = 2\pi f$$

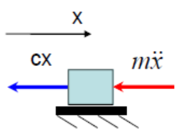
$x(t) = C\cos(\omega t - \alpha)$ harmonische Schwingung mit beliebigen Startwert

$x(t) = A\cos\omega t + B\sin\omega t$ harmonische Schwingung als Überlagerung von cos- und sin-Schwingung



Ungedämpfte Schwingung:





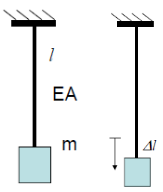
$$\ddot{x} + \omega^2 x = 0 \qquad \omega^2 = \frac{c}{m}$$

Energie für ungedämpfte Schwingung:

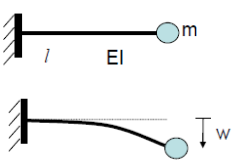
$$E_k = \tfrac{1}{2}m\dot{x}^2 = \tfrac{1}{2}m\omega^2C^2\sin^2(\omega t - \alpha) = \tfrac{1}{4}m\omega^2C^2[1 - \cos(2\omega t - 2\alpha)]$$

$$E_p = \tfrac{1}{2}cx^2 = \tfrac{1}{2}cC^2\cos^2(\omega t - \alpha) = \tfrac{1}{4}cC^2[1 + \cos(2\omega t - 2\alpha)]$$

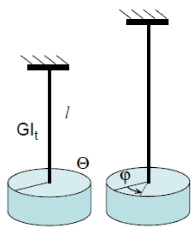
Federzahlen elastische Systeme:



$$c = \frac{F}{\Delta l} = \frac{EA}{l} \qquad \Delta l = \frac{Fl}{EA}$$



$$c = \frac{F}{w} = \frac{3EI}{l^3} \qquad w = \frac{Fl^3}{3EI}$$

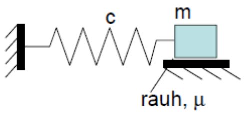


$$c_T = \frac{M_t}{\varphi} = \frac{GI_t}{l} \qquad \varphi = \frac{M_t l}{GI_t}$$

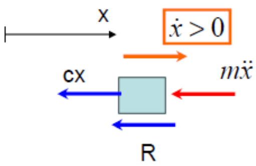
DGL: $\Theta\ddot{\varphi} + c_T\varphi = 0$

Parallelschaltung: $\boxed{c^* = \sum_j c_j}$ **Reihenschaltung:** $\boxed{\frac{1}{c^*} = \sum_j \frac{1}{c_j}}$ **Nachgiebigkeit:** $\boxed{h = \frac{1}{c}}$

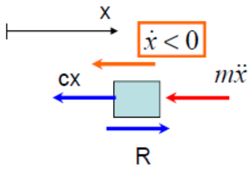
Gedämpfte freie Schwingung:



1.Fall:



2.Fall:



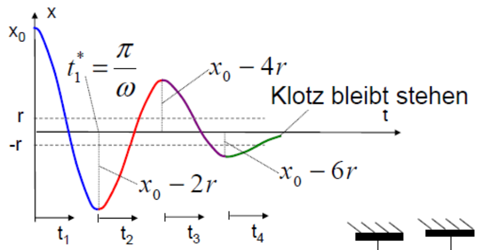
$$\leftarrow: \; m\ddot{x} + cx = \begin{cases} -R & \text{für } \dot{x} > 0 \\ +R & \text{für } \dot{x} < 0 \end{cases}$$

mit $\boxed{\omega^2 = \frac{c}{m}, \quad r = \frac{R}{c}}$ folgt:

$$\ddot{x} + \omega^2 x = \begin{cases} -\omega^2 r & \text{für } \dot{x} > 0 \\ +\omega^2 r & \text{für } \dot{x} < 0 \end{cases}$$

1.Abschnitt: $\boxed{x = x_h + x_p}$ $\boxed{x_p = r}$ $\boxed{x_h(t_1) = A_1 \cos \omega t_1 + B_1 \sin \omega t_1}$

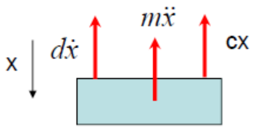
$\rightarrow$ $\boxed{x(t_1) = A_1 \cos \omega t_1 + B_1 \sin \omega t_1 + r}$

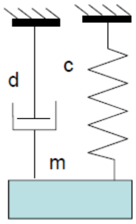


2.Abschnitt: $\boxed{\ddot{x} + \omega^2 x = -\omega^2 r}$

$\rightarrow$ $\boxed{x(t_2) = A_2 \cos \omega t_2 + B_2 \sin \omega t_2 - r}$

Dämpfung: $\boxed{\omega^2 = \frac{c}{m}, \quad 2\delta = \frac{d}{m}}$ $\boxed{\ddot{x} + 2\delta\,\dot{x} + \omega^2 x = 0}$

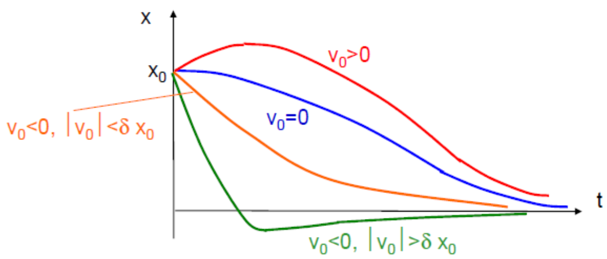




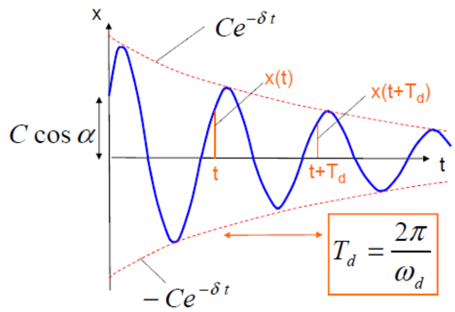
Dämpfungsgrad: $\boxed{D = \frac{\delta}{\omega}}$

logarithmische Dekrement: $\boxed{\Lambda = \ln \frac{x(t)}{x(t+T_d)} = \delta\, T_d = \frac{2\pi\delta}{\omega_d} = 2\pi \frac{D}{\sqrt{1-D^2}}}$

starke Dämpfung:



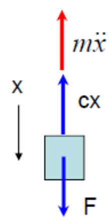
schwache Dämpfung:

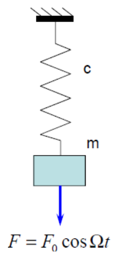


<u>Erzwungene Schwingungen:</u>

Ungedämpfte Schwingung: $\boxed{\uparrow: m\ddot{x} + cx = F_0 \cos \Omega t}$

statische Verlängerung: $\boxed{\ddot{x} + \omega^2 x = \omega^2 x_0 \cos \Omega t}$ $\boxed{\omega^2 = \frac{c}{m}, \quad x_0 = \frac{F_0}{c}}$





Frequenzverhältnis: $\boxed{\eta = \dfrac{\Omega}{\omega} \qquad V = \dfrac{1}{1-\eta^2}}$

allgemeine Lösung: $\boxed{x(t) = x_h + x_p = C\cos(\omega t - \alpha) + x_0 V \cos\Omega t}$

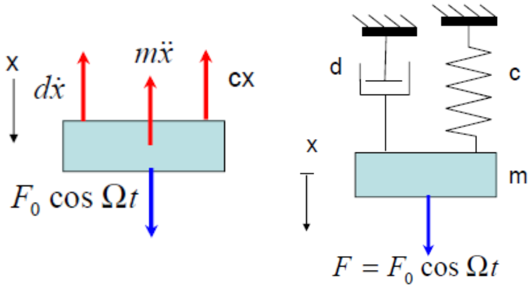
Resonanz: $\boxed{\Omega = \omega}$ $\rightarrow$ $\boxed{x_p = 0{,}5 x_0 \omega t \sin \omega t}$

Gedämpfte Schwingung:

1a. Fall: (Krafterregung)

$$\boxed{2\delta = \frac{d}{m},\ \omega^2 = \frac{c}{m},\ x_0 = \frac{F_0}{c}}$$

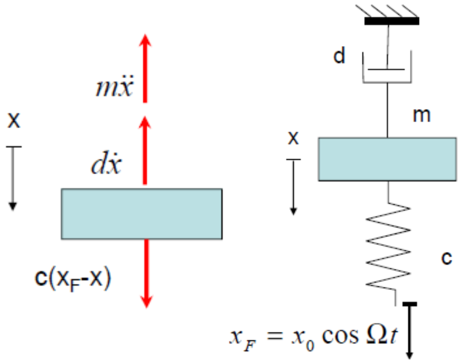
DGL: $\boxed{\ddot{x} + 2\delta\,\dot{x} + \omega^2 x = \omega^2 x_0 \cos\Omega t}$



1b. Fall: (Endpunkterregung über Feder)

- DGL und Formel wie bei 1a.

- E=1

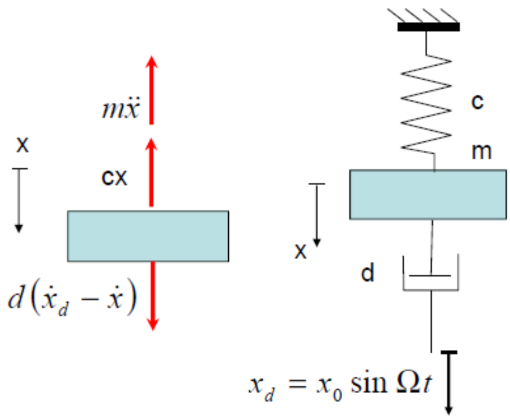


2. Fall: (Endpunkterregung über Dämpfer)

$$\boxed{D = \frac{\delta}{\omega},\ \eta = \frac{\Omega}{\omega}}$$

DGL:
$$\boxed{\begin{aligned}&\ddot{x} + 2\delta\,\dot{x} + \omega^2 x = 2\delta\,\Omega x_0 \cos\Omega t\\ &\ddot{x} + 2\delta\,\dot{x} + \omega^2 x = 2D\eta\omega^2 x_0 \cos\Omega t\end{aligned}}$$

- E=2Dη

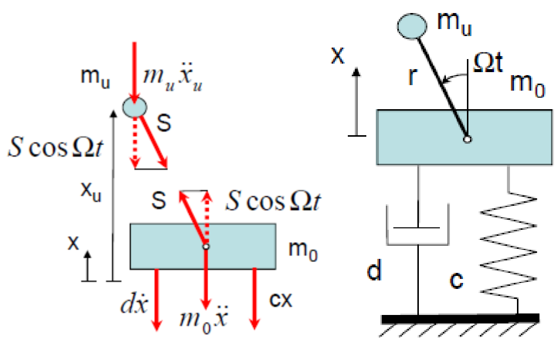


3. Fall: (Erregung über rotierende Unwucht)

$$\boxed{m = m_0 + m_u,\ x_0 = \frac{m_u}{m} r}$$

DGL: $\boxed{\ddot{x} + 2\delta\,\dot{x} + \omega^2 x = \omega^2 \eta^2 x_0 \cos\Omega t}$

- E=η²



Phasen-Frequenzgang: $\boxed{\tan\varphi = \dfrac{2D\eta}{1-\eta^2}}$ **Amplituden-Frequenzgang:** $\boxed{V = \dfrac{E}{\sqrt{(1-\eta^2)^2 + 4D^2\eta^2}}}$

5. Prinzipien der Mechanik:

Formale Rückführung der Kinetik auf die Statik:

$$m\vec{a} = \vec{F} \qquad \Theta_S \ddot{\varphi} = M_S \qquad \vec{F} + \vec{F}_T = \vec{0} \qquad M_S + M_{T,S} = 0$$

Prinzip der virtuellen Arbeit:

$$m\vec{a} = \vec{F}^{(e)} + \vec{F}^{(z)} \qquad \delta W = \vec{F}^{(e)} . \delta\vec{r} \qquad \delta W_T = \vec{F}_T . \delta\vec{r} = -m\vec{a} . \delta\vec{r}$$

$$\delta W + \delta W_T = 0$$

Ein Massenpunkt bewegt sich so, dass bei einer virtuellen Verrückung die Summe der virtuellen Arbeiten der eingeprägten Kräfte und der Trägheitskräfte zu jedem Zeitpunkt verschwindet.

Lagrandsche Gleichungen 2. Art:

$$f_{3D} = 3n - r \qquad f_{2D} = 2n - r$$

Zahl kinematischer Bindungen

$$L = E_k - E_p \qquad \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_j}\right) - \frac{\partial L}{\partial q_j} = 0, \quad j = 1, \ldots, f$$

---

6. Relativbewegungen des Massenpunktes:

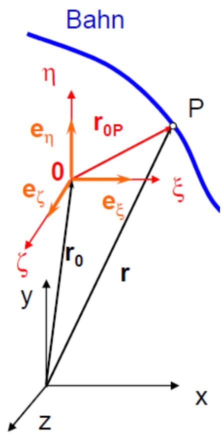
Translation des Bezugssystemes:

$$m\vec{a} = \vec{F}$$

$$\vec{r} = \vec{r}_0 + \vec{r}_{0P} \qquad \vec{r}_{0P} = \xi\, \vec{e}_\xi + \eta\, \vec{e}_\eta + \zeta\, \vec{e}_\zeta$$

$$\vec{v}_a = \vec{v}_f + \vec{v}_r \qquad \vec{v}_f = \dot{\vec{r}}_0 \qquad \vec{v}_r = \dot{\vec{r}}_{0P}$$

$$\vec{a}_a = \vec{a}_f + \vec{a}_r \qquad \vec{a}_f = \ddot{\vec{r}}_0 \qquad \vec{a}_r = \ddot{\vec{r}}_{0P}$$



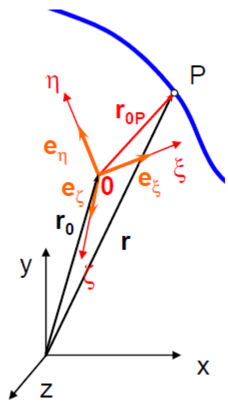
Translation und Rotation des Bezugssystemes:

$$\vec{r} = \vec{r}_0 + \vec{r}_{0P} \qquad \dot{\vec{r}}_{0P} = \frac{d^*\vec{r}_{0P}}{dt} + \vec{\omega} \times \vec{r}_{0P}$$

$$\vec{v}_a = \vec{v}_f + \vec{v}_r \qquad \vec{v}_r = \frac{d^*\vec{r}_{0P}}{dt} \qquad \vec{v}_f = \vec{v}_0 + \vec{\omega} \times \vec{r}_{0P}$$

$$\vec{a}_a = \vec{a}_f + \vec{a}_r + \vec{a}_c \qquad \vec{a}_f = \vec{a}_0 + \dot{\vec{\omega}} \times \vec{r}_{0P} + \vec{\omega} \times (\vec{\omega} \times \vec{r}_{0P}) \qquad \vec{a}_c = 2\vec{\omega} \times \vec{v}_r$$

$$\vec{a}_r = \frac{d^*\vec{v}_r}{dt} = \frac{d^{2*}\vec{r}_{0P}}{dt^2}$$



Sonderfall ebene Bewegung: $\vec{v}_f = \vec{v}_0 + r\omega\vec{e}_\varphi \qquad \vec{a}_f = \vec{a}_0 + r\dot{\omega}\vec{e}_\varphi - r\omega^2\vec{e}_r$

Kinetik der Relativbewegung:

$$m\vec{a}_r = \vec{F} + \vec{F}_f + \vec{F}_c \qquad \vec{F}_f = -m\vec{a}_f \qquad \vec{F}_c = -m\vec{a}_c$$

$$m\vec{a}_r = \vec{F}$$