

Weibull

Verteilungsdichtefkt.
kumul. Verteilung
Zeit für $V \leq V_m$
 $V \geq V_m$

$$\begin{aligned} f(V_i) &= \frac{k_i}{A_i} \left(\frac{V_i}{A_i}\right)^{k_i} \exp\left(-\left(\frac{V_i}{A_i}\right)^{k_i}\right) \\ F(V_i) &= 1 - \exp\left(-\left(\frac{V_i}{A_i}\right)^{k_i}\right) \\ T(V \leq V_m) &= F(V_m) \cdot \text{Zeitraum} \cdot N_{\text{Mess}} \left[\frac{\text{Zeit}}{s}\right] \\ T(V \geq V_m) &= F(V_{\text{max}}) - F(V_m) \cdot \text{Zeitraum} \cdot N_{\text{Mess}} \end{aligned}$$

Mittlere Windgeschw.

$$V_m \approx A(0.568 + \frac{0.434}{k})^{1/k}$$

$$V_m = A \Gamma(1 + \frac{1}{k})$$

log. Windprofil

$$V_z = V_{z_0} \cdot \frac{\ln(z/z_0)}{\ln(z_m/z_0)} ; A_z = A_{z_0} \frac{\ln(z/z_0)}{\ln(z_m/z_0)}$$

Bei gleichem Standort: $k_z = k_{z_0}$

Pures Law

$$V_z = V_{z_0} \left(\frac{z}{z_0}\right)^k$$

AEP (Jahresenergieertrag)

$$AEP = 8760 \cdot \sum_i (F(V_i) - F(V_{i-1})) \left(\frac{P_{i-1} + P_i}{2}\right) N_{\text{Mess}} \left[\frac{\text{W}}{\text{a}}\right]$$

$$E_{\text{ges}} = AEP = \sum E_i = \sum_i f(V_i) \cdot P_i \cdot T$$

Jährliche Volllast in std.

$$T_{\text{voll}} = \frac{AEP}{P_{\text{Nenn}}} [h]$$

Auslastungsfaktor

$$C_{\text{ap}} = \frac{AEP}{P_{\text{Nenn}} \cdot 8760h} = \frac{T_{\text{voll}}}{8760h} [-] \quad 20\% - 70\%$$

Rorleigh

$$f(V) = \frac{\pi}{2} \left(\frac{V}{V_m}\right) \exp\left(-\frac{\pi}{2} \left(\frac{V}{V_m}\right)^2\right)$$

$$F(V) = 1 - \exp\left(-\frac{\pi}{2} \left(\frac{V}{V_m}\right)^2\right)$$

Weibull für $k=2$

$$A = \frac{2}{\sqrt{\pi}} \cdot V_m = \frac{V_m}{\Gamma(1 + \frac{1}{k})}$$

Dynamik

kräftesatz

$$\vec{F} = m \cdot \vec{a} = m \cdot \ddot{\vec{q}}(t) [N]$$

Federgesetz

$$\vec{F}_h = k \cdot \vec{q}(t)$$

Dämpfungsgesetz

$$\vec{F}_d = b \cdot \dot{\vec{q}}(t)$$

Bewegungsgleichung

$$M \cdot \ddot{\vec{q}}(t) + B \cdot \dot{\vec{q}}(t) + K \cdot \vec{q}(t) = \vec{f}(t)$$

$$[kg] \cdot [m/s^2] + [Ns] [m/s] + [N/m] [m] = [N] = [kg \cdot m/s^2]$$

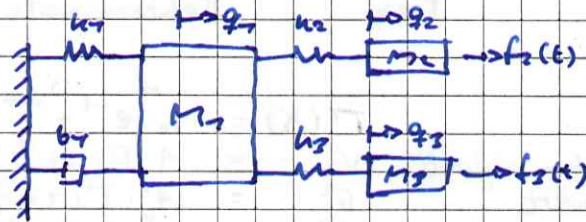
Normalform

$$\ddot{q}(t) + 2\zeta\omega_0 \dot{q}(t) + \omega_0^2 q(t) = \omega_0^2 u(t)$$

Eigenfrequenz

$$\omega_0 = \sqrt{k/m} [\text{rad/s}] \rightarrow f_0 = \frac{\omega_0}{2\pi} [1/s]$$

Ersatzmodell: Windturbine mit zwei Blättern:



$$M = \begin{bmatrix} M_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix}; \quad B = \begin{bmatrix} b_1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}; \quad K = \begin{bmatrix} k_1 + k_2 + k_3 & -k_2 & -k_3 \\ -k_2 & k_2 & 0 \\ -k_3 & 0 & k_3 \end{bmatrix}$$

3 Eigenfrequenzen

3 Eigenformen

$$\vec{f} = \begin{bmatrix} 0 \\ f_2(t) \\ f_3(t) \end{bmatrix}$$

1D: Allg. Ansatz: $\vec{q}(t) = \vec{q} e^{i\omega t}$
Sonst: $\vec{q}(t) = \vec{q} e^{i\omega t}$

statistik

Arithm. Mittel

Median

Empir. Varianz

Empir. Streuung

Empir. Kovarianz

Empir. Korrelationskoeff.

Lineare Gerade / Zshg

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

Wert in der Mitte : 29 $\hat{=}$ 15. Element

$$s^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2$$

$$s = \sqrt{s^2}$$

$$s_{xy} = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})$$

$$r_{xy} = \frac{s_{xy}}{s_x \cdot s_y} \approx 1 \rightarrow \text{lin. Zshg gerechtf.}$$

$$y = ax + b \quad a = \frac{s_y}{s_x} \cdot r_{xy}$$

$$b = -\frac{s_y}{s_x} \cdot r_{xy} \cdot \bar{x} + \bar{y}$$

$$b = \bar{y} - a \bar{x}$$

Windatlas

Rauhigkeitsklasse

Sect	z_{01}	x_1	z_{02}	x_2
Windrichtung [°] 0° = Norden	Rauhigkeitslänge [m] u. Veränderung über Entfernung			Entfernung [m]

Vert. der Windmessung
und tgl. / jährliche
Variation

Sect	Freq	< τ	τ	$V_{wind} [\frac{m}{s}]$	τz	$> \tau z$	A	k
Windrichtung [°]	Häufigk. Vert. d. Windes pro Sect.							Weibull-Param. für jeden Sect.
				Verteilung der Windgeschw. (Häufigkeit pro Windgeschw. [%])				[m/s] [-]
Total								

UTC	Jan	Feb	Dez	Year
Zeit [h]	-	-	-	-
	-	- $V_{wind} [\frac{m}{s}]$	-	-
Day	-	-	-	-

Rauhigkeitsklasse X

z	Class 0	Class 1	z	0	30	Winds [°]	330	Total
z			z	-	-	$A [\frac{m}{s}]$	-	-
			z	-	-	$k [-]$	-	-
H			200	-	-		-	-
[V]	$V_{wind} [\frac{m}{s}]$ ges. mittl. Leistung der Winder [W]		Freq			Sektorenweite Verteilung der Windgeschw.		1000

Gammafunktion

Mittlere Windgeschwindigkeit

Quadrat. Mittelwert

Kubischer Mittelwert

Leistungsdichte

$$\Gamma(x) = \int_0^{\infty} e^{-t} t^{x-1} dt$$

$$V_m = A \Gamma(1 + \frac{1}{k}) = M = \sum f_i \cdot m_i$$

$$\bar{U}^2 = A^2 \cdot \Gamma(1 + \frac{2}{k}) \quad [\frac{m^2}{s^2}]$$

$$\bar{U}^3 = A^3 \cdot \Gamma(1 + \frac{3}{k}) \quad [\frac{m^3}{s^3}]$$

$$E = \rho_a \cdot \bar{U}^3 = A^3 F_0(k) \quad [\frac{W}{m^2}]$$

$$E_i = A_i \cdot F_0(k_i) \quad [\frac{W}{m^2}] = f(v_i) \cdot P_i \cdot T$$

Formfaktor

Verteilungsdichtefunktion

$$k = \frac{F_0(\frac{1}{\bar{U}^2})}{F_0(\frac{1}{\bar{U}^3})}$$

$$f(v) = \frac{k}{A} (\frac{v}{A})^{k-1} \exp(-(\frac{v}{A})^k)$$

Energie in $[\frac{Wh}{m^2}]$

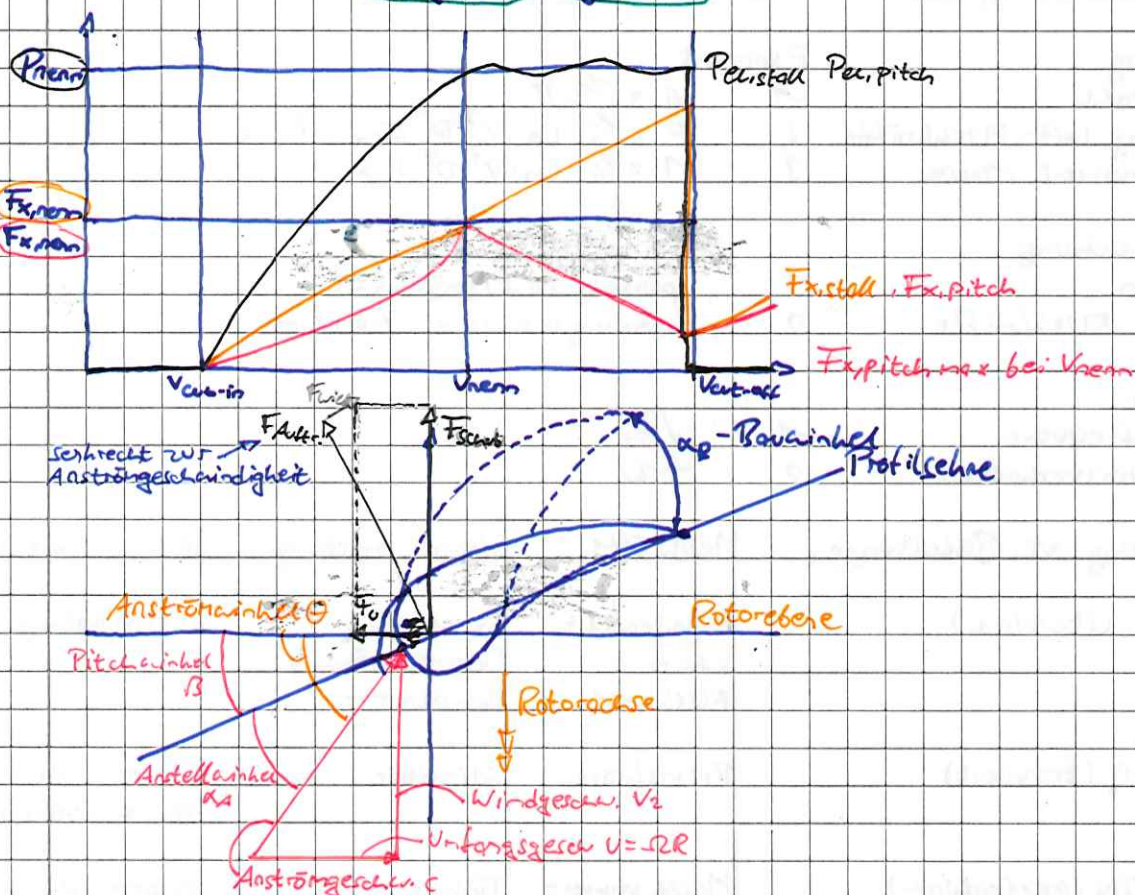
$$E = E_i \cdot f_i \cdot T_i$$

Ausgangspunkt
Nennpunkt

Auslegungspunkt
Nennpunkt

 λ_A, ρ_A, V_A

Prüfungsfragen ab Varen

$$\Omega_{\text{gen, norm}}, \Omega_{\text{gen, norm}} \rightarrow \text{ab } V_A$$


Lineares interpolieren: $y(x) = y_1 + \frac{y_2 - y_1}{x_2 - x_1} (x - x_1)$

Aerodynamik

Profilgüte

Gleitvorh. $E = \frac{C_L}{C_D} = \frac{V}{E} = \frac{1}{E}$ Gleitzahl
 ↳ Bestes Gleiten Erreicht → Tangente an Polare

Auftrieb

$$F_A = \frac{\rho}{2} \cdot C_L \cdot V_{\infty}^2 \cdot A$$

Widerstand

$$F_W = \frac{\rho}{2} \cdot C_D \cdot V_{\infty}^2 \cdot A$$

Schub

$$F_x = \frac{\rho}{2} \cdot C_s \cdot V_{\infty}^2 \cdot F = C_s \cdot \text{Staudruck} \cdot \text{Rotor-Fläche}$$

$$F_x = F \cdot \frac{\rho}{2} \cdot (V_1^2 - V_2^2) = \frac{\pi R^2}{2} \cdot \frac{\rho}{2} \cdot (V_1^2 - V_2^2)$$

Betz-Optimum

$$\alpha = \frac{1}{3} \quad C_D = 4\alpha \cdot (1-\alpha)^2$$

$$V_2 = (1-\alpha) V_1 \quad C_L = 4\alpha \cdot (1-\alpha)$$

$$V_3 = (1-2\alpha) V_1 \quad C_M = \frac{C_P}{\lambda} = M_{\text{Rotor}} \cdot \left(\frac{\rho}{2} \cdot V_1^2 \cdot \pi R^2\right)^{-1}$$

Profiltiefe

$$t(r) = 2\pi R \cdot \frac{1}{2} \cdot \frac{\rho}{2} \cdot \frac{1}{C_D} \cdot (\lambda_0 - \sqrt{\lambda_0^2 (r/R)^2 + 4\alpha})^{-1}$$

Bauwinkel

$$\alpha_{\text{Bau}} = \arctan\left(\frac{2}{\pi \lambda_0 (r/R)}\right) - \alpha$$

↳ Entwurfswert

Windleistung

$$P_{\text{Wind}} = \frac{\rho}{2} \cdot V_{\infty}^3 \cdot \pi R^2$$

Rotorleistung

$$P_{\text{aero}} = P_{\text{rotor}} = \frac{\rho}{2} \cdot C_P \cdot V_{\infty}^3 \cdot \pi R^2$$

Mech. Leistung

$$P_{\text{mech}} = P_{\text{aero}} \cdot \eta_{\text{getr}} = M_{\text{gen}} \cdot \Omega_{\text{gen}}$$

El. Leistung

$$P_{\text{el}} = P_{\text{mech}} \cdot \eta_{\text{gen}} = C_P \cdot \eta_{\text{getr}} \cdot M_{\text{gen}}$$

Schnelllaufzahl

$$\lambda_1 = \frac{V_{\text{tip}}}{V_{\text{wind}}} = \frac{\Omega \cdot R}{V_{\text{wind}}} = \frac{2\pi n R}{V_{\text{wind}}}$$

Übersetzung

$$i = \frac{n_{\text{gen}}}{n_{\text{ab}}} = \frac{n_{\text{aero}}}{n_{\text{gen}}} = \frac{M_{\text{aero}}}{M_{\text{gen}}}$$

Ähnlichkeitsregeln

$$X_{\text{neu}} = X_{\text{alt}} \cdot \left(\frac{D_{\text{neu}}}{D_{\text{alt}}}\right)^{\text{Exponent}} \quad R: \text{Exp} = 1$$

Belastung

Drehzahl

Exponent

$$-1 \quad \Omega = \frac{1}{D} \cdot \pi$$

Leistung, Luft-, Fliehkräfte

$$2 \quad P = \frac{\rho}{2} \cdot C_P \cdot V^3 D^2 \pi / 4 = f(\Omega^2)$$

Drehmoment, Masse

$$3 \quad M = \frac{\rho}{2} \cdot C_M \cdot V^2 D^3 \pi / 8$$

Beanspruchung

Material

1

Spannung aus Eigengewicht

Luft-, Fliehkräfte

0

Spannung aus Wind / Rotation

Dynamik

Eigenfrequenz

-1

$$\sqrt{\lambda_0}$$

Frequenzverhalten

0

$$\frac{\Omega}{\omega}$$

Einteilung v. Belastungen

Merkmale

Einwirk. Umgebung

Betriebszustände

konstant (statisch)

Eigengewicht,
Schwer-/
Fliehkraft

F_x aus V_{∞} ,
Reiserströmung,
Temperatur

Rotorbelohnung

kurzzeitig (transient)

Bremskraft

Windböe

Bremsen, Zu-/Abschalten
des Generators, Netzstörung

Regelmäßig (periodisch)

Massenverwund

Türvorstoß,
Schrägenströmung

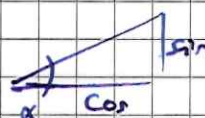
Aerodyn. Unwucht,
Phasen-/Leistungswert Gen

Regellos (stochastisch)

—

Windturbulenz,
Seegang,
Erdbeben

—



$$Re = \frac{\omega_m E}{\nu} \quad \text{Schlechter}$$

$$Re_{\text{krit}} = 200000 \lesssim Re$$

$$\rho = \frac{p}{RT}$$

$$R_L = R_s \cdot (1 - \epsilon \frac{p_a}{p_s} (1 - \frac{p_a}{p_s}))$$

$$T_{\text{bar}} = 7000 \text{ K}$$

Rel. Luftdichte

$$P = \Omega \cdot M$$

$$\Omega = 2\pi \cdot n$$

$$M = J \cdot \dot{\omega}$$

$$= k \cdot \Omega^2$$

Mit $k = \frac{1}{2} \pi R^2 \left(\frac{\rho}{2} \cdot \frac{V_{\text{tip}}^2}{\Omega^2} \right)$

$\Omega: \left[\frac{\text{rad}}{\text{s}} \right]$

$n: \left[\frac{\text{U/min}}{60} \right]$

$\Omega = \frac{2\pi n}{60}$

$k = \frac{1}{2} \pi R^2 \left(\frac{\rho}{2} \cdot \frac{V_{\text{tip}}^2}{\Omega^2} \right)$

Windenergie I

Wind Modeling - How to describe wind

- Wind profiles: Power and log
- Time and Frequency domain transfer
- Turbulence intensity

Rotor Aerodynamics - How to calculate forces on the blade

- Global momentum theory - thrust coefficient
- Blade forces - Lift and drag, acting angles
- Iterations for induction factor
- Stall margin

Dynamics - How to evaluate the design of the tower-nacelle-system

- Bending natural frequency of the nacelle-tower-system
- Blade design principles: soft-stiff intervals
- Campbell diagram for permissible operation ranges

Fatigue - How to calculate the fatigue damage

- S-N-Curves
- Rainflow counting method
- Fatigue damage D
- Damage equivalent load with 7 and 2 slopes

Offshore Hydrodynamic Load - How to describe wave and wave loads

- Wave velocities: water particle, wave phase, wave group velocity
- Wave spectrum
- Rigid Body motions for 6DOF
- Motion equations and stiffness calculation

Online Tests :

1



4



7



2



5



3

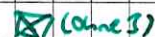


6



Exercise :

1



4



2

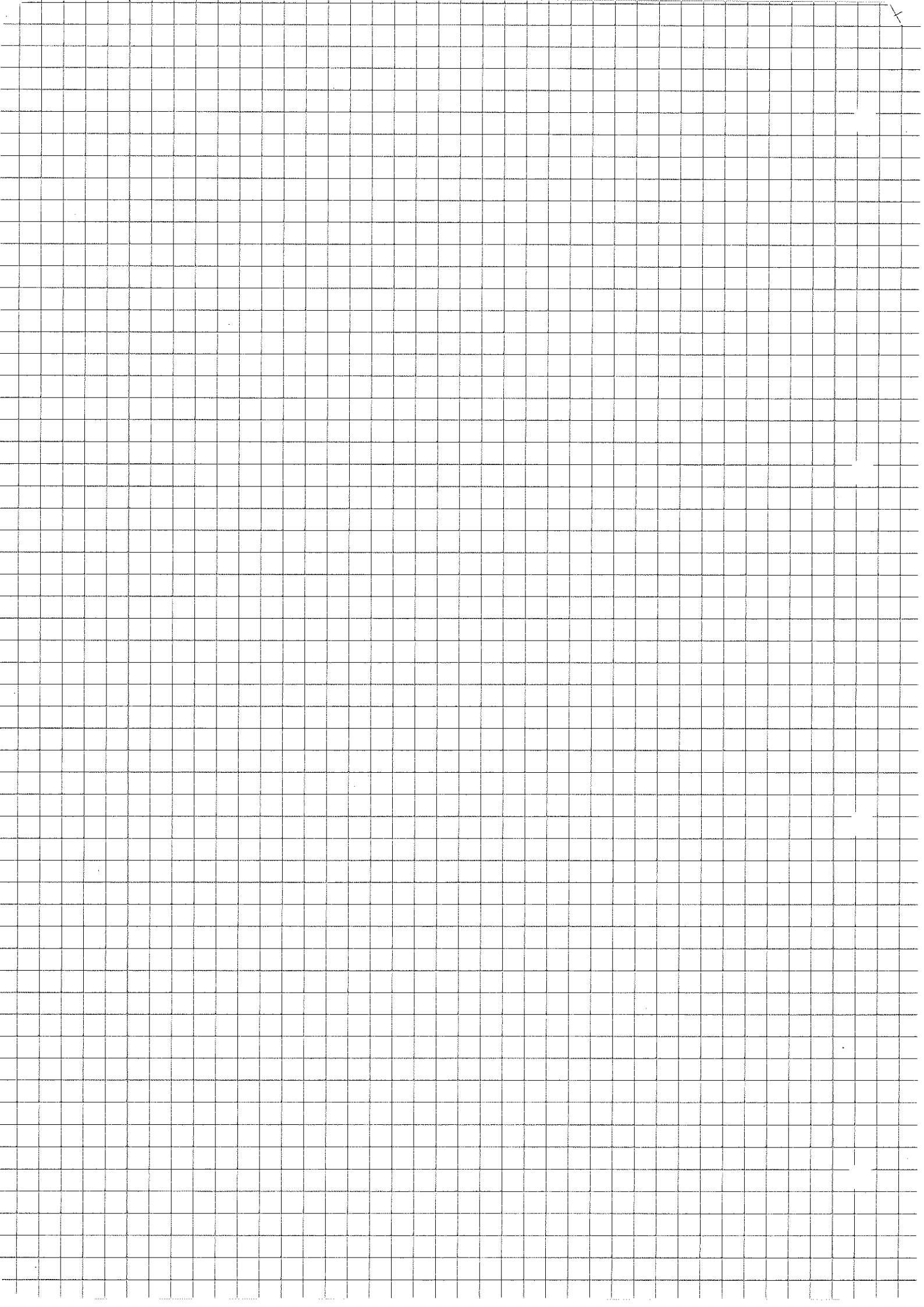


5



3





Wind III Übung 7

①

$$R = 720m \quad h_{hub} = 735m \quad P_{nenn} = 1571W$$

$$D = 720m$$

$$h_{ref} = 70m$$

$$V_m = 15 \frac{m}{s}$$

$$z_{0,1} = 0,00005m \quad z_{0,2} = 0,05m \quad z_{0,3} = 0,5m$$

a) $\alpha = 0,2 \rightarrow V_{hub} = 8,475 \frac{m}{s}$

b) Tip of Blade at highest Point: $h_{hub} + R = 255m$

$$V_{max} = 9,556 \frac{m}{s} \cdot \frac{1}{5} = 9,057 \frac{m}{s}$$

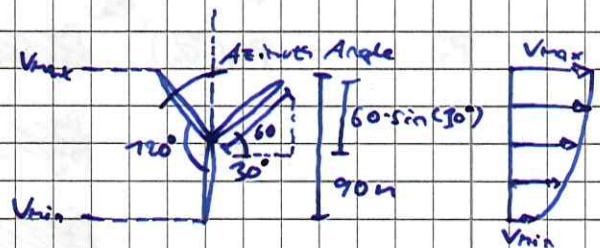
Solution calculates with diameter = 720m, not radius $\rightarrow$ using the same numbers now

c) max. Diff between lowest and highest point: 720m diff

$$V_{max} - V_{min} = \Delta V_{max} = 7,576 \frac{m}{s}$$

max Diff between blades at this pos

$$V_{max} - V_{min} = \Delta V_{max} = 7,278 \frac{m}{s}$$



d) Highest difference at $\Theta(\Delta V_{max}) = 180^\circ$

lowest difference at $\Theta(\Delta V_{min}) = \{90^\circ, 270^\circ\}$

e) Wind speed diff between ~~75m~~ 75m and 765m

	$V_{min} [\frac{m}{s}]$	$V_{max} [\frac{m}{s}]$	$\Delta V [\frac{m}{s}]$	
$z_{0,1}$	5,825	6,748	0,9230	Flat
$z_{0,2}$	6,907	7,646	0,7447	normal
$z_{0,3}$	8,363	9,671	1,306	Rough

② a) Calculated in Matlab online in "Wind3.m"

$$V_m = 16,81 \cdot 76,40 \frac{m}{s}$$

$$s^2 = 3,025 \frac{m}{s}$$

$$T1 = 70,73\%$$

Histogram with 70 bins as probability distribution function

③ a) Nach messen

① ~~Wasser~~ ~~Wasser~~
 a) $q = \frac{1}{4}$

$$G = 40(1-q) = 0,75$$

$$P = \frac{MRT}{V}$$

$$V = \frac{MRT}{P}$$

$$P = \frac{P}{R_i}$$

Bernoulli von V_1 bis V_2^+

$$\frac{1}{2} P_1 V_1^2 = \frac{1}{2} P_2^+ V_2^2$$

Von V_2^- bis V_3

$$\frac{1}{2} P_2^- V_2^2 = \frac{1}{2} P_3 V_3^2$$

$$V_2^+ > V_2^- = V_2$$

$$V_2^2 = \frac{P_1}{P_2^+} V_1^2$$

$$V_2^2 = \frac{P_3}{P_2^-} V_3^2$$

$$P_2^+ = P_1 \left(\frac{V_1}{V_2} \right)^2$$

$$P_2^- = P_3 \left(\frac{V_3}{V_2} \right)^2$$

$$P_2^- = P_3 \left(\frac{V_3}{V_2} \right)^2$$

$$\frac{P_1}{P_2^+} = \frac{P_3}{P_2^-}$$

$$\frac{P_1}{P_2^+} = \frac{P_3}{P_2^-}$$

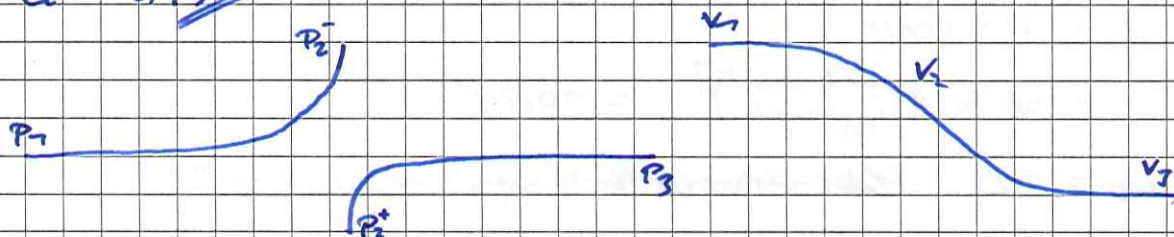
$$P_1 (P_2^- - P_2^+) =$$

Wind III Übung 2:

⑦

a) $C_t = 49(1-q)$ with $q = \frac{1}{4}$

$C_t = 0,75$



$$P_1 + \frac{\rho}{2} V_1^2 = P_2 + \frac{\rho}{2} V_2^2$$

$$P_2 + \frac{\rho}{2} V_2^2 = P_3 + \frac{\rho}{2} V_3^2$$

~~Wiederholen~~

~~$P_1 - P_2 + \frac{\rho}{2} V_1^2 - \frac{\rho}{2} V_2^2 = P_2 - P_3 + \frac{\rho}{2} V_2^2 - \frac{\rho}{2} V_3^2$~~

$$P_2 = \frac{\rho}{2} (V_1^2 - V_2^2) + P_1$$

$$P_2 = \frac{\rho}{2} (V_3^2 - V_2^2) + P_3$$

$$\Delta P = P_2^* - P_2 = \frac{\rho}{2} (V_3^2 - V_1^2 - V_2^2 + V_2^2) + P_3 - P_1$$

$$\Delta P = -\frac{\rho}{2} (V_3^2 - V_1^2)$$

$$\Delta P = -107,3 \text{ MPa}$$

b) Solving with calculator program...

$q = 0,23$ $\alpha_{AoA} = 7,73^\circ$

$C_t = 49(1-q) = 0,77$

$$dL = \frac{\rho}{2} W^2 c C_L ds$$

$$W = \sqrt{U_\infty^2 (1-q) + r^2 \Omega^2 (1+q)^2} = 8,08 \frac{m}{s}; \lambda = \frac{r\Omega}{U_\infty} \rightarrow \Omega = 2 \frac{rad}{s}$$

$dL = \frac{\rho}{2} W^2 c C_L ds$ $\rightarrow$ fast auf genau richtiges Ergebnis, wenn r anstelle von C_L verwendet wird.

$$dD = \frac{\rho}{2} W^2 c C_D ds$$

$$dD = 178,3 \frac{N}{m} ds$$

$\rightarrow$ Vielleicht Sicherheitsmargin?
Wurde in Lösung wohl als 170 gelesen...
~~Wurde in Lösung wohl als 170 gelesen~~

c) Aus Diagramm: $\alpha_{stall} = 72^\circ$

$$\alpha_{margin} = \alpha_{stall} - \alpha_{AoA} = 72^\circ - 4,87^\circ = 67,13^\circ$$

Higher inflow velocity during gust, which increases

α_{AoA} , which decreases α_{margin} .

this gets bigger

Increase chord length $\rightarrow$ reduce inflow velocity $U_p(1-q)$

$\rightarrow$ reduce $\alpha_{AoA} \rightarrow$ increase margin (which got smaller because of wind gusts)

Wind III Übung 2

① d) $S_g = 0.25$

$$U_{m,g} = (1 + S_g) U_0 = 18.75 \frac{m}{s}$$

$$\frac{S_g}{2} \pi = a = \text{const}$$

$$\phi = \arctan\left(\frac{\sin(1+0.1)}{U_{m,g}(1-a)}\right) = 10.23^\circ$$

$$\alpha_{stall} = 12^\circ \quad (\text{Vorherige Rechnung, eigentlich } 12^\circ)$$

$$\alpha_{margin} = \alpha_{stall} - (\phi - \alpha_{twist}) = 2.67^\circ$$

less margin!

In Lösung wurden $\alpha_{stall} = 17^\circ$ genutzt und α_{twist} nicht berücksichtigt

e) $S_g = 0.5 \quad \alpha_{margin} = 4.5^\circ \quad a = 0.23$

~~$S_g = 0.97$~~ Jetzt α_{margin} von 4.5° nutzen, wie in handgezeichnete Lösung (sehr ähnlich zu selbst berechneten Wert aus c)

$$U_{m,2} = (1 + S_g) U_0 = 22.5 \frac{m}{s}$$

$$U_{m,new} = U_{m,2} (1 - a) = 17.33 \frac{m}{s}$$

~~Handgezeichnete Lösung~~

$$\Omega_{new} = \Omega \cdot 0.705 = 2.7 \frac{rad}{s}$$

$$\tan(\phi) =$$

$$\tan(\alpha_{AoA} + \alpha_{twist}) = \frac{U_{m,new}}{\Omega_{new} r (1-a)} \quad \alpha_{AoA} = 7.5^\circ$$

$$\alpha_{twist} = \phi = 4.757^\circ$$

(In handgezeichnete Lösung e.g. über eher 4° , aber Tutor hat einfach 5° angenommen)

~~Handgezeichnete Lösung~~

$$\frac{(7.5^\circ)^2 + (4.757^\circ)^2}{\pi r^2 (1-a)} \cdot \frac{1}{2} W^2 B t = 2\pi r S U_0 (1-a) \cdot 2.9 U_0 \cdot \frac{1}{2} W^2 B t$$

$$t = 3.53$$

Axial thrust on an annular ring of the actuator disk:

$$\frac{\rho}{2} W^2 B t (C_u \cos \phi + C_d \sin \phi) \cdot \frac{1}{2} W^2 B t = 2\pi r S U_0 (1-a) \cdot 2.9 U_0 \cdot \frac{1}{2} W^2 B t$$

$$t = 3.53 \quad (\text{Mit Werten aus Lösung weitergerechnet!})$$

Wind III Übung 3

a) $f_1^2 \approx \frac{3,04}{4T^2} \frac{EI}{(m_{top} + 0,227 \cdot \mu L) L^3}$

$\mu = \pi \cdot R_o^2 \cdot \rho \cdot m - \pi \cdot R_i^2 \cdot \rho \cdot m$

$R_o = 8,25m = D_o$
 $R_i = 8,277m = D_i$

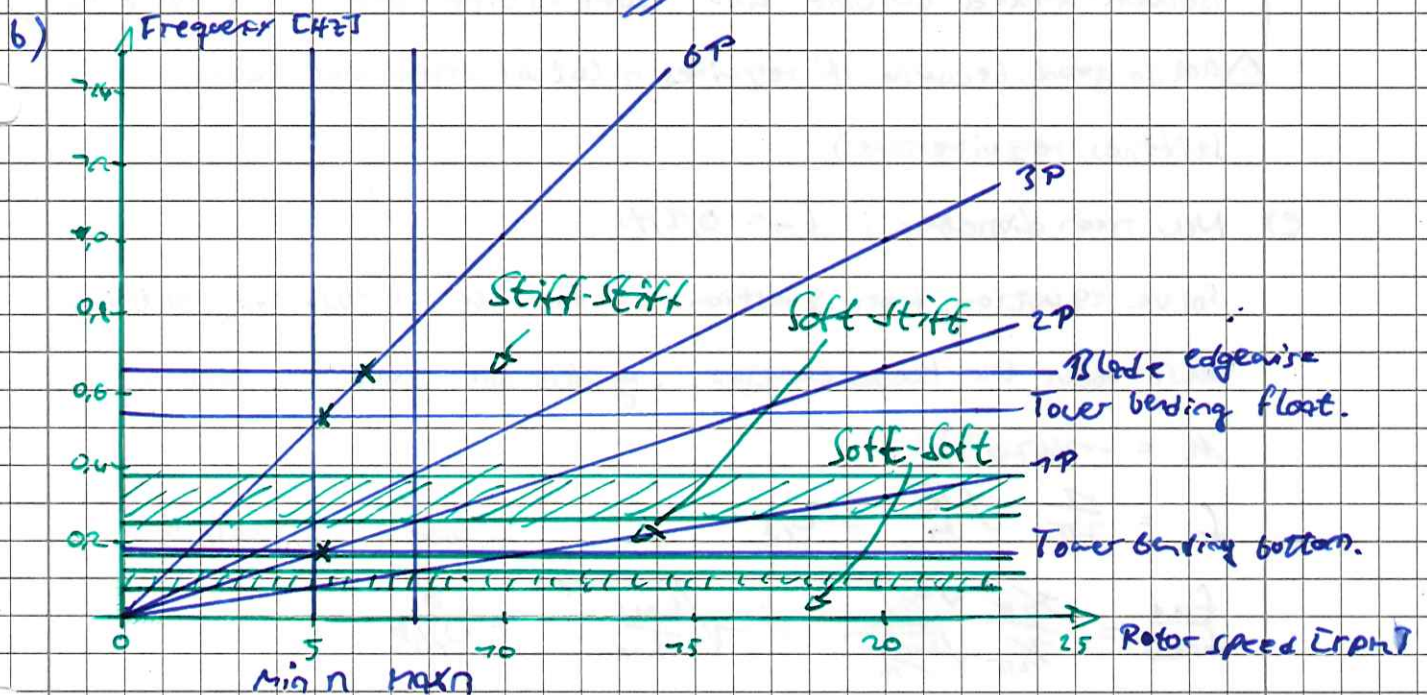
$\mu = 3,474 \text{ t/m}$

~~mass increase~~
~~height increase~~
~~mass increase~~

~~mass increase~~
~~height increase~~
 $m_{top} = 7077 \text{ t}$

$f_1 \approx 0,2015 \text{ Hz}$

Mass increase $\rightarrow f_1$ decrease
 height increase $\rightarrow f_1$ decreases



Resonant frequencies matched with 2P and 6P within the operational range of the rotor.

c) Cantilever bending stiffness $C \approx \frac{3EI}{L^3} = 1,775 \cdot 10^6 \frac{N}{m}$

Different value as in solution... also different if you use

$C = \frac{1}{\delta}$ with $\delta = \int_0^L \frac{z^2}{EI(z)} dz$; $I(z) = \frac{\pi}{8} (D(z))^3 t(z)$

stiffness increases if mass increases

stiffness increases if mean tower diameter increases

Wind III Übung 3

① d) See Diagram from 6) (can be looked up there)

~~soft-soft~~

Can also be calculated:

~~soft-soft~~

$$\text{stiff-stiff} : 0 \text{ Hz} - 0,08333 \text{ Hz}$$

$$\text{soft-stiff} : 0,126 \text{ Hz} - 0,25 \text{ Hz}$$

$$\text{stiff-stiff} : 0,378 \text{ Hz and onwards!}$$

Floating turbine ~~design~~ has stiff-stiff design

Bottom-fixed turbine has soft-stiff design (large range)

△ Not so good, because it requires a lot of material (high-stiffness requirement)

e) New mean diameter : $f_n = 0,3 \text{ Hz}$

Solve equation from question a) for μ (Assuming nothing else about the tower changes... $\hookrightarrow$ does not work, μ becomes negative

$$\mu = -76670 \frac{\text{kg}}{\text{m}}$$

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}} = 0,3$$

used $f_{nd} = 0,204$ here

$$\frac{f_{nd}}{f_{new}} = \frac{\frac{1}{2\pi} \sqrt{\frac{k_{old}}{m}}}{\frac{1}{2\pi} \sqrt{\frac{k_{new}}{m}}} = \sqrt{\frac{k_{old}}{k_{new}}} = 0,68$$

$$k_{new} = 4,044 \cdot 10^6 \frac{\text{N}}{\text{m}} \quad \text{used } k_{old} = 7,87 \cdot 10^6 \frac{\text{N}}{\text{m}}$$

$$I \approx \frac{3EI}{L^3} \rightarrow I = \frac{3}{8} \pi D_{new}^3 \cdot t$$

$$D_{new} = 10,86 \text{ m} \quad \text{near the solution!}$$

New turbine sits right inside the 3P excitation band!

(between $0,25 \text{ Hz}$ and $0,378 \text{ Hz}$)

$\hookrightarrow$ This is not good, the new design is worse!

Wind III Übung 4

①

a) Cycle	stress range load [Pa]	cycle count
✓ 0-1	2,29	0,5
✓ 1-6	6,74	0,5
✓ 2-3	7,08	1
✓ 4-5	7,69	1
✓ 6-70	7,70	] This is split into two modules in solution?
✓ 7-8	0,60	

$$b) \log(N_c(s)) = \log(Q_0) - m \log(s)$$

$$N = 10^{\log(Q_0) - m \log(s)}$$

Cycle 2-3 :

$$N_i = \frac{Q_0}{\sigma^m} = \frac{6 \cdot 10^{10}}{(7,08)^3} = 4,763 \cdot 10^{10} \text{ cycles}$$

$$D_i = \frac{n \cdot \sigma^m}{Q_0} = \frac{7 \cdot (7,08)^3}{6 \cdot 10^{10}} = 2,71 \cdot 10^{-11}$$

Cycle 4-5 :

$$N_i = 1,243 \cdot 10^{10} \text{ cycles}$$

$$D_i = 8,045 \cdot 10^{-11}$$

Cycle 7-8 :

$$N_i = 2,778 \cdot 10^{11} \text{ cycles}$$

$$D_i = 3,6 \cdot 10^{-12} \text{ ~~cycles~~}$$

Cycle 0-1: (Half)

$$N_i = 4,996 \cdot 10^9 \text{ cycles}$$

$$D_i = 7,007 \cdot 10^{-10}$$

Cycle 1-6 : (Half)

$$N_i = 7,96 \cdot 10^8 \text{ cycles}$$

$$D_i = 2,552 \cdot 10^{-9}$$

Cycle 6-70: (Half)

$$N_i = 1,676 \cdot 10^8 \text{ cycles}$$

$$D_i = 2,987 \cdot 10^{-9}$$

$$D = \sum D_i = 5,74 \cdot 10^{-9}$$

Why slightly different?

② Wind III Übung 4

c) Measured total damage $D = 0,25$

$$D = \frac{N_{\text{res}}(\text{DEL})^m}{n_0} \rightarrow \text{DEL} = \underline{208 \text{ MPa}}$$

d) Cycle 7-6 : $N_i < 1 \cdot 10^9$

$$N_i = 7,96 \cdot 10^8 \text{ Cycles}, D_i = 2,552 \cdot 10^{-9}$$

Cycle 6-10 : $N_i < 1 \cdot 10^9$

$$N_i = 7,676 \cdot 10^8 \text{ Cycles}, D_i = 2,923 \cdot 10^{-9}$$

Cycle 4-5

Cycle 7-8

Cycle ~~10~~ 0-1

Cycle 2-3

Wind III Übung 5

1) a) $\omega = \sqrt{gk} \rightarrow k = 0,7998 \frac{\text{rad}}{\text{m}}$

$c_{\text{phase}} = \frac{\omega}{k} = 7,007 \frac{\text{m}}{\text{s}}$

b) $c_{\text{group}} = c_{\text{phase}} / 2 = 3,504 \frac{\text{m}}{\text{s}}$

c) $\left(\frac{c_{\text{group}}}{L}\right)^{-1} = 28,54 \text{ s}$

d) $\eta'(t) = -\frac{H}{2} \sin(t\omega - kx) \omega$

$\eta''(t) = -\frac{H}{2} \cos(t\omega - kx) \omega^2$

$\eta'''(t) = \frac{H}{2} \sin(t\omega - kx) \omega^3$

Schnellste Geschl. bei beliebigen x bei $\eta''(t) = 0 \rightarrow t_{\text{max}} = 0,4037 \text{ s}$

Schnellste Geschw. bei beliebigen x bei $\eta'''(t) = 0 \rightarrow t_{\text{max}} = -0,7783 \text{ s}$

$V_{\text{max}} = 7,4 \frac{\text{m}}{\text{s}}$

$a_{\text{max}} = 7,96 \frac{\text{m}}{\text{s}^2}$

e) $p = \frac{\rho g H}{2} e^{kz} \cos(kx - \omega t)$

Max. bei $\cos(kx - \omega t) = 1$

Water surface: $z = 0$; Maximum at $\cos(kx - \omega t) = 1$

$p_{\text{dr}} = 7,006 \cdot 10^4 \text{ Pa}$

2) $\eta = \frac{H_0}{2} \cos(kx - \omega t)$ $T_0 = 2\pi \frac{M_0}{M_1}$

$\eta = \frac{H_0}{2} \cos(kx - \omega t)$ $m_0 = \int \rho \eta^2 dx$

$\frac{\omega T_0}{2\pi} = b \cdot \frac{H_0^2 T_0}{H_1^2 T_0}$

$\frac{\omega T_0}{2\pi} = b \cdot \frac{H_0^2 T_0}{16 H_1^2 T_0}$

$\frac{\omega T_0}{2\pi} = b \cdot \frac{H_0^2 T_0}{32 \pi \frac{M_0^2}{H_1^2}}$

$\frac{\omega T_0}{2\pi} = b \cdot \frac{H_0^2 T_0}{32 \pi \frac{M_0^2}{H_1^2}}$

$\frac{\omega T_0}{2\pi} = b \cdot \frac{H_0^2 T_0}{32 \pi \frac{M_0^2}{H_1^2}}$

$\frac{\omega T_0}{2\pi} = b \cdot \frac{H_0^2 T_0}{32 \pi \frac{M_0^2}{H_1^2}}$

Wind III Übung 5

② a) $\frac{M_0}{H_{1/3}^2 T_1} = \frac{S(\omega)}{H_{1/3}^2 T_1}$
 müssen gleich sein

$$\frac{M_0}{H_{1/3}^2 T_1} = \frac{S(\omega)}{H_{1/3}^2 T_1}$$

$$\frac{32\pi M_0^3}{H_{1/3}^2 S(\omega)} = \frac{1}{2}$$

$$\frac{M_0}{H_{1/3}^2 T_1} = \frac{S(\omega)}{H_{1/3}^2 T_1}$$

$$\frac{32\pi M_0^3}{H_{1/3}^2 S(\omega)} = \frac{1}{2}$$

$$H_{1/3} = \frac{M_0}{H_{1/3}^2 T_1}$$

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$$H_{1/3} = \frac{M_0}{H_{1/3}^2 T_1}$$

$$\frac{M_0}{H_{1/3}^2 T_1} = \frac{S(\omega)}{H_{1/3}^2 T_1}$$

Betrachten des Intervalls: $[0.5, 9]$

$$\frac{S(\omega)}{H_{1/3}^2 T_1} = 6 \rightarrow S(\omega) = 6 H_{1/3}^2 T_1$$

$$M_0 = \int_{0.5}^9 6 H_{1/3}^2 T_1 d(x)$$

Mit Substitution $x = \frac{\omega T_1}{2\pi} \rightarrow \omega = \frac{2\pi x}{T_1}$

$$M_0 = (2a-1) 6 H_{1/3}^2 \pi ; H_{1/3} = 4\sqrt{M_0}$$

I $H_{1/3} = 4\sqrt{(2a-1) 6 H_{1/3}^2 \pi}$

$$M_1 = \dots = \int_{0.5}^9 6 H_{1/3}^2 T_1 \omega dx = \dots \frac{(4a^2-1) 6 h^2 \pi^2}{2 T_1}$$

II $T_1 = 2\pi \frac{M_0}{M_1} = \frac{4\pi}{2a+1}$

Lösen von I und II als LGS:

$$a = \frac{3}{2} ; b = \frac{1}{32\pi}$$

Wind III übung 5

② b) $H_{1/3} = 2 \text{ m}$ $T_2 = 70 \text{ s}$

$$T_2 = 2\pi \left(\frac{m_0}{m_2} \right)^{1/2}$$

$$m_2 = \int_{0.5}^1 b H_{1/3}^2 T_2 \omega^2 dx$$

$$= \int_{0.5}^1 b H_{1/3}^2 T_2 \left(\frac{2\pi x}{T_2} \right)^2 dx = 0,7702 \frac{\text{t}}{\text{s}^2}$$

$$m_0 = 0,25$$

$$T_2 = 7,675 \text{ s} \quad \text{q.b. } m_2 \text{ correct, but somehow } T_2 \text{ is incorrect?}$$

③ a) $C_{33} = \rho \cdot g \cdot A_{wp}$ mit $A_{wp} = \pi \cdot \left(\frac{10}{2} \right)^2 \cdot 4$ (hier steht)

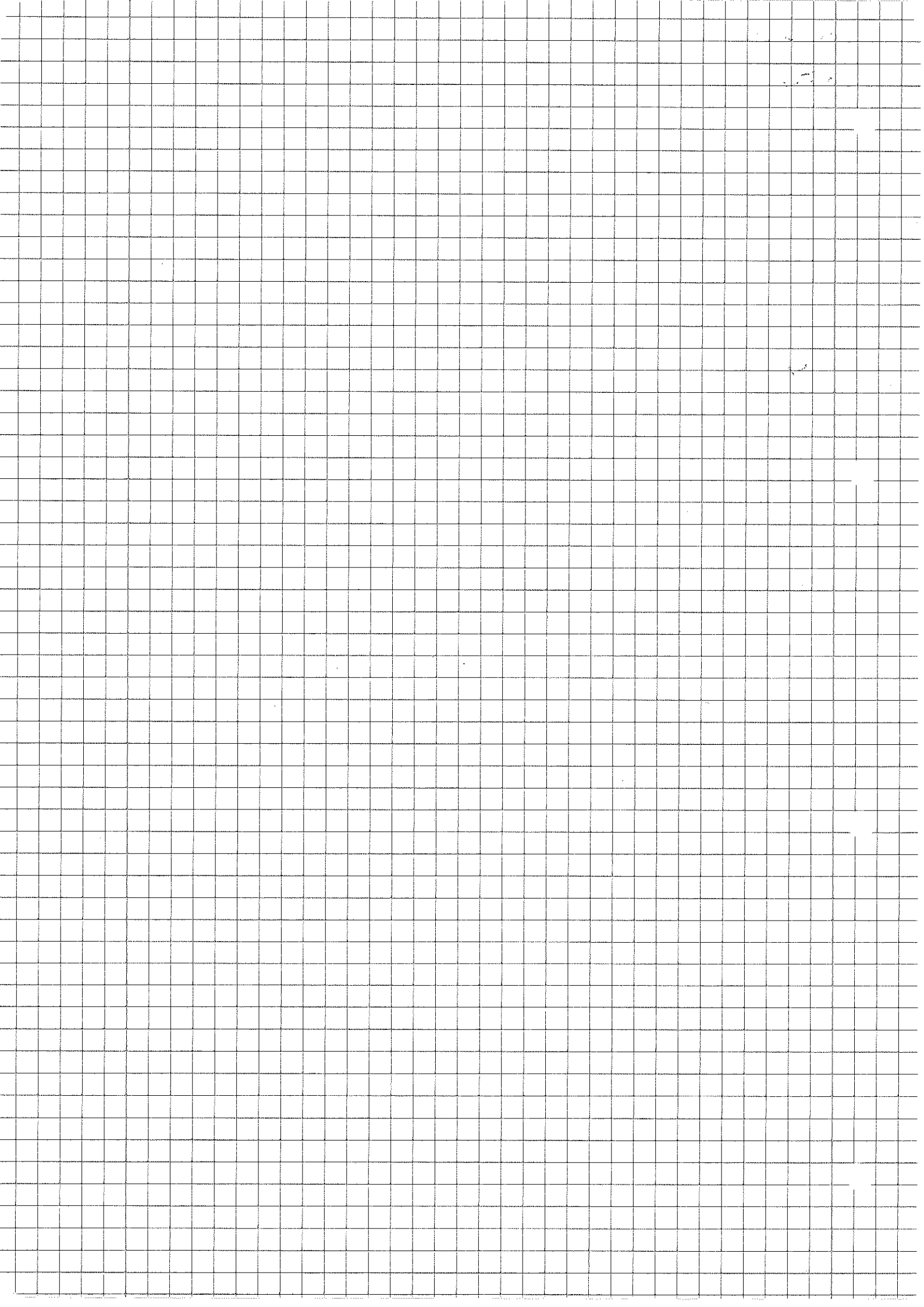
$$= 3,759 \cdot 10^6 \frac{\text{kg}}{\text{s}^2}$$

$$C_{55} = \rho g \int_A x^2 dA + \rho g V_0 (z_6 - z_3)$$

$$= \rho g (I_{\text{locum}} + A d^2) + \rho g V_0 (z_6 - z_3)$$

$$z_B = \frac{\sum V_i x z_{Bi}}{\sum V_i}$$

Aufgeht bei Frage 6



Wind III

1.7

a) $\lambda = 0,2$ $V_{hub} = V_{nom} \cdot \left(\frac{V_{ref}}{7,5} \right)^{0,2} = 8,475 \frac{m}{s}$

b) $V_{max} = V_{nom} \cdot \left(\frac{(7,35 + 0,2)}{7,5} \right)^{0,2} = 9,057 \frac{m}{s}$

c) $\Delta V_{max} = \dots$

$\Delta V_{max} = V_{10} \left(\frac{(7,35 + 0,2)}{7,5} \right)^{0,2} - V_{10} \left(\frac{(7,25 - 0,2)}{7,5} \right)^{0,2} = 7,576 \frac{m}{s}$

$\Delta V_{max, blade} = V_{10} \left(\frac{(7,35 - 0,2)}{7,5} \right)^{0,2} - V_{10} \left(\frac{(7,25 + \sin(90^\circ) \cdot 0,2)}{7,5} \right)^{0,2} = 7,278 \frac{m}{s}$

d) ΔV highest at $\theta = 780^\circ$
 ΔV lowest at $\theta = \{90^\circ, 270^\circ\}$

e) $\Delta V_{max, blade, 7} = V_{10} \left(\frac{\ln \left(\frac{7,35 + \sin(90^\circ) \cdot 0,2}{7,5} \right)}{\ln \left(\frac{7,5}{7,5} \right)} \right) - V_{10} \left(\frac{\ln \left(\frac{7,35 - 0,2}{7,5} \right)}{\ln \left(\frac{7,5}{7,5} \right)} \right)$

$\Delta V_{max, blade, 7} = 0,323 \frac{m}{s}$

$\Delta V_{max, blade, 2} = 0,7647 \frac{m}{s}$

$\Delta V_{max, blade, 3} = 7,7376 \frac{m}{s}$

2.7

a) $G = 49(1-0) = 0,75$

$P_1 + \frac{\rho}{2} V_1^2 = P_2 + \frac{\rho}{2} V_2^2$; $P_2^+ + \frac{\rho}{2} V_2^2 = P_3 + \frac{\rho}{2} V_3^2$

$P_2^- = P_1 + \frac{\rho}{2} (V_1^2 - V_2^2)$; $P_2^+ = P_3 + \frac{\rho}{2} (V_3^2 - V_2^2)$

$\Delta P = P_2^+ - P_2^- = P_3 - P_1 + \frac{\rho}{2} (V_3^2 - V_2^2 - V_1^2 + V_2^2)$

$\Delta P = \frac{\rho}{2} (V_3^2 - V_1^2) = 707,3 P_0$

b) Solve using RETN calculator

$Q_0 = \frac{1}{3}$ $Q_1 = 0,2693$ $Q_2 = 0,2493$ $Q_3 = 0,2439$

$G = 0,7377$



$W = \sqrt{V_{\infty}^2 (1-a)^2 + r^2 \Omega^2 (1+a')^2}$
 $W \approx 0$ at $\lambda = \infty$

$\lambda = \frac{r \Omega}{V_{\infty}} \rightarrow \Omega = 2 \frac{rad}{s}$

$V = 80,8 \frac{m}{s}$

$C_L = 7,79$; $C_D = 0,07$

$\delta L = \frac{\pi}{2} \rho W^2 c C_L \delta T = 83975 \frac{N}{m}$

$\delta D = \frac{\pi}{2} \rho W^2 c C_D \delta r = 70,575 \frac{N}{m}$

Wind III

c) From diagram: stall happens at $\alpha_{stall} = 12^\circ$

$$\alpha_{margin} = \alpha_{stall} - \alpha_{AoA}$$

$$\alpha_{margin} = 4,878^\circ$$

U_{rel} increases with gusts $\rightarrow \alpha_{AoA}$ increases $\rightarrow \alpha_{margin}$ decreases

~~margin has to increase to maintain the same relative velocity~~

margin has to increase $\rightarrow a$ has to increase $\rightarrow t$ has to increase

d) $q = 0,2439 \quad \Omega = 2$

$$U_{og} = U_b (1 + f_g) = 78,75 \frac{m}{s}$$

~~Wg = 87,25~~

~~$$W_g = 87,25 \frac{m}{s}$$~~

$$W_g = 87,25 \frac{m}{s}$$

$$\sin \phi = \frac{U_{og}(1-q)}{W_g} \rightarrow \phi = 10,05^\circ \quad \alpha_{twist} = 9,90^\circ \quad \alpha_{AoA} = 9,749^\circ$$

$$\alpha_{margin} = 2,857^\circ$$

e) $\Omega_{new} = 2,7 \frac{rad}{s} \quad f_g = 0,5$

$$U_{og} = 22,5 \frac{m}{s}$$

$$W_g = 85,77 \frac{m}{s}$$

$$\sin \phi = \frac{U_{og}(1-q)}{W_g} \rightarrow \phi = 7,45^\circ$$

$$\alpha_{margin} = \alpha_{stall} - \alpha_{AoA} (\phi - \alpha_{twist})$$

$$\alpha_{twist} = 2,307^\circ$$

q stays the same $\rightarrow C_T$ stays

~~$$\frac{1}{2} \rho S W^3 B t (C_L \cos \phi + C_D \sin \phi) \Omega = 2 \pi \Gamma S \rho U_{og} (1-q) 2 q U_{og}$$~~

~~$$t = 3,665 \frac{s}{s}$$~~

$$\frac{1}{2} \rho S W^3 B t (C_L \cos \phi + C_D \sin \phi) \Omega = 2 \pi \Gamma S \rho U_{og} (1-q) 2 q U_{og}$$

$$t = 3,665 \frac{s}{s}$$

~~Wg = 87,25~~
~~Wg = 87,25~~

Wind III

3.7

a) $D_m = 8.25m$ $t_m = 0.033m$

$I = \frac{1}{8} \pi D^3 t = 7.277 m^4$

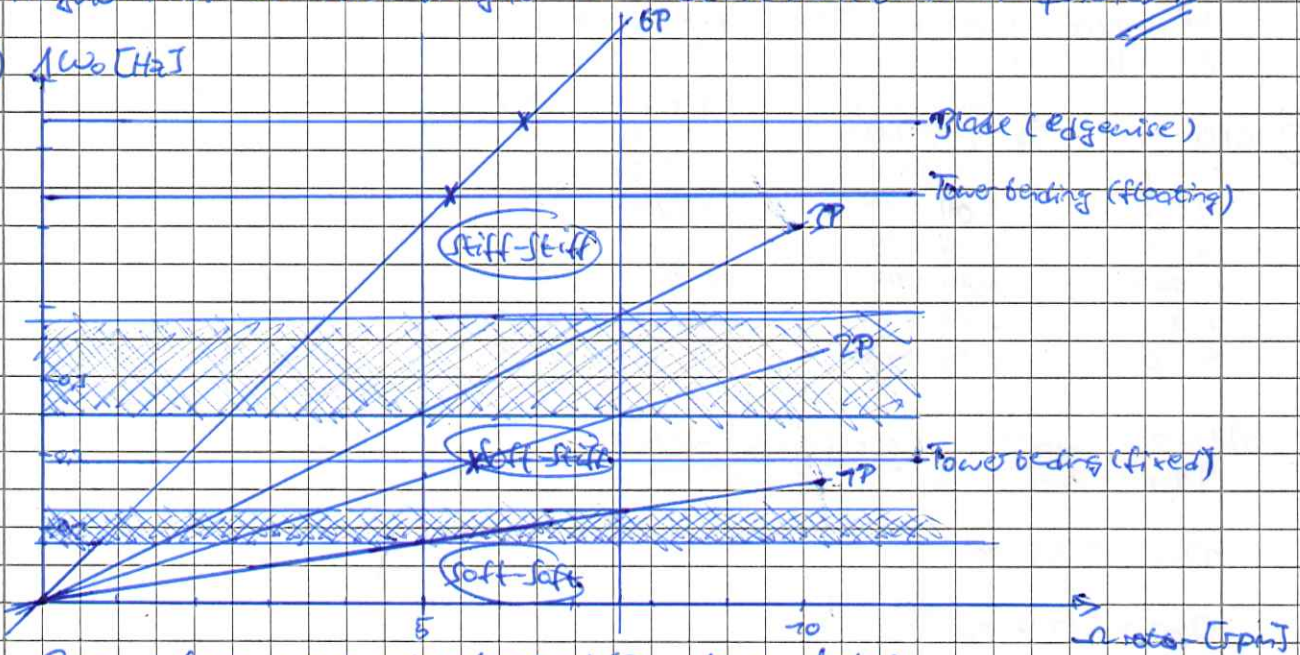
$f_n \approx \sqrt{\frac{3.04}{(1.072)} \cdot \frac{E I}{(m_{top} + 0.227 \mu L)^3}}$

$M = \pi \cdot \left(\frac{D_m}{2}\right)^2 \cdot \rho \cdot L = \pi \left(\left(\frac{D_m}{2}\right)^2 \cdot t_m\right) \cdot \rho = 6875 kg/m$

$f_n \approx 0.7928 Hz$

Higher mass or more height will decrease natural frequency

b) $\omega [Hz]$



Resonant frequencies at 2P and 6P - three total

c) $C = \left(\int_0^L \frac{z^2}{EI(z)} dz \right)^{-1}$

$EI(z) = E \left(\frac{1}{8} \pi D(z)^3 t(z) \right)$; $D(z) = 7.0m - \frac{3.5}{135} \cdot z$; $t(z) = 0.049 - \frac{0.019}{135} \cdot z$

$C = 7.004 \cdot 10^6 \frac{N}{m}$

$C = 7.729 \cdot 10^6 \frac{N}{m}$ if you use 7.5m less on the integral, but keep everything else

m_{top} increases $\rightarrow$ Has no effect on stiffness, if geometry and material stay the same

D decreases $\rightarrow$ Stiffness increases

d) Soft-Soft : 0 Hz - 0.333 Hz

Soft-Stiff : 0.726 Hz - 0.25 Hz

Stiff-Stiff : 0.378 Hz - /

Fixed version is good, Floating version worse - stiff stiff takes a lot of material, expensive

3.7 Wind III

c) $f_1 = 0,3 \text{ Hz}$

$m_{tower} = 11 \cdot 735 = 920025 \text{ kg}$

~~with the tower~~

$f = \frac{1}{2\pi} \sqrt{\frac{c}{m_{tower}}}$ $\rightarrow c = 4,437 \cdot 10^6 \frac{\text{N}}{\text{m}}$
 $c = \frac{3EI}{L^3} = \frac{3E(2\pi D^3 t)}{L^3}$

$D = 77,79 \text{ mm}$

New design is inside SP excitation band. (0,25 Hz - 0,3780 Hz)
 New design is worse.

4.7 a)

	Tension force	Pressure on mooring	Half / Full cycle
0-7	0,19 MN	$2,286 \cdot 10^6 \text{ Pa}$	0,5
7-6	0,56 MN	$6,737 \cdot 10^6 \text{ Pa}$	0,5
2-3	0,09 MN	$1,058 \cdot 10^6 \text{ Pa}$	1
4-5	0,74 MN	$7,685 \cdot 10^6 \text{ Pa}$	1
6-109	0,57 MN	$6,859 \cdot 10^6 \text{ Pa}$	0,5
7-8	0,05 MN	$0,6077 \cdot 10^6 \text{ Pa}$	1
9-70	0,02 MN	$0,2407 \cdot 10^6 \text{ Pa}$	0,5

b) $\frac{D_{0-7}}{D_{0-7}} = \frac{m_{0-7}}{m_{0-7}} = \frac{0,5(2,286 \cdot 10^6 \text{ Pa})^3}{6 \cdot 10^{10}} = 9,955 \cdot 10^{-11}$

$D_{7-6} = 2,55 \cdot 10^{-7}$

$D_{2-3} = 2,777 \cdot 10^{-77}$

$D_{4-5} = 7,973 \cdot 10^{-77}$

$D_{6-9} = 2,689 \cdot 10^{-9}$

$D_{7-8} = 3,637 \cdot 10^{-12}$

$D_{9-70} = 7,748 \cdot 10^{-14}$

$D = \sum D_i = 5,444 \cdot 10^{-9}$ (Over measured 700 seconds)

c) $D = 0,75$ (Over several years)

$D = \frac{N_{ref} \cdot DEL^M}{Q_D} \rightarrow DEL = 208 \text{ MPa}$

d) $N_{0-7} = \frac{Q_D}{m_{0-7}} = 5,023 \cdot 10^7 \text{ cycles}$ $N_{ref} = 7 \cdot 10^9 \text{ cycles}, M=3$

$N_{7-6} = 7,960 \cdot 10^8 \text{ cycles}$ $N_{7-8} = 2,754 \cdot 10^{17} \text{ cycles}$

$N_{2-3} = 4,724 \cdot 10^{10} \text{ cycles}$ $N_{9-70} = 4,303 \cdot 10^{12} \text{ cycles}$

$N_{4-5} = 7,254 \cdot 10^{10} \text{ cycles}$

$N_{6-9} = 7,159 \cdot 10^8 \text{ cycles}$

(4.7)

d) $N_{ref} = 7 \cdot 10^9$ cycles, $M=4$

$$N_{0-7} = 2,797 \cdot 10^9 \text{ cycles} \quad D_{07} =$$

$$N_{1-6} = 2,909 \cdot 10^9 \text{ cycles} \quad D_{16} =$$

$$N_{2-5} = 4,362 \cdot 10^{10} \text{ cycles} \quad D_{25} =$$

$$N_{3-4} = 7,447 \cdot 10^9 \text{ cycles} \quad D_{34} =$$

$$N_{6-9} = 2,737 \cdot 10^7 \text{ cycles} \quad D_{69} =$$

$$N_{7-8} = 4,578 \cdot 10^{11} \text{ cycles} \quad D_{78} =$$

$$N_{9-10} = 7,788 \cdot 10^{13} \text{ cycles} \quad D_{9-10} =$$

~~all values are in MPa~~

$$D_{max} = 3,877 \cdot 10^{-10}$$

$$D = 5,627 \cdot 10^{-9}$$

$$D_{max3} = 5,239 \cdot 10^{-9}$$

$$DEL_{max} = 0,6942 \text{ MPa}$$

$$DEL_{max3} = 1,5 \text{ MPa}$$

$$DEL = 2,794 \text{ MPa}$$

e) At 75 years, 85% occurrence, $5,744 \cdot 10^5$ cycles with

$$D = 5,44 \cdot 10^{-9} \rightarrow D_{75\text{ years}} = 3,725 \cdot 10^{-3} < D_{design}$$

Lines would hold!

(5.7)

$$a) \text{ ~~all values are in MPa~~ } \quad \omega = \sqrt{g/L} \rightarrow L = 0,7998$$

$$C_{phase} = \frac{\omega}{L} = 7,007 \frac{m}{s}$$

$$b) C_{group} = \frac{g}{2\omega} = \frac{C_{phase}}{2} = 3,504 \frac{m}{s}$$

$$c) \frac{L}{C_{group}} = 28,54 \text{ s}$$

d) ~~all values are in MPa~~~~all values are in MPa~~~~all values are in MPa~~~~all values are in MPa~~

Wind III

5.7 d) $\eta(t) = \frac{H}{2} \cos(kx - \omega t)$ x

$\eta'(t) = -\frac{H}{2} \sin(kx - \omega t) \omega$ v

$\eta''(t) = -\frac{H}{2} \cos(kx - \omega t) \omega^2$ a

$\eta'''(t) = \frac{H}{2} \sin(kx - \omega t) \omega^3$

max vel at $\eta'(t_{\max}) = 0 \rightarrow t_{\max} = -0,40845$

$v_{\max} = 7,14 \frac{m}{s}$

Max acc at $\eta''(t_{\max}) = 0 \rightarrow t_{\max} = 0,77265$

$a_{\max} = 7,96 \frac{m}{s^2}$

e) ~~Pressure~~

$P_{\text{hydro,max}} = \frac{\rho \cdot g \cdot H}{2} e^{kz} \cos(kx - \omega t)$
 $\rightarrow$ max. pressure at $z=0$ at water surface

$P_{\text{hydro,max}} = 7006 \cdot 10^4 \text{ Pa}$

5.2

a) Interval $[0,5;9]$

$\frac{S(\omega)}{H_{1/3}^2 T_1} = 6 \rightarrow S(\omega) = 6 H_{1/3}^2 T_1$

$M_0 = \int_{0,5}^9 S(\omega) d\omega$

substitution: $\omega \Rightarrow x = \frac{\omega T_1}{2\pi}$

$M_0 = \int_{0,5}^9 6 H_{1/3}^2 T_1 \frac{2\pi}{T_1} dx$

$\omega = \frac{2\pi x}{T_1}$

~~Handwritten scribbles~~

$H_{1/3} = 4 \sqrt{M_0}$

$M_0 = 2\pi (9 - \frac{1}{2}) 6 H_{1/3}^2$

$H_{1/3} = 4 \sqrt{2\pi (9 - \frac{1}{2}) 6 H_{1/3}^2} \quad (I)$

$M_1 = \int_{0,5}^9 S(\omega) \omega d\omega$

$M_1 = \int_{0,5}^9 6 H_{1/3}^2 T_1 \frac{2\pi}{T_1} \cdot \frac{2\pi x}{T_1} dx$

$M_1 = \frac{7}{2T_1} ((4 \cdot 9^2 - 1) 6 H_{1/3}^2 \pi^2)$

$T_1 = \frac{2\pi M_0}{M_1}$

$T_1 = \frac{8T_1 (9 - \frac{1}{2})}{4 \cdot 9^2 - 1} \quad (II)$

$a = 7,5 \quad b = 9,947 \cdot 10^{-3}$

Wind III

5.2

$$b) T_2 = 2\pi \left(\frac{m_0}{m_2} \right)^{1/2}$$

$$m_2 = \int_{0.5}^0 S(\omega) d\omega$$

$$m_2 = \int_{0.5}^0 6 H_2^2 T_2 \frac{2\pi}{T_2} \left(\frac{2\pi x}{T_2} \right)^2 dx$$

$$m_2 = \frac{(80^3 - 1) 6 H_2^2 \pi^3}{3 T_2^2}$$

$$H_2 = 2m ; T_2 = 70s$$

$$T_2 = 9,608 s$$

5.3

$$a) C_{33} = \rho g A_{wp} = 3,759 \cdot 10^6 \frac{kg}{s^2}$$

$$C_{55} = \rho g \left(\iint_A x^2 dA + V_0 (z_0 - z_g) \right)$$

$$\text{Center of gravity: } z_g = -70m$$

$$\text{Center of buoyancy: } V_{submerged} = 2 \cdot 700 \cdot 75 \cdot 7 + 4 \cdot (22-7) \cdot \pi \cdot 5^2$$

$$V_{submerged} = 25710 m^3$$

$$z_b = \frac{\frac{(22-7)}{2} \cdot 4 \cdot (22-7) \cdot \pi \cdot 5^2 + \frac{(22-7)}{2} \cdot (22-7) \cdot 2 \cdot 700 \cdot 75 \cdot 7}{V_{submerged}} = -76,44m$$

$$\iint_{A_{wp}} x^2 dx = I_{local} + A d^2$$

↳ Water plane area

$$\iint x^2 dx = \left(\frac{\pi}{4} 5^4 + \pi \cdot 5^2 \cdot 37,5^2 \right) \cdot 4 = 4,478 \cdot 10^5 m^4$$

$$C_{55} = 2,765 \cdot 10^9 \frac{kg m^2}{s^2}$$

b) ~~unverändert~~

$$\omega = 0i + 5j + 0k$$

$$r = 70i + 70j + 70k$$

$$s = 2i + 0j - 7k + \omega \times r$$

$$s = 2i + 0j - 7k + 50i + 0j + 50k$$

$$s = -48i + 49k$$

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