Calcul des efforts maxi sur les pales de l’éolienne

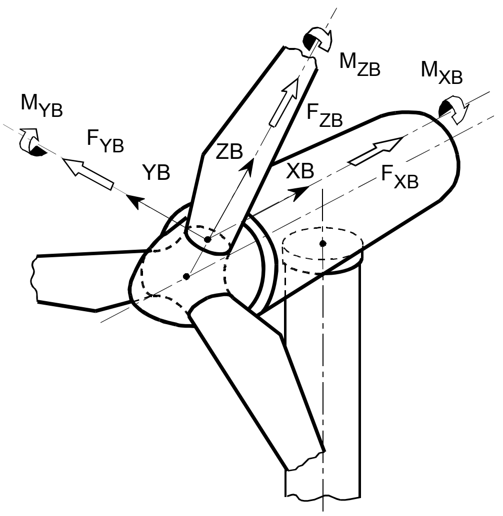
Selon la norme Allemande

Appendix 4.A Coordinate Systems

In general, the coordinate systems can be chosen freely. By way of suggestion, possible coordinate systems, together with their origin and orientation, are shown in the following diagrams. As a simplification, representation of the rotor axis tilt angle and cone angle was omitted.

4.A.1 Blade coordinate system

The blade coordinate system has its origin at the blade root and rotates with the rotor. Its orientation to the rotor hub is fixed.

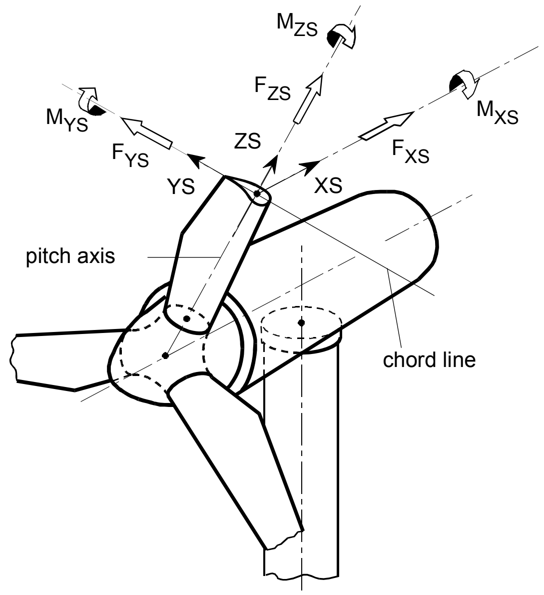


XB in direction of the rotor axis
ZB radially
YB so that XB, YB, ZB rotate clockwise

Fig. 4.A.1 Blade coordinate system

4.A.2 Chord coordinate system

The chord coordinate system has its origin at the intersection of the corresponding chord line and the blade pitch axis. It rotates with the rotor and the local pitch angle adjustment.

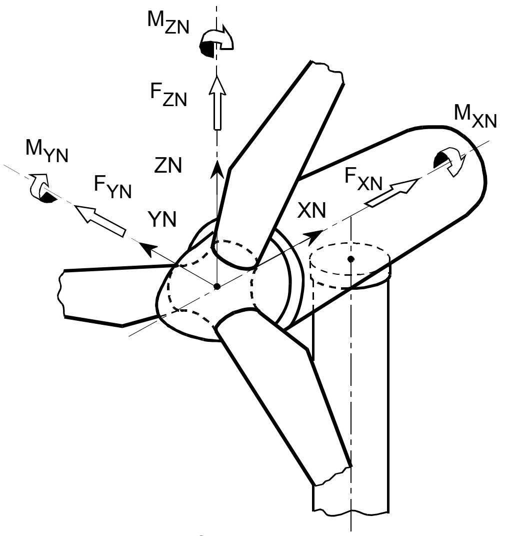


YS in direction of the chord, orientated to blade trailing edge
ZS in direction of the blade pitch axis
XS perpendicular to the chord, so that XS, YS, ZS rotate clockwise

Fig. 4.A.2 Chord coordinate system

4.A.3 Hub coordinate system

The hub coordinate system has its origin at the rotor centre (or any other position on the rotor axis, e.g. hub flange or main bearing) and does not rotate with the rotor.

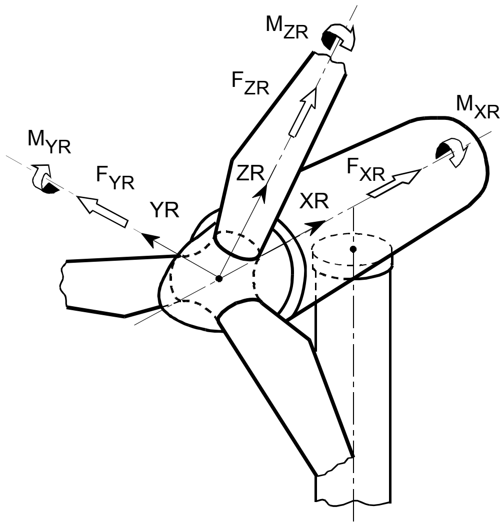


XN in direction of the rotor axis
ZN upwards perpendicular to XN
YN horizontally sideways, so that XN, YN, ZN rotate clockwise

Fig. 4.A.3 Hub coordinate system

4.A.4 Rotor coordinate system

The rotor coordinate system has its origin at the rotor centre (or any other position on the rotor axis, e.g. hub flange or main bearing) and rotates with the rotor.

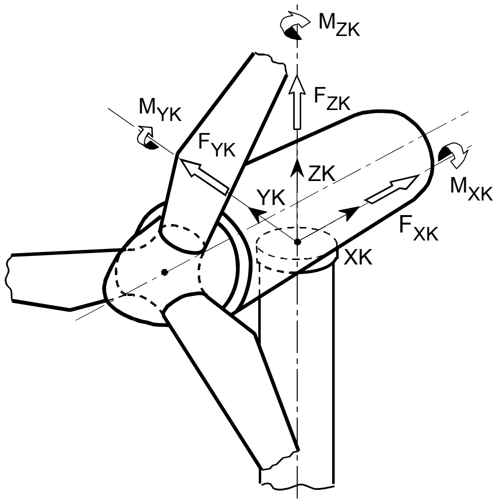


XR in direction of the rotor axis
ZR radially, orientated to rotor blade 1 and perpendicular to XR
YR perpendicular to XR, so that XR, YR, ZR rotate clockwise

Fig. 4.A.4 Rotor coordinate system

4.A.5 Yaw bearing coordinate system

The yaw bearing coordinate system has its origin at the intersection of the tower axis and the upper edge of the tower top and rotates with the nacelle.

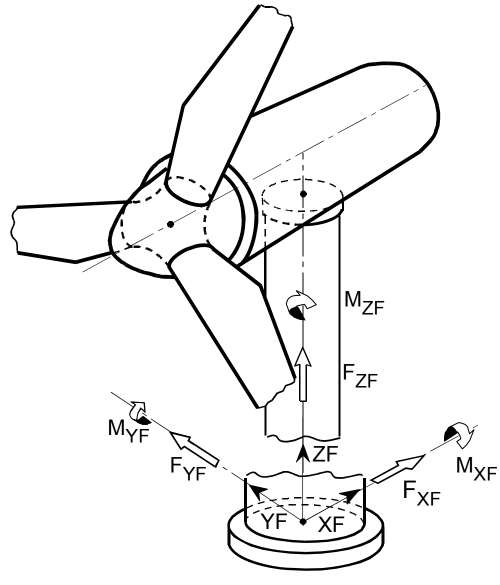


XK horizontal in direction of the rotor axis, fixed to nacelle
ZK vertically upwards
YK horizontally sideways, so that XK, YK, ZK rotate clockwise

Fig. 4.A.5 Yaw bearing coordinate system

4.A.6 Tower coordinate system

The tower coordinate system has its origin at the intersection of the tower axis and the upper edge of the foundation, and does not rotate with the nacelle. In addition, other locations on the tower axis are also possible.



XF horizontal
ZF vertically upwards in direction of the tower axis
YF horizontally sideways, so that XF, YF, ZF rotate clockwise

Fig. 4.A.6 Tower coordinate system

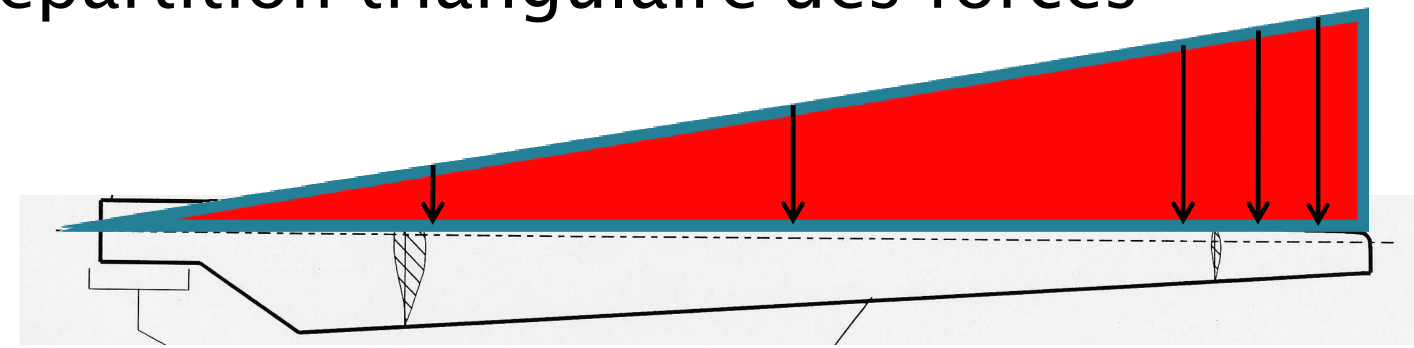
Calcul des forces Maxi sur la nacelle

- A aire balayée
- V_R vent nominal
- P_N pression nominale : $P = 8/9\ \rho/2\ V_R^2$
- F_{XN} poussée axiale sur l'hélice : $F_{XN} = P_N\ A$
- M_{XN} Couple moteur sur l'arbre hélice:

$$M_{XN} = P_{elec} / (\omega\ \eta) \text{ avec } \eta = 0.85 \text{ à } 0.9$$

Dans le cas d'un entraînement direct, la vitesse ω peut doubler (environ) par rapport à la vitesse de meilleur rendement (ici 150 tr/mn)

Forces aérodynamiques Maxi sur les pales

- Répartition triangulaire des forces
- 

- $f_{XB}(r) = 2\ F_{XN}\ r\ /\ Z\ R^2$
- $f_{YB}(r) = 3\ M_{XN}\ r\ /\ Z\ R^3$

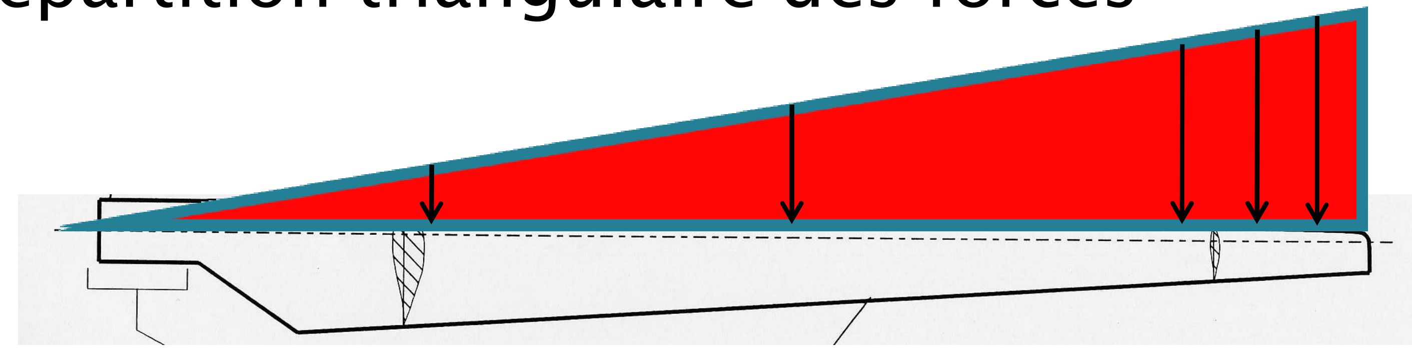
Effort Résultant en pied de pale

- $F_{XB} = F_{XN} / Z$
- $F_{YB} = 3/2 \; M_{XN} / Z R$
- $M_{XB} = M_{XN} / Z$
- $M_{YB} = 2/3 \; F_{XB} \; R$

EFFORTS de RAFALES

- La vitesse de vent nominal doit être multipliée par 5/3
- Vitesse de vent de rafale : $V_B = 5/3\ V_R$
- P_N pression nominale : $P_B = 8/9\ \rho/2\ V_B^2$
- Couple Moteur $M_{XN\_Raf} = 2\ M_{XN}$
- $F_{XB\_Raf} = F_{XN\_Raf}\ /\ Z$
- $F_{YB\_Raf} = 3/2\ M_{XN\_Raf}\ /\ Z\ R$
- $M_{XB\_Raf} = M_{XN\_Raf}\ /\ Z$
- $M_{YB\_Raf} = 2/3\ F_{XB\_raf}\ R$

Forces aérodynamiques de Rafale

- Répartition triangulaire des forces
- 
- $f_{XB\_Raf}(r) = 2\ F_{XN\_Raf}\ r\ /\ Z\ R^2$
- $f_{YB\_Raf}(r) = 3\ M_{XN\_Raf}\ r\ /\ Z\ R^3$

Pour le calcul des roulements, les efforts nominaux doivent être multipliés par 0.6 puis par 1.11

2.1 Use of the representative load spectrum

Where a representative load spectrum is used, an equivalent dynamic bearing loading P_i is to be calculated for each load increment and from this the mean equivalent dynamic bearing loading P:

$$P = \sqrt[3]{\frac{\Sigma P^3_i \, n_i}{N}}$$

where

P_i = equivalent dynamic bearing loading

n_i = number of revolutions when P_i acts

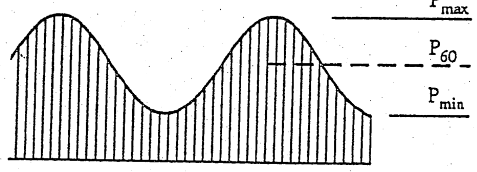
N = total number of revolutions.

2.2 Analysis where the WECS is designed using the simplified single-range spectrum in accordance with Chapter 4, Appendix 4.2.

2.2.1 Lacking a representative load spectrum, the mean equivalent dynamic bearing loading can be calculated as follows:

2.2.2 The equivalent dynamic bearing loading is determined on the basis of the forces P_{60} at 60 % of the rated loading. A sinusoidal alternating component of ± 30 % is to be superimposed on this loading.

sinusoidal



$P = 0.68\, P_{max} + 0.32\, P_{min}$

$P_{max} = 1.3 \cdot P_{60}$

$P_{min} = 0.7 \cdot P_{60}$

Figure 6.4: Bearing loading

2.2.3 The mean equivalent dynamic bearing loading P according to figure 6.4 amounts to:

$$P = 1.11 \cdot P_{60}$$

2.2.4 The calculated service life using the extended service life calculation should not be less than 130000 hours. The use of bearings with lower service life is to be discussed with GL.

2.2.5 The input parameters required for the extended service life calculation are to be set out in the calculation: bearing temperature, lubricant additive treatment and viscosity, measures taken to maintain the lubricant's qualities (lubricant change intervals, lubrication checks, etc.).

2.3 Minimum loading

To avoid slip during the operation of bearings with a speed rating $n \cdot d_m$ larger than 50000 [mm/min] a minimum loading shall be maintained. This is for roller bearings $0.02 \cdot C_{dyn}$, for ball bearings $0.01 \cdot C_{dyn}$

where

n	=	rated speed of the shafting	[1/min]
d_m	=	mean diameter of bearing	[mm]
C_{dyn}	=	dynamic loading number	[N].

3. Additional analyses

Additional calculations may be necessary in individual cases (e. g. calculations for screws, toothing calculations in the case of live-ring bearings).

F. Miscellaneous

1. On principle, the lubricants and lubricating oils recommended by the manufacturer are to be used.

2. During assembly, the manufacturer's instructions are to be observed. The transport of bearings for machinery components is to be undertaken in such a way that damage to track surfaces or rolling bodies is prevented.

3. The bearings are to be sealed in such a way that there is no detrimental effect on the functioning of adjoining components.

Extrait de la norme Allemande

Calcul des coef. de concentration des contraintes

$$K_t\,\sigma_{eq} \le \frac{R_e}{S_e}\;;\; K_t\,\sigma_{eq} \le \frac{R_{p0,2}}{S_{p0,2}}\;;\; K_t\,\sigma_{eq} \le \frac{R_r}{S_r}\;;\; K_t\,\sigma_{eq} \le \frac{R_m}{S_m}$$

Selon le comportement du matériau on choisit le critère de calcul de σ_{eq}.

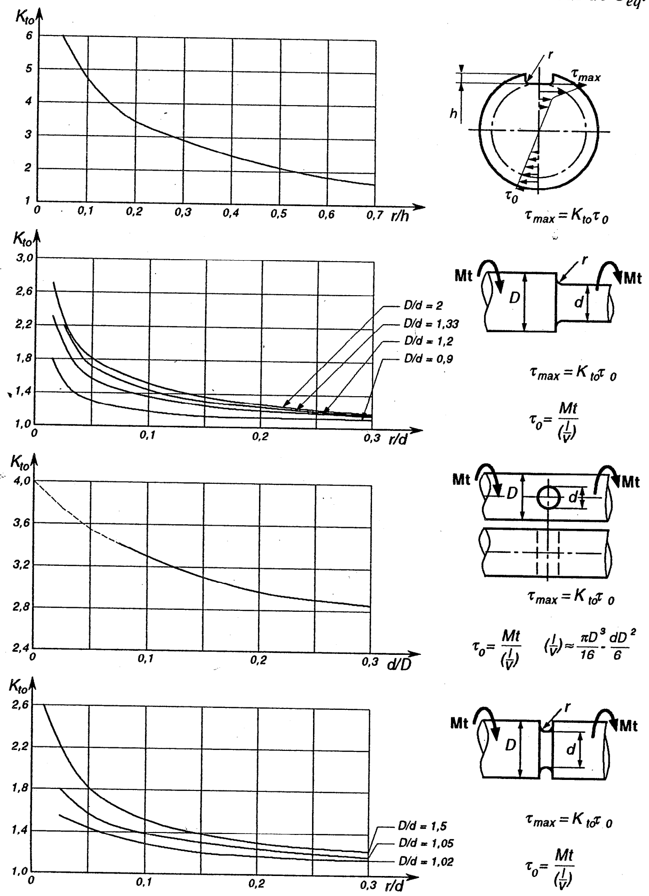
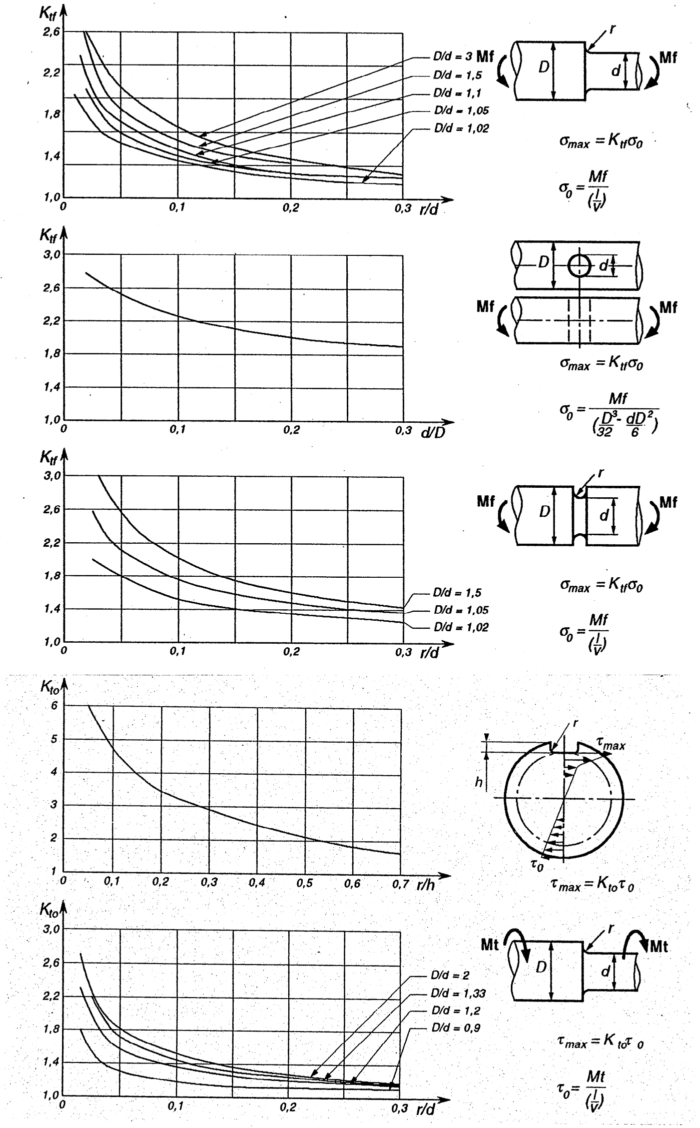


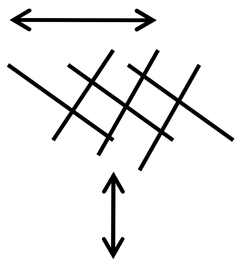
Figure 12.9 – *Valeur de K_{t0} en torsion pure pour différents types d'entailles*



LES Matériaux Composites

Exemple de drapage pour une pale de 12m

- Plis 1 à 2 UD 90°
- Plis 3 à 9 bibiais ± 45°
- Plis 9 à 16 UD 0°
- Plis 17 à 18 UD 90°
- Plis 19 à 26 UD 0°
- Plis 27 à 32 bibiais ± 45°
- Plis 33 à 34 UD 90°
- Plis 35 à 40 UD 0°
- Le Øint est de 635mm (0° est l'axe de la pale)



Calcul de l'épaisseur d'un pli pour une teneur de 60% de fibre en volume

- Grammages disponibles : 100g/m² ; 200; 300; 400; 500; 800g/m²
- Masse volumique fibre : $\rho_f = 2600 kg/m^3$
- Masse volumique matrice : $\rho_m = 1200 kg/m^3$
- Masse volumique équivalente :

- $\rho_e = 0.6\, \rho_f + 0.4\, \rho_m$

Calcul de l'épaisseur d'un pli

- V_t volume total d'un pli de 1m²
- h épaisseur du pli
- $V_t = h \cdot 1m^2$
- $0.6\, V_t\, \rho_f = \text{grammage} \cdot 1m^2$
- D'où $h = \text{grammage} / 0.6\, \rho_f$

- Exprimer le grammage en kg/m²