POSTER 414

Partial Safety Factors for Fatigue Design of Wind Turbine Blades

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Abstract

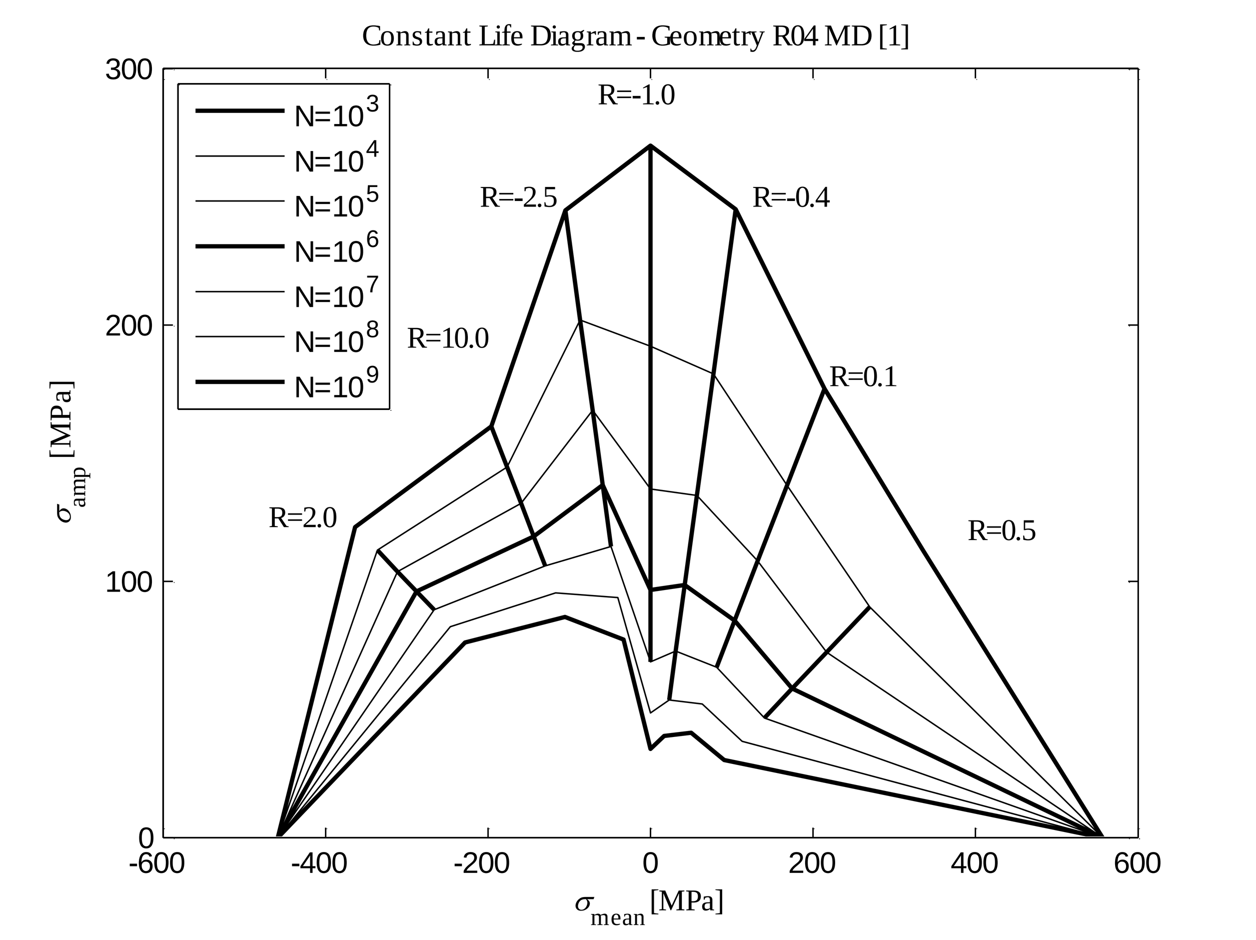
In the present paper calibration of partial safety factors for fatigue design of wind turbine blades is considered. The stochastic models for the physical uncertainties on the material properties are based on constant amplitude fatigue tests and the uncertainty on Miners rule for linear damage accumulation is determined from variable amplitude fatigue tests with the Wisper and Wisperx spectra. The statistical uncertainty for the assessment of the fatigue loads is also investigated.

The partial safety factors are calibrated for design load case 1.2 in IEC 61400-1. The fatigue loads are determined from rainflow-counting of simulated time series for a 5MW reference wind turbine [1]. A possible influence of a complex stress state in the blade is not taken into account and only longitudinal stresses are considered.

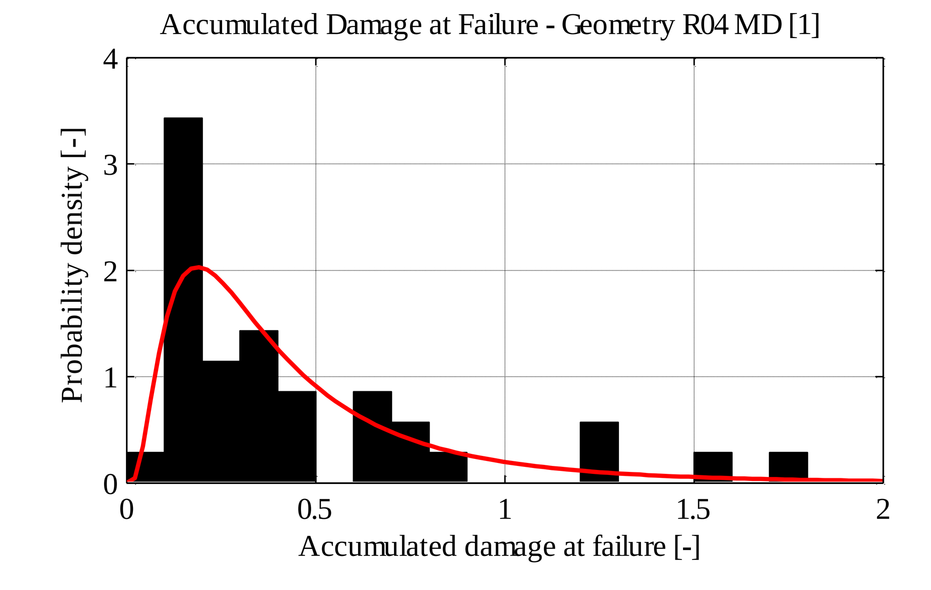
Objectives

Design of wind turbine components is normally based on a deterministic approach where partial safety factors are applied to the loads and resistances in order to obtain a predefined reliability level of the components. The partial safety factors thereby reflect a trade off between the material consumptions and the probability of failure and the associated costs.

In present fatigue design of composite materials for e.g. wind turbine blades a constant life diagram is normally used for representing the relationship between the stress amplitude and the number of cycles to failure. By using a constant life diagram instead of only one SN-curve it is possible to take the influence of mean stress into account. In the present paper the uncertainty related to using a constant life diagram is quantified based on constant amplitude coupon tests from the OptiDAT database [2].



Damage accumulation from the individual load cycles has been widely considered in the literature and several models have been proposed. However, Miners rule for linear damage accumulation is still the most commonly used model in deterministic design, partly because of its simplicity and partly because none of the proposed models are superior. In the present paper the uncertainty on Miners rule is quantified based on variable amplitude coupon tests from the OptiDAT database [2].



Wind turbine blades are normally designed in component class 2 corresponding to normal consequences. The partial safety factors used in IEC 61400-1 for fatigue design of wind turbine blades are given below. In the present paper the partial safety factor for consequences of failure γ_n is defined to 1.00 when component class 2 (normal consequence class) is used.

Partial Safety Factor	IEC 61400-1	Code format present paper
γ_m - Material properties	1.20	1.38
γ_n - Consequences of failure	1.15	1.00
γ_f - Load	1.00	1.00

Uncertainties

In the calibration of the partial safety factors is used an annual target probability of failure on $P_F=10^{-3}$ corresponding to a reliability index on $\beta=3.09$. The uncertainties taken into account are listed below along with there stochastic models [3]. In order to extrapolate the fatigue cycles a Weibull distribution is fitted to the largest stress ranges using a threshold value corresponding to the 98% quantile.

Variable	Description	Distribution	Mean	Std.
Δ	Model Uncertainty Miners Rule	Lognormal	0.33	0.21
X_{exp}	Model Uncertainty Exposure	Lognormal	1.00	0.05
X_{aero}	Model Uncertainty Aerodynamics	Lognormal	1.00	0.10
X_{dyn}	Model Uncertainty Dynamic Response	Lognormal	1.00	0.05
X_{stress}	Model Uncertainty Stress Calculation	Lognormal	1.00	0.05
X_{stat}	Statistical Uncertainty Load Assessment	Lognormal	1.00	0.020
$\log K$	Physical Uncertainty SN-curve (R=0.5)	Normal	27.77	0.36
m	Parameter SN-curve (R=0.5)	Deterministic	10.54	-
ν_{th}	Load cycles per year above threshold	Deterministic	$1.49 \cdot 10^6$	-
T	Life time in years	Deterministic	20	-

Results

The partial safety factors calibrated based on the uncertainties estimated are shown in the table below. The partial safety factors are also calibrated for different values of the uncertainties.

Case	Stochastic Model	Component Class	Partial Safety Factor γ_m	Partial Safety Factor γ_n
1	**Reference**	**2**	**1.37**	**1.00**
	Uncertainty Miners rule			
2	Δ ~ LN(0.46;0.42)	2	1.36	1.00
3	Δ ~ LN(1.00;0.30)	2	1.20	1.00
	Model uncertainty exposure			
4	X_{exp} ~ LN(0.95;0.05)	2	1.30	1.00
5	X_{exp} ~ LN(1.05;0.05)	2	1.43	1.00
	Model uncertainty aerodynamic			
6	X_{aero} ~ LN(1.00;0.05)	2	1.31	1.00
7	X_{aero} ~ LN(1.00;0.15)	2	1.44	1.00
	Model uncertainty SN-curve			
8	$\log K$ ~ N(27.77;0.20)	2	1.34	1.00
9	$\log K$ ~ N(27.77;0.50)	2	1.41	1.00
	Component class			
10	Reference	1	1.37	0.86
11	Reference	3	1.37	1.05

For the reference uncertainties listed above a partial safety factor for the material properties γ_m equal to 1.37 is calibrated using an annual reliability index equal to $\beta=3.09$. This corresponds approximately to the total partial safety factor 1.38 used in IEC 61400-1.

In [4] a partial safety factor equal to 1.25 is determined using an annual target reliability index $\beta=4.27$. The lower partial safety factor obtained in [4] for a higher reliability is due to a low model uncertainty together with a linear SN-curve. In [5] a material partial safety factor 1.29 is obtained for an annual reliability index $\beta=2.70$. This reliability index was found to be optimal for blades based on a cost-benefit analysis. In [5] bias in Miners rule is not taken into account.

Conclusions

Partial safety factors are calibrated for a reference stochastic model leading to a partial safety factor $\gamma_m = 1.37$. If the uncertainties differ significantly from those specified for the calibration of the partial safety factors a new calibration should be performed.

A sensitivity analysis for the individual stochastic variables indicates that the model uncertainty related to the aerodynamics has the largest influence on the reliability followed by the physical uncertainty on the constant life diagram and the model uncertainty related to Miners rule.

Acknowledgement

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