Assessment of fatigue life for small composite wind turbine blades

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Introduction

The present design and assessment of fatigue life for the small composite wind turbine blades (SCWTBs) can be certified by IEC 61400-2 "Wind Turbines - Part2: Design requirements of small wind turbines [1]". The paper will establish an analytical method on the fatigue life analysis of SCWTBs. Using the Microsoft Office EXCEL to calculate the maximum stress, minimum stress and stress ratio of the SCWTBs under the fatigue loading. Also utilizing the above stress data to construct the Goodman diagram (GD-diagram) using the Autodesk AutoCAD software plot. Finally, we can estimate the fatigue life of the SCWTBs.

A valid certification[2-4] issued by an accredited third-party body should be obtained so as to get the permission of installing wind turbine blades in several rapidly-developed wind energy countries, such as Germany, Denmark, India. Being a key component, the rotor blade should certify before the assessment of the total system by the assigned certified body. Anyhow the blades are highly stressed and supposed to sustain their own service life of twenty years that means they should safely withstand extreme loads, mainly the fifty years gust and fatigue within the expected period.

Fatigue life analysis

1. Stress analysis

The section 7.4 of the IEC 61400-2 standard: *Simplified load model* show clearly the design load for "normal operation" is a fatigue load. The load case assumes the constant range fatigue loading for the blades. The equivalent stresses are the combination of the centrifugal loading and the bending moments.

The SCWTBs were made of Glass fiber /Epoxy prepreg tapes. Consider the SCWTBs composed four (or more) balance orthotropic layers of equal thickness. The total thickness is 1.0 mm (or more). The total design parameters will be input Microsoft Office EXCEL to calculate the maximum stress and minimum stress of the SCWTBs. The calculation results are showing in table 1. And the mean stress, stress amplitude and stress ratio are showing in table 2.

2. Construct the Goodman diagram

First, the standard specimens were made of Glass fiber /Epoxy prepreg tapes. The fatigue life of composite materials depends both on the mean stress and the stress amplitude. Normally test series for fatigue strength are organized as testing at different stress ratios between minimum and maximum stress in the load cycles on the coupons. This stress ratio is referred to as the *R-ratios*.

The Stress amplitude (S) and number of cycles (N) can be established S-N curve diagrams for each *R-ratios* by testing at different stress amplitudes. Typically, the S-N data imply a linear relationship when log S is plotted versus log N.

The GD-diagram is constructed by several S-N curves determined from constant amplitude tests at several different *R*-ratios with coupons of the material. The range of the constant amplitude tests are indicated at each *R*-ratio by a line. Between the different *R*-ratios the fatigue strength is estimated by linear interpolation which is also applied to the ultimate tension and compression strength outside the *R*-ratios.

3. Estimate the fatigue life

Real fatigue stress cycles will never be limited to the specific *R*-ratios given in GD-diagram by means of which interpolation is necessary. In present method [5] is described for transforming fatigue cycles with random *R*-ratios into one of the *R*-ratios given in the GD-diagram. In the following this method is briefly explained and sketched in figure 1.

Steps in obtaining the expected number of cycles to failure N :

1. The observed stress cycle P is located in the GD-diagram as the point with mean stress σ_{mean} and stress amplitude σ_{amp}.
2. Draw a line a from the origin of the GD-diagram through and beyond the point P.
3. Identify the two constant life lines closest to P, denoted n_1 and n_2
4. Calculate the length a_1 on line a between the two constant life lines n_1 and n_2.
5. Calculate the length a_2 on line a between point P and the constant life line n_2.
6. Find the R-ratio closest to P.
7. Calculate the length b_1 between n_1 and n_2.
8. Calculate: $b_2 = \dfrac{b_1 a_2}{a_1}$

9. Find the stress amplitude σ_{GD} corresponding to point *Q*.
10. Obtain the expected number of cycles to failure *N* using the S-N curve for the given *R*-ratio.

Results and Discussion

The GD-diagram of the SCWTBs showing in figure 2 was plotted by the Autodesk AutoCAD software. The GD-diagram is constructed by two S-N curves determined from constant amplitude tests at *R*-ratios are 0.1 and 0.5 individually with coupons of the material. And the material partial safety factor of 5.0 is assumed.

The observed stress cycle *P* is located in the GD-diagram as the point with mean stress is 15.015 Mpa and stress amplitude is 7.605 Mpa. Using the above method and Enlarged GD-diagram of the SCWTBs showing in figure 3 can find the stress amplitude σ_{GD} corresponding to point *Q* is 6.75 Mpa. And the number of fatigue life is 30,705,215 cycles.

If the rotor rotational speed of the SCWTBs is 100 r.p.m., then the fatigue life cycles can be calculated by eq. (1)

$$n = \frac{n_{design} T_d}{60} \qquad (1)$$

Where n is the number of fatigue life cycles, n_{desin} is the rotor rotational speed at the design wind speed, T_d is the design life of turbine in seconds.

The design life of turbine is 18,423,129 seconds. Approximately was equal to 213 days.

Conclusion

A procedure for assessment of fatigue life for SCWTBs has been developed on the S-N curve diagrams of the composite materials. Using above method, we can easily find the fatigue life cycles of the SCWTBs.

References

1. IEC 61400-2 “Wind Turbines - Part2: Design requirements of small wind turbines”, Edition 2006.
2. IEC 61400-1 “Wind Turbine generator systems, Part 1: Safety requirements”, Edition 1999.
3. IEC TS 61400-23 “Wind Turbine generator systems - Part23: Full-scale structure testing of rotor blades”, Edition 2001.
4. IEC TR 61400-24 “Wind Turbine generator systems - Part24: Ligtning protection”, Edition 2002.
5. H. Stensgaard, J.D. Sørensen., “Stochastic Models for Strength of Wind Turbine Blades using Tests”, Aalborg University, Denmark and Risø National Laboratory. EWEC (2008)

Table 1. The equivalent stresses on fatigue loading

maximum stress(Mpa)	minimum stress(Mpa)
22.62	7.41

Table 2. Fatigue stresses

mean stress (Mpa)	stress amplitude (Mpa)	stress ratio
15.015	7.605	0.3275

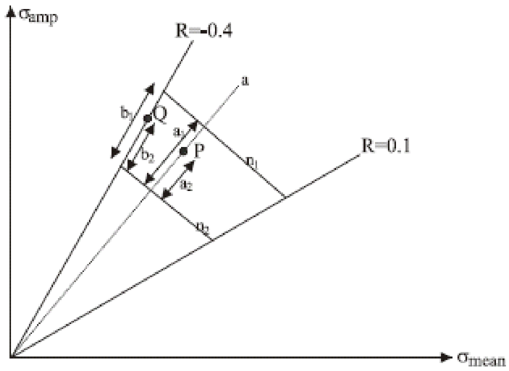

Fig. 1. Graphical interpretation of the transformation to known R-ratios

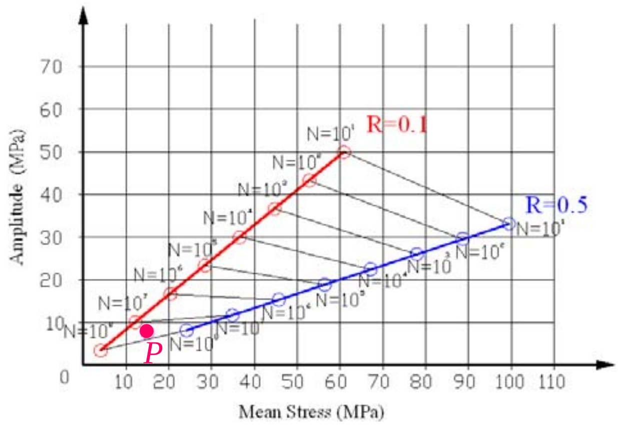

Fig. 2. GD-diagram of the SCWTBs with material partial safety factor 5.0

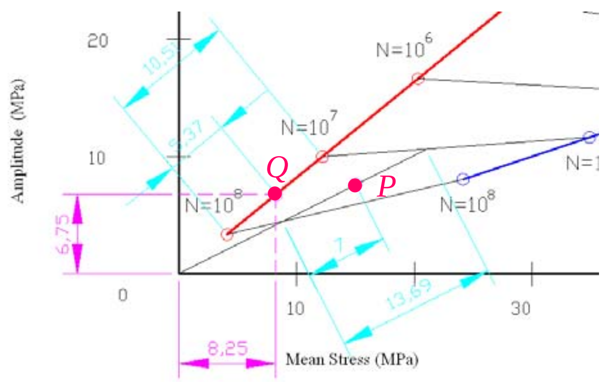

Fig. 3. Enlarged GD-diagram of Fig. 2