Fatigue Performance of Bolted Connections of Offshore Wind Turbines

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Introduction

Bolted ring flange assemblies are used to connect the transition piece to the monopile of offshore wind turbines. These connections are subjected to fatigue loading due to environmental loading. Applicable S-N curves are only verified up to size M36 bolts in standards. This research aims to increase level of confidence in the fatigue performance of bolted connections, with a focus on M72 bolts and to provide a comprehensive understanding to the factors affecting it.

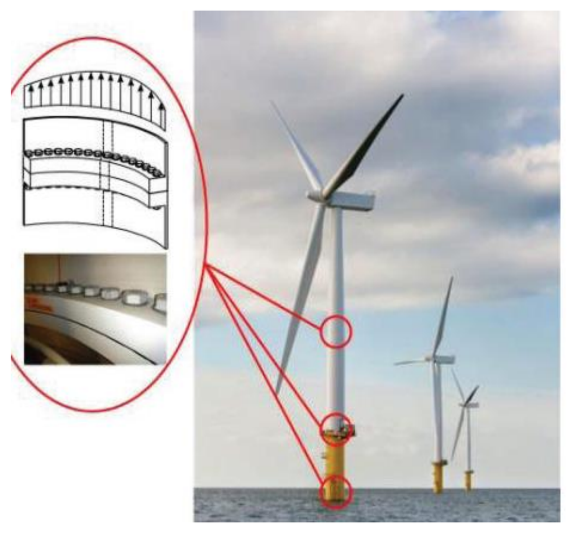

Figure 1: Showing the location of bolted connections in the offshore wind turbine.[1]

Aims and objectives

The aim of this research is to determine the fatigue performance of bolted connections of offshore wind turbines and establish recommendations for use in industry.

Objectives:

- ❑ To investigate the fatigue performance of M72 bolts in offshore wind turbines by performing finite element analysis.
- ❑ To analyze the whole bolted connection and determine service life and critical factor influencing fatigue strength.
- ❑ To perform experiments on M72 bolts to investigate and quantify the influence of coatings and different lubricants on fatigue life.

Determine What Factors Affect Fatigue Properties Of Bolts → Investigate Current Standards And Regulations Governing Bolted Connections → Perform FEA On M72 Bolts And Determine Fatigue Life → Perform Experiments With Coatings On M72 Bolts And Quantify Effect Of Fatigue Strength → Analyse The Flange Connection To Determine Critical Factors Of The Assembly → Provide Guidelines With High Level Of Confidence Of Bolted Connections Offshore

Analysis of Bolted Connections

Hochfest Vorgespannt (HV) bolts are used, see Table 1 and Figure 2. For M72 bolts, about 100 bolts are required for the flanged connection.

Table 1: Properties of HV Bolt

Properties of HV Bolt	
Ultimate tensile strength	1000 MPa
Yield stress	900 MPa
Strength class	10.9
Pitch	6 mm
Material	Steel

Wind Turbine Connections Analysis

- ❑ Bolts are preloaded to approximately 70% of the yield stress of the bolt material.
- ❑ In bolted connections, the first few engaged threads of the bolt are critical, and are subjected to the highest forces, see Table 2.
- ❑ The stress gradient inside the bolt is higher for larger bolts under the same nominal stress.

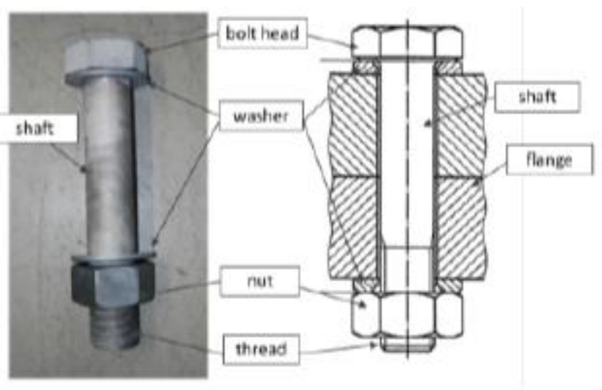

Figure 2: HV Bolt Assembly [2]

Installation

- ❑ For bolts bigger than M20, inclination of bolt support surface to bolt axis is limited to 2°.[3]
- ❑ During installation the main reason for clamp load loss is elastic interaction which can cause bolts to lose about 98% of initial preload after bolt tightening of adjacent bolts. [4]

Table 2: HV Bolt Assembly [5]

Table 1: Stress Distribution in Fastener Threads

Thread No.	Load Percent	Load Percent, Sum
1	34	34
2	23	57
3	16	73
4	11	85
5	9	93
6	7	100

Fatigue Assessment

Fatigue assessment methods are used to estimate the fatigue life on the bolted connection and include nominal stress approach, structural stress approach, notch stress approach, notch strain approach, experimental approach and probabilistic approach.

S-N curves

Due to eccentricity between the tower wall and the bolts, both bending and axial stresses exist within the bolted assembly. S-N curves in standards are based on pure axial loading, and are only validated for M36 and smaller.

Comparison of S-N design curves for bolts

DNVGL-RP-C203 (F1), BS 7608 (Class X) and BS EN 1998-1-9 (Detail category 50) have recommendation for S-N curves regarding bolts, but it should be noted the validated curves in air for M25 still differ, with the thickness correction accounted for by the same equation.

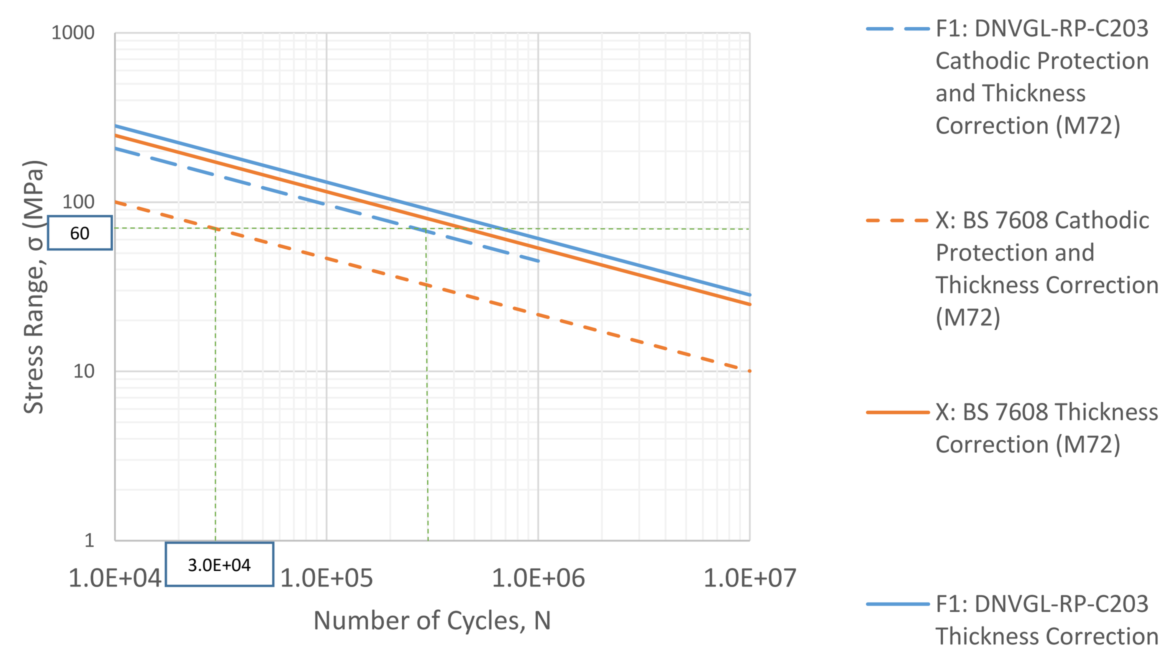

Figure 2: Comparison of S-N Curves for M72 Bolt in Air with M72 Bolt with Cathodic Protection

Conclusions

- ❑ There is limited validated fatigue strength data for bolts bigger than M36.
- ❑ Experiments pertaining to the fatigue performance of large diameter bolts require representative load levels, which is not only limited due to available test equipment, but expensive and time consuming.
- ❑ Analytical and numerical methods can provide and alternative but mechanical and fatigue properties of this complex geometry have to be taken into account and limitations of fatigue assessment methods need to be identified.
- ❑ Influences such as notch effect the thread root, accurate preload application and measurement, manufacturing process, surface finish, coatings and lubricant can adversely affect the fatigue strength of these bolts, and quantification of this reduction can provide useful information for bolted connections.

Further Work

- ❑ Investigation to securely account for hot-dip galvanized layer in analytical or numerical calculations.
- ❑ Flange thickness varies due to designer but the result effect on bolt tension does not follow any particular pattern, this requires further study.
- ❑ Fabrication and installation tolerances need to accounted for in numerical models.

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[2] P. M. Achmus et al., "Work Package 2 : Ocean Energy System Test – Standardisation and Best Practice Testing D2 . 6 : Report on Offshore Wind System Monitoring Practice and Normalisation Procedures."

[3] M. Schwedler, S. Dörfeldt, F. Lüddecke, M. Seidel, and M. Thiele,"Einflussfaktoren auf die Vorspannkraft von Schrauben mit Durchmessern bis M72 in Ringflanschverbindungen," Stahlbau, vol. 87,no.2,pp149–161, 2018.

[4] L. Zhu, A.-H. Bouzid, and J. Hong, "Numerical and Experimental Study of Elastic Interaction in Bolted Flange Joints," J. Press. Vessel Technol., 2017.

[5] The structural integrity of the bolted flange connection is affected by fatigue loading, influenced by environmental loads, material and geometry.

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