Research on stress and strain of the Flange Bolts Connection of Wind Turbine based on Finite Element Analysis

Jianping Liu[1a], Teng Han[1], Derui Su[1], Changguo Ji[1], Junping Chen[1]

[1]Department of Electrical Engineering and Automation, Luoyang Institute of Science and Technology, Luoyang, 471023, China

[a]email: liujianping1415@163.com

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Abstract. Wind energy as an inexhaustible green energy is the development trend of the future. Wind turbine bolts play an important role for the service safety of wind turbine, and have become the new promising product of the fastener industry in the world. But because of the high strength bolt connection failure caused by a tower pour accident, caused the attention of the scientific research workers, and put forward to improve reliability, high strength bolt connection to ensure that the wind turbine operation research problems. The rigid strength, toughness and hardenability requirements of the wind turbine bolt steels are really challenging work. In order to study the mechanism of high strength bolt connection failure, the stress and strain of the high strength bolts of a MW wind turbine was researched by finite element analysis.

Introduction

Wind energy as an inexhaustible green energy is the development trend of the future. But because of the high strength bolt connection failure caused by a tower pour accident, caused the attention of the scientific research workers, and put forward to improve reliability, high strength bolt connection to ensure that the wind turbine operation research problems. In order to study the mechanism of high strength bolt connection failure, the high strength bolts of a MW wind turbine as an example, to study the influence of micro crack on stress of bolt and different preload of bolt fatigue strength.

The use of wind power, a form of renewable energy, is soaring in the 21st century. World wind generation capacity has doubled about every three years between 2000 and 2006. The World Wind Energy Association forecast that, by 2010, over 200 GW of capacity will have been installed worldwide, predicting another impressive 30% yearly growth rate from 2006 to 2010.

A wind turbine is a rotary device that extracts energy from the wind. Horizontal-axis wind turbines, the most popular ones, generally consist of a foundation, tower, nacelle and blades. With the vast growth world-wide in the construction of wind farms in recent years, wind turbine bolts have become a new promising product for the Taiwan fastener industry, one of the leading fastener export countries in the world. Wind turbine bolts for nacelles and blades, like all bolts for aerospace use, have higher standards than other bolts as shown in Fig.1. The rigid strength, toughness and hardenability requirements of the wind turbine bolt steels are challenging work for a steel manufacturing company (1-2).

Screws and bolts are made from a wide range of materials, with steel being perhaps the most common, in many varieties. ISO 898.1 specification is the primary specification used in wind turbine bolt produc-tion. Some other specific requirements may be negotiated between buyers and suppliers. Tables 1 and 2 show the requirements of material, chemical composition, and mechanical and physical properties in ISO 898.1 Steel bolts usually have a hexagonal head with an ISO strength rating (called the property class) stamped on the head. The property classes most often used are 5.8, 8.8, 10.9, and 12.9. High-strength steel bolts have property classes of 8.8 or above, and wind turbine bolts have property classes of 10.9 or above. For the materials with property classes of 8.8 and above, there must be a sufficient hardenability to ensure a structure consisting of approximately 90% martensite in the core of the threaded sections for the fasteners in the “as-hardened” condition before tempering(3-6).

Wind turbine bolts have become the newest product of Taiwan fastener industry in this decade. SCM435 (AISI 4135) steel was the material for producing M24-M27 bolts, and SCM440 (AISI 4140) steel was for M30-M36 bolts. The nominal diameter of a metric bolt is the outer diameter of the thread, and M36 means that the nominal diameter of the bolt is 36mm. Our customers have consistently complained about the inhomogeneous mechanical properties of M42 bolt manufactured with SCM440 since 2009, and their com-plaints included unstable and insufficient hardness and strength reading. Mass effect caused this instability in the M42 bolts and above. The M48 bolt would be new product developed by our customers in 2011, and a new steel should be designed in time. Some quench cracking, and longitudinal cracks along the bolt body, have happened in production. The cause of this quench cracking, as requested by our customers, is examined in this study(7)

Theoretical model analysis

Tensile or Compressive Stress - Normal Stress

Tensile or compressive stress normal to the plane is usually denoted "normal stress" or "direct stress" and can be expressed as

$\sigma = Fn / A$ (1)

where

σ = normal stress ((Pa) N/m2, psi)

Fn = normal component force (N, lbf (alt. kips))

A = area (m2, in2)

a kip is a non-SI unit of force - it equals 1,000 pounds-force

1 kip = 4448.2216 Newtons (N) = 4.4482216 kilonewtons (kN)

Example - Tensile Force acting on a Rod

A force of 10 kN is acting on a circular rod with diameter 10 mm. The stress in the rod can be calculated as

σ = (10 103 N) / (π ((10 10-3 m) / 2)2)

= 127388535 (N/m2)

= 127 (MPa)

Example - Force acting on a Douglas Fir Square Post

A compressive load of 30000 lb is acting on short square 6 x 6 in post of Douglas fir. The dressed size of the post is 5.5 x 5.5 in and the compressive stress can be calculated as

σ = (30000 lb) / ((5.5 in) (5.5 in))

= 991 (lb/in2, psi)

Shear Stress

Stress parallel to the plane is usually denoted "shear stress" and can be expressed as

$\tau = Fp / A$ (2)

where

τ = shear stress ((Pa) N/m2, psi)

Fp = parallel component force (N, lbf)

A = area (m2, in2)

Strain

Strain is defined as "deformation of a solid due to stress" and can be expressed as

$\varepsilon = dl / lo$

$= \sigma / E$ (3)

where

dl = change of length (m, in)

lo = initial length (m, in)

ε = unit less measure of engineering strain

E = Young's modulus (Modulus of Elasticity) (N/m2 (Pa), lb/in2 (psi))

Young's modulus can be used to predict the elongation or compression of an object.

Example - Stress and Change of Length

The rod in the example above is 2 m long and made of steel with Modulus of Elasticity 200 GPa. The change of length can be calculated by transforming (3) as

dl = σ lo / E

= (127 106 Pa) (2 m) / (200 109 Pa)

= 0.00127 (m)

= 1.27 (mm)

Young's Modulus - Modulus of Elasticity (or Tensile Modulus) - Hooke's Law

Most metals deforms proportional to imposed load over a range of loads. Stress is proportional to load and strain is proportional to deformation as expressed with Hooke's law

E = stress / strain

= σ / ε

= (Fn / A) / (dl / lo) (4)

where

E = Young's modulus (N/m2) (lb/in2, psi)

Modulus of Elasticity, or Young's Modulus, is commonly used for metals and metal alloys and expressed in terms 106 lbf/in2, N/m2 or Pa. Tensile modulus is often used for plastics and is expressed in terms 105 lbf/in2 or GPa.

Shear Modulus

S = stress / strain

= τ / γ

= (Fp / A) / (s / d) (5)

where

S = shear modulus (N/m2) (lb/in2, psi)

τ = shear stress ((Pa) N/m2, psi)

γ = unit less measure of shear strain

Fp = force parallel to the faces which they act

A = area (m2, in2)

s = displacement of the faces (m, in)

d = distance between the faces displaced (m, in)

Results and Discussion

(1)build the finite element model

As the requirement, the CAD model was built as follows:

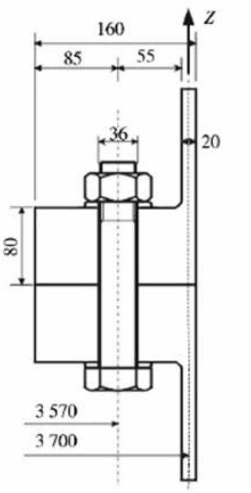


Fig 1 CAD model of bolt

And the finite element model is as follows:

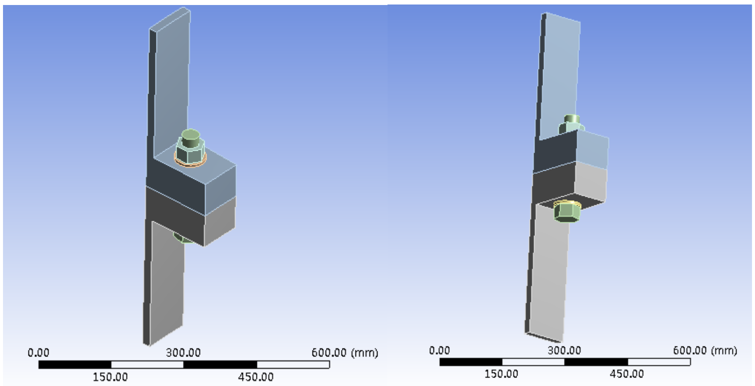


Fig 2. the finite element model

The geometrical parameters as shown in Figure 1, the other parameters are as follows: high strength bolts of grade 10.9, M36 * 226 specifications, the preload of FV = 510 kN DH = 39 mm, bolt, gasket gasket inner diameter Daw = 66mm, DIW = 37 mm TW = 6 mm, the thickness of the gasket, the number of bolts n = 112.

The model includes the upper flange and the lower flange, bolts, nuts, washers and part of the tower wall. Each component materials are high strength low alloy structural steel, elastic modulus is 2.06 * 106MPa, the Poisson's ratio of 0.3, the density of 7.85 * 103 kg/m3.

Flange connection model as shown in Figure 2, flange contact finite element model as shown in figure 3.

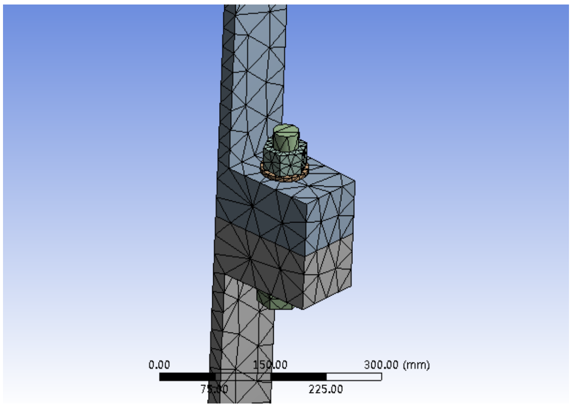


Fig 3. connection model

The contact relation between the contact settings: nuts and washers and bolts arranged in contact is rigid and the upper and lower flange contact set to contact friction, gasket and flange contact set to friction and friction coefficient on the contact between the 0.15.

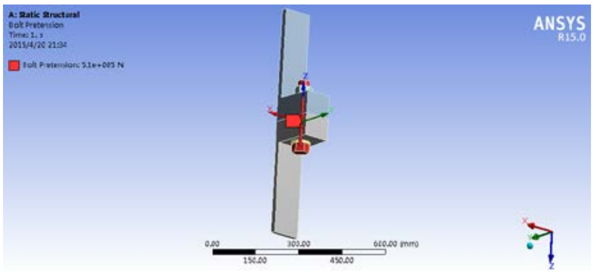
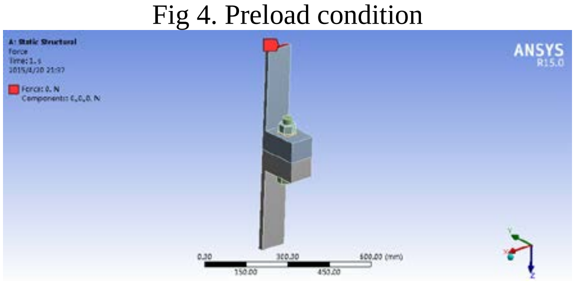


Fig 4. Preload condition



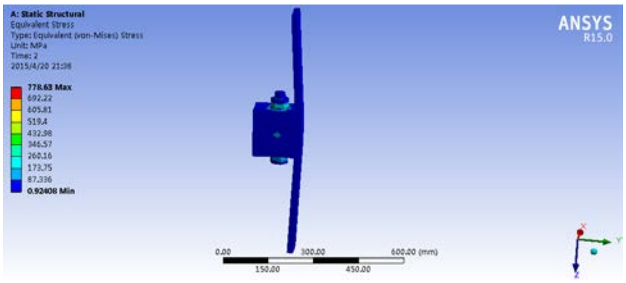
Tabular Data

	Steps	Time [s]	X [N]	Y [N]	Z [N]
1	1	0.	0.	0.	0.
2	1	1.	0.	0.	0.
3	2	2.	= 0.	= 0.	-1.2e+005

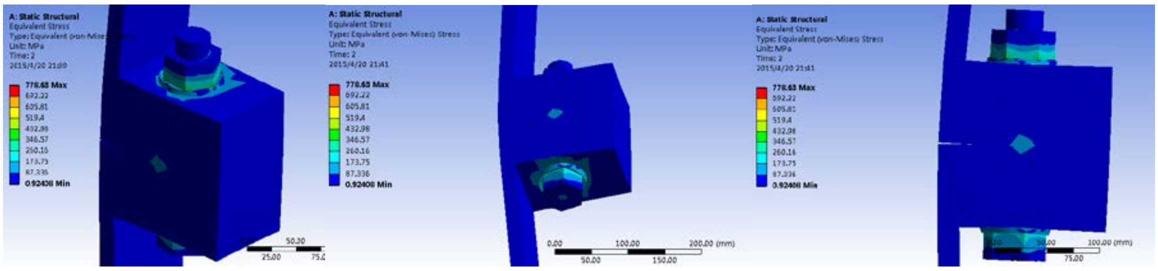
Fig.5 Applied working load

In the flange contact analysis, the analysis process for pre tightening and two conditions. Figure 4 shows the preload condition of high strength bolt preload 510kN. Figure 5 is applied work load, work load is 120kN.

(2) Stress analysis



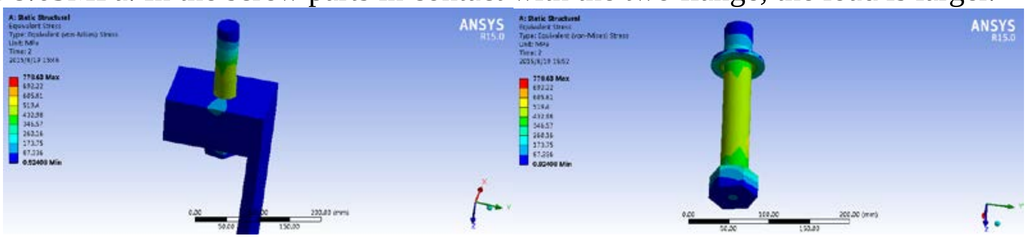
（a）



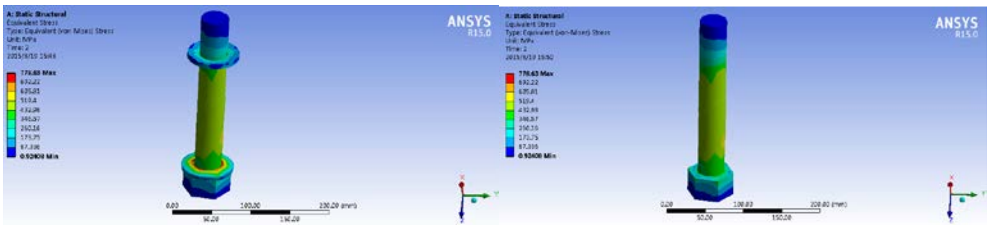
（b） （c） （d）

Fig. 6 Equivalent stress distribution

Figure 6 is a bolt connection by equivalent stress distribution results. The maximum equivalent stress is 778.65MPa. In the screw parts in contact with the two flange, the load is larger.



（a） （c）



（b） （d）

Fig. 7 Equivalent stress distribution

Figure 7 is a bolt connection by distribution of the equivalent stress (the hidden on the upper and lower connecting piece washers, and nuts). From the above several bolt to bolt ends can be seen, the load is small, relatively speaking, the central region of the bolt load is large, approximately between 500~700MPa.

Conclusions

Based on the analysis of this paper, the stress and strain have been analyzed by finite element analysis. As the result shows that the most import harmfully place in the bolt is the connected point. And the maximum equivalent stress is 778.65MPa. In the screw parts in contact with the two flange, the load is larger, and the central region of the bolt load is large, approximately between 500~700MPa.

References

[1] World Wind Energy Report 2009 (PDF), Report of World Wind Energy Association, 2009.

[2] Http://www.gepower.com/businesses/ge_wind_energy/ en/index.htm.

[3] International Standard ISO 898-1, ”Mechanical Properties of Fasteners Made of Carbon Steel and Alloy Steel Part 1: Bolts, Screws and Studs with Specified Property Classes Coarse Thread and Fine Pitch Thread”, 2009.

[4] ASTM A354 - 07a, “Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners”, 2007.

[5] ASTM A490M - 09a , “Standard Specification for High-Strength Steel Bolts, Classes 10.9 and 10.9.3, for Structural Steel Jo ints (Metric)”, 2009.

[6]ASTM A574M - 08, “Standard Specification for Alloy Steel Socket-Head Cap Screws [Metric]”, 2008.

[7] E Jiaqiang, LI Zhenqiang, QIAN Cheng, et al. Strength analysis of bolt connection on yaw gear of the MW wind turbine generator system[J]. Advanced Materials Research, 2013,724-725: 14-618.