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Wind turbines - Tower

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Table of Contents

Foreword	3
1 Scope	5
2 Normative references	5
3 Terms and definitions	9
4 Symbols and abbreviated terms	11
5 Design principles	14
6 Steel tower	16
7 Concrete tower	52
Appendix A (Informative) Tower structure damping ratio	100
Appendix B (Informative) Simplified buckling analysis method for tower door frame opening	103
Appendix C (Informative) Fatigue strength analysis of steel tower.....	106
Bibliography	107

Wind turbines - Tower

1 Scope

This document specifies the design principles, design requirements, process requirements, test methods, inspection rules, completion data and accompanying documents, marking, packaging, storage and transportation requirements of wind turbine towers.

This document applies to the design, manufacture, construction and acceptance of horizontal-axis wind turbine towers.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the version corresponding to that date is applicable to this document; for undated references, the latest version (including all amendments) is applicable to this document.

GB 175, Common Portland Cements

GB/T 470, Zinc ingots

GB/T 700, Carbon structural steels

GB/T 709, Dimension shape weight and tolerances for hot-rolled steel plates and sheets

GB/T 985.1, Recommended joint preparation for gas welding, manual metal arc welding, gas-shield arc welding and beam welding

GB/T 985.2, Recommended joint preparation for submerged arc welding

GB/T 1228, High strength bolts with large hexagon head for steel structures

GB/T 1231, Specifications of high strength bolts with large hexagon head, large hexagon nuts, plain washers for steel structures

GB/T 1591, High strength low alloy structural steels

GB/T 3098.1, Mechanical properties of fasteners - Bolts, screws and studs

GB/T 3098.2, Mechanical properties of fasteners - Nuts

5 Design principles

5.1 The design service life of the tower shall not be less than the design service life of the wind turbine.

5.2 The tower shall meet the following functional requirements within the specified design service life:

- During normal construction and use, it shall be able to withstand various loads and effects that may occur;
- During normal use, it shall have good working performance;
- Under normal maintenance, it shall have sufficient durability;
- In case of accident, the structure shall be able to maintain overall stability.

5.3 The tower load shall be calculated and analyzed in accordance with the relevant provisions of GB/T 18451.1.

5.4 In addition to the calculation and analysis of tower loads in accordance with 5.3, additional loads caused by the inclination of the tower and foundation shall also be considered. The tower inclination caused by factors such as installation, manufacturing and temperature should be calculated at 5 mm/m, and the tower inclination caused by factors such as foundation deformation and uneven settlement shall be calculated at 3 mm/m.

5.5 The modal damping ratio of the tower shall be obtained through testing or analysis, and can be selected by referring to Appendix A during design.

5.6 The tower design shall be calculated and analyzed by selecting the most unfavorable load condition combination among all design conditions.

5.7 The tower design shall consider the influence of vortex-induced vibration on the tower when the tower is hoisted, shut down or out of wind. The calculation and analysis can be carried out according to the method in Appendix E of EN 1991-1-4:2005 or other methods of the same safety level. The first-order vortex-induced vibration of the tower shall be considered in the calculation and analysis, and the second-order and higher-order vortex-induced vibration shall be considered when necessary. Aerodynamic damping shall not be considered when calculating vortex-induced vibration.

5.8 When the cumulative fatigue damage caused by vortex induction is not greater than 0.1, its influence can be ignored; when the cumulative fatigue damage caused by vortex induction is greater than 0.1, it shall be superimposed with the cumulative damage caused by fatigue load. A vortex-breaking structure can be added to the tower to destroy the vortex induction formation or a damper can be added to reduce the influence of vortex-induced vibration.

materials meet the design requirements. It can only be implemented after confirmation by the design unit.

6.1.2.2 Flange

The flange steel shall comply with the provisions of GB/T 1591, and the thickness direction performance (if required) shall at least comply with the Z25 requirements specified in GB/T 5313-2010. The ultrasonic testing requirements shall at least comply with the quality classification level I requirements in NB/T 47013.3-2015.

The quality grade of flange steel shall not be lower than that of tower tube steel. Flanges shall be forgings. Forging steels shall be steel ingots refined outside the furnace, vacuum degassed or continuous casting round billets. Continuous casting slabs are not allowed.

The ordering content, technical requirements, sampling, test methods, inspection rules, markings, labels and accompanying documents as well as packaging, transportation and storage of flanges shall comply with the provisions of JB/T 11218.

6.1.2.3 Welding materials

The welding materials (welding rods, welding wires, welding flux) used in tower manufacturing shall comply with the regulations and design requirements of GB/T 5117, GB/T 5118, GB/T 5293, GB/T 8110, GB/T 10045, and shall have a valid quality certificate.

The welding materials (welding rods, welding wires, welding flux) used in tower manufacturing shall match the base material, and the impact absorption energy shall not be lower than the base material requirements.

6.1.2.4 Fasteners

The steel and performance grade of fasteners used for tower connections shall be selected by the design unit in accordance with GB/T 5782, GB/T 1228, GB/T 1231, GB/T 3098.1, GB/T 3098.2, GB/T 32076 (all parts) and NB/T 31082, and the performance requirements shall be clearly stated in the design documents.

6.2 Analysis of the inherent characteristics of the tower

The analysis of the inherent characteristics of the tower shall take into account:

- In general, there shall be an appropriate interval between the natural frequency $f_{0,n}$ and the excitation frequencies f_R , $f_{R,m}$, which can be calculated according to Formula (1) and Formula (2):

The stability analysis of the tower shall take into account the relevant failure mode of the specific type of structure, namely the buckling of the tower.

If the two ends of the tower section are L-shaped or T-shaped flanges, only the stability of each tower section can be analyzed; if the two ends of the tower section are of other types, it shall be confirmed that the two ends of the tower section can provide the necessary boundary conditions in order to analyze the stability of each tower section, otherwise the stability of the entire tower frame shall be analyzed.

6.3.2.2 Analysis methods

The buckling analysis of the tower tube take into account the geometric, structural and material defects that may occur during the manufacturing and installation process. The buckling analysis shall be carried out using any of the following methods.

- Analysis is performed based on relevant industry-recognized standards and specifications, such as EN 1993-1-6.
- Computer-aided buckling analysis. The effects of material nonlinearity (MNA), material and geometric nonlinearity (GMNA), and material and geometric nonlinearity taking into account imperfections (GMNIA) on buckling shall be considered.

6.3.2.3 Door frame/reinforcement structure

For openings on tower sections with or without reinforced structures, buckling analysis shall be performed using any of the following methods.

- numerical buckling analysis including material and geometric nonlinearity taking into account imperfections (GMNIA).
- analysis and verification performed according to the method recommended in Appendix B. For openings with door frames, the door frame cross section shall be aligned with the center of the tower tube wall at the 3 o'clock and 9 o'clock positions (as shown in Figure 1).
- If other alternative methods can ensure the safety of opening buckling, modifications, simplifications or extensions of the alternative methods may be adopted.

The material of the gasket or other filler shall have a similar elastic modulus and compression strength to the flange material. Perform filling near each bolt or between each bolt and the tube wall. The filler shall ensure that the flange is fully in contact with the filled area before the bolts are pre-tightened or after applying 10% of the design pre-tightening force.

If the inclination angle α_s of the flange outer surface exceeds 2° after the bolts have applied the pre-tightening force, a conical gasket with strength not less than that of the flange shall be used to fill it.

In the following cases, it can be assumed that the welding between the flange and the tube wall is not affected by the edge-error of the tube wall:

- The radius r between the flange surface and the weld neck is at least 10 mm;
- The distance between the circumferential weld and the upper surface of the flange shall meet the requirements of 6.4.1;
- The distance requirement between weld toe and the upper surface of the flange applies to production and repair welding;
- The maximum limit of the internal taper of a single flange is 0.7° .

If the flange meets the above requirements, only the fatigue strength of the bolts and circumferential welds needs to be analyzed.

If the above requirements are not met, detailed ultimate strength and fatigue strength analysis of the flange, the weld between the flange and the tube wall, and the tube wall near the weld shall be performed. The weld fatigue detail classification shall select the value of the non-weld neck flange connection structure.

6.4.3 Ultimate strength analysis of flange and bolt connections

For the ultimate strength analysis of flange and bolt connections, simplified calculation methods such as the Petersen/Seidel method can be used. However, the finite element calculation method that does not consider the flange clearance and other calculation methods that lead to similar results are not allowed.

The simplified calculation method needs to consider at least the following three failure modes:

- Failure caused by bolt breakage;
- Failure caused by plastic hinges on the tower tube wall and/or flange and bolt breakage;
- Plastic hinges appearing on the tower tube wall and/or flange.

Non-destructive testing personnel shall be assessed and identified in accordance with the requirements, pass the relevant professional qualification assessment, and obtain a valid qualification certificate.

6.7.2 Raw material inspection

6.7.2.1 After the raw materials enter the factory, the tower manufacturing unit shall conduct a detailed quality and qualification document review of the raw materials (not limited to tube steel plates, flanges, door frames, welding materials, coatings, etc.), and they can only be used after they are qualified. All welding materials shall be provided with inspection reports regarding impact absorption energy, chemical composition, and mechanical properties, and meet the standard requirements.

6.7.2.2 Raw materials shall be tested in accordance with 6.1.2 and meet the requirements.

6.7.2.3 After the tower body steel plates enter the factory, 10% of the furnace batch numbers must be retested for chemical composition and mechanical properties. Those that fail the retest are not allowed to be used.

6.7.2.4 The selected testing organization shall have relevant qualifications, which shall include the competence to test mechanical and chemical components.

6.7.3 Appearance and dimensional deviation requirements

6.7.3.1 Cutting

The cut surface of steel plates shall not have defects such as cracks, delamination, inclusions, etc., and shall not affect the quality of welding and product appearance.

The dimensional deviation of the tube blanking shall meet the following requirements:

- The length deviation of the large and small mouth strings is ± 2 mm;
- The length deviation between diagonals is ± 3 mm;
- The slant height deviation is ± 2 mm.

The door frame blanking dimensional deviation is ± 3 mm. There shall be no micro cracks on the cut surface after forming, and the cutting edge shall have a smooth transition.

6.7.3.2 Roll forming

6.7.3.2.1 The roundness tolerance requirement for any cross section of the tube is $(D_{\max} - D_{\min})/D_{\text{nom}}$ not to exceed 0.01, as shown in Figure 7.

- measures to be taken to avoid lamellar tearing;
- weld acceptance criteria;
- inspection and testing plan before and during welding;
- weld identification requirements;
- surface treatment requirements.

6.7.5.3 Welding procedure qualification report

The welding process of the welds between tubes and the welds welded to the tube (including the door frame) shall be supported by the corresponding welding process qualification. The welding process qualification shall be carried out in accordance with the provisions of NB/T 47014 and ISO 15614-1, and a welding procedure qualification report (WPQR) shall be prepared, which shall include the quality certificate of the materials used.

When the repair weld does not use the same welding process as the original weld, the repair process shall be evaluated separately. The welding process of the full penetration T-butt weld shall be evaluated separately.

6.7.5.4 Welding preparation and implementation

6.7.5.4.1 Weld joint preparation

The joint preparation shall match the welding method. The joint preparation shall meet the preparation form requirements in the welding procedure qualification. The tolerance range of joint preparation and pairing shall be specified in the welding procedure specification (WPS).

The joint groove shall be designed according to the requirements of GB/T 985.1 and GB/T 985.2, and the groove form and geometric dimensions shall be determined through welding process assessment.

Processing methods for joint grooves: mechanical method, flame cutting, plasma cutting and other processing methods. The surface quality of flame cutting or plasma cutting shall meet the requirements of Level II in JB/T 10045-2017. Oxide scale, slag and surface layer that affects the welding quality shall be removed from the cut grooves.

The oil, paint, dirt, rust, burrs and galvanized layer within a range of not less than 15 mm on the joint groove and its inner and outer surfaces shall be cleaned, and there shall be no defects such as cracks and interlayers. When repairing large gaps or other geometric size problems on the joint groove, approved welding procedures need to be used, and the above areas shall be polished and smoothly transitioned in time.

6.7.5.4.2 Storage and circulation of welding materials

The storage, circulation and use of welding materials shall be in accordance with the manufacturer's recommendations. The drying and storage of welding rods and welding flux shall meet the appropriate temperature and time. If welding materials (welding rods and welding flux) are not used up after welding, they shall be dried again as required. Welding rods can only be dried twice at most.

6.7.5.5 Welding environment

Welding operations shall be carried out indoors. In special cases when outdoor operations are required, the requirements of drawings and technical specifications shall be met. Welding shall not be carried out when any of the following situations occur and there are no effective measures:

- Wind speed: greater than 2 m/s for gas shielded welding, greater than 5 m/s for arc welding, and 10 m/s for submerged-arc welding;
- Relative humidity greater than 90%;
- Rainy and snowy environment.

When the material to be welded is below 0 °C, it can be heated appropriately.

When the welding environment temperature of steel with a grade not less than Q355 is lower than 5 °C, preheating is required before welding.

6.7.5.6 Welding pairing

To ensure the size and deformation control of welded parts, use spot welding or external equipment to fix the position before welding. The final size of the joint pair during assembly shall be within the tolerance range, and deformation shall be reserved for shrinkage and deformation.

During assembly and tack welding of welded parts, the welds shall be accessible and visible.

6.7.5.7 Preheating

Preheating shall be carried out in accordance with GB/T 18591 and ISO/TR 17671-2.

Preheating shall be carried out in accordance with the applicable WPS, including tack welding and welding of temporary accessories.

6.7.5.8 Temporary accessories

If temporary welding accessories are required during the assembly process (flanges and door frames are not allowed to be welded with temporary accessories), the location of the accessories shall be easy to remove, and the removal of the accessories shall not

- method used to measure temperature;
- results of mechanical property tests carried out for process qualification;
- identification of operators qualified to perform the process.

6.7.5.14 Dissimilar steel welding

Requirements for welding different types of stainless steel and welding with other steel grades shall be specified.

The person responsible for welding shall consider the selection of appropriate welding technology, welding methods and welding materials. Stainless steel contamination and electrochemical corrosion issues shall be carefully considered.

6.7.5.15 Post-welding heat treatment

If post-welding heat treatment is required after welding, appropriate procedures shall be in place.

6.7.5.16 Welding implementation

Effective measures shall be taken to avoid arc scratches. If arc scratches occur, the steel plate surface shall be slightly polished and inspected. After the appearance inspection, PT or magnetic particle inspection MT shall be used.

Before each welding, cracks, holes and other unacceptable defects in the previous weld shall be removed.

Before each welding, the slag on the surface of the previous weld and the cover weld shall be removed. Special attention shall be paid to the connection between the weld and the base material.

Requirements for grinding and finishing after welding are completed shall be specified.

6.7.5.17 Welding repair

6.7.5.17.1 Surface repair

All defects exceeding the standard on the weld and parent material surface shall be repaired according to the process requirements.

6.7.5.17.2 Weld repair

For welds that need to be repaired, the causes of internal defects shall be analyzed, improvement measures shall be proposed, and repairs shall be carried out according to the qualified welding repair process. The number of repairs on the same part of the weld shall not exceed two times. If it exceeds two times, the repair shall be approved by the technical person in charge of the manufacturing unit before repair. After welding, the

weld, base material and heat-affected zone shall be hardness tested (the hardness value shall not exceed HV₁₀380). At the same time, the number of repairs and the repaired parts shall be recorded in the quality certification materials.

6.7.5.18 Product welding test plate

6.7.5.18.1 If necessary, while welding the tower, make the longitudinal weld test plate of the tube according to the same requirements. The thickness range of the product welding test plate shall be within the product thickness range covered by the process qualification represented.

6.7.5.18.2 The inspection items of product welding test plates shall be carried out in accordance with the provisions of NB/T 47016. If the test plate fails, double the welding test plate shall be made. The unqualified test plate represents the product weld failure and shall be repaired or scrapped.

6.7.6 Welding inspection

6.7.6.1 Inspection before and during welding

Check the following items before and during welding:

- applicability and validity of welder/welding operator certificates;
- applicability of WPS;
- identification of base materials and welding materials;
- welding groove (form and size);
- pairing, tooling and positioning;
- suitability of working conditions (including environment) for welding;
- main welding process parameters (welding current, arc voltage and welding speed);
- cleaning and shape of weld bead, number of layers of weld metal;
- root gouging;
- preheat/interpass temperature;
- welding sequence;
- correct use and storage of welding materials;
- control of welding deformation.

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