Market Trends for Wind Turbine and Bearing Technologies

1. Introduction

The total electricity generation capacity of wind power generation plants worldwide reached 122 GW as of the end of 2008 business year, and according to a report, this value means a 30% increase over the BY2007 level.

Fig. 1 graphically plots the trends in the total wind power electricity generation capacities of the world and major participating nations in the BY2004–2008 period. During this period, three major nations—USA, Germany and China—accounted for approximately 50% of the total installed capacity. In particular, the total installed capacity significantly increased in USA and China in the same period. 50% of the increase in newly installed capacity in the world in BY2008 is accounted for by USA and China.

Wind power generation, which contributes to the prevention of global warming, is being actively introduced to the worldwide market as a clean energy source. Bearings are increasing in size accordingly with the growth in the size of wind power generation equipment. Evaluation tests of bearings that simulate actual performance are important for selecting suitable bearings, but they are becoming difficult with equipment that is very large, so conducting structural analysis, including for shafts and bearing housings, for example, is necessary. This article introduces some of these analysis techniques.

2. Market trend

2.1 Scale-up

In 1985, the rated output of a typical wind turbine with rotor diameter 15 m stood at 50 kW. About twenty years later, mass-production began with a larger wind turbine that boasts a rotor diameter of 126 m and is rated at 5,000 kW (5 MW).

In the engineering aspect, the contributing factors that have helped realize scale-up of wind turbines are improved mechanical strength for rotor blades by introduction of carbon fiber monolithic impregnated structure, advancement in mechanical strength design and analysis technique for the structures of tower and nacelle, and progress in design and production techniques for producing larger wind turbine bearings.
Research works for super-large wind turbine designs are in progress in particular for offshore wind turbine power generators that are rated at 10 MW to 20 MW.

2.2 Offshore site production
Few sites are available on land where the wind profile is appropriate for wind power generation. For this reason, offshore wind farms site production has been increasing, especially in Europe. Fig. 2 shows an example of typical offshore wind farm in Europe.

2.2.1 Offshore wind power generation programs in Europe
In Europe, there is a vast spread of continental shelves down to a depth of 40 m, and wind farms are often constructed on seabed foundation. In particular in the north Europe, there are large scale offshore wind farm projects. Fig. 3 maps the currently present offshore wind farm projects in the north Europe scheduled in the timeframe up to the year 2020.

2.2.2 Offshore wind power generation programs in Japan
In Japan, application of seabed foundation for wind farms is difficult owing to topographical limitations. Therefore, joint industry-university teams have been developing floating platform wind power generation plants. Note that floating platform plants can be categorized into an anchor-secured type (floating platform structure is secured with the anchoring point at seabed) and a sailing type (floating platform structure can freely move on the ocean surface). Research into a sailing type platform is attracting attentions as this platform type appears to be promising because offshore areas in Japan are often much deeper and Japan’s long-established shipbuilding technologies can be applied to these sailing type structures.

3. Applicable bearing technologies

3.1 Efforts for analysis techniques for large bearings
3.1.1 Main-shaft bearing
To cope with the scale-up of wind turbines, the sizes must be larger for the bearings that support the main shaft, speed-up gearing and generator. In particular, the larger main-shaft bearings that support the larger rotors often measure 2,000 mm OD or greater, and their types include self-aligning roller bearing, double row tapered roller bearing, and cylindrical roller bearing.

To be able to determine the final specifications for a main-shaft bearing, an intended bearing needs to be tested by running on a test rig that can simulate the intended wind turbine so that the bearing in question can stably perform for an extended period. However, a simulation test of the bearing in question on an actual wind turbine requires a large test facility, higher cost and longer preparation period before actual test, and, therefore, cannot be readily executed. To address this issue, NTN has been performing not only simulation tests on an actual wind turbine but also finite element method-based structural analysis for the bearings and auxiliaries including the bearing housing and bearing bed so that a more reliable bearing design is achieved.

Figs. 4 and 5 show a result of the analysis with a main-shaft model. By an external force, the bearing as well as the bearing housing and shaft get deformed.

A larger wind turbine develops greater deformation owing to the greater external load it receives, and greater this deformation on the wind turbine more adversely affects the bearing clearance. Therefore, it is necessary to take into account this deformation for
correct analysis of the main-shaft system. NTN performs design reviews after taking into account the effect of deformation on the entire wind turbine structure, and then finalizes the bearing specification optimized for the wind turbine in question. Fig. 5 shows an example of the structure for a bearing that supports the main shaft in nacelle, wherein the bearing structure comprises a double row tapered roller bearing in the blade side and a cylindrical roller bearing in the speed-up gearing side. Fig. 6 provides structural diagrams of the bearings used in this analysis model.

The diagrams in Fig. 7 show the results of the analysis of the effect of deformation on the bearing housing and other structural members. In Fig. 7, the load distribution pattern over the rolling elements is shown for each of two assumptions—where deformation is taken into account and where it is not taken into account.

In FEM analysis procedures, an “elastic body” element is used for the deformation analysis. If the element is assumed to be a “rigid body”, then calculations are possible without taking into account deformation.

The diagrams in Fig. 7 show that when deformation on a bearing housing and bearing are taken into account, the load zone expands and, consequently, load peak is mitigated, meaning the overall load imposed over the rolling elements is reduced. Compared with the “solid body” scenario, the bearing life resulting from the “elastic body” scenario is apparently longer—the life of tapered roller bearing is approximately 20% longer and that of cylindrical roller bearing is 10% longer.

It is true that deformation helped increase bearing life in the example above. However, deformation in
other scenarios can lead to reduced bearing life. Therefore, NTN is executing deformation analysis for the entire wind turbine system in order to design an optimal bearing for the main shaft on wind turbine.

3.1.2 Planet bearing for speed-up gearing

Figs. 8, 9 and 10 provide information obtained from structural analysis with bearings incorporated into speed-up gearings in larger 2-2.5 MW class wind turbines. Note that through this analysis, the specification for relevant planet bearing has been developed while taking into account the magnitude of possible deformation on the carrier, pinion shaft and planetary gearing.

Fig. 9 shows an analysis example of the deformation mode with planetary gearing wherein gear load and centrifugal force are imposed onto the planetary gearing.

In the main mode, the force resulting from two tangential loads $F_t$ shown in Fig. 7 acts on the bearing as a radial load. Consequently, the outer ring is deformed by two radial loads $F_r$, thereby the load zone expands.

**Fig. 8** Planet gear

**Fig. 9** Analysis example of planet gear

**Fig. 10** schematically illustrates the calculation result. If the deformation on the carrier and planetary gear resulting from the input torque is taken into account, the load acting on the rolling elements in rows 1 through 4 on the two double row cylindrical roller bearings is mitigated, compared with a case where deformation is not taken into account. Compared with a case where deformation is not taken into account, the calculated bearing life with deformation being taken into account more closely matches the actual life obtained from the bearings installed to an actual wind turbine. In our test, the life of the two double row cylindrical roller bearings with deformation taken into account was approximately 50% longer compared with a case where deformation was not taken into account.

**Fig. 10** Load distribution of each low
3.1.3 Thermal analysis

When assessing the performance of bearings incorporated into larger wind turbines, thermal deformation needs to be taken into account. Fig. 11 shows an example of a bearing model that was subjected to our thermal analysis. In the analysis work, the temperature distribution over the entire model was determined based on the heat release performance of the bearing as a heat source. Through analysis for a combination of heat and structure, it will be possible to develop bearing specifications that better reflect operating conditions of bearings installed on actual wind turbines. Note that in the thermal analysis work, the thermal characteristics including the heat transfer coefficient and heat release coefficient are affected by various factors including surface properties of the bearings, the weather, the ambient temperature, the humidity and the wind velocity. Therefore, we have attempted to improve precision of thermal analysis by feeding back data obtained from field tests. This effort is later described.

3.2 Simulation on actual wind turbines

NTN owns and operates a unique test facility that is capable of simulating performance of super large bearings for the main shaft of a 2–2.5 MW class wind turbine while subjecting the bearing to a load that will occur on an actual wind turbine. Utilizing this facility, NTN has been performing tests on the bearings simultaneously with FEM analysis to improve precision of FEM analysis, so that the bearing development period is shortened.

Fig. 12 shows an example of results of the FEM analysis with a bearing model (double row tapered roller bearing: 2,000 mm pitch diameter with roller set) for 2–2.5 MW class wind turbine, wherein a moment load of 1700 kN-m was applied to the inner ring.

Table 1 summarizes the information about a comparison between analytical results of FEM and measured value on a particular point (point A in Fig. 12) where the inclination of the inner ring is greatest.

In the test result data in Table 1, the difference between the pre-run analytical value and measured value is 5%, which qualifies as a fairly good match. In contrast, the difference between a post-run analytical value and a measured value is as great as 25%. A result of a post-run analysis is provided below. For this analysis, the heat transfer coefficient was determined based on the temperature rise on the inner and outer rings, and the coefficient was applied to the thermal analysis about the increase in bearing preload and change in bearing rigidity resulting from operation of the bearing.

The bearing housing in Fig. 13 houses a double row tapered roller bearing. This analysis model was continuously run thereby resulting in a temperature
distribution on the bearing and bearing box to be analyzed.

Incidentally, for an estimation of temperature distribution on the bearing through thermal analysis, tuning (a technique that approximates analytical results to measured values obtained by experiment) was employed. More specifically, with this technique, temperatures measured on various test points on the bearing of an actual wind turbine are incorporated into analytical results to adjust the heat transfer coefficient thereby increasing the reliability of the temperature distribution analysis.

The example of bearing temperature distribution inside a bearing housing in Fig. 14 reflects measured values for ambient temperature, nacelle inside temperature, and temperature on the outer circumference surface of the outer ring. Table 2 summarizes information about the comparison between analytical result of thermal analysis and measured values.

Based on the estimated analytical value of temperature difference across the inner ring and outer ring, as given in Table 2, the decrease in bearing clearance on the running bearing was estimated, and then, adequate initial bearing clearance has been accordingly determined. As a result, the difference between analytical value and measured value has decreased to 1%.

Considering the findings obtained from these analytical results, NTN has developed an optimal bearing design that has been installed in an actual wind turbine and is reliably running.

4. Conclusion

Wind power generation as a clean energy source has been increasing its output. The quantity of installed offshore wind turbine plants will further increase. At the same time, wind turbines will increasingly feature greater output and larger size, while they are required to withstand severer natural elements more reliably.

In this context, the bearing designs adopted for wind turbines need not only to satisfy conventional standards but also to be optimized for intended wind turbines through wind turbine-specific detailed analysis technique and review of analysis result.

Wishing to contribute to development of wind power generation which is a new energy source possibly helping prevent global warming, NTN will further develop and stably supply highly reliable and durable bearing products.

References
2) SCOTTISH Development International: Offshore Wind Power Generation in Scotland and the UK