

Bearings for Wind Turbine



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In 2002, worldwide electricity production was about 31,000MW. This is a 27% increase over the previous year.

In the past few years, the wind turbine generating system, which emits no carbon dioxide, has gained widespread acceptance as the cleanest and most environmentally friendly energy. The technical trend for wind turbines is to increase reliability and efficiency while reducing the cost of operation. The bearings, which are one of the most important components for wind turbines, require designs that optimize reliability and economic efficiency while considering the characteristics of this applications.

This report introduces special characteristics for wind turbine bearings and a method to optimize wind turbine bearing design.

1. Introduction

Worldwide electricity production reached about 31,000MW by the end of 2002. This is a 27% increase over the previous year. In the past few years wind power generation, which emits no carbon dioxide, has gained widespread acceptance as the cleanest and most environmentally friendly form of energy. Technical issues remaining in the development of wind power generation include increasing reliability of the system while reducing the cost of operation. Bearings are one of the most important components of wind turbines and require designs that optimize reliability and economic efficiency while taking into account the characteristics of the applications. This report introduces a method to optimize wind turbine bearing design and the features of bearings developed for wind turbines.

2. Structure of Wind Turbines and Bearings

Fig. 1 shows the nacelle of 1 to 2MW wind turbines. Bearings are used in various places of the nacelle: rotor shaft, gearbox (step-up gear), generator, yaw gearbox (reduction), yaw slewing table, blade pitch revolving seat and hydraulic pump.

3. Bearing Operating Conditions

The rotor shaft bearing supports the blades and rotor and transmits torque to the gearbox. The bearing loads and rotating speeds vary considerably due to constantly changing winds.

At wind speeds below the cut-in wind speed (i.e. the minimum wind speed required for power generation), the rotor shaft will idle resulting in low-speed, low-load operation. At wind speeds above the cut-in speed, the

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4. Rotor Shaft Bearings

Table 1 shows the structures of the shafts that use a gearbox to increase blade speed to the rated speed of the induction generator. Bearings suitable for each rotor shaft type are also shown. Table 2 shows the structures of the shaft of synchronous generators not equipped with a gearbox.

Table 1 Wind turbine rotor shaft bearing assembly (with gearbox)

Structure	Blade-side bearing	Generator-side bearing	Features
	SRB SRB SRB	SRB CRB DTRB	<ul style="list-style-type: none"> Two bearings are used. The gearbox is supported on the rotor shaft.
	SRB	CRB	<ul style="list-style-type: none"> The generator-side bearing is also used as the gearbox's input bearing.
	SRB	CRB	<ul style="list-style-type: none"> The generator-side bearing is also used as the gearbox's input bearing. The load on the blade-side bearing is supported by the nacelle.
	TRRB DTRB	—	<ul style="list-style-type: none"> No rotor bearing is used and the rotor load is borne by the gearbox bearing.

SRB : Spherical roller bearing CRB : Cylindrical roller bearing
 DTRB : Double-row tapered roller bearing TRRB : Triple-row cylindrical roller bearing

Table 2 Wind turbine rotor shaft bearing assembly (without gearbox)

Structure	Blade-side bearing	Generator-side bearing	Features
	TRRB DTRB	CRB	<ul style="list-style-type: none"> Direct drive Outer ring rotation
	SRB DTRB	CRB CRB	<ul style="list-style-type: none"> The load on the blade-side bearing is supported by the nacelle. Inner ring rotation

When designing the bearing, first calculate the bearing life for the maximum required strength of the housing and the average deformation of the housing. Then design a slim housing and choose a shaft bearing that meets the required calculated life.

With deformation of the housing and outer ring raceway taken into account, calculate the load on each rolling element to obtain the life of the rotating and stationary rings.

$$Q_R = \left[\frac{1}{Z} \sum_{j=1}^Z (Q_{Rj})^{w_i} \right]^{1/w_i}$$

$$Q_S = \left[\frac{1}{Z} \sum_{j=1}^Z (Q_{Sj})^{w_e} \right]^{1/w_e}$$

Q_R, Q_S : Average load on rotating and stationary rings

Z : Number of rolling elements

w_i, w_e : Constant

$L_R = (C_n / Q_R)^p$: Life of rotating ring

$L_S = (C_n / Q_S)^p$: Life of stationary ring

$L = (L_R^{-e} + L_S^{-e})^{-1/e}$: Life of bearing

C_n : Dynamic rated load on contact point

p : For ball bearing 3

For roller bearing 10/3

e : For ball bearing 10/9

For roller bearing 9/8

Spherical roller and tapered roller bearings are mainly used. However, spherical roller bearings, that feature low misalignment rates, are widely used. Normally, misalignment of $\pm 0.5^\circ$ needs to be taken into account.

With B type spherical roller bearings, the rollers are guided by the inner ring's center rib. This enables operation with stable torque, low skew and low heat generation in a wide load range from the minimum to the maximum load. Fig. 4 shows the structure of NTN's spherical roller bearings (both B and C types).

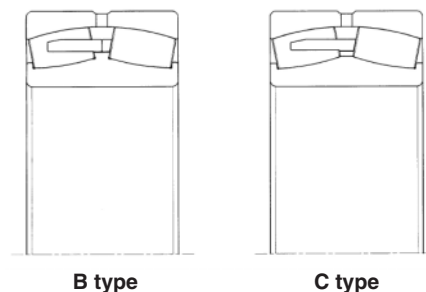
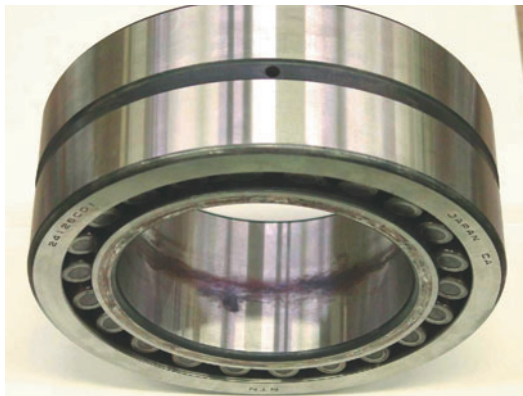


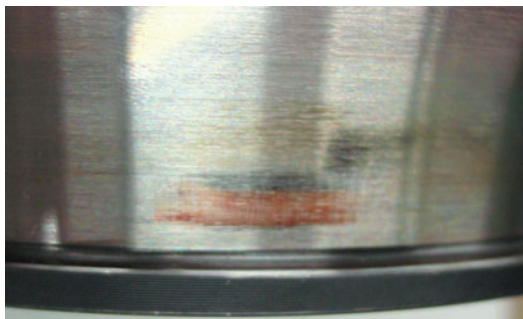
Fig. 4 Spherical roller bearing, B type and C type

Since rotor shaft bearings are exposed to vibration of blades and gearbox, fretting corrosion may occur. Therefore, selection of appropriate bearings and grease, as well as optimization of clearance and fitting are important factors.

Photo 1 shows an external view of a bearing at the end of vibration test.



(1) Fretting on inner ring bore



(2) Fretting on inner ring raceway

《Vibration test》

Bearing : 24126CL1
 Vibration acceleration : 9G
 Vibration cycles : 10 million cycles
 Maximum surface pressure : 1080MPa

Photo 1 Vibration test results

Fig. 5 shows an example of the deformation of a rotor shaft bearing outer ring and housing. The bearing and housing are optimized by calculating the bearing life, including housing deformation and bearing clearance and also confirming the housing strength based on a stress analysis. In this example, a bearing for 1.5-MW wind turbines was used, and the maximum deformation in the axial direction was 0.07mm. The difference in the bearing life calculated with this deformation and bearing clearance taken into account and the one calculated with the housing and outer ring considered to be non-deformed was within 5%, which is not problematic in actual use. If this difference is excessively large and the life is short, the design of the housing needs to be changed to improve rigidity.

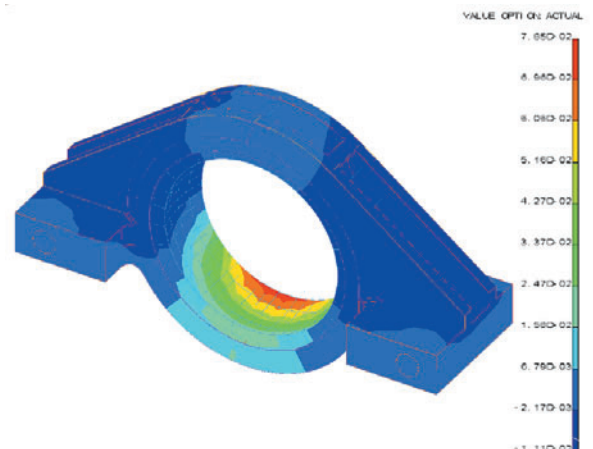


Fig. 5 Bearing outer ring and Pillow Block deformation

5. Planet Bearings for Gearbox

A gearbox consists of an input shaft, planet gear, low-speed shaft, intermediate shaft and high-speed shaft. Fig. 6 shows the structure of a gearbox, and **Photo 2** shows an external view of a full complement cylindrical roller bearing, that is used for input and low-speed shafts.

Fig. 7 shows an example of planet gear mechanism.

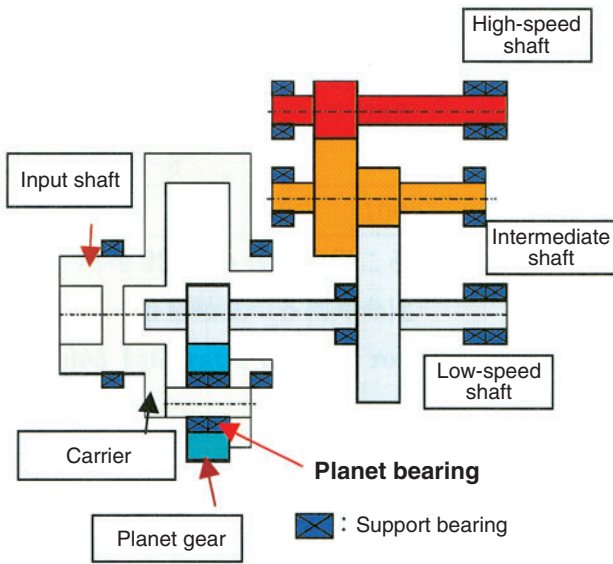


Fig. 6 Gearbox for wind turbine



Photo 2 NTN Full complement cylindrical roller bearing

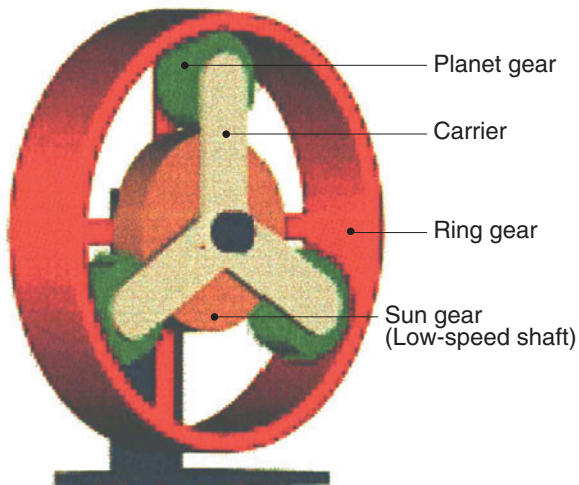


Fig. 7 Planetary gear model

Spherical roller bearings or full complement cylindrical roller bearings are used as planet bearings. An analysis model of the planet bearing is used to calculate the life of bearing with deformation of the outer ring taken into account. When calculating, make sure that the load on the bearing is considered to be the one exerted on rolling elements and the gear engagement point between the ring gear and sun gear is fixed.

Fig. 8 shows an example of deflection analysis results of a planet bearing used for 1.5-MW gearbox. The planet bearing used for analysis consists of two double-row cylindrical roller bearings with four rows of rolling elements, and the maximum deflection was 0.21mm.

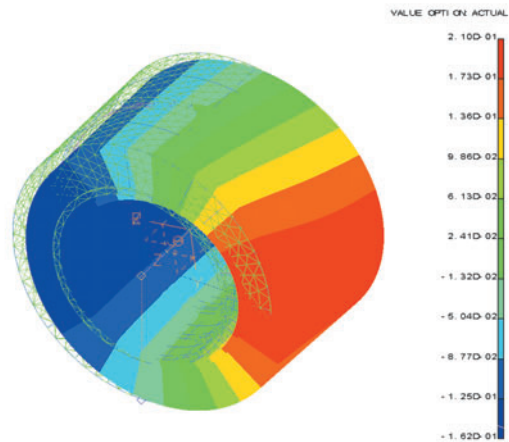


Fig. 8 Deflection of planet bearing

The life, calculated from the analysis results with elastic deformation of the rings taken into account, varies by a maximum of 58% among rows. The carrier-side rows have higher load ratio than the others, resulting in shorter calculated life. Fig. 9 illustrates the arrangement of bearings, and Table 3 shows the calculated results.

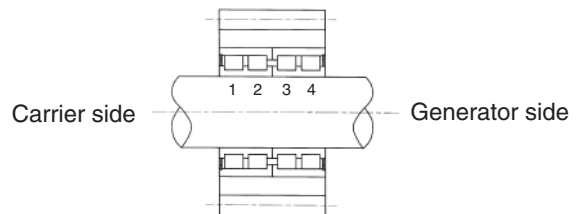


Fig. 9 Arrangement of bearings

Table 3 Life ratio of each row for planet bearing

Row No.	Life ratio
1	85
2	143
3	133
4	100

Inner diameter ϕ 220mm
Double-row cylindrical roller bearing

The maximum contact surface pressure (P_{\max}) for gearbox bearings is calculated based on point contact for spherical roller bearings, and line contact for cylindrical roller bearings. In most cases misalignment is taken into account when specifying the maximum contact surface pressure.

$$P_{\max} = K_{lc} K_m P_{line} \text{ (Cylindrical roller bearing)}$$

K_{lc} : Crowning correction factor

K_m : Misalignment factor

P_{line} : Maximum line contact surface pressure

In the case of spherical roller bearings, if the maximum contact surface pressure exceeds the limit, the bearing size needs to increase. This will increase the calculated life and reduce the maximum contact surface pressure. However, in the case of light loads the rolling elements may not roll properly on the raceway and will begin to slide. This sliding may cause damage to the raceway. Because of this, **NTN** recommends the minimum load be at least 4% of the basic static load rating.

Concerning lubrication, some measures need to be

implemented to prevent a situation in which the planet bearing is exposed to insufficient lubrication when it begins to move.

The problems concerning the planet bearings can be summarized into the following three points.

- Influences by plastic deformation of gears and bearing
- Influences by misalignment of planet bearing caused by twisting of carrier
- Influences by dry start up (insufficient lubricating oil)

The specifications for the optimal bearing must be take into account these properties. **NTN** has been working on the design of ribs that have high load capacity and that provide sufficient resistance against sliding and scuffing under light loads, as well optimal axial clearance. In addition, **NTN** has also been working to prolong the life of bearings by employing special heat treatment.

Furthermore, **NTN** has introduced the special test machines shown in **Figs. 10** and **11**, to promote the development of next generation planet bearings.

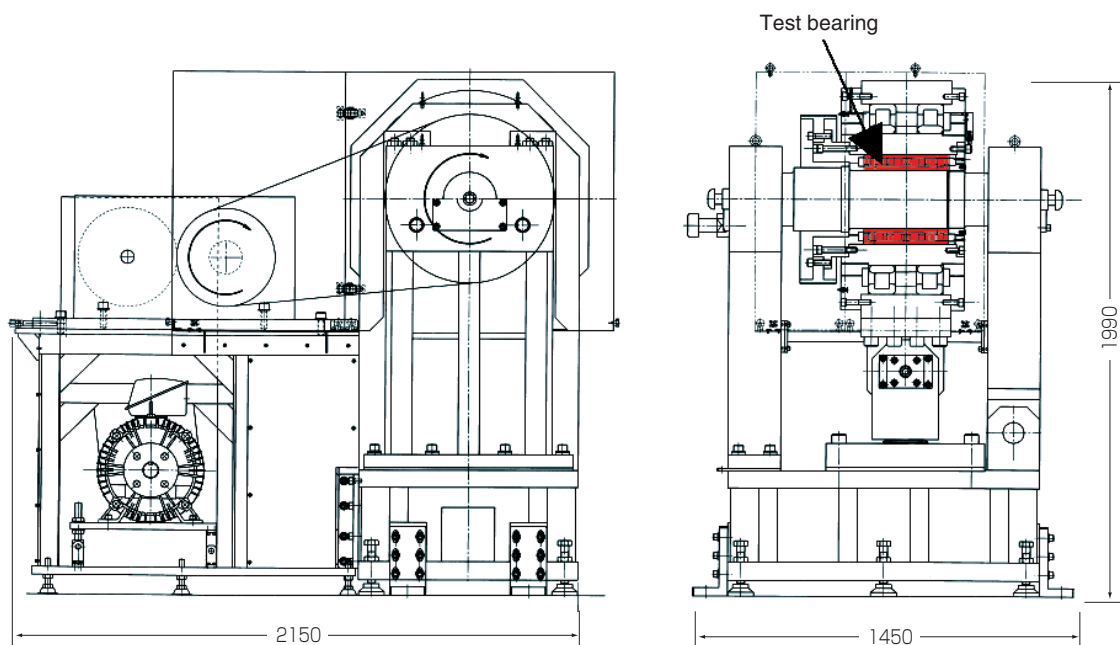


Fig. 10 NTN outer ring rotating test machine

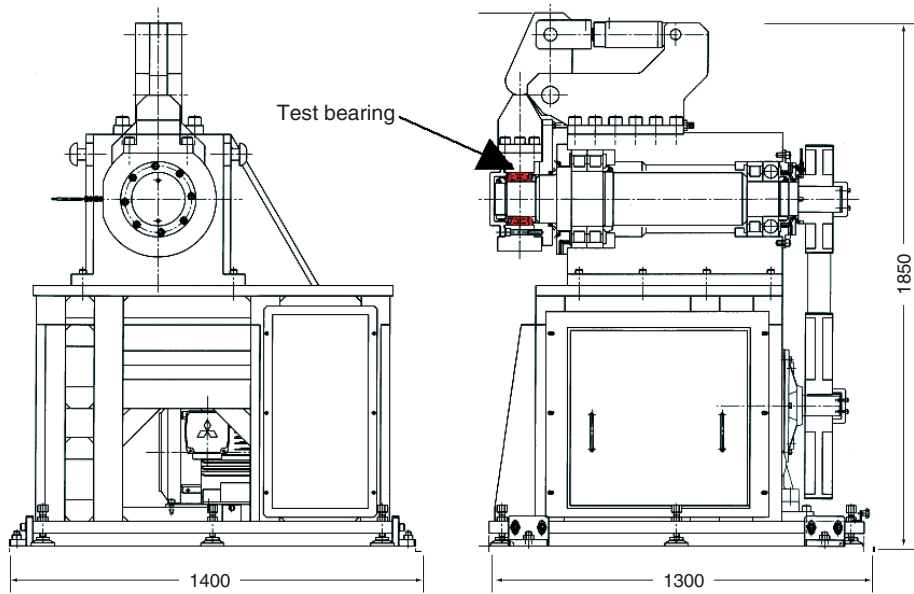


Fig. 11 NTN inner ring rotating test machine

6. Insulated Bearings for Generator

To improve the reliability of bearings used in generators, it is necessary to prevent sparks (galvanic corrosion) caused by electric current passing through the bearings. NTN has produced a new single-layer bearing having sufficient insulation capability and reliability by adopting special ceramics and improving the spray-coating method.

This bearing provides insulation resistance of $100M\Omega$ or higher and dielectric breakdown voltage of 2kV or higher, meeting the insulation performance required for wind turbines.

Photo. 3 shows an external view of this insulated bearing.

For details, refer to "Insulated Bearing "MEGAOHM" Series" in this book.

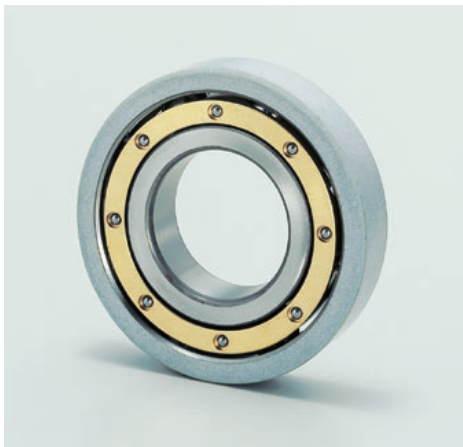


Photo 3 Insulated Bearing

7. Bearings for Yaw Gearbox

Since yaw gearboxes need to be small and capable of conveying large torque, the bearings to be used for them must be compact and have high load capacity. Because of this, angular contact ball bearings with thin inner/outer rings and tapered roller bearings are often used.

With angular contact ball bearings, which are exposed to large axial load, the resistance to axial load has been improved by increasing the groove depth on the inner and outer rings. Fig. 12 shows the cross-sectional view of the standard bearing and that of special design bearings for yaw gearboxes. The special design bearing has a high axial load resistance, approximately 9 times higher than the standard bearing.

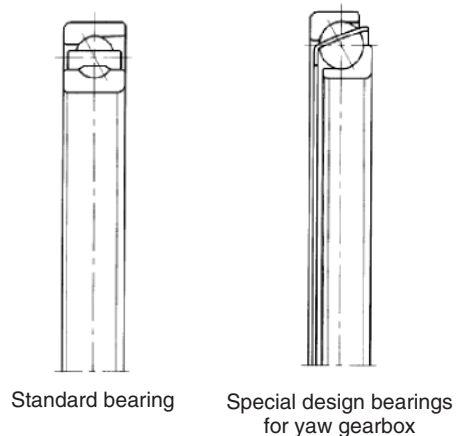


Fig. 12 Special design angular contact ball bearings

For tapered roller bearings, carbonitrided ETA bearings are used to provide longer life.

ETA bearings are long-life bearings with high thermal stability gained by optimizing distribution of retained austenite and carbide present on the surface through special heat treatment. They feature high resistance to contaminants contained in lubricating oil and high peeling resistance. **Table 4** shows the life test conditions and **Fig. 13** shows the results.

Such implementation has enabled **NTN** to provide compact, highly reliable bearings.

Table 4 Test conditions (30206, ETA30206)

	Normal lubricating oil	Contaminated lubricating oil (Reference)
Radial load (kN)	17.64	
Rotating speed (min^{-1})	2000	
Lubricating oil	Turbine oil 56	Turbine oil 56 + NTN's standard contaminants

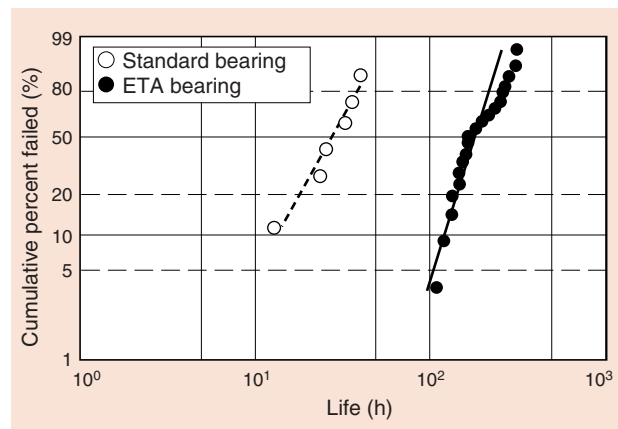


Fig. 13 Comparison of life of ETA tapered roller bearing and standard bearing (with contamination)

8. Conclusion

Compared with Europe and North America, where the use of wind turbines is widespread, Japan often suffers from considerable atmospheric turbulence, severe tropical storms and lightning (winter). Thus, wind turbines that are reliable and suit Japan's climatic conditions are desired. **NTN** has been working on improving the reliability of bearings designed for wind turbines. By choosing optimal bearing specifications that satisfy wind turbine manufacturers and users and supplying high-quality products, **NTN** will contribute to the development of an eco-friendly wind power generation.

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LOAD DATA ANALYSIS FOR WIND TURBINE GEARBOXES

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