[ New Product ]

# Asymmetrical Spherical Roller Bearings for Wind Turbine Main Shafts

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Wind turbine main shaft bearings are subjected to axial loading caused by wind loads. The use of spherical roller bearings for such applications results in one row being subjected to larger loads as compared to the opposite row. Additionally, spherical roller bearings have a characteristic of rolling and sliding due to inherent internal geometry. These conditions, combined with insufficient lubrication at the roller/raceway contact, lead to wear at the outer raceway surface. As a result damage might occur particularly in the outer ring raceway surface.

**NTN** has developed “Asymmetrical Spherical Roller Bearings” for wind turbine main shafts that have an asymmetrical design utilizing different length rollers and a different contact angle between internal left and right roller rows in order to address these issues.

## 1. Introduction

Wind power generation has evolved globally into a clean energy with little impact on environment and no $CO_2$ emissions.

According to an announcement from Global Wind Energy Council (GWEC), the installed capacity of wind turbines at the end of 2017 was 540 GW, an increase of over 5 times from the previous 10 years. In addition, according to GWEC's market prediction, the increase will continue at the pace of approximately 9% to 10% a year (**Fig. 1**).

Previously, adoption of wind turbines has been promoted by national policy such as Feed-in Tariff (FIT). However, Europe and the U.S. are promoting wind turbines to become a profitable energy source without subsidies so that it can compete against thermal or hydroelectric power generation, by gradually reducing subsidies.

Wind turbine manufacturers are now engaged in full development of off-shore turbines for improving power generation efficiency and equipment availability, as well as a countermeasure against a reduction in the number of sites adequate for on-shore wind turbines.

The construction costs of off-shore turbines are significantly higher compared to on-shore models; as a result, the power generation capacity per facility is larger, in some cases up to 12 MW.

On the other hand, much higher reliability is required for bearings for larger and off-shore wind turbines since the replacement cost is significant once failures are found.

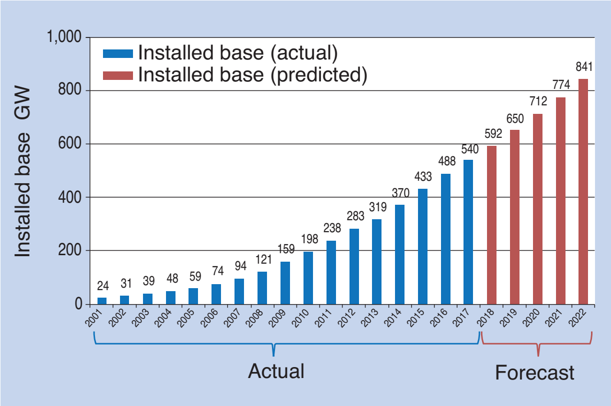


**Fig. 1** Global cumulative installed wind capacity [1)]

## 2. Structure of wind turbines

### 2.1 Location where bearings are used

Wind turbines come in different types such as horizontal axis and vertical axis. We will introduce you to the representative type for large commercial use:the three-blade (wing) horizontal axis type.

**Fig. 2** shows the nacelle portion of the induction generator, which is the mainstream design for on-

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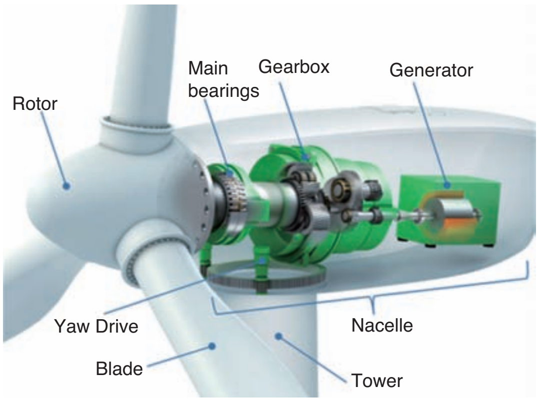



**Fig. 2** Internal structure of wind turbine

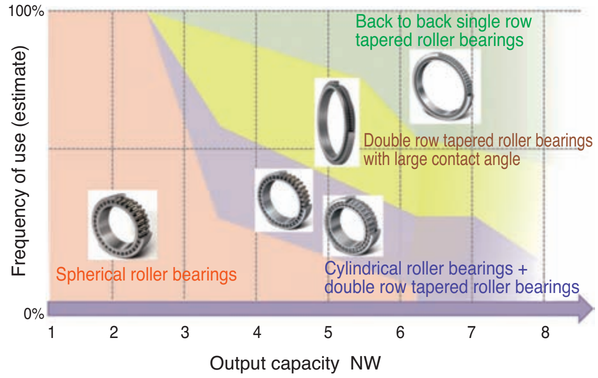



**Fig. 3** Relationship between generation capacity and type of main shaft bearings [2)]

shore turbines with around 2 MW of output. Receiving wind energy, the blades enable the rotor to rotate; the rotational speed is increased by the gearbox, which is converted to electric energy by the induction generator.

Bearings are used to support the rotor shaft, within the gearbox and generator, as well as to allow pitch control of each blade, yaw control of the tower top and within the reducer which drives them. Approximately 20 to 30 bearings are used per wind turbine.

### 2.2. Type of main bearings

Main bearings that support rotor shafts have become larger and larger over the years. Off-shore wind turbines use bearings of extremely large size, over 2m of outer diameter, which are not used in regular industrial machines. In addition, different types of bearings are used depending on the power capacity. In wind turbines of around 2 MW of generation capacity, spherical roller bearings are often used as they have high load capacity and superior allowable capability toward mounting errors.

On the other hand, for models with over 2 MW of capacity, bearing types used in them are varied such as back-to-back single row tapered roller bearings, double row tapered roller bearings with large contact angle, combination of cylindrical roller bearings and double-row tapered roller bearings, etc., depending on the structure and power generation methods of different wind turbine manufacturers. In the case of off-shore models with over 5 MW of capacity, tapered roller bearings are more frequently used because of their advantage of contact angle and moment load carrying capacity. **Fig. 3** shows the relationship between generating capacity and type of main bearings.

## 3. Cases of damage and countermeasures

### 3.1 Technical challenges that the market faces

As mentioned before, high reliability is required for bearings of wind turbines; however, there are cases where main bearings fail before the theoretical calculated operating life. Demand for long operating life is high, especially for spherical roller bearings, which are the current mainstream model widely used for main bearings of wind turbines with around 2 MW of generating capacity.

For main bearings of wind turbines, in addition to radial load applied vertically from the weight of the rotor and blade, unidirectional axial load is applied horizontally from the wind; therefore, larger load is applied to the rear row (away from the blades) compared with the front row (near the blades) in upwind model※1 turbines, which is the current mainstream model (**Fig. 4**).

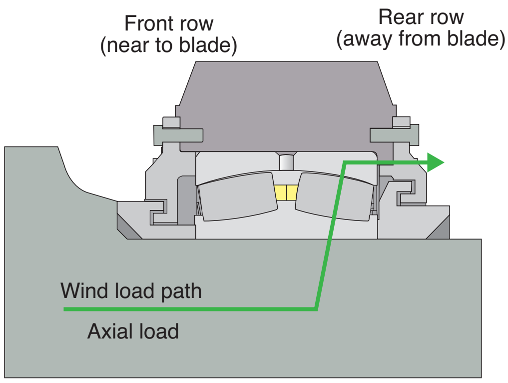
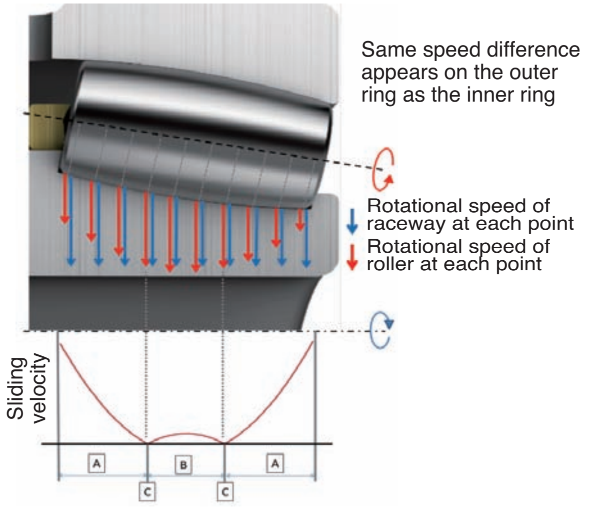



**Fig. 4** Loading condition of SRB for main shaft bearings

※1 Upwind type: wind turbine with the rotor to receive the wind positioned in the upwind side.

In addition, due to the metal contact between the raceway surface and the rollers from rolling and sliding, typical of spherical roller bearings※2 (**Fig. 5**), and poor lubrication (insufficient oil film), stepped wear may propagate on the surface of the raceway from the points with a high *PV* value※3. Due to this phenomenon, stress concentration on the rolling-only points, where no wear occurs, may cause flaking and cracking, especially on the rear row outer ring where high load is applied (**Fig. 6**, **Fig. 7 (a) - (c)**). While uniform load is applied about the entire raceway of the rotating inner ring, load is concentrated within a certain load zone of the fixed outer ring; therefore, when the load is repeatedly applied, damage may occur.




A：Roller rotational speed < raceway rotational speed
B：Roller rotational speed > raceway rotational speed
C：Roller rotational speed = raceway rotational speed

**Fig. 5** Image of rolling and sliding in SRB

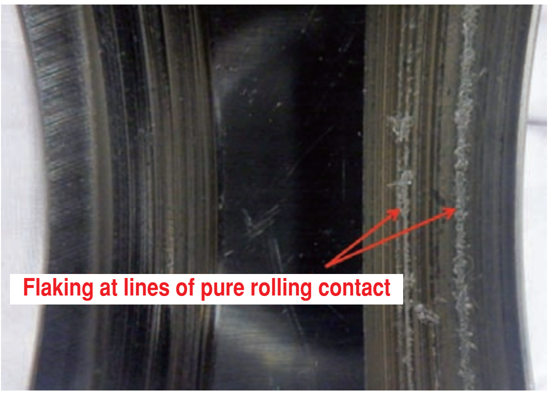
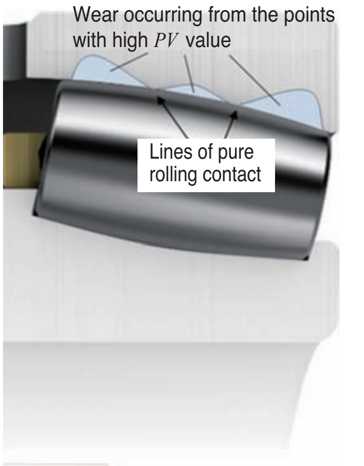



**Fig. 6** Flaking on non-slip line




**(a)** Area of wear occurrence


**(b)** Area of stress concentration occurrence


**(c)** Area of flaking occurrence

**Fig. 7** Mechanism of flaking on non-slip line

※2 Rolling and sliding: sliding due to the difference of rotational speed between the roller and raceway.
※3 *PV* value: product of contact pressure (*P*) and rolling and sliding velocity (*V*).

### 3.2 Countermeasure by asymmetric design

NTN has reviewed the design of rollers for use under the conditions typical to wind turbines to improve operating life and wear resistance and developed "Asymmetrical Spherical Roller Bearings (hereafter, developed product) as a measure to counteract the aforementioned damage. Specifically, the developed product adopts a smaller contact angle for the front row and larger contact angle for the rear row, as well as longer rollers for the rear row and shorter rollers for the front row to efficiently carry uniaxial wind loading at the rear row and to actively accept radial loading at the front row. With this change, the load can be appropriately shared by the rollers of the front and rear rows (**Fig. 8**) [3), 4)].

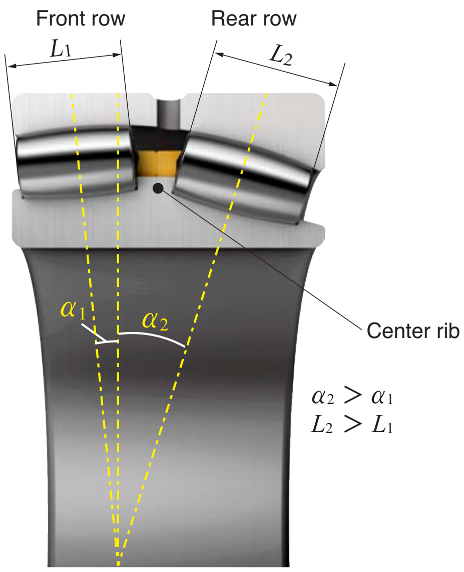



**Fig. 8** Cross section of Asymmetrical SRB

This developed product can be designed within the same dimensions as the conventional product; therefore, it can replace existing conventional product in the operating wind turbines to enable longer operating life and prevent early failure, contributing to the reduction of maintenance cost. The developed product has around 2.5 times the calculated operating life of the conventional product and achieves around 30% reduction of $PV$ value, which is an indicator for wear, under the typical environment conditions of the wind turbine main bearings (**Fig. 9** and **10**).

Alternately, the design allows approximately 10% reduction in bore diameter for a bearing with equivalent life as the conventional product, resulting in approximately 30% less weight. For example, the operating life of the conventional product of 240/600B ($\phi$600×$\phi$870×width 272) and that of the developed product of 240/530B ($\phi$530×$\phi$780×width 250) are the same. By adopting this developed product when wind turbines are newly designed, bearings can be downsized, contributing to compact and lightweight wind turbines overall (**Fig. 11**).

The developed product has a center rib on the inner ring so that the roller position is supported at three points, namely, the inner ring raceway, outer ring raceway and the inner ring center rib (**Fig. 8**). This prevents skew※4 of rollers to reduce sliding between the raceway and the rollers.

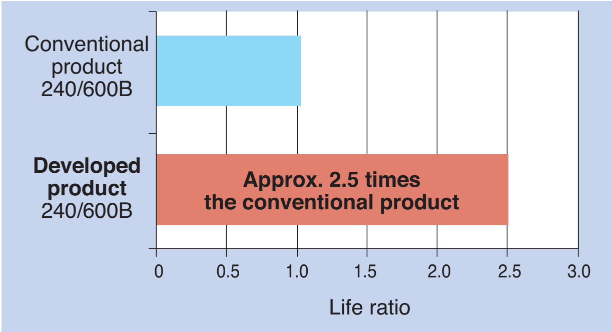



**Fig. 9** Comparison result of calculation life of conventional SRB and asymmetrical SRB

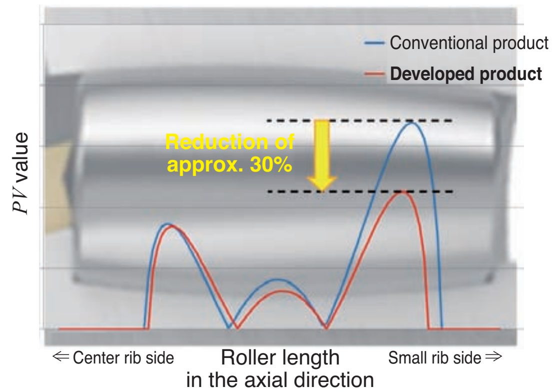



**Fig. 10** Comparison result of $PV$ value on rear side row of conventional SRB and asymmetrical SRB

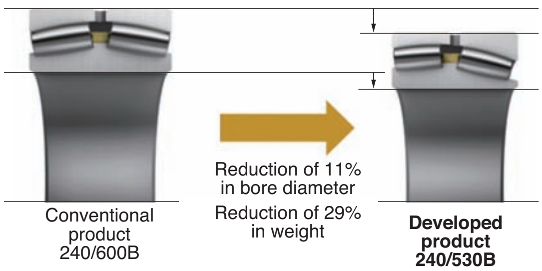



**Fig. 11** Example of design for down sizing

※4 Skew: roller inclination over its normal axis of rotation in roller bearings.

## 4. Evaluation of the bearings of the actual size

Fig. 12 and Table 1 shows the test equipment and test conditions, respectively. The load was assumed to be a combination of radial load and axial load averaged from bearing loading of actual wind turbines. The test was conducted by measuring the operating temperature under three discrete rotational speeds which occur within actual wind turbines.

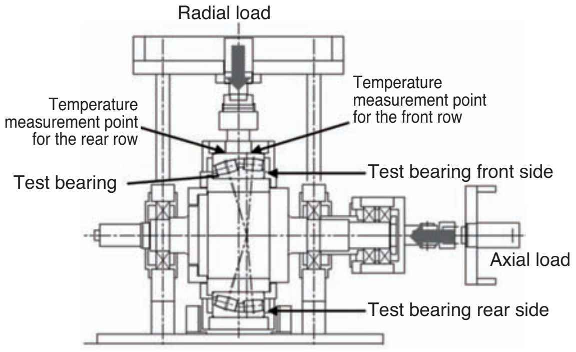



Fig. 12 Testing machine for actual size bearings test

Fig. 13 shows the test results and the calculation results of the rolling element load distribution of each bearing. By comparing the test results, it was revealed that the rise of temperature of the rear row of the developed product was 2 to 3˚C lower than the conventional product, and the difference in temperature between the front row and rear row was also smaller. From this result, we can conclude that the developed product efficiently distributes the load to each row compared with the conventional product under the average load conditions of wind turbines, as shown in the calculation results of the rolling element load distribution.

Table. 1 Test condition of actual size bearing test

| Test bearing | | Conventional product | Developed product |
|---|---|---|---|
| Bearing size (mm) | | ID 600 x OD 870 x W 272 | |
| Bearing design | | Standard | Asymmetric |
| Rotational speed (min$^{-1}$) | | 10, 30, 50 (step-up) | |
| Test duration (h) | | 32 at each rotational speed | |
| Load (kN) | Radial | 392 (0.06$C_r$) | |
| | Axial | 115 | |

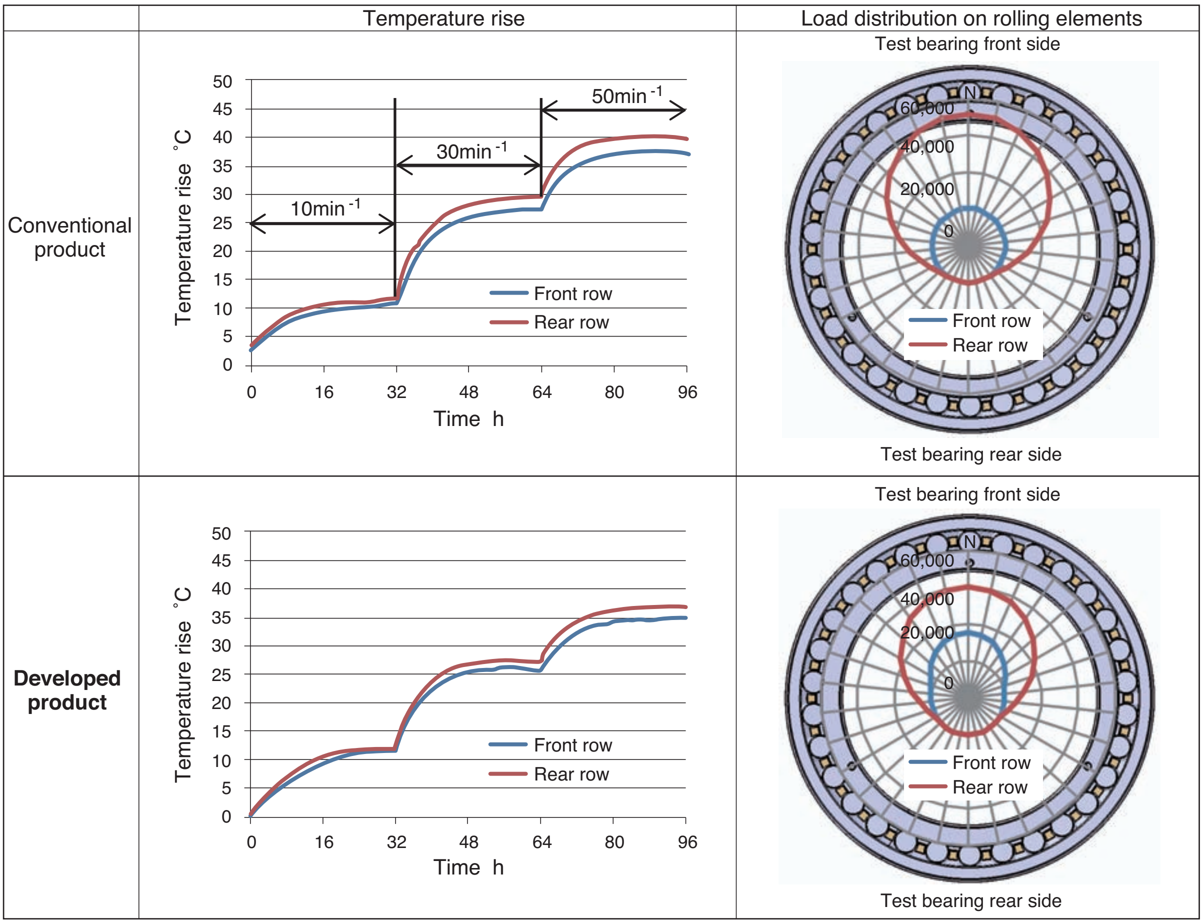



Fig. 13 Test result and calculation result of load duration distribution with actual size bearings

## 5. Summary


With spherical roller bearings used for main bearings of wind turbines, flaking and cracking may occur due to wear on the outer ring raceway of the rear row. This damage may be a result of rolling and sliding movement typical of these types of the bearings and poor lubrication, as well as unidirectional axial wind load applied to the rear row.

**NTN** developed "Asymmetrical Spherical Roller Bearings" for wind turbine main shafts which have different lengths and contact angles for the rollers of different rows. The following are features of the developed product.

· **Asymmetric design with different lengths and contact angles for rollers of different rows.**
· **Improved calculated life of approx. 2.5 times (compared with the conventional product)***
· **30% reduced PV value (compared with the conventional product) for improved wear resistance***
· **Design that allows bearings with equivalent life as the conventional product with approx. 10% less bore diameter and approx. 30% less weight**

* Calculated under average fatigue load applied to the wind turbine main bearings assumed by **NTN**.


### References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2) Michio Hori, Natsumi Itou, Makoto Shizunai, Toru Takahashi, Technical Trends of Bearings for Wind Turbines, Japan Wind Energy Association, Special Issue for the 40th Anniversary, Vol. No. 123 (November, 2017), pp 454.
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