NSK

ROLLING BEARINGS FOR WIND TURBINE GEARBOXES

PERFORMANCE-OPTIMIZED SOLUTIONS FOR EVERY POSITION

STAY IN MOTION. STAY IN CONTROL.

SUSTAINABLE SOLUTIONS

ROLLING BEARINGS FOR WIND ENERGY

Modern turbines are immense structures, typically weighing over 200 tons with each rotor blade spanning 120 feet or more. Operating in high and frequently changing winds, the mass of these systems, the staggering kinetic forces, and the uniquely challenging operating conditions place significant demands on a wind turbine's components - particularly the bearings.

Reliability is essential. With remote and restricted access onshore and offshore, service and maintenance on these machines is complex and costly and scheduled sparingly – with intervals as long as fifteen years. Any incident of unplanned downtime for bearing repairs or replacement has intolerable consequences to cost-competitive energy generation.

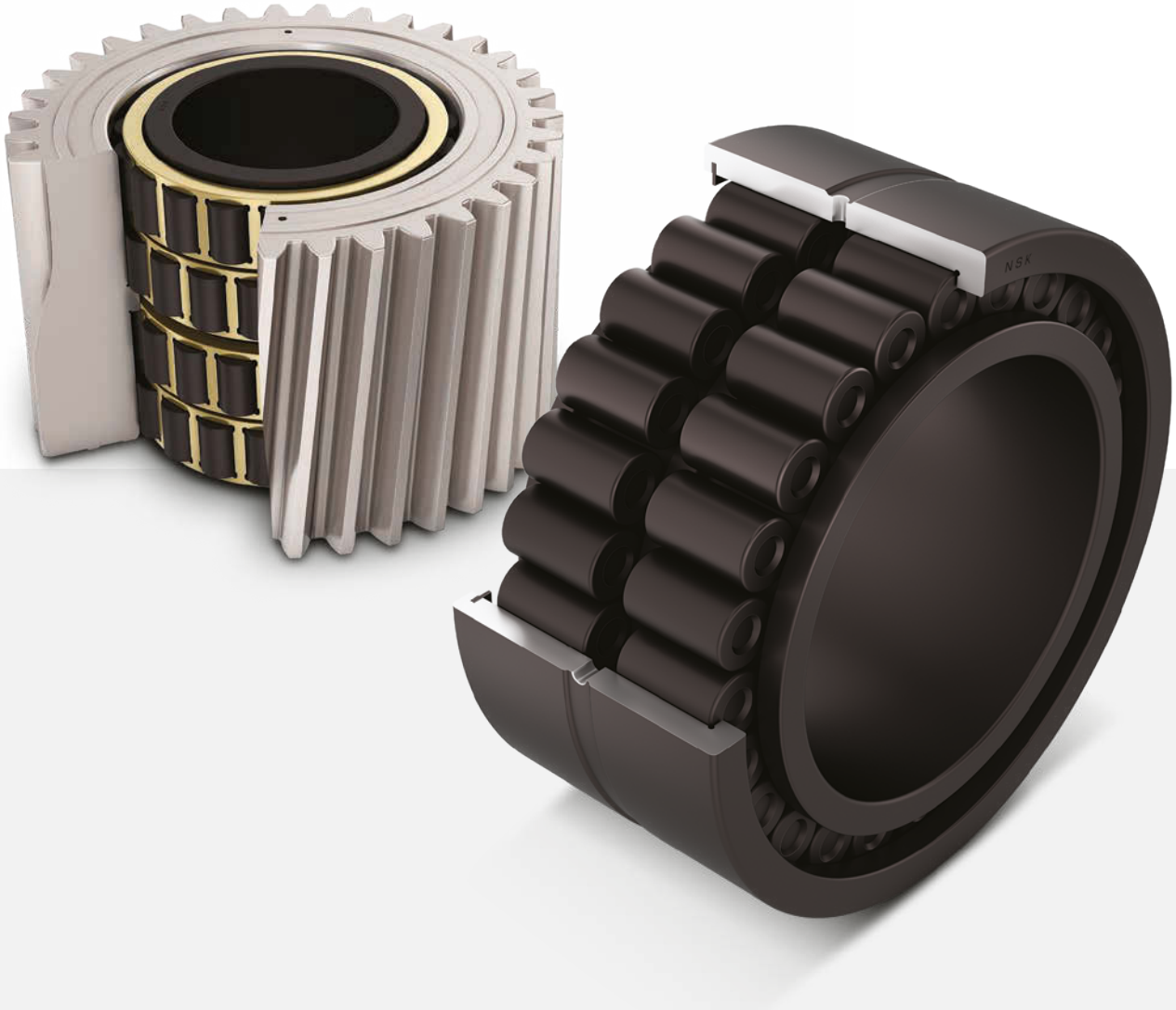
For turbine builders and operators alike, predictable and cost-effective operation requires a development partner to simulate, test, and deploy advanced product technologies that deliver the highest level of performance and efficiencies.

A partner like NSK.

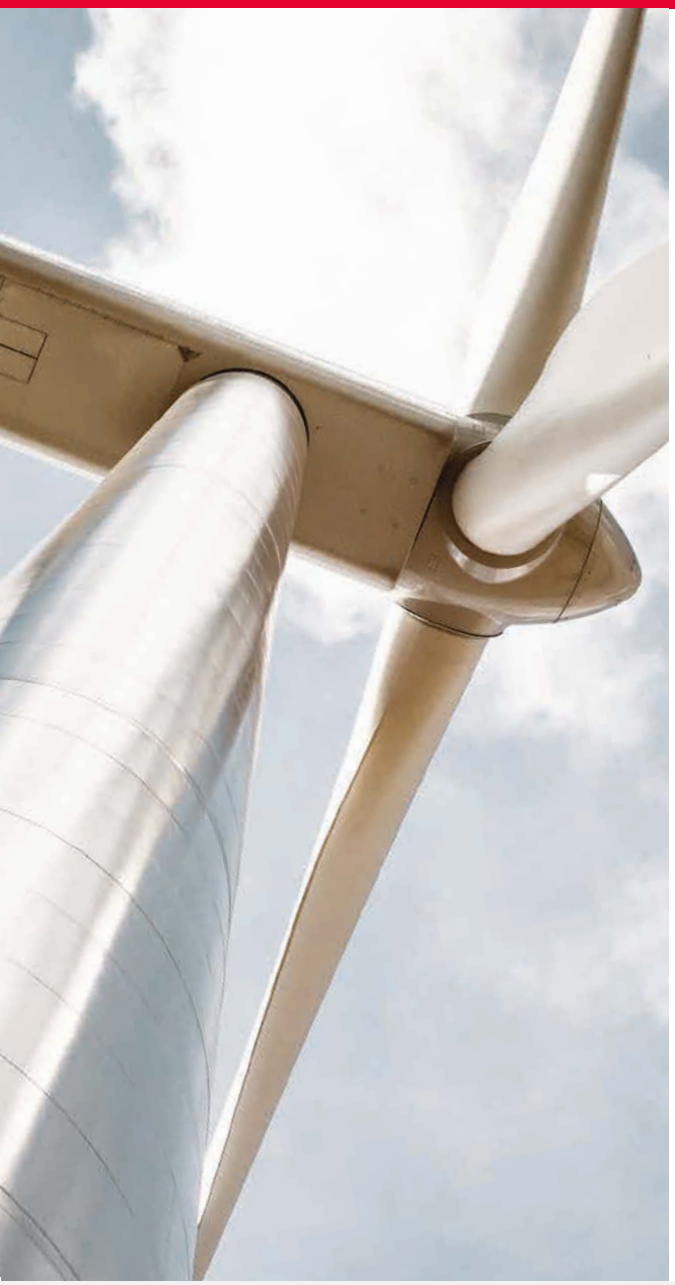
LONG-LIFE RELIABILITY: NSK SOLUTIONS FOR GEARBOXES

Wind turbine drivetrain components are subjected to a constant combination of immense and adverse operating challenges: heavy dynamic and impact loads, rapid accelerations and decelerations of gearbox shafts, system-wide lubrication challenges, and potentially harsh environmental conditions. And with the size and performance expectations for turbine gearboxes continuously increasing, so too is the magnitude of demands placed on supporting rolling bearings.

For NSK, our product development is focused squarely on end-to-end gearbox solutions that are tested and field proven to withstand these complex operating stresses. Through optimization of design and performance parameters to applying advanced long-life material technology for durability and wear resistance, NSK offers solutions for every bearing position that are predictably reliable and deliver undeterred system performance.



HIGH PERFORMANCE FACTORS: BEARINGS FOR GEARBOXES



LONG-LIFE SUPER-TF STEEL

Through advanced material engineering and heat treatment technology, NSK Super-TF bearings exponentially outperform conventional carburized bearings under contaminated and boundary lubrication conditions. Inherently higher material strength also mitigates surface and subsurface crack propagation, and yields superior resistance to wear, seizure and high heat.

AWS-TF STEEL

Adapting our Tough Steel technology specifically to the phenomenon of white etching cracks (WEC), NSK has refined the chemical composition of our steel to deliver our most advanced countermeasure to decrease the diffusion rate of hydrogen and delay microstructural change, thereby increasing resistance to white structure flaking.

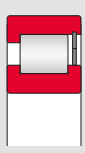
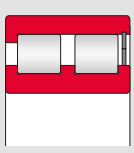
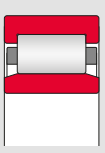
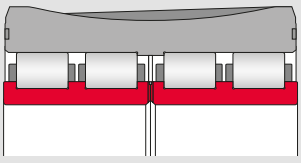
BLACK OXIDE COATING

Black oxide coating is an effective surface treatment recommended by NSK for all gearbox positions. It improves run-in behavior and counteracts bearing damage due to slippage that occurs typically during start-up. It also offers protection against corrosion and a layer of defense against hydrogen penetration.

NSKHPS HIGH PERFORMANCE STANDARD

Single row cylindrical roller bearings are optimized to deliver dramatically increased bearing life and performance benefits including:

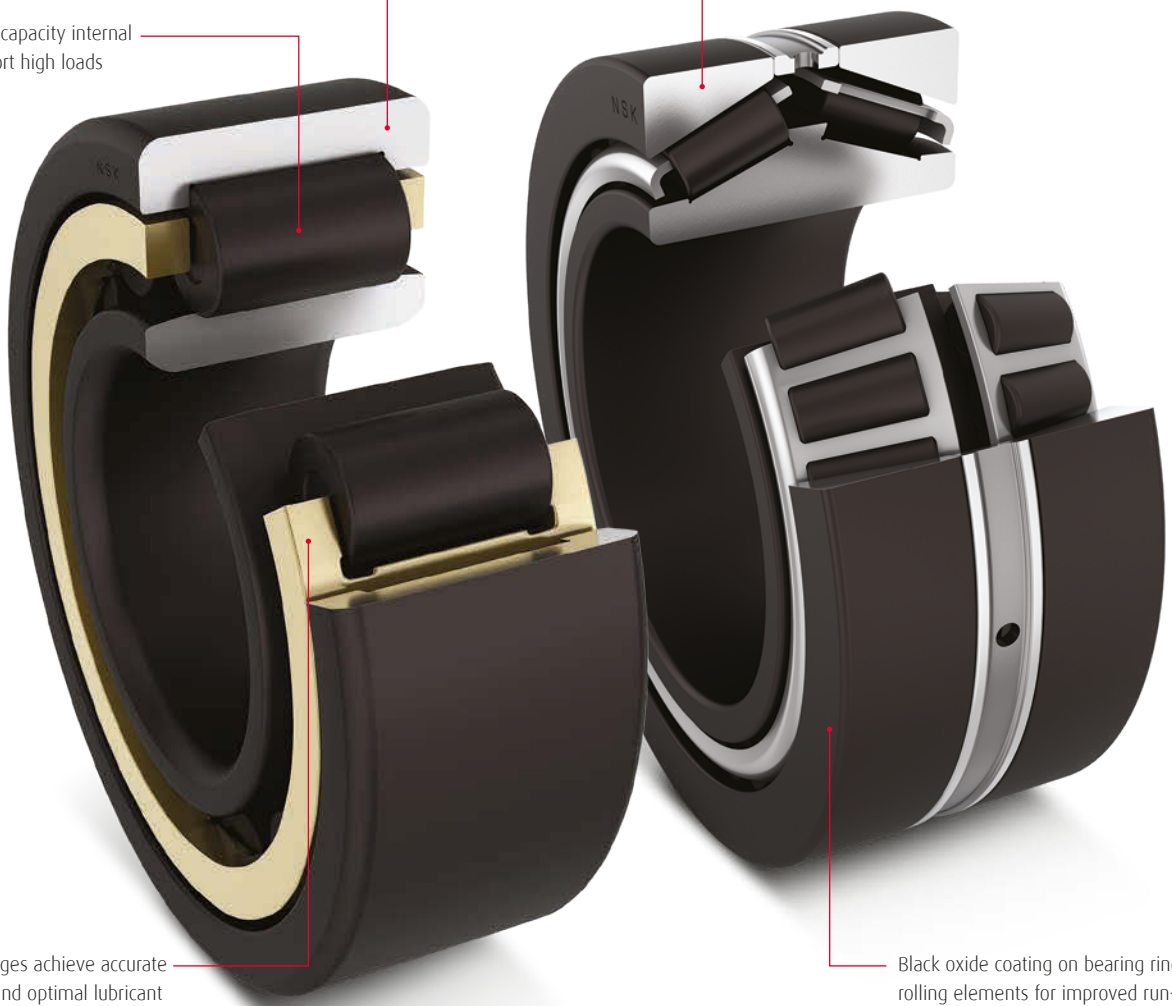
- as much as 23% higher basic load rating
- high strength and maximum rigidity for high speeds
- higher permissible misalignment

Rolling Bearing Types for Main Gearbox	Cylindrical Roller Bearings			Cylindrical / Tapered Roller Bearings
				
	Full Complement - Single and Double Row		Single Row	Multi-Row, Integrated Outer Ring

AWS-TF steel inner and outer rings for increased resistance to white structure flaking

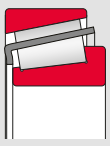
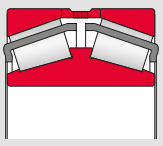
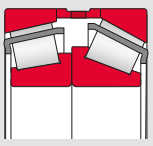
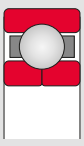
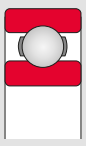
Optimized, high-capacity internal designs to support high loads and high speeds

Super-TF steel inner and outer rings for long-life, wear-resistant performance



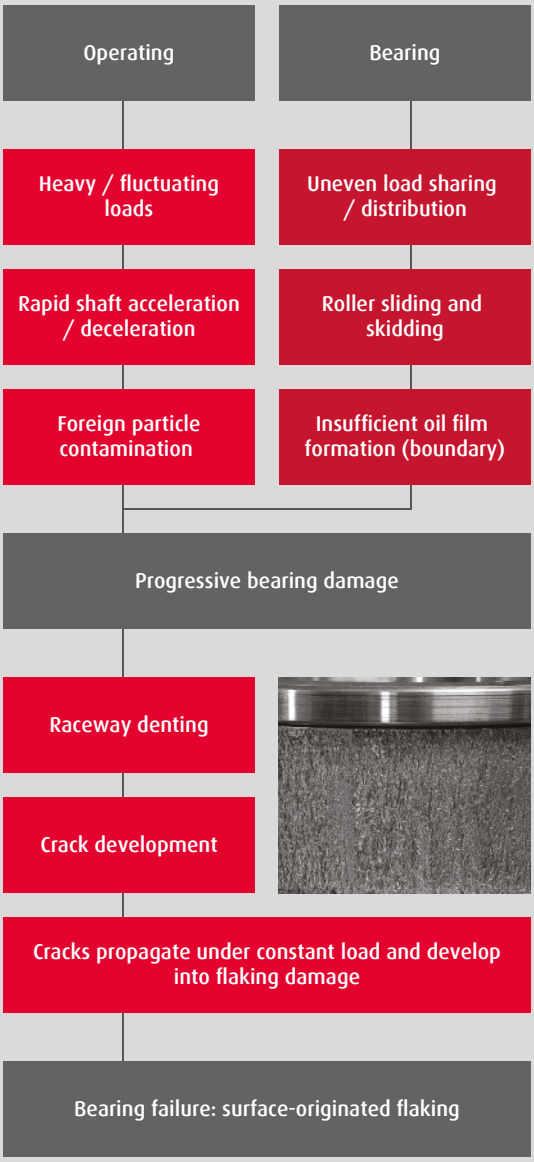
High-strength cages achieve accurate roller guidance and optimal lubricant flow with low temperature rise

Black oxide coating on bearing rings and rolling elements for improved run-in behavior and protection from damage

Tapered Roller Bearings			Ball Bearings		Rolling Bearing Types for Main Gearbox
					
Single Row	Double Row	Duplex	Four-Point Contact	Deep Groove	

HIGH PERFORMANCE FACTORS: SUPER-TF STEEL

FAILURE MECHANISMS IN MAIN GEARBOX



SUPER-TF (STF) MATERIAL TECHNOLOGY

With an ideal expectation to operate for decades without incident, durability by design is critical for rolling bearings used throughout the main gearbox positions of a wind turbine. During their operating life they must endure extreme and unpredictable combinations of loads, speeds and lubrication challenges in a magnitude that would push conventional bearing solutions well beyond their limitations.

NSK's long-life Super-TF (STF) series rolling bearings are designed to deliver outstanding durability in these environments. Through advanced material engineering and heat treatment technology, Super-TF steel mitigates the impact of these conditions and delivers superior resistance to wear, seizure and heat.

Material composition	Containing appropriate levels of chrome and molybdenum for increased hardness
Special heat treatment	Optimized dispersion of finer carbide and carbonitride particles
Retained austenite	Alleviation of the stress concentration on the contact surface

In severe, contaminated, and boundary-lubrication conditions, Super-TF bearings deliver exponentially longer life when compared to conventional carburized bearings. Resulting rate of wear is 1/3 that of standard bearing steel, with 40% greater seizure resistance.

For turbine operators this translates to achieving total cost and performance expectations without unexpected downtime and maintenance incidents.

Life test: Result under foreign contamination

1	Catalog life
0.2	General carburized steel
2	Super-TF steel

* tapered roller bearings

Life test: Result under boundary lubrication (Λ=0.3)

1	General carburized steel
5.5	Super-TF steel

* ball-rod rolling contact fatigue test

WHITE STRUCTURE FLAKING AND AWS-TF STEEL

FAILURE MECHANISM: WHITE STRUCTURE FLAKING

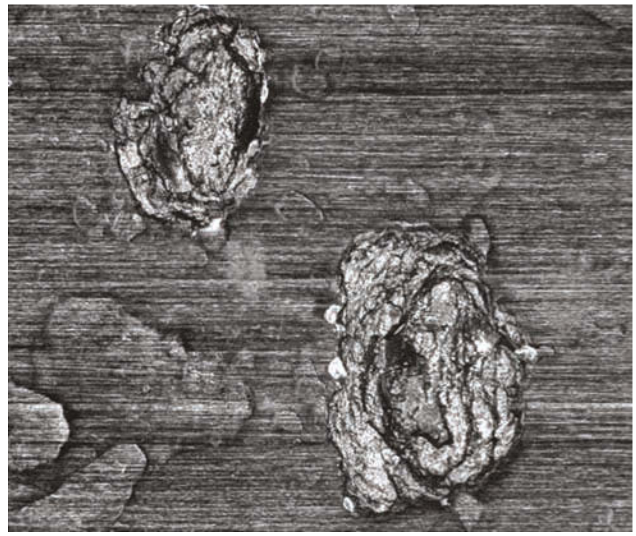
A unique phenomenon that afflicts wind turbine gearbox bearings is the type of damage known as White Structure Flaking (WSF) or White Etching Cracks (WEC). In the case of both failure modes, localized areas of steel in the bearing raceway subsurface show embrittlement. These areas of brittle structure cannot withstand loading and become the nucleus of cracks. Propagation of these cracks inevitably reaches the bearing raceway surface, creating a scenario for imminent bearing failure.

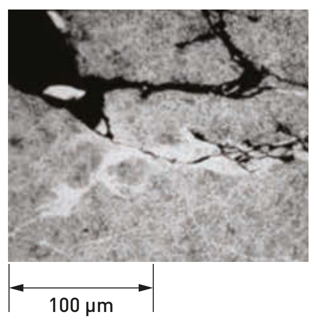
Under picral etching, these localized microstructural changes have a white appearance and as such are referred to as white structures.

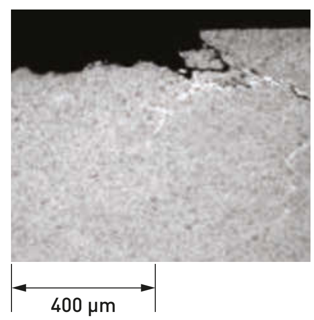
NSK's research has been able to replicate the damage and draw conclusions about its origin - namely, hydrogen penetration. This hydrogen penetration is most likely affected by several factors and their combination, including axial or circumferential slippage between rollers and raceways, presence of electricity, and certain types of lubrication.

Hydrogen generation and diffusion	Hydrogen permeates the bearing steel, instigating degradation
White structure formation	Indicative of subsurface microstructural changes in the steel
Crack formation	Around the boundaries of the white structure, under repetitive stress
Flaking	Cracks propagate under load and develop into flaking

Hydrogen itself is generated by tribomechanical and tribochemical events occurring to the bearing lubricant during operation. NSK has substantiated this premise by reproducing typical damage symptoms of white structures in hydrogen generating environments, confirming the effectiveness of our recommended countermeasure: AWS-TF steel.







Top:
Small white structure flaking damage - raceway, cylindrical roller bearing

Bottom left:
Formation of white structure and etching cracks in the microstructure

Bottom right:
Cross-section of the small raceway surface flaking

LONG-LIFE AWS-TF STEEL

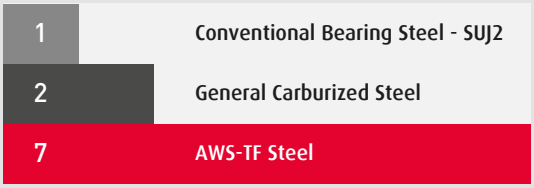
With our AWS-TF steel, NSK has developed a new alloy that yields better results during rolling contact fatigue tests. In tests with hydrogen charging, optimizing the chemical composition of the bearing steel led to a five-fold increase in WSF resistance compared with conventional bearing steels.

Additional and significant improvement is also achieved by employing NSK Tough Steel heat treatment technology. Here, the process of carbonitriding increases compressive residual stress to delay initiation and propagation of cracks within the white structure.

Material composition	Special chemical composition including increased chromium concentration
Tough Steel heat treatment	Increased compressive stress achieved through carbonitriding

Tests have shown that while bearings made with AWS-TF steel do not totally eliminate the risk of WEC, the delay before damage appears is seven times longer compared with conventional bearing steels.

Life test: Result under hydrogen charged lubricant



6206 special lubrication oil test
P/C = 0.46; N = 3000 min^{-1}; Oil bath lubrication

Left:
Single row cylindrical roller bearing made with long-life AWS-TF steel

MAIN GEARBOX BEARING TYPES AND DESIGNATIONS

Design Type		Bore Reference Number		Full Complement		Controlled Internal Design	
NNCF	50	44	/S/	V	C3	DR	U303
Dimension Series		Black Oxide Coating		Internal Clearance		Process Control Specification	

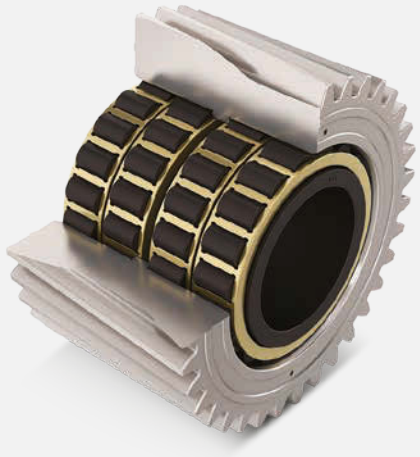
CYLINDRICAL ROLLER BEARINGS, FULL COMPLEMENT

Full complement cylindrical roller bearings are equipped with the maximum possible size and number of rollers, and as such can sustain much heavier loads than cylindrical roller bearings of the same size with cages. Available in single row NCF and double row NNCF series.

* Available with long-life Super-TF steel and black oxide coating.

Bearing Position: Planetary Carrier (NCF)
Planetary Gear (NNCF)

Special Design Type		NSK Serialization	Cage Type		Surface Finish Specification	
2LV	260	-7	MM	DR	U1	U303
Bore Diameter			Controlled Design Arrangement		Process Control Specification	



INTEGRATED OUTER RING BEARINGS

Multi-row cylindrical and tapered roller bearings without outer rings are integrated directly into the planetary gear. With an optimized internal design and roller complement, they deliver extremely high radial load carrying capacity within a compact design envelope.

* Available with long-life Super-TF steel and black oxide coating.

Bearing Position: Planetary Gear

Nomenclature examples shown for individual bearing types is a representative, but not complete, view of NSK designation systems.
In all cases, only standard bearing material options are shown.

Special Dimension Type		NSK Serialization		Outer Ring Notch	
R	431Z	-3	/S/	E	U303
Bore Diameter		Black Oxide Coating		Process Control Specification	

TAPERED ROLLER BEARINGS, SINGLE ROW

Single row tapered roller bearings possess high radial and axial rigidity, and are capable of accommodating high radial loads and moment loads as well as axial loads in one direction. NSK offers a range of large-size, dimensionally specialized bearings for main gearbox applications in both metric and inch configurations.

* Available with long-life Super-TF steel and black oxide coating.

Bearing Position: Planetary Carrier

Bore Diameter		Outer Diameter Reference Number		Special Tolerance		Special Axial Clearance	
431	KH	51	55	SA	+ K	CA640	U303
Design Type		Tolerance for Inch Size Bearing		Outer Ring Spacer		Process Control Specification	

TAPERED ROLLER BEARINGS, DOUBLE ROW

Double row tapered roller bearings feature two roller/cage sets, two outer rings with an outer ring spacer and a single inner ring. They can accommodate heavy radial loads and axial loads in both directions. Available in normal contact angle (KH design) or with steep angle races (KDH design) for increased axial load capacity.

* Available with long-life Super-TF steel and black oxide coating.

Bearing Position: Low-Speed Intermediate Shaft

MAIN GEARBOX BEARING TYPES AND DESIGNATIONS

High Capacity		Bore Ref. Number			Capacity	Dimension Series		ISO Conformance			Spacer	Internal Clearance	
HR	303	26	J	/	HR	313	26	J	DF	+	KR	C3	U303
Dimension Series		ISO Conformance				Bore Ref. Number		Arrangement			Process Control Specification		

TAPERED ROLLER BEARINGS, DUPLEX

Duplex tapered roller bearings feature two single row bearings with an outer ring spacer, as equivalent singles or as a major/minor set. They accommodate heavy radial loads and axial loads in both directions.

* Available with long-life AWS-TF steel specialized to combat white structure flaking. Also available with long-life Super-TF steel and black oxide coating.

Bearing Position: High-Speed Intermediate Shaft
High-Speed Shaft
Low-Speed Intermediate Shaft

Design Type		Bore Diameter		Cage Type		NSKHPS Symbol	
NU	23	26	E	M	C3	&	U303
Dimension Series		Internal Design		Internal Clearance		Process Control Specification	

CYLINDRICAL ROLLER BEARINGS, SINGLE ROW

Optimized to deliver dramatically increased bearing life and performance parameters, NSKHPS single row cylindrical roller bearings deliver strength and radial rigidity to support high loads and high speeds.

* Available with long-life AWS-TF steel specialized to combat white structure flaking. Also available with long-life Super-TF steel and black oxide coating.

Bearing Position: High-Speed Intermediate Shaft
High-Speed Shaft

Nomenclature examples shown for individual bearing types is a representative, but not complete, view of NSK designation systems.
In all cases, only standard bearing material options are shown.

Design Type		Bore Reference Number		Outer Ring Notch	Internal Clearance	
QJ	3	28	M	E	C3	U303
Dimension Series		Cage Type			Process Control Specification	

FOUR-POINT CONTACT BALL BEARINGS

Four-point ball bearings are designed with a 35° contact angle and an inner ring that is split radially into two pieces. The cage is machined brass. Their design allows one bearing to sustain significant axial loads in either direction with high capacity. They are capable of accommodating pure axial loads or combined loads where the axial load is higher.

* Available with long-life Super-TF steel and black oxide coating.

Bearing Position: High-Speed Intermediate Shaft
High-Speed Shaft

Dimension Series		Closure		NSKHPS Symbol	
60	26	DDU	C3	&	AS2S
Bore Reference Number		Internal Clearance		Grease Type and Fill	

DEEP GROOVE BALL BEARINGS

Precision high-grade balls and super-finished raceways deliver smooth and quiet operation for low to medium radial loads and smaller axial loads in both directions. Advanced lubricant technology and sealing options ensure optimal performance and reliability. Available in NSKHPS series with pressed steel cage or machined brass cage.

Bearing Position: Conduit Tube

INDUSTRY-LEADING CONDITION MONITORING

MAXIMIZING THE VALUE OF YOUR INVESTMENT

For wind park operators, maintenance can be the single most important controllable factor for achieving profitability. In that effort, condition monitoring plays an indispensable role, as 58% of total operating costs are maintenance related. The value of a condition monitoring solution is the optimized return on investment, through increased availability and reduced life-cycle costs of the turbines. This is accomplished by addressing unbalance, misalignment, and lubrication problems before they result in unplanned downtime.

HOLISTIC MONITORING

Brüel & Kjær Vibro, a member of the NSK Group, is one of the pioneers in wind turbine condition monitoring. Utilizing the powerful DDAU3 advanced data acquisition and processing system, a customized, seamless hardware and software solution monitors every operational aspect of your turbines. Bearing performance, vibration, wind speed, power, wear debris, temperatures, blade pitch, yaw, and more are monitored continuously, giving you total system visibility and comprehensive prognostic data.

DATA MANAGEMENT

The unique VibroSuite software package provides market-leading monitoring, diagnostics, and data mining analysis capabilities. Data can be stored and then remotely accessed and processed as a service for diagnostics and statistical analysis. VibroSuite enables all customers to host, process, and analyze the data in-house.
The result is actionable information for ensuring ample lead-time for strategic maintenance of your wind turbines, maximizing uptime.

360° SERVICES THAT COVER THE ENTIRE VALUE CHAIN

TURNKEY SOLUTIONS

- PLANNING
- INSTALLATION

DATA SERVICE

- DATA SECURITY
- DATA HOSTING
- FLEET MONITORING

REMOTE MONITORING SERVICES

- CONDITION MONITORING
- DIAGNOSTIC SERVICES
- PROGNOSTIC SERVICES

ACCUMULATED EXPERTISE

Optimum engagement with our global technology network and design solutions. Intensive project management. Comprehensive engineering support. For main shaft, gearbox and generator applications alike, NSK deploys our accumulated expertise in collaboration with turbine builders and operators to achieve:

- advanced design and material technologies for high-capacity, long-life performance
- innovative solutions to negate unique phenomena such as white etching cracks (WEC) and electrical erosion
- undeterred equipment performance with condition monitoring
- control measures and processes - the NSK Wind Standard

With NSK as a development partner, our customers embark on a critical path to realizing a high level of performance, predictable reliability and total cost-efficiency in renewable energy generation.

NSK

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