Technologies Contributing to Reduced Life Cycle Cost of Agricultural and Construction Machinery

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Reducing the life cycle cost of agricultural and construction machinery is the issue of highest concern for machinery manufacturers. This report discusses JTEKT's various technologies contributing to the reduction of life cycle cost for agricultural and construction machinery, such as the long life bearing and low friction bearing.

Key Words: *construction, agricultural, reliability, robustness, bearing, driveshaft, life cycle cost, LCC*

1. Introduction

Agricultural and construction machinery, such as dump trucks, tractors and so on, have importantly contributed to improve work efficiency in the infrastructure, resources and agricultural fields. Low operation cost is most required factor for the agricultural and construction machinery. Operational cost is generally called as "life cycle cost" (LCC), and an important indicator for customers to select agricultural or construction machinery. Therefore, agricultural and construction machinery's manufacturers have been developing their productions and proposing services in order to reduce LCC with competing each other.

LCC is consisted from two types of costs, vehicle price and operational costs (fuel, labor, maintenance). In general, operational costs are several times higher than vehicle cost, therefore it is important to reduce LCC and there is several ways for that.

Figure 1 shows needs and keywords of JTEKT's development for agricultural and construction machinery's driveline. In accordance with these six keywords, JTEKT has been developing new technologies and services to contribute reduction of LCC.

This report introduces JTEKT's developments and productions to reduce LCC of agricultural and construction machinery.

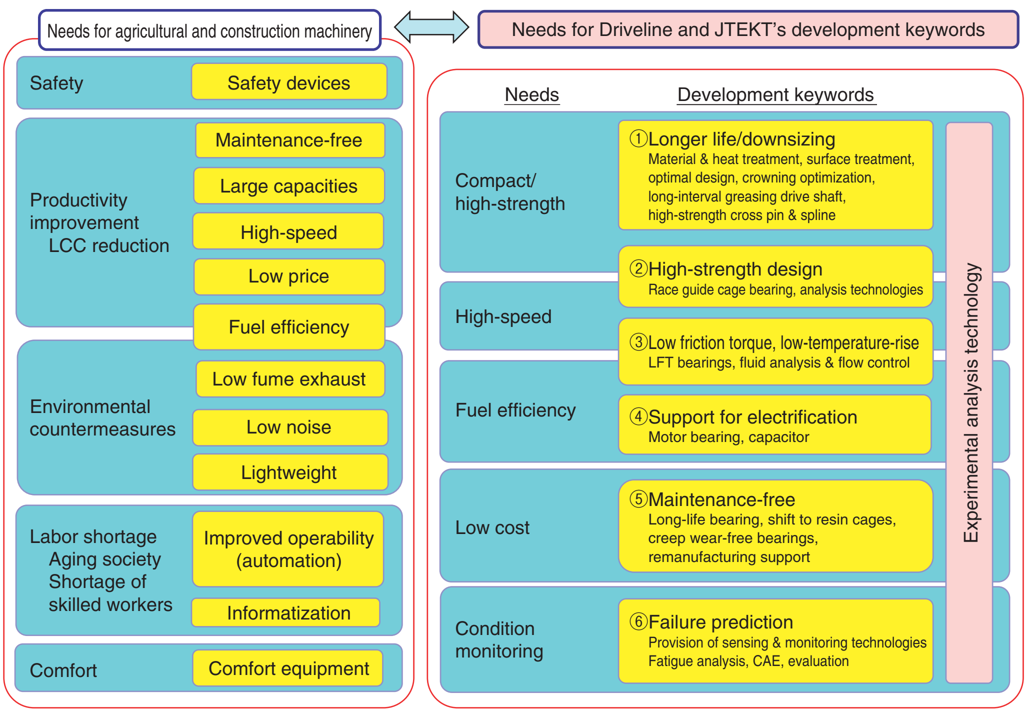


Fig. 1 Agricultural and construction machinery needs and JTEKT's development keywords

2. Technologies for Longer Life and downsizing

2. 1 Developments for Longer Bearing Life

Figure 2 shows analysis results of failure modes of bearings for agricultural and construction machinery (returned to JTEKT from customers), and one of the challenges was development to resolve problems caused by stress concentration (edge stress) and improper lubrication. Improving bearing robustness through the development of such technologies would significantly contribute to reduced maintenance cost and downsizing of components.

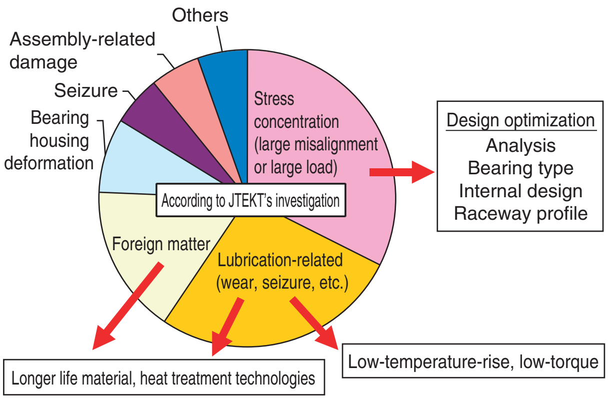


Fig. 2 Failure mode analysis (as investigated by JTEKT) of agricultural and construction machinery bearings and bearing support technology

In results of our R&D efforts in the past, JTEKT has contributed to longer life and size reduction through optimization of internal design by Shaft System Analysis Program (S.S.A.P.), JTEKT's proprietary, to prevent flaking due to such as concentrated stress (edge stress) created by large misalignment or large load.

For example, **Fig. 3** shows the analysis results of edge stress of a pinion gear bearing by S.S.A.P. Based on these results, we designed internal design of tapered roller bearing to reduce edge stress, and succeeded in extending bearing life.

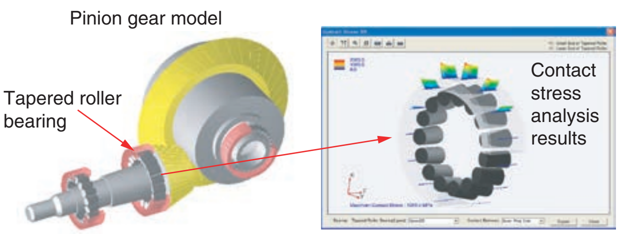


Fig. 3 Example of an S.S.A.P. analysis model

Next, in regards to problems, temperature rise and seizure, caused by improper lubrication, JTEKT contributes low temperature rise and minimization of seizure through development of low-friction torque and low-temperature rise bearing. (Details of this low torque bearing are shown in **Section 4** of this report).

Next, in terms of flaking caused by foreign matter, as shown in **Fig. 4**, we have confirmed that "high surface hardness on raceways" and "appropriate amount of retained austenite (retained γ)" are effective, and have commercialized two bearings which apply these characteristic by JTEKT's heat treatment technologies; SH bearing (whereby bearing steel has been subjected to special heat treatment - primarily applied to ball bearings) and KE bearing (whereby case hardening steel has been subjected to special heat treatment, primarily applied to tapered roller bearings)[1)-3)].

Figure 5 shows the results of fatigue life evaluation of the KE and SH bearings tested in contaminated oil, and under these conditions, we confirmed around two times longer life than standard bearings.

However, agricultural and construction machinery manufacturers have high expectations of further bearing life improvements, therefore JTEKT is continuously promoting development of next-generation long-life bearings.

2. 2 Next-generation, Long-life Bearing [NK Bearing]

In order to respond to the requests of further bearing life improvements from agricultural and construction machinery manufacturers, JTEKT has developed the NK bearing, which has a long-life performance by optimizing material composition and heat treatment conditions, which is normally difficult to achieve by standard steels.

As explained in detail in the "Development of Medium Carbon Bearing Steel Achieving Life Improvement and Resource Saving" (page 22 of this report), area shown in the development concept Phase II in **Fig. 6** is what we achieved with our developed material and heat treatment technology. **Figure 7** shows bearing life evaluation results of the NK and KE bearings in contaminated oil, and these confirm that the NK bearing has 1.5 times longer life than the KE bearing under these conditions.

NK bearing is expected for the benefits of improved reliability and longer maintenance intervals in applications with severe contaminated lubricant conditions such as those of axles and transmissions.

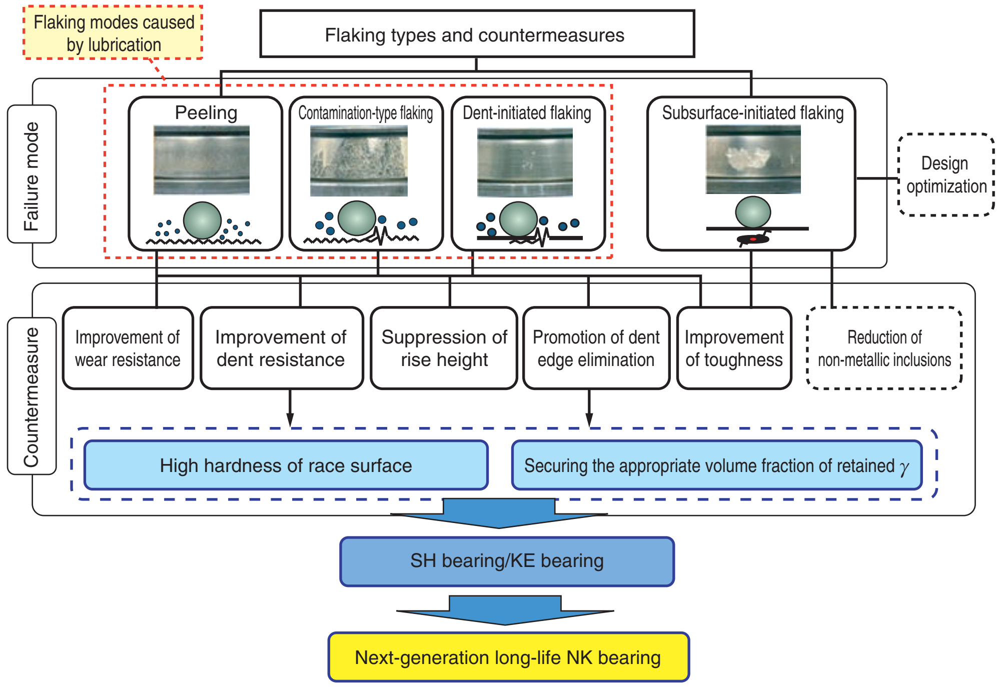
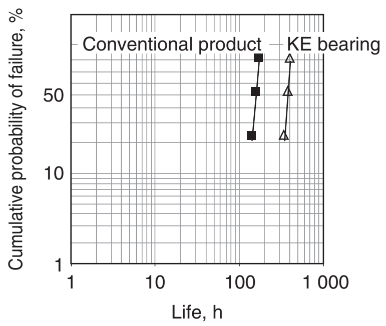


Fig. 4 Flaking types and countermeasure[3)]

Test equipment	Combined load life test equipment
Bearing	Tapered roller bearing ϕ85×ϕ150×49
Load	Fr=70 kN, Fa=70 kN
Rotational speed	1 000 min^{-1}
Lubrication	Contaminated oil



Test equipment	Combined load life test equipment
Bearing	Deep groove ball bearing ϕ30×ϕ62×16
Load	Fr=9 kN
Rotational speed	2 500 min^{-1}
Lubrication	Contaminated oil

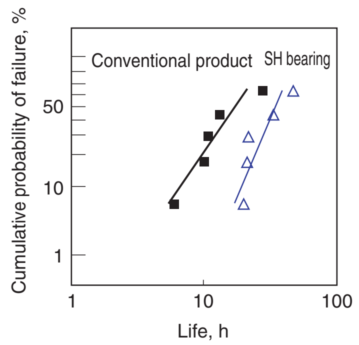


Fig. 5 Life test result of KE and SH bearings in contaminated oil[2)]

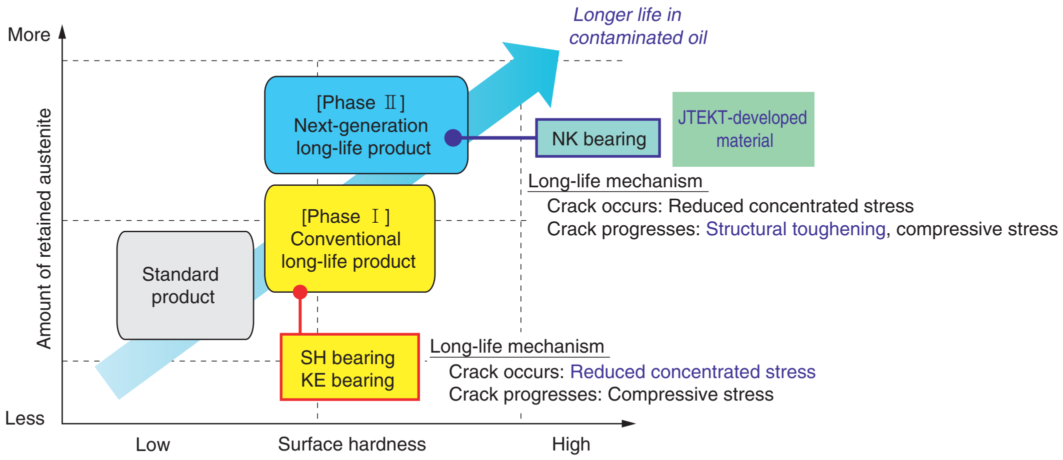


Fig. 6 Development concept of long life bearing material

Test equipment	Thrust load life test equipment
Test bearing	Tapered roller bearing ϕ30×ϕ72×20.75
Load	Fa=25.89 kN
Rotational speed	2 000 min^{-1}
Lubrication	Gear oil 85W-90 (oil bath) Contaminated oil

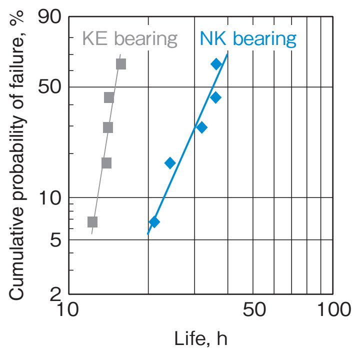


Fig. 7 Life test result of NK bearing in contaminated oil

3. High-strength Design Technology

Vehicles have been becoming more high-speed for improving production efficiency, and adopting drive systems with multi-stage transmissions because of changing electric motor drive. All of this means that driveline parts such as bearings and drive shafts are used with higher speeds and harsher operating environments than in the past. Cage of bearing would especially have issue due to high-speed drive systems. Bearing cages rotate under the influence of the rotation and revolution of rolling elements, however if the force working on the cage increases due to high-speed operation, and the distortion of the cage exceeds the limit, abnormal contact occurs inside the bearing. Abnormal cage contact causes heat generation and cage breakage. As such, if a bearing is used under conditions exceeding the limitations of the conventional cage, there is a need to design a high-strength (high-rigidity) cage that minimizes cage distortion, such as those shown in **Fig. 8** and **9**.

Figure 10 is an example of calculation result of cage strength of a deep groove ball bearing by JTEKT's independently-developed cage dynamic analysis tool. JTEKT uses this dynamic analysis tool to design our cages shown in **Fig. 8** and **9**, which have optimized cage design for applications of high-speed drive system.

4. Low Friction Torque, Low-temperature Rise Technologies

In order to improve the fuel efficiency of vehicles, it is necessary to improve power train efficiency. As we have been focusing development of long-life and compact bearings, we also have been developing bearings with low friction torque and, consequently, have been producing low friction torque tapered roller bearings (LFT) for over thirty years now[5) - 8)]. **Figure 11** outlines the history of JTEKT's LFT tapered roller bearing development. The 4th generation (LFT-IV) developed in 2015 adopts a heat-resistant resin cage which has flexibility of design (the conventional product uses a steel cage), leverages fluid analysis and fluid measurement technology to optimize internal design and, as a result, we have significantly reduced resistance to stirring to lower friction torque by a maximum of 65%. Moreover, **Fig. 12** shows the measurement results of oil temperature for the LFT tapered roller bearing and it is evident that low friction torque technology also helps to improve the bearing's reliability by being effective in lowering temperature rise and preventing overheating.

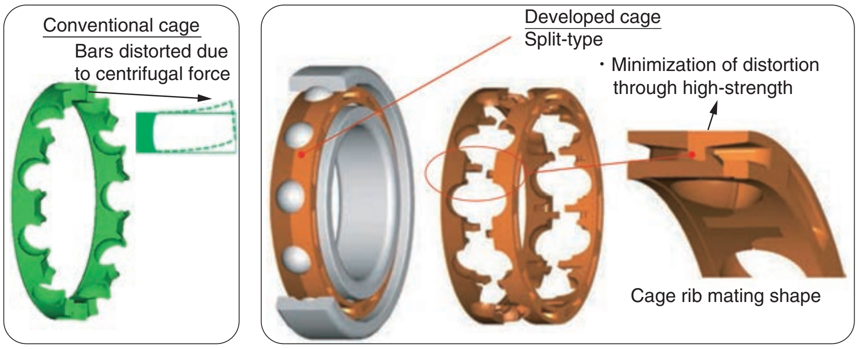


Fig. 8 Ball bearing with high-strength resin cage[4)]

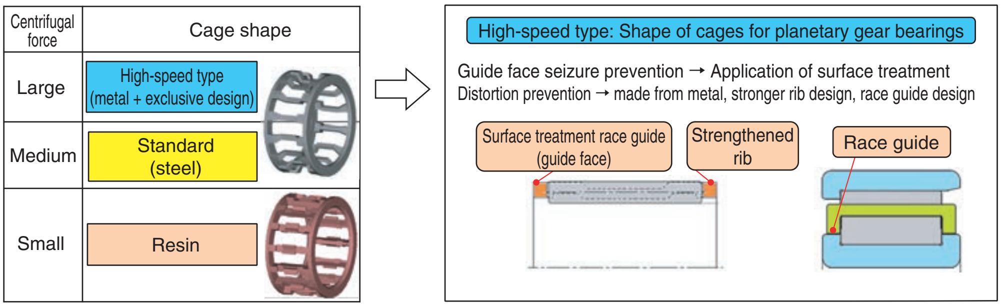


Fig. 9 Cage type for planetary gear

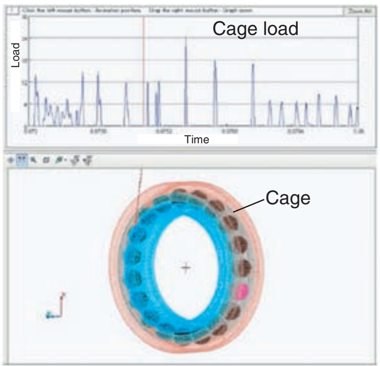


Fig. 10 Bearing cage dynamic analysis

	LFT- I	LFT- II	LFT- III	LFT- IV
Evolution of the TRB-LFT				
Features	Optimization of the shape and roughness of the collar - roller contact	Special crowning on the inner/outer ring races	Optimization of inflow oil volume control/internal dimensions	Optimized control of inflow oil amount with a resin cage
Torque reduction effects (Compared to standard product)	–10%	–20%	–50%	–65%
Main resistances reduced	Sliding friction resistance	Rolling viscosity resistance	Resistance to stirring	Resistance to stirring
Development timing	1983	1994	2005	2015

Fig. 11 History of LFT Tapered Roller Bearings[8)]

Test equipment	Combined load life test equipment
Bearing	Tapered roller bearing ϕ50×ϕ110×29.25mm
Radial load	20.35 kN
Axial load	20.35 kN
Rotational speed	500 ～ 2 500 min^{-1}
Lubricant	5W-30 Axis core oil bath

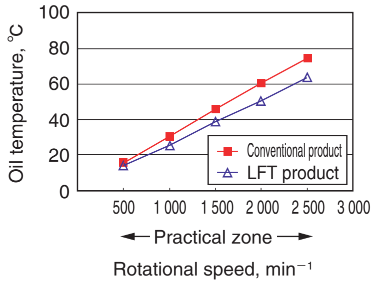


Fig. 12 Oil temperature measurement results of LFT tapered roller bearings (LFT-Ⅱ)

Moreover, in regards to attachments of agricultural machinery, many high-sealability bearings with seals are used with the aim of improving mud resistance. JTEKT is contributing to better low friction torque and mud resistance performances through applying our technology for automobile wheels to a low friction torque bearing with a high sealability pack seal. **Figure 13** shows the typical shape and torque evaluation results for a low friction torque bearing with a high sealability pack seal. The developed product has 40% lower friction torque than the conventional product, thus is contributing to higher fuel efficiency of agricultural machinery.

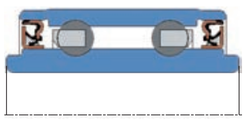
Figure 14 shows the lineup of JTEKT's flagship LFT bearings. We have developed LFT bearings to suit the specific applications, and are contributing to higher fuel efficiency in the automotive and industrial machineries.

5. Response to Electrification

In recent years, as with the automotive industry, a proactive shift towards electrical vehicles in the agricultural and construction machinery area is also taking place with the aim of achieving higher fuel efficiency. **Figure 15** shows JTEKT's promotion of product development for each field in response to EV development.

5. 1 Electrolytic Corrosion Resistant Bearing for Electric Motors

Due to the EV shift, drive is set to migrate from the engine to the electric motor (motor). However, one issue with bearings used on motors is how to best prevent the phenomenon whereby the bearing interior is damaged by electrolytic corrosion. Electrolytic corrosion is where there is an electric discharge in the bearing interior



Test bearing	Double-row angular contact ball bearing ϕ16×ϕ40×44

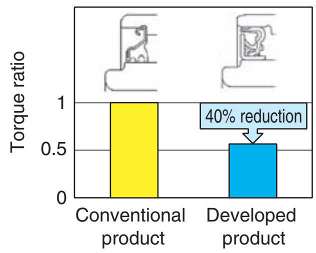
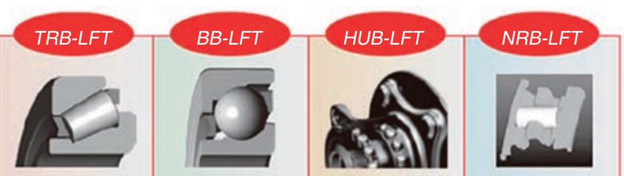


Fig. 13 Bearings with low friction pack seal for attachment



Technologies incorporated in the LFT series	TRB-LFT	BB-LFT	HUB-LFT	NRB-LFT
Reduction of lubricant mixing resistance	○	○	○	○
Reduction of rolling viscosity resistance (Bearing rings - rolling elements)	○	○	○	○
Reduction of sliding friction resistance (Rollers - inner ring collar)	○	–	–	–
Reduction of sliding friction resistance (Rollers - cage)	–	–	–	○
Reduction of sealing friction resistance	–	–	○	–

Fig. 14 Series of Low Friction Torque Bearings[8)]

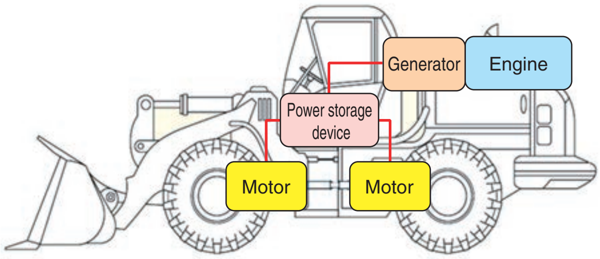


Fig. 15 Structure of hybrid-type EV machinery (image)

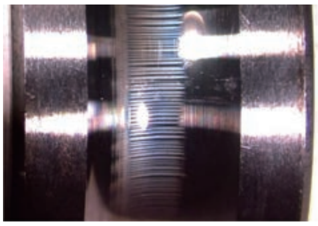


Fig. 16 Example of electrolytic corrosion

causing damage of the rolling contact surfaces (such as that seen in **Fig. 16**) which can progress to ultimately cause problems such as abnormal noise or reduced life. As such, bearings used in motors must be properly insulated.

The most reliable countermeasure for electrolytic corrosion (insulative countermeasure), is to change the material used for rolling elements (balls) from the metal normally used to ceramic, which is a highly insulative material. In 1984, JTEKT became the first in the world to successfully mass produce ceramic bearings, and these are contributing to electrolytic corrosion countermeasures in motor bearings. **Figure 17** shows an example of a ceramic bearing's structure.

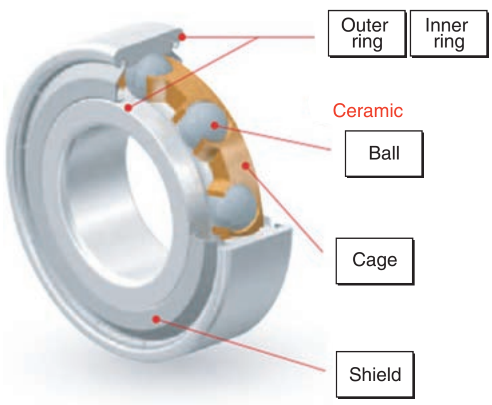


Fig. 17 Example of ceramic bearing structure[9]

Test bearing	Deep-groove ball bearing 6004 $\phi 20 \times \phi 42 \times 12$
Radial load	98 N
Rotational speed	81 min^{-1}
Measurement method	Electrical resistance between the axle and housing measured with an ohmmeter

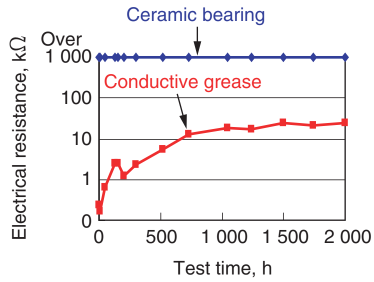


Fig. 18 Insulation performance of ceramic bearing compared with conductivity of conductive grease

Figure 18 shows the results of a comparison in the usage period and change in electrical resistance of the ceramic bearing and conductive grease, which uses the same electrolytic corrosion countermeasures as ceramic. It is apparent that the ceramic bearing offers a stable insulation performance.

5. 2 High-heat Resistant Lithium-ion Capacitor[10)]

As with automobiles, high-performance power storage devices are essential for the electrification of agricultural and construction machinery. Due to the fact that this machinery requires a large amount of power during operation, power storage devices must offer high output properties and, as such, there are a high number of cases where capacitors are adopted, as these have the ability to discharge high energy instantaneously.

However, conventional capacitors have limitations in regards to operating temperature range, therefore entail issues such as cooling system is accompanied, etc.

As such, JTEKT expanded the operating temperature range of the Lithium-ion Capacitor through our independent development efforts, and became the first in the world to achieve an operating temperature range of – 40 to 85℃ (up to 105℃ with operating voltage restrictions). A wider temperature range means that cooling systems can either be eliminated or simplified, therefore expanding the potential for EV applications.

Moreover, to support the diverse needs of agricultural and construction machinery customers, JTEKT will apply the charging/discharging control technology of power storage devices cultivated through development of auxiliary power supply systems to the electric power steering for automobile[11)] (**Fig. 19**).

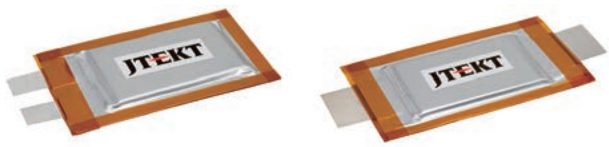


Fig. 19 Lithium ion capacitor (product conceptual image)

6. Maintenance-free

Large agricultural and construction machinery are used for many years, therefore overhauls of major components are performed periodically.

On such occasions, the internal parts of the applicable component are damaged, therefore requires replacement or repair, which in turn results in hefty overhaul-related costs. As such, technologies to prevent part damage and reduce overhaul costs are also effective in reducing LCC.

6. 1 Fitting Surface Damage and Countermeasures Thereof

One particular problem that occurs in the bearing proximity during overhauls is damage to fitting surfaces.

Bearings operate whilst being subjected to a dynamic load, therefore fitting surfaces are susceptible to fretting wear and creep wear caused by vibration and bearing ring creep. This kind of fitting surface damage is not limited to agricultural and construction machinery, but also applies to aluminum housing of automobiles, therefore wear countermeasures and low-maintenance methods are major issues of focus.

In general, the most effective way to prevent this type of fitting surface damage is to increase the interference of the fitting surface. However, increasing interference makes bearing attachment/removal difficult, therefore this approach is not ideal for large bearings. Furthermore, if the coefficient of linear expansion differs greatly with the bearing material, such as in the case of aluminum, it is difficult to create a design where interference is maintained in all temperature zones.

As such, in addition to increasing interference, machinery manufacturers have expectations regarding wear control technology. Countermeasures for fitting surface wear consist of a design-related approach which focuses on minimizing creep itself (minimizing movement), and a tribology-related approach, which focuses on reducing wear.

6. 2 Anti-creep Ball Bearing[12] (Design-related Approach)

Figure 20 shows the mechanism of creep occurrence due to outer ring strain. Strain continuously occurs on the bearing rings as rolling elements pass through, and this leads to creep occurrence. Creep resulting from this mechanism can be reduced by making the bearing rings thicker and reducing strain occurrence. However, there is the conflicting issue of the bearing becoming difficult to handle or there being dimensional restrictions due to an increase in diameter dimensions, which results in a shorter life expectation due to a decrease in dynamic load rating.

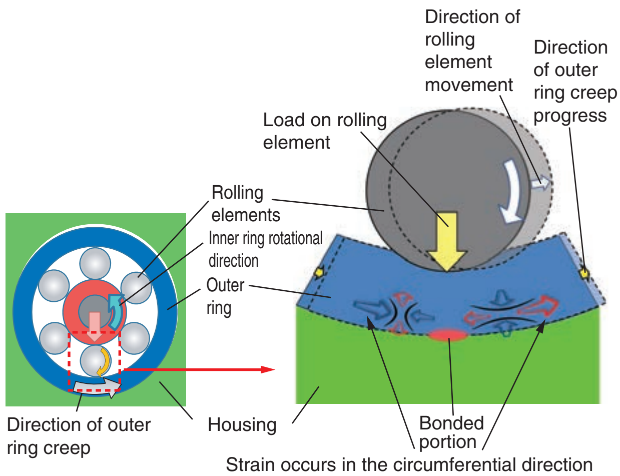


Fig. 20 Mechanism of creep occurrence due to outer ring strain[12]

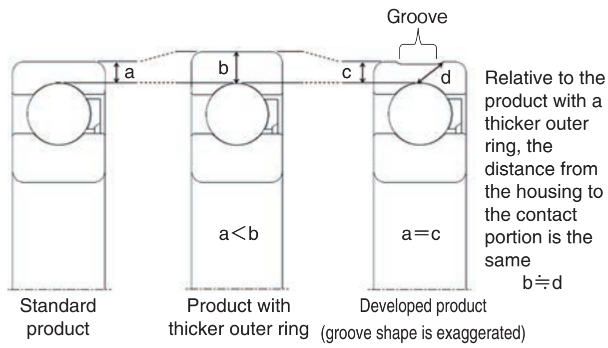


Fig. 21 Anti creep ball bearings[12]

As such, JTEKT focused on bearing ring shape, and developed an anti-creep ball bearing[12] as shown in **Fig. 21** which can offer the same anti-creep effect as a thicker product, without the need to apply a special, thicker shape. **Figure 22** shows the evaluation results of our developed bearing.

The developed product was recognized as having higher radial load and being capable of reducing creep amount.

Test bearing size (deep groove ball bearing)	Conventional product	ϕ33×ϕ70×19
	Product with thicker outer ring	ϕ33×ϕ72×19
	Developed product	ϕ33×ϕ70×19
Radial load	1 kN, 2 kN, 4 kN	
Rotational speed	10 000 min^{-1}	
Lubrication	Oil coated	

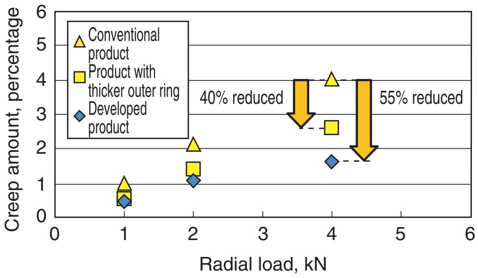


Fig. 22 Relationship of radial load and creep amount[12)]

6. 3 Bearings with Special Surface Treatment (Tribology-related Approach)

In the same way as the thicker product discussed in **Section 6. 2**, bearings with special surface treatment have conventionally been used in automobile applications. As **Fig. 23** shows, by implementing special surface treatment on fitting surfaces to lower their friction coefficient, fretting and creep wear can be minimized.

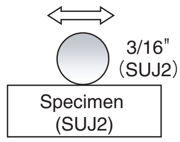
Fig. 23 Special surface treatment bearings (image)

Figure 24 shows the results of a comparison of the friction coefficients for a bearing with special surface treatment and a bearing without one. Under this test condition, the bearing with special surface treatment has a low friction less than one-quarter of a bearing without special surface treatment.

Figure 25 shows the results of a wear resistance evaluation for a tapered roller bearing which has undergone the same surface treatment on its internal diameter as that mentioned in the evaluation of **Fig. 24**. Through conducting this evaluation, we were able to confirm that the bearing with special surface treatment can better suppress shaft wear than a bearing without surface treatment.

The application of special surface treatment introduced here has been evaluated to a certain extent as a technology minimizing wear in aluminum housing in the automotive field, therefore, moving forward, is anticipated as a technology that can also be applied for wear minimization purposes in the agricultural and construction machinery field.

Average linear speed, mm/s	40
Sliding distance, mm	10×2 (reciprocatively)
Load, N	10
Contact surface pressure, GPa	1.6
Test time, min	60
Lubricant, coating	Dry



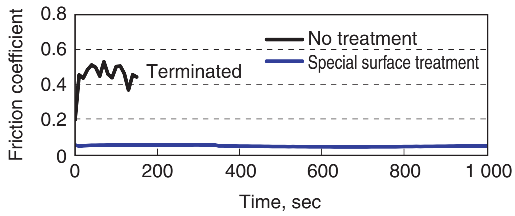
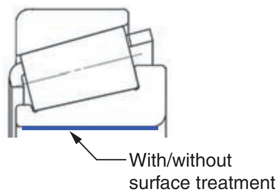


Fig. 24 Test results of friction coefficient

Test equipment	Wheel bearing test equipment
Test bearing	Tapered roller bearing ϕ90×ϕ140×32
Load	Pattern evaluation
Rotational speed	Pattern evaluation
Lubricant	Oil bath



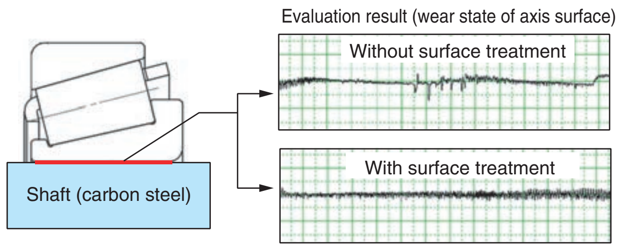


Fig. 25 Test results of surface condition by creeping

7. Failure Prediction

Leveraging various sensors and analysis equipment, JTEKT has developed the bearing sensing technologies shown in **Fig. 26**.

By applying this initiative to the status monitoring of agricultural and construction machinery, we believe we can contribute to the reduction of life cycle cost by identifying the right time for overhauls to improve operating rate, reducing maintenance costs through failure prediction, etc., as well as shorten machinery development period through design optimization.

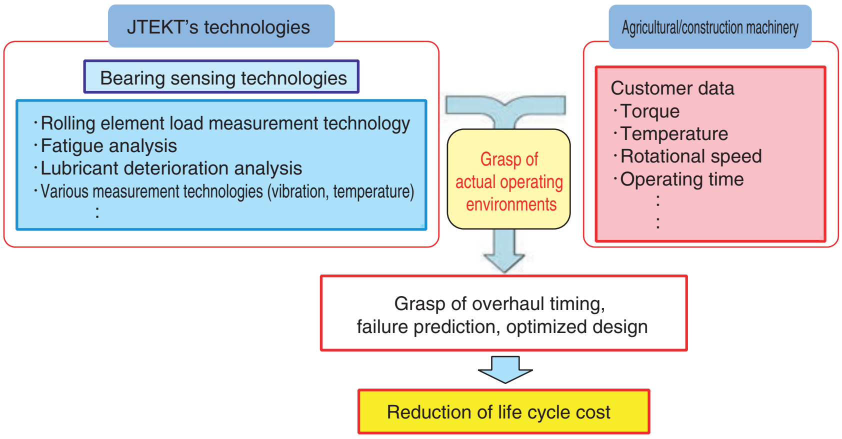


Fig. 26 Conceptual image for vehicle status monitoring

8. Conclusion

Initiatives to reduce life cycle cost in order to support profitability improvements of agricultural and construction machinery manufacturers are predicted to accelerate even further moving forward. So that JTEKT may swiftly respond to such initiatives by machinery manufacturers, we will continue engaging in proposal-type technological development based on our customers' needs, and contribute to the reduction of life cycle cost for agricultural and construction machinery.

*1 LFT is a registered trademark of JTEKT Corporation.

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