Development of High Reliability Rolling Bearings and Drive Shafts for Agricultural and Construction Machinery

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Agricultural and construction machinery support economic development. Equipment used in these markets requires high reliability and multi-functional flexibility while operating in very severe environments. A high priority is placed on the selection of key components such as bearings and drive shafts, which are required to perform with a high level of reliability.

This report deals with the development of high reliability drive shafts seals and long life, low torque, low heat generation bearings for agricultural and construction machinery.

***Key Words**: construction agricultural reliability robustness bearing driveshaft*

1. Introduction

Agricultural and construction machinery, which support economic growth and infrastructure, are indispensable to our daily lives. These products have continued transition into larger and multi-functional machinery to accommodate market demands. Economic changes and the development of agricultural and construction machinery are shown in **Fig. 1**. In addition to usage for long hours in extremely severe environments, agricultural and construction machinery also suffer tremendous losses in the event of breakage, including reduction in rate of operation and high repair costs. For this reason, customers primarily request machinery with excellent durability and robustness. Recent year, The reliability and maintainability of such machinery was improved through the utilization of remote control of operation status through GPS and the high level IT technology concerning automation of operations.

Furthermore, the serious problem of global warming demands the measures from not only automobiles, but agricultural and construction machinery as well. Consequently, JTEKT is active in the development of technologies for emissions control and low fuel consumption, and there are high expectations for technologies and products which contribute to countermeasures against global warming.

JTEKT rolling bearings and drive shafts are important functional components widely used to support power transmission and rotating shafts in the drive systems of agricultural and construction machinery.

Examples of rolling bearing and drive shaft application in agricultural and construction machinery are shown in **Fig. 2**.

This report introduces JTEKT activities and utilitarian products for improving the reliability of rolling bearings and drive shafts used in agricultural and construction machinery.

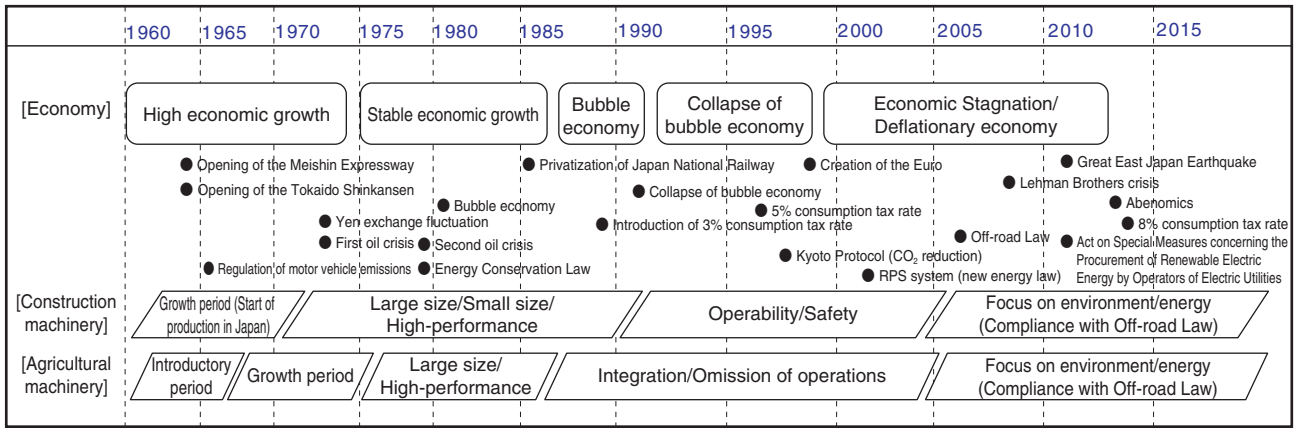


Fig. 1 History of economic changes and evolution of agricultural and construction machinery

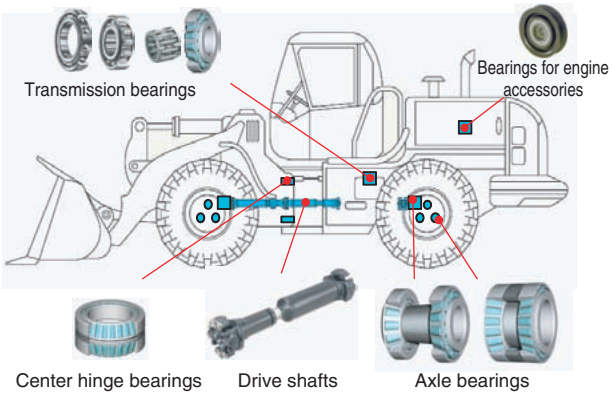


Fig 2 Bearing and drive shaft for agricultural and construction machinery

2. Activities for improving reliability of tapered roller bearings

The requirements and necessary technologies for rolling bearings (hereafter, "bearings") used in agricultural and construction machinery are listed in **Fig. 3**.

Trends of agricultural and construction machinery include improved productivity and compliance with emission standards through automation and computerization. There is great expectation for high reliability in bearings as functional parts.

In-company investigation

Demands for agricultural and construction machinery	Bearing requirements	Necessary technology for bearings
Improved productivity Automation Computerization Breakage reduction Low fuel consumption Global environment conservation Emission standards/ Noise pollution Safety	High reliability High durability Impact resistance Low heat generation Low torque Maintenance-free Improved ease of assembly	Long-life materials/Heat treatment Design optimization Analysis accuracy Optimal crowning High load capacity Low heat generation/Low torque Improved accuracy Unitization Creep-free Against high centrifugal, etc.

Fig. 3 Needs and required technologies for agricultural and construction machinery bearings

Next, the failure mode analysis results for bearings used in agricultural and construction machinery are shown in **Fig. 4**.

Results show that over 75% of all damage to bearings was due to large misalignment, foreign particle infiltration and poor lubrication. Improved bearing performance, which is effective in preventing these types of damage, is therefore effective in preventing problems in the field.

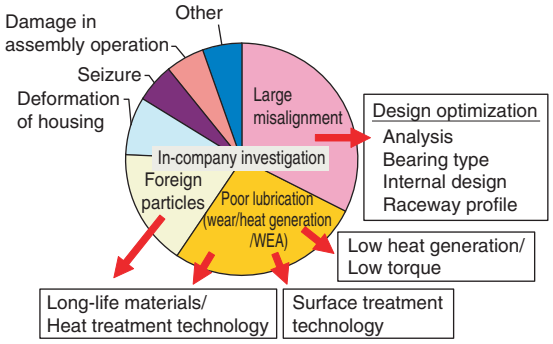


Fig. 4 Failure mode analysis of agricultural and construction

As the demand for tapered roller bearings used in agricultural and construction machinery is particularly high, JTEKT has developed a high performance tapered roller bearing (**Fig. 5**) with improved bearing performance which is promoting introduction to the market.

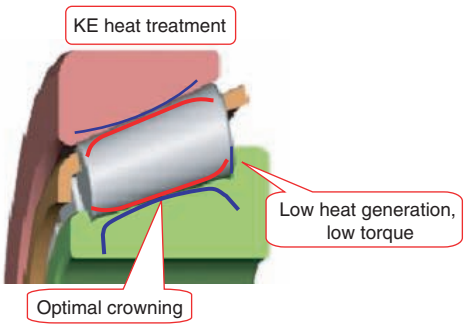


Fig. 5 High performance tapered roller bearings

Below is an introduction of the JTEKT technologies and products that improve bearing performance and are applied in high performance tapered roller bearings.

2. 1 Long-life materials and special heat treatment technology

The types of bearing flaking and effective corresponding countermeasures are shown in **Fig. 6**.

The most problematic of these types are peeling and flaking from dent, which are due to raceway surface damage caused by poor lubrication.

A major reason for this is that the lubrication method of agricultural and construction machinery drive systems is mainly oil bath or splash lubrication, resulting in the use of the same lubrication oil for bearings as for the clutch, brakes and gears in accordance with the mechanism. This stimulates heat generation and foreign particle intrusion into the lubrication oil.

Countermeasures against flaking which occurs due to poor lubrication are greatly needed as this type of flaking significantly lowers the expected bearing life.

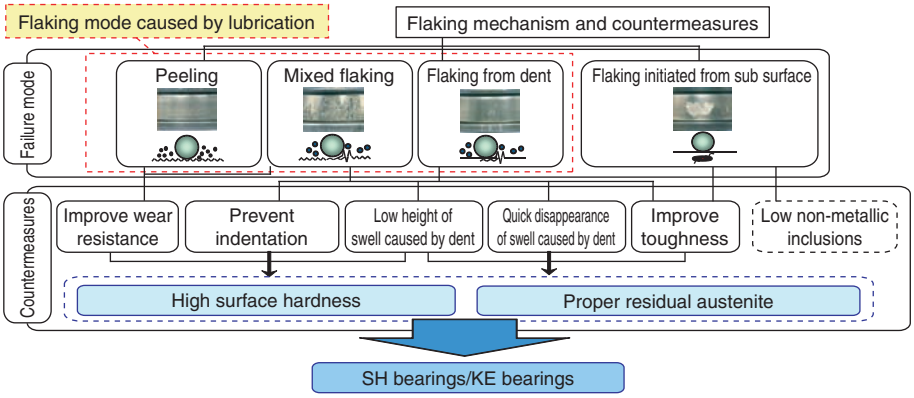


Fig. 6 Bearing flaking types and countermeasures[3)]

JTEKT has confirmed with past research that optimization of "surface hardness" and "residual austenite" is effective against surface flaking in lubrication oil with foreign particles. JTEKT has commercialized[1-3)] SH bearings (mainly ball bearings and needle roller bearings) and KE bearings (mainly tapered roller bearings), which apply these technologies.

The results of a life evaluation of KE bearings (KE heat treatment) and SH bearings (SH heat treatment) in oil contaminated with foreign particles is shown in **Figs. 7** and **8**. The results of a peeling resistance evaluation are shown in **Fig. 9**. Peeling is a type of damage that occurs on the bearing surface, in which micro flaking, which occurs when oil film condition on the rolling contact surface is insufficient, becomes deteriorated. As shown in the evaluation, the developed products exhibit long life within oil with foreign particles and improved peeling resistance under poor lubrication conditions, and are therefore highly suited for use as bearings for transmissions, differentials, and planetary reduction gears.

Testing device	Durability test equipment
Bearing	Tapered roller bearing ϕ30×ϕ72×20.75
Load	Fr=20.6 kN, Fa=13.7 kN
Rotation speed	2 000 min^{-1}
Foreign particles	830 HV, 27 μm, 0.55 g/L 700 HV, 125 μm, 0.55 g/L

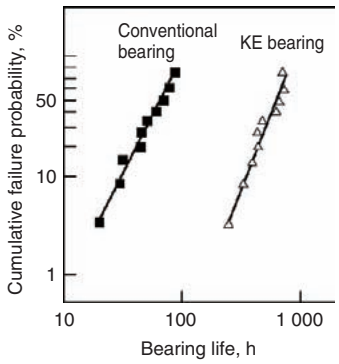


Fig. 7 Life test results of KE bearing in contaminated oil

Testing device	Durability test equipment
Bearing	Deep groove ball bearing ϕ30×ϕ62×16
Load	Fr=9 kN
Rotation speed	2 500 min^{-1}
Foreign particles	750 HV, 125 μm, 0.2 g/L

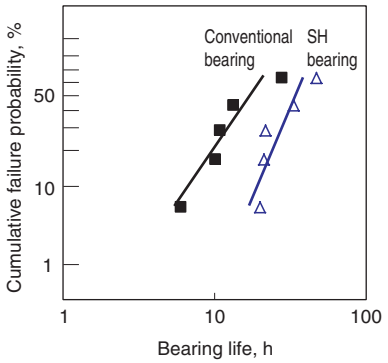


Fig. 8 Life test results of SH bearing in contaminated oil

Contact stress	2 260 MPa
Rotation speed	Drive cylinder: 1 000 min^{-1} Driven cylinder: Driven only by drive cylinder
Drive cylinder	Standard heat treatment (SUJ2) Target roughness: Rmax 5
Driven cylinder	Standard heat treatment (SUJ2), SH heat treatment, KE heat treatment Target roughness: Rmax 0.2
Lubrication	VG32 (turbine oil)
Temperature	Room temperature
Evaluation time	1.2×10^6 rev

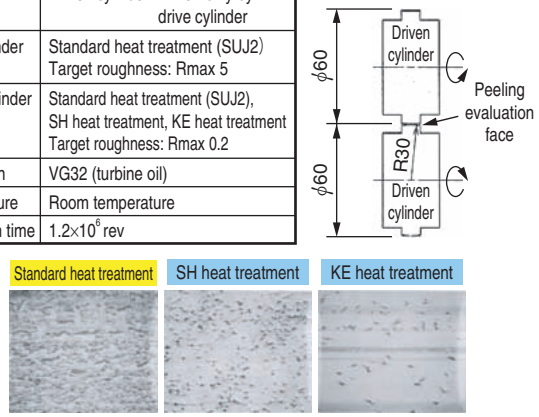


Fig. 9 Test results of peeling characteristics

2. 2 Bearing design optimization

An example of bearing usage by the differential pinion gear is shown in **Fig. 10**.

Gear side bearings for applications which use bearings subjected to moment load are greatly affected by shaft misalignment. Consequently, inadequate internal bearing design causes flaking after a short duration due to edge loading, as shown in **Fig. 11**.

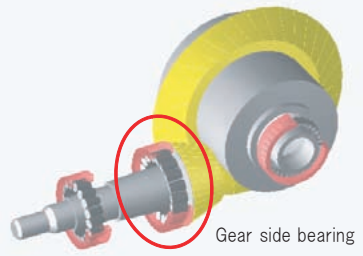


Fig. 10 Structure of differential pinion gear

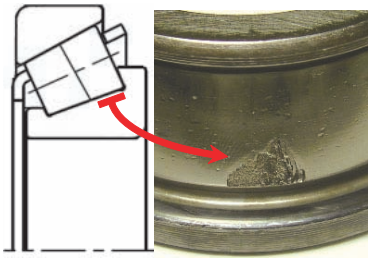


Fig. 11 Example of flaking on bearing inner ring

Optimization[4] of internal design and raceway shape during the design stages is important to prevent bearing damage caused by edge loading.

JTEKT utilizes our internally developed Shaft System Analysis Program (hereafter SSAP) for bearing design to improve bearing reliability by optimizing design and raceway shape.

The main functions of SSAP are shown in **Fig. 12**, and technical study procedures are shown in **Fig. 13**. An example of contact stress analysis using SSAP is shown in **Fig. 14**.

Use of this analysis software enables estimation of problem areas within the design stages and optimization of internal design in a short period of time.

Figure 15 shows the results of a misalignment life evaluation for the optimally designed bearing and conventional bearing, demonstrating that the life of the optimally designed bearing is over three times longer than that of the conventional bearing.

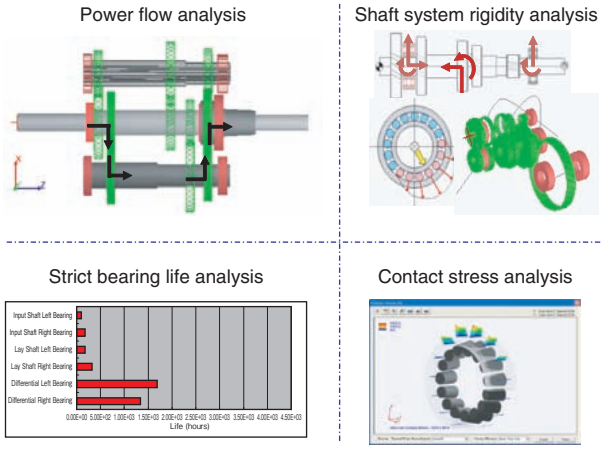


Fig. 12 Function of SSAP

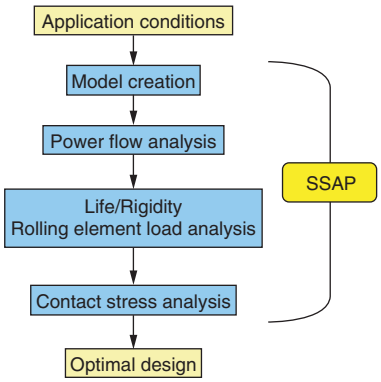


Fig. 13 Process flow for optimized design

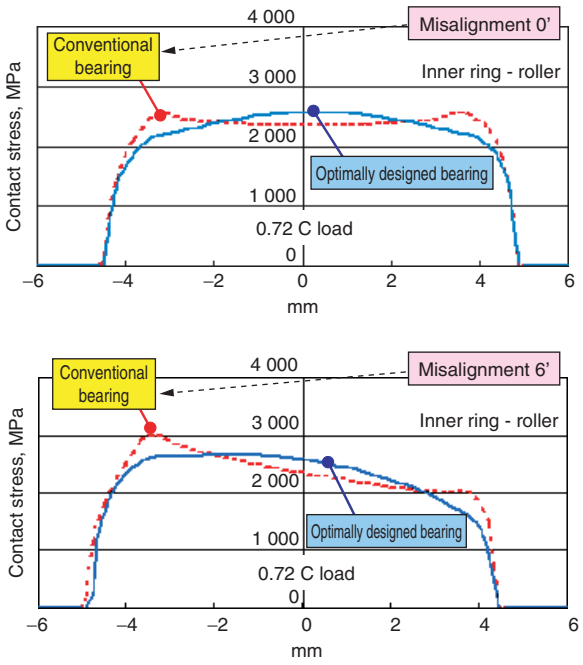


Fig. 14 Contact stress calculation results

Testing device	Durability test equipment
Bearing	Tapered roller bearing $\phi50\times\phi110\times29.25$mm
Radial load	24 kN
Axial load	50 kN
Rotation speed	1 500 min^{-1}
Misalignment amount	0.0044 rad
Lubrication oil	5W-30 oil bath (shaft center)

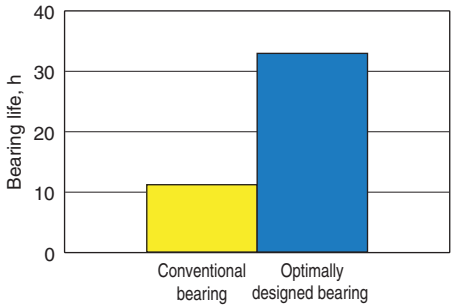


Fig. 15 Life test results in misalignment condition

Testing device	Durability test equipment
Bearing	Tapered roller bearing $\phi50\times\phi110\times29.25$mm
Radial load	20.35 kN
Axial load	20.35 kN
Rotation speed	500 to 2 500 min^{-1}
Lubrication oil	5W-30 Shaft center oil bath

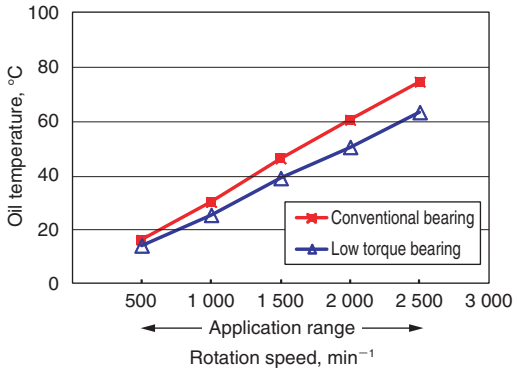


Fig. 16 Oil temperature measurement results

Testing device	Vertical torque measuring unit
Bearing	Tapered roller bearing $\phi50\times\phi110\times29.25$mm
Axial load	10 kN
Rotation speed	50 to 2 500 min^{-1}
Lubrication oil	5W-30 Force feed lubrication 0.6 L/min

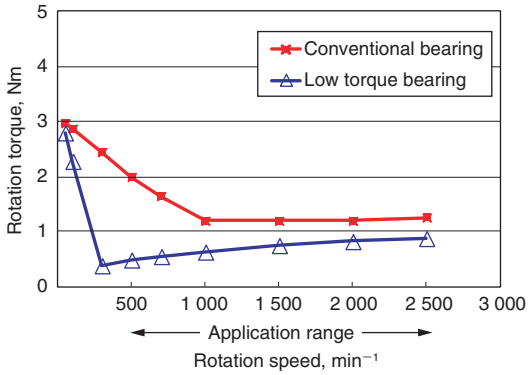


Fig. 17 Bearing torque measurement results

2. 3 Low heat generation and low torque technologies

Bearings for agricultural and construction machinery are often used in high temperature ranges exceeding 120°, which greatly requires low heat generation and improved lubricating ability. The Low Friction Torque bearing[5-7] (hereafter LFT bearing) produced by JTEKT has excellent low heat generation and low torque characteristics, and can contribute to improved reliability by suppressing overheating, etc.

Figures 16 and **17** show the results of a heat generation and torque comparative test for the conventional bearing and LFT bearing under the condition of low viscosity oil.

The evaluation confirmed a 3-10°C lower operating temperature and 30-70% lower torque in the applicable rotation range.

JTEKT is currently expanding the application of LFT bearings to include agricultural and construction machinery in order to improve the reliability of these machinery.

3. Activities for improving the reliability of drive shaft

Figure 18 shows drive shafts for construction machinary. Like bearings, drive shafts for construction machinery must respond to severe application environments, and as such JTEKT has been engaged in improvements to raise drive shaft reliability. This section introduces activities for improving the strength and life of cross bearings and for raising muddy water resistance in spline seals.

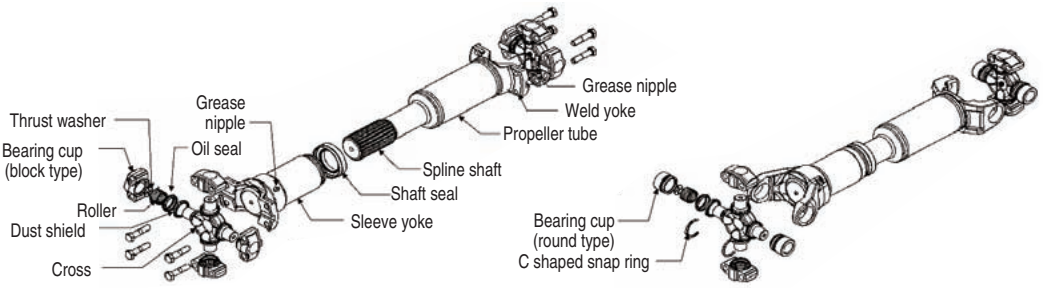


Fig. 18 Drive shaft for construction machines

3. 1 Cross bearing with long greasing interval

3. 1. 1 Background

Two types of seal structure cross bearings, the standard type and non-greasing type shown in **Fig. 19**, were manufactured at JTEKT. The standard type required frequent greasing every 250 hours. The non-greasing type needed no maintenance, but required replacement of the cross bearing kit after 12 000 hours of use, in spite of its extremely high cost. So it was a problem that non-greasing type could not be used until the end of the bearing life by greasing.

JTEKT has developed a cross bearing with a long greasing interval which, with the appropriate maintenance, can be used until the end of the bearing's life, despite having a seal performance equivalent to the non-greasing type.

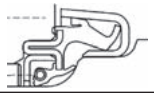
	Standard type	Non-greasing type	Long greasing interval type
Seal structure			
Seal lip	2 Layers (Flattened type)	5 Layers + Spring	4 Layers (Bend type)
Greasing interval	250 h	Cannot add grease	2 000 to 4 000 h
Cost	1	5	1

Fig. 19 Seal of cross bearing

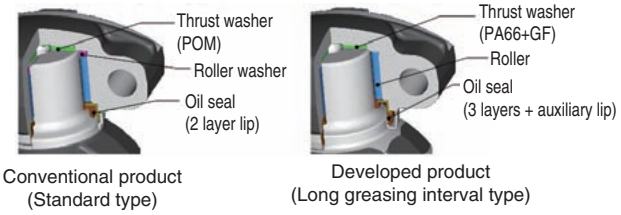


Fig. 20 Construction of cross bearing

3. 1. 2 Characteristics

An overview structure of the standard type and long greasing interval type is shown in **Fig. 20**. Except the seal structure shown in **Fig. 19**, the long greasing interval type also includes the following features.

①Improved service life through the reduction of contact stress between roller and cross during torque load condition by optimizing roller crowning.

②Reduced cost due to the disuse of roller washer after reviewing the shape of the bearing cup.

3. 1. 3 Evaluation results

The results of the evaluation are shown in **Fig. 21**. The greasing interval of the long greasing interval type was able to be extended to over ten folds that of the standard type.

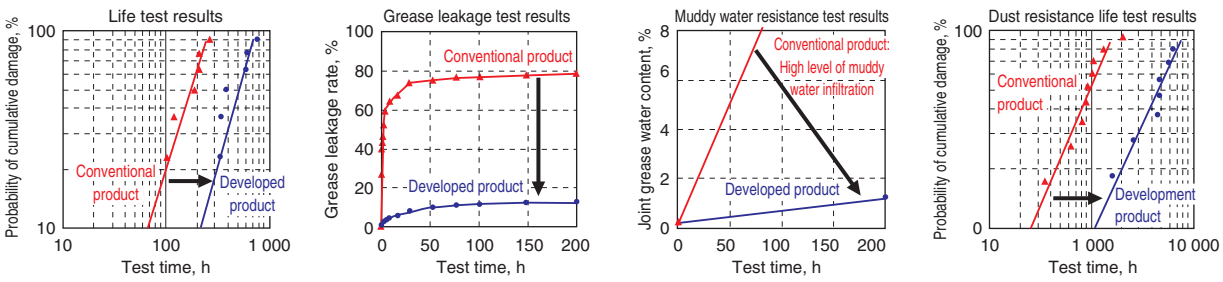


Fig. 21 Test results of cross bearing

3. 2 Improvement of spline seal muddy water resistance

3. 2. 1 Background

Spline seal performance was raised by changing the conventional felt seal to a nitrile rubber shaft seal (**Fig. 22**). However, the shaft seal had the following issues.

①During seal assembly, it is necessary to bend the lip to exceed the diameter of the spline, and therefore lip rigidity cannot be raised.

②Because the close proximity of the seal and spline, muddy water easily reached the spline.

As trouble due to absorb of muddy water have occurred sporadic in vehicles used in tough environments, such as articulated dump trucks, we have taken steps to further improve the muddy water resistance of the seal.

3. 2. 2 Characteristics

The cover tube type spline seal, developed to improve muddy water resistance, is shown in **Fig. 23**. Because the structure that the sleeve (female spline) outer diameter is sealed, the cover tube type have the following characteristics.

①Does not require bend of the lip during assembly (utilization of high-rigidity urethane rubber).

②The distance from the spline to the seal has been lengthened, preventing muddy water from reaching the spline.

3. 2. 3 Evaluation results

The results of the spline muddy water resistance test are shown in **Fig. 24**. The cover tube type has considerably greater muddy water resistance than the shaft seal type.

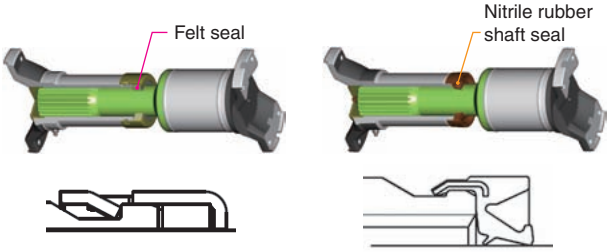


Fig. 22 Construction of conventional spline seal

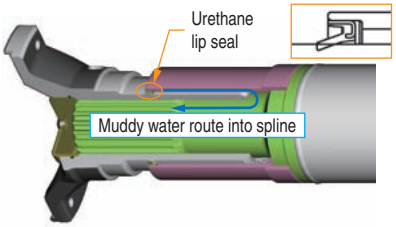
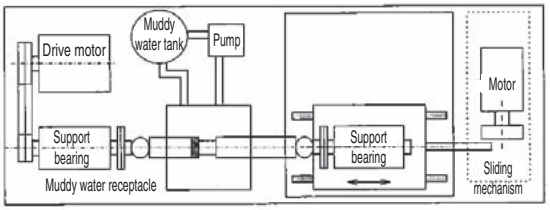
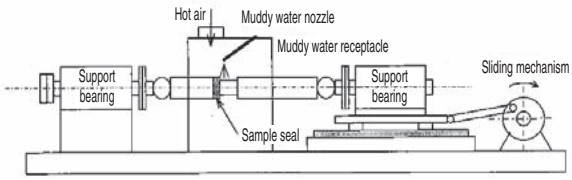


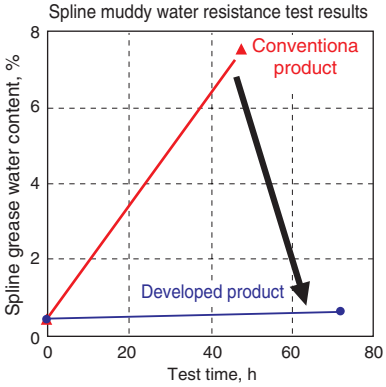
Fig. 23 Construction of cover tube type spline seal

Test conditions

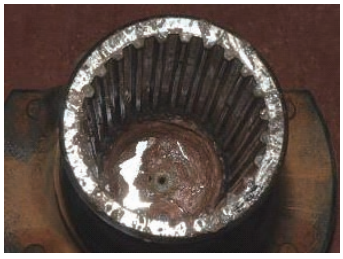
Item		Condition
Slide length		40mm
Extension/contraction speed		0.5 Hz
Rotation speed		1 000 min^{-1}
Grease		Approx. 60 g
Muddy water	Type	JIS 8 type 12.5 wt%
	Water injection position	Seal lip
	Water injection amount	3 L/min
	Water injection time	Repeated Water injection and Drying (60°C) for each 2 hours







Conventional product (Shaft seal type)



Developed product (Cover tube type)

Fig. 24 Muddy water test for spline seal

4. Conclusion

Agricultural and construction machinery produced by emerging nations hold an increasingly larger share within the market, and this is expected to further accelerate actions to improve added value and price competition between machinery manufacturers. In order to respond to the demands of these machinery manufacturers in a timely manner, JTEKT will continue to conduct technological development based on the requirements of individual customers and provide the market with highly reliable products authorized from analysis and verified results. Through these actions, our company aims to improve the reliability and economic development of agricultural and construction machinery.

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