

# Development of Hydraulic Expansion Type Torque Limiter for Steel Mill Large-Size Driveshafts

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An effective method of preventing machine failure loss due to accidents that occur during rolling operation and protecting surrounding equipments at such times is to install an over-loading prevention device (torque limiter) in the steel rolling mill. A torque limiter for rolling mills requires such performance features as high accuracy, high durability, high rotational performance both before and after torque release operation, and excellent maintenance features. JTEKT has developed a hydraulic expansion type torque limiter to satisfy these requirements by making use of its experience as a leading manufacturer of driveshafts and bearings.

**Key Words:** driveshaft, rolling mill, universal joint, torque limiter, safeset, hydraulic, maintenance

## 1. Introduction

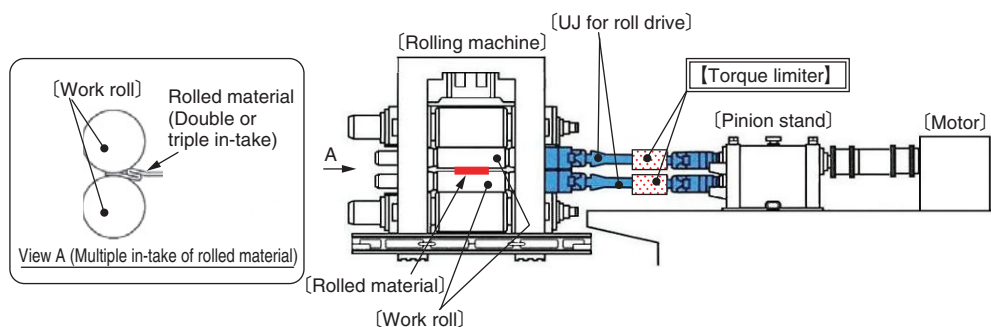
Cross shaft type universal joints (here-after described as UJ) are used not only for automobile propeller shafts but also for coupling system of all industrial machine shafts. Among them, the UJ for roll drives under rolling mills is often used in high load regions against the loading capacity of the UJ as the loaded torque is extremely high and also the size is quite limited depending on its installation space.

The basic structure of a rolling mill is shown in **Fig. 1**. Due to the operational characteristics of rolling mills, it is not possible to prevent torques that exceed the capacity of the UJ during operation. When the multiple in-take of rolled material happens during rolling operation, an excessive inertia moment due to the sudden stop of the roll rotation instantaneously acts on the whole transmission system, which may possibly damage the equipment including the UJ in the drive shaft, and eventually cause significant delays in rolling operation in

the worst case.

Over the years JTEKT has worked to improve the load carrying capacity of the UJ for steel manufacturing machines and has been able to obtain many accomplishments with regard to the improvement in fatigue limit torque. (Refer to details in the reference 2). However, to improve the strength against the momentary excessive torque, it is necessary to further improve the static load rating of the UJ. As the static load rating is related to the strength of material itself rather than the design specifications of the UJ, it is difficult to achieve any further improvements of the strength against the momentary excessive torque.

In situations where the momentary excessive torque occurs, there is currently a method for protecting the rolling equipment by releasing instantly the torque transmitted through the UJ. Therefore, JTEKT has recognized the advantage of this method and started to develop a torque limiter with higher accuracy and reliability. In recent years, as customer needs for reducing



**Fig. 1** Layout of rolling mill and installation position of over-loading prevention device

maintenance cost and man-hours have been increasing, JTEKT has started the development in consideration for such needs and the structure with better workability (shown in Fig. 2). As a result JTEKT has developed a torque limiter which is both highly reliable and easy to service.

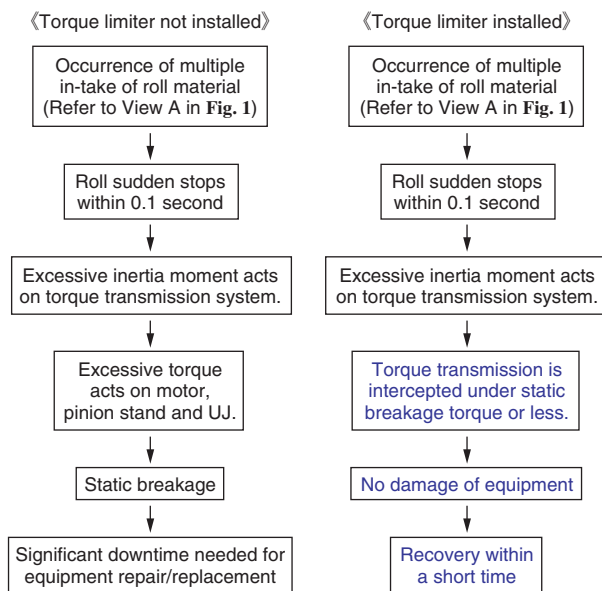


Fig. 2 Effect of torque limiter installation

## 2. Development of Hydraulic Expansion Type Torque Limiter

### 2.1 Conventional Technology (Shear Pin Type Torque Limiter)

The structure and the operating principle of the shear pin type torque limiter commonly used are shown in Fig. 3.

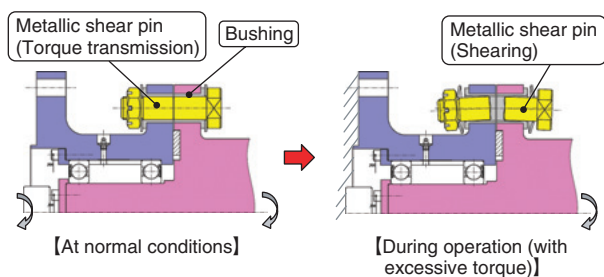


Fig. 3 Structure and operating principle of shear pin type torque limiter

The shear pin type torque limiter works on the principle of releasing the torque by shearing the metal pin. However, as the shearing torque depends on the strength of material, the dispersion of the shearing torque in operation is great. Also, from a maintenance aspect, as the metal fatigue is accumulated on the stress concentrated area of the shear pin, it is necessary to replace the shear pins regularly. Furthermore, the part surrounding the

shear pin needs refurbishment after the operation of the torque limiter, which takes considerable maintenance time and effort. JTEKT has developed a hydraulic expansion type torque limiter, which has improved the operating performance and ease of maintenance, and reduced man-hours needed to bring the mill back on line.

### 2.2 Development Target

In recent years, there are, as functions required for rolling mills, an improved rolling efficiency (increased torque capacity for the same sized UJ, improved operating ratio) and quick recovery from operational trouble. In accordance with these required functions, the hydraulic expansion type torque limiter with the following functions has been developed.

#### 2.2.1 Improvement in Operation Accuracy

In recent years, the tendency has been toward increasing rolling torque and in order to accommodate this trend, improvements in fatigue strength has been achieved without increasing the size of the UJ by adopting various new technologies.

As a result, the fatigue strength of a modern the UJ is now nearing the static strength which depends on the material strength and is more difficult to improve than the fatigue strength. Therefore, the torque limiter needs to be set at the value which is larger than the fatigue strength but smaller than the static strength. In order to accomplish this, it is necessary for the limit torque to have a narrow range and to have high accuracy and reliability. (Refer to Fig. 4)

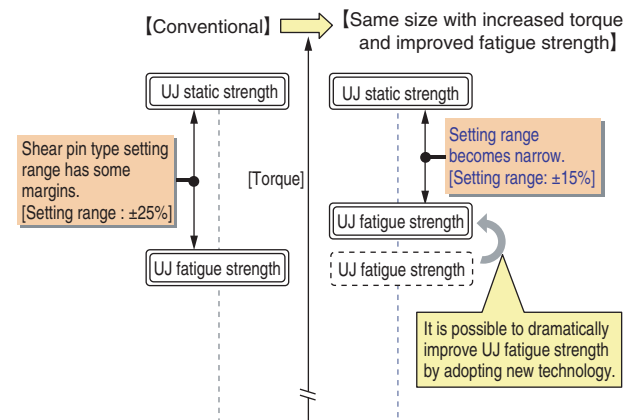


Fig. 4 Required performance for torque limiter

Under conventional rolling conditions, a shear pin type torque limiter has been capable of having a shearing torque with a tolerance of around  $\pm 25\%$ , but because of the improvements detailed above, it is necessary to narrow this torque setting to within  $\pm 15\%$ . Therefore, JTEKT has developed a hydraulic torque limiter for the target of an operating accuracy within  $\pm 10\%$  in consideration of further needs by customers in the future.

### 2. 2. 2 Durability Improvement

The torque limiter is a device designed to protect the rolling equipment (including drive shafts) when over torque situations occur and to quickly bring the rolling equipment back on line at the same time. However, if the torque limiter itself suffers some damage and such situation occurs as it can not withstand long-term use, the durability on the overall rolling equipment will be lost. Therefore, it is necessary for the torque limiter to have sufficient durability for the frequency of usage. JTEKT has developed the torque limiter which can reduce the wear at the time of the torque limiter operation by adopting the special surface treatment technology.

### 2. 2. 3 Rotational Performance Improvement

In torque limiters, it is common to mount rolling bearings into the support parts so that they can make relative movement in operation. Normally, the inner and outer rings of these bearings are not rotating relatively but when the torque limiter engages, they suddenly begin relative rotation. In order to secure the bearing rotational performance at the time of sudden acceleration and the support stiffness during rotation, we have conducted various studies as a bearing manufacturer.

### 2. 2. 4 Maintenance Improvement

With regard to equipment maintenance, there have been strong demands towards the reduction of man-hours needed for both recovery operation and inspection, which gives great advantages to customers. In comparison with the conventional shear pin type torque limiter, JTEKT has developed a structure that does not require regular replacement of parts with easier recovery operation. Additionally, we designed the equipment to be easy to inspect and maintain after using the torque limiter for a long period.

## 2. 3 Basic Design

The structure of the hydraulic expansion type torque limiter equipped with the required functions mentioned in Chapter 2. 2 is shown in Fig. 5. As its basic structure, the cylindrical bore flange equipped with hydraulic expansion chamber is connected with the cylindrical shaft flange and their both ends are supported by two bearings.

The operating principle of the hydraulic expansion type torque limiter is to control the transmission torque by changing the static friction force of the contact surfaces between the cylindrical bore flange and cylindrical shaft flange by filling the oil in the hydraulic expansion chamber, and then releasing it. Its operating principle is shown in Fig. 6.

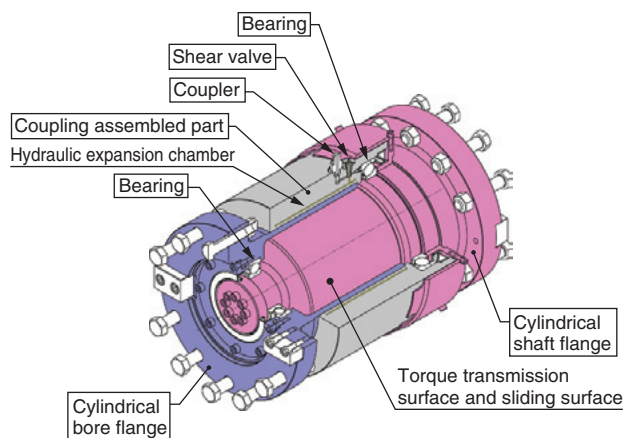


Fig. 5 Structure of hydraulic expansion type torque limiter

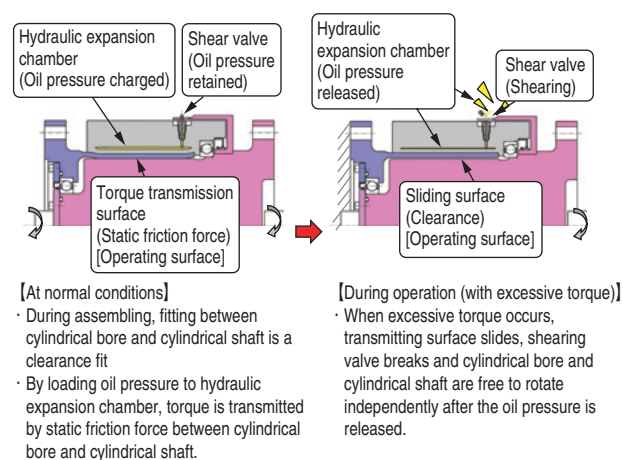


Fig. 6 Operating principle diagram of hydraulic expansion type torque limiter

## 3. Hydraulic Expansion Type Torque Limiter Performance

### 3. 1 Efforts for Stabilization of Operating Torque

For the developed product, the operating torque (static friction force) is set with the hydraulic value by the oil supplied to the inside of the hydraulic expansion chamber. Therefore, it is important to stabilize and control the static friction force on the operating surfaces (torque transmission surface or sliding surface). Since the operating torque (static friction force) is controlled by the hydraulic value inside the hydraulic expansion chamber, JTEKT has made an effort to develop a surface pressure model of the sliding surface by using three-dimensional FEM analysis. Also, in an attempt to stabilize the static friction force, in order to reduce the dispersion by each time of operation, JTEKT has worked to optimize the specifications of the operating surfaces.

### 3. 2 Surface Pressure Analysis on Operating Surface

In order to select the proper operational torque (static friction force), it is necessary to establish the analysis of

the surface pressure distribution on the operating surface based on the pressure value and the structural data inside the hydraulic expansion chamber. Therefore, JTEKT has created an original analysis on the following items 1) and 2) by using the three-dimensional model and confirmed the consistency with the result of the test with a miniature sample. The three-dimensional analysis model with the miniature sample is shown in Fig. 7 and the bench test machine is shown in Fig. 8. (Size of miniature sample: OD (outside diameter) of 190mm, total length of 265mm)

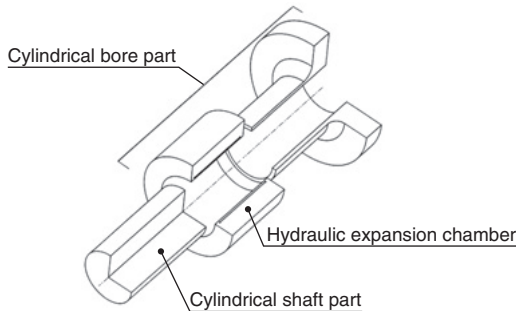


Fig. 7 Three-dimensional analysis model

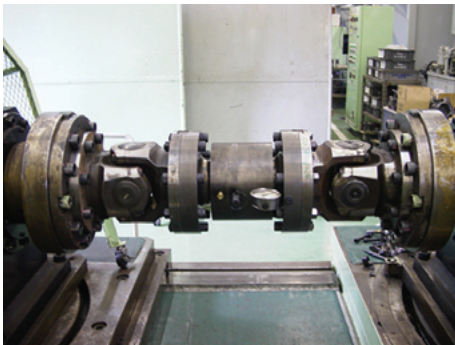


Fig. 8 Bench test machine

1) ID (inside diameter)/OD (outside diameter) displacement in hydraulic expansion chamber by oil pressure

JTEKT has confirmed the ID/OD displacement of the hydraulic expansion chamber by oil pressure with the miniature sample. As shown in Fig. 9, the analysis results correspond to the measurement values.

2) Surface pressure loading conditions on operating surface

JTEKT has investigated the surface pressure distribution by the analysis with the miniature sample and the contact width after loading the oil pressure on the sample. The analysis results shown in Fig. 10 correspond to the measurement results shown in Fig. 11.

From the above results, JTEKT has confirmed that the analysis results by the three-dimensional model are well consistent with those in the actual machines and that the model has sufficient viability for designing the actual machines.

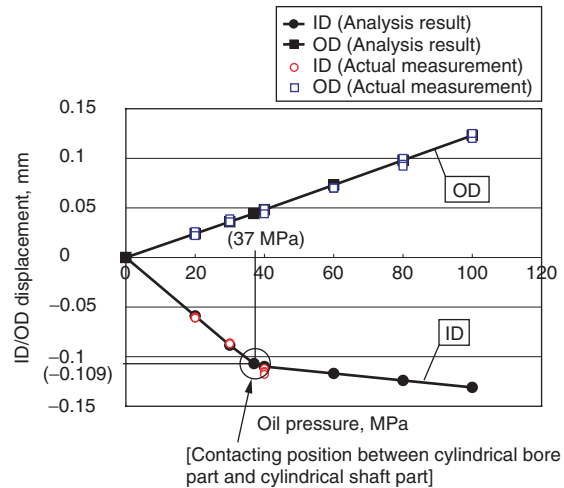


Fig. 9 ID/OD displacement in hydraulic expansion chamber

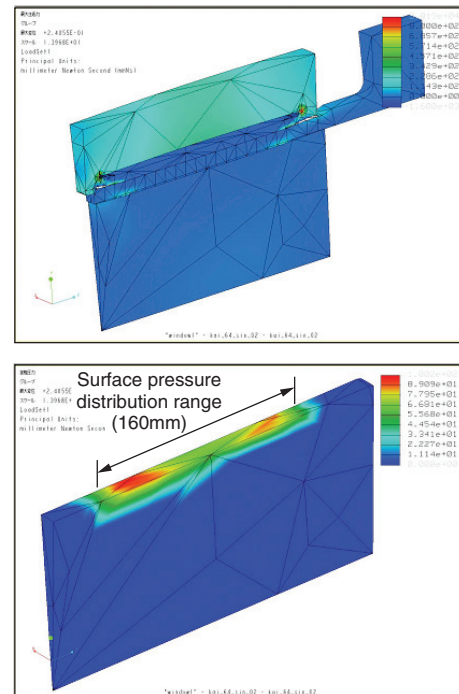


Fig. 10 Results of operating surface pressure distribution analysis

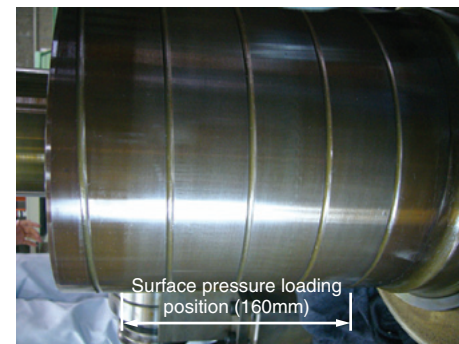


Fig. 11 Loaded surface after disassembling (Cylinder shaft)

### 3. 3 Surface Specifications of Operating Surface

#### 3. 3. 1 Operating Torque Stability

The stability of the operating torque (static friction force) is the most important performance characteristics for this product. The number of operations is greatly influenced by the dispersion of the operating torque on the developed product used under boundary lubrication conditions. JTEKT has achieved the stability of the surface conditions before and after the operation by performing our newly developed special surface treatment on the operating surface.

The results of plotting actually measured operating torque values, in comparison with the operating torque obtained from the surface pressure distribution analysis on the miniature sample, are shown in Fig. 12. The dispersion of actually measured operating torque is within  $\pm 10\%$  at each oil pressure, which is on the acceptable level for actual use. Also, the actual measured values at each oil pressure are similar to the values (theoretical line) obtained from the analysis, resulting in confirming the consistency with the three-dimensional FEM analysis results mentioned in Chapter 3. 2.

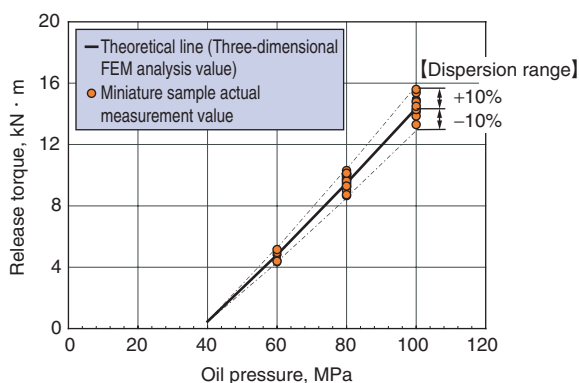
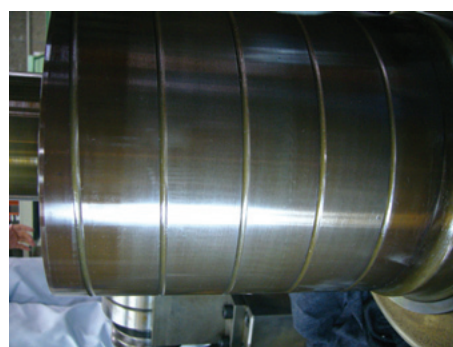


Fig. 12 Relation between oil pressure and release torque

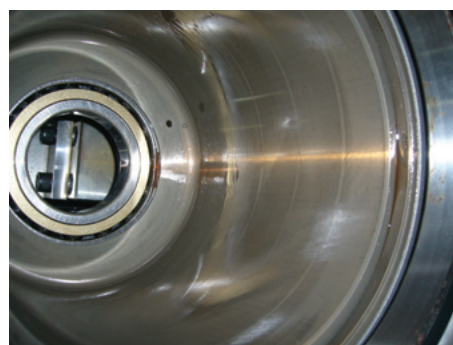
#### 3. 3. 2 Durability Performance Evaluation of Operating Surface

The condition of the sliding surfaces after 150 operations under oil pressure loaded is shown in Fig. 13. The investigation results of the operating surface are as follows.

- The operating surfaces of both cylindrical bore and cylindrical shaft are in good condition without any galling, scuffing or scratching.
- Wear is not observed on the operating surfaces of both the cylindrical bore and cylindrical shaft.



Appearance of cylindrical shaft



Appearance of cylindrical bore

Fig. 13 Appearance of operating surface after durability evaluation

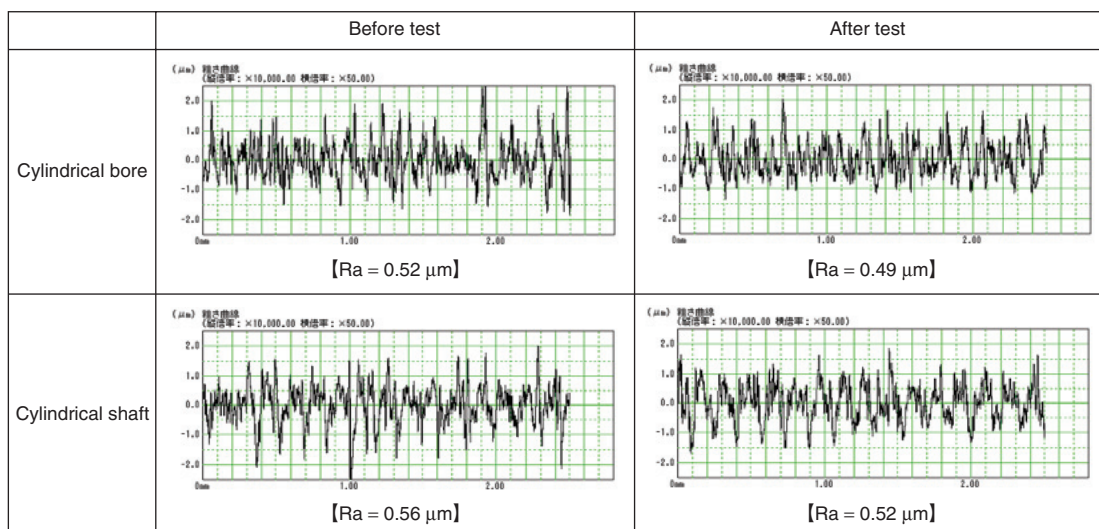


Fig. 14 Change of operating surface roughness

**Table 1** Other required evaluation items and results

Evaluation items		Study contents	Results
Oil pressure retaining capability		<ul style="list-style-type: none"> <li>Strength of hydraulic expansion chamber</li> <li>Shape and capability of shear valve</li> </ul>	<ul style="list-style-type: none"> <li>Evaluation possible by the three dimensional FEM analysis</li> <li>Shape established for retaining high surface pressure</li> </ul>
Oil pressure releasing capability		<ul style="list-style-type: none"> <li>Shortening of oil pressure releasing time</li> </ul>	<ul style="list-style-type: none"> <li>Design possible for shortening the oil pressure releasing time by fluid FEM analysis</li> </ul>
Rotational performance	When oil pressure is retained (Integrated rotation)	<ul style="list-style-type: none"> <li>Seal performance</li> <li>Effect by centrifugal force</li> </ul>	<ul style="list-style-type: none"> <li>Seal specifications established</li> <li>Setting value established in each mounting process</li> </ul>
	When oil pressure is released (Relative rotation)	<ul style="list-style-type: none"> <li>Evaluation on sudden operation of bearing</li> <li>Seal performance</li> </ul>	<ul style="list-style-type: none"> <li>Bearing internal structure established</li> <li>Seal specifications established</li> </ul>

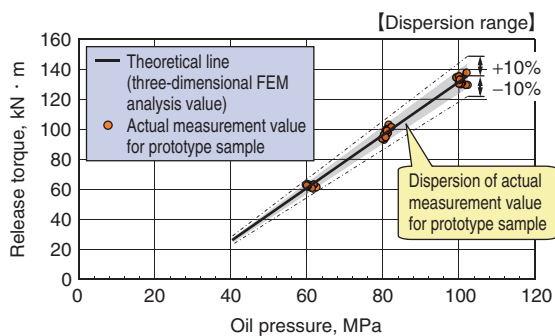
Also, the result of surface roughness measurements by each loading time is shown in Fig. 14. It can be seen from the results that there was no significant change in the surface roughness. It can therefore be concluded that the operating surface has sufficient durability under high surface pressure.

**3. 4 Performance Evaluation of Product Equivalent to Actual Machine**

Based on the theoretical analysis and the evaluation of the miniature sample mentioned in the previous section, a full scale prototype product has been produced and the evaluation test under actual operating conditions has been carried out. The result is shown as follows. (Prototype sample size: OD of 350mm, total length of 520mm)

1) Operating torque

The three-dimensional FEM surface pressure analysis results and the operating torque evaluation results of the prototype sample are shown in Fig. 15. The dispersion under the actual machine against the operating performance value is satisfactorily within ±10%. In addition, the above operating performance values shall be presented to a customer as our delivery record when the product is put into actual production.



**Fig. 15** Relation between oil pressure and release torque

2) Other evaluation items

Functions required for this product are not only the stabilization of the operating torque but also the functions

shown in Table 1, and therefore, JTEKT has carried out the evaluation on these items with consideration of actual machines. The result is also shown in Table 1.

**4. Conclusion**

As mentioned in this report, the hydraulic expansion type torque limiter has satisfied the target performances in our in-house evaluation as a device for the prevention of excessive loading on the rolling equipment. Also, with regard to operating accuracy, durability, rotational performance and ease of maintenance, JTEKT has improved such performance more significantly when compared to the conventional shear pin type. Proper applications of the developed product will be very effective in securing stable operation of the rolling equipment and will be able to greatly contribute to our customers.

**References**

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