Development of Spacer Balls for Rack Parallel Type Electric Power Steering

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We have developed rack parallel type electric power steering (RP-EPS) for large and premium class vehicles.

Premium class vehicles require high quality in terms of the steering feeling. In order to provide smooth steering, spacer balls were adopted in the ball screw of RP-EPS.

Torque variation is reduced significantly as the spacer balls have the effect of reducing the slip between balls. In addition, in accordance with reduced slip, the durability of the ball screw was also improved.

Key Words*: electric power steering, torque variation, ball screw, spacer balls*

1. Introduction

Changes in the market such as a heighted awareness of the environment and sophistication of driver-assistance systems in recent years has increased the demand for electric power steering (EPS) in large and premium class cars. For large cars, the increase in vehicle weight is related to a demand for greater assist power in EPS.

JTEKT also developed the rack parallel type electric power steering (RP-EPS, **Fig. 1**) as a product suitable for large cars and began its production in December 2016. The RP-EPS is of a configuration whereby the motor output that assists steering force is reduced in two stages with a toothed belt and ball screw (**Fig. 2**). This product is also more space-saving than conventional EPS and boasts higher output.

Compared to small cars, etc. there is a demand for premium class cars to offer high quality in terms of the steering feeling. The RP-EPS developed by JTEKT has adopted spacer balls on the ball screw in order to satisfy this demand for high quality.

Fig. 1 RP-EPS

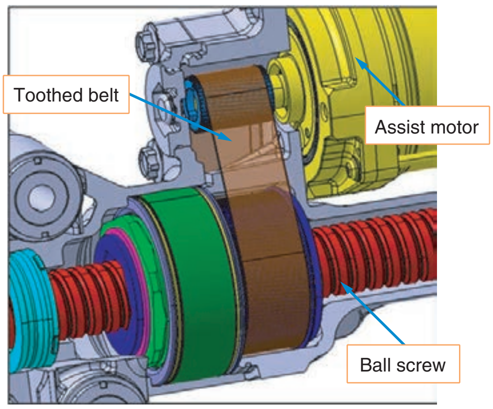

Fig. 2 Reducer of the RP-EPS

2. Torque variation

If variation of steering torque occurs, the driver gets a feeling that something is not right through the steering wheel. In the case of steering gears that use a ball screw as the reducer, this feeling is felt after repeated small angle steering movements (in the range of ±10 to 40 deg) such as that required for changing lanes.

Figure 3 shows the waveform of steering torque when torque variation occurs. Torque variation occurs at a constant cycle and that cycle is consistent with the ball movement cycle, which indicates that the torque variation is caused by the ball screw.

Figure 4 shows the results of X-ray observations of the inside of the ball screw both with and without torque variation. This reveals that the balls are evenly spaced when there is no torque variation, but if there is torque variation due to repeated small angle steering movements, the balls will clump together in some spots but be wide-apart in others. This is believed to be a result of the balls gradually and continuously making contact with one another due to repeated small angle steering movements.

If balls side-by-side make contact with each other due to small steering, slip friction will occur between them. This slip friction will have the effect of inhibiting ball rolling motion therefore repeated small steering will result in continuous contact between balls. The slip friction between balls is greater when multiple balls conjunct therefore this will promote further continuous ball-to-ball contact.

As described above, the slip friction that occurs between balls greatly impacts torque variation.

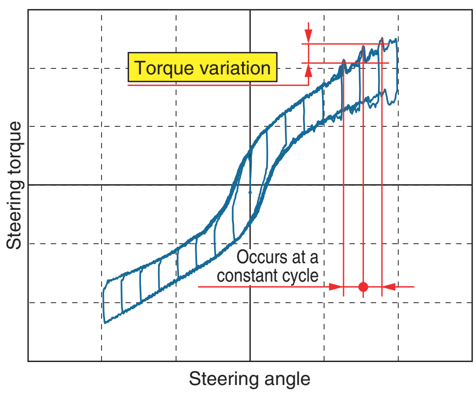

Fig. 3 Torque variation

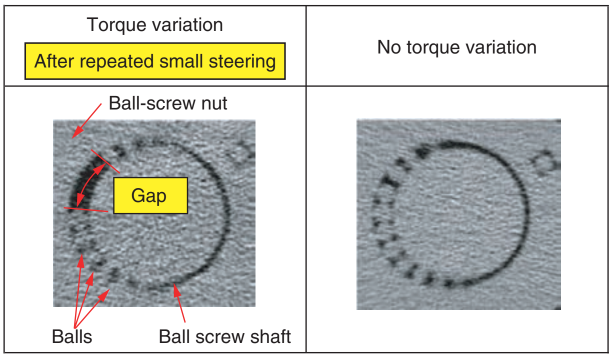

Fig. 4 X-ray observation of ball screw

3. The Principle of Spacer Ball Action

Using spacer balls as a method to reduce slip friction between balls in a ball screw is already known and there are some cases where such a method has been commercialized in industrial ball screws, etc.

In a ball screw, load is transferred by the ball held between the ball screw shaft and ball screw nut.

Spacer balls are the balls placed between two support balls with a smaller diameter than that of a support ball. The principle of spacer ball action is as per the following explanation.

Figure 5 (a) shows a situation where spacer balls are not used. At this time, each ball is rolling in the same direction therefore slip friction occurs between the balls which make contact with one another and this has a significant impact on the torque variation and durability of the ball screw.

Figure 5 (b) shows a situation where spacer balls are used. The spacer balls have a smaller diameter than the support balls therefore are free of restraints related to the ball screw groove and able to rotate in the opposite direction to the support balls. As such, slip friction does not occur between balls even in a state where balls come in contact with each other.

For the developed product, in order to maximize the inter-ball slip friction reduction effect of spacer balls, one spacer ball is placed after every support ball. **Figure 6** shows the waveform for steering torque on the steering gear for which spacer balls are applied in the steering gear which torque variation was observed in **Fig. 3**. It is apparent that the spacer balls have had the effect of significantly reducing torque variation.

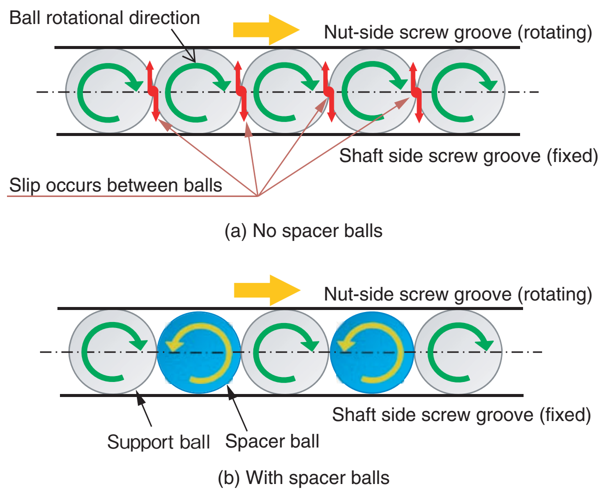

Fig. 5 Principle of spacer ball action

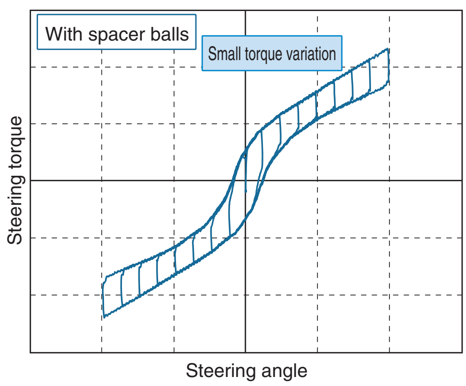

Fig. 6 Torque variation with spacer balls

4. Ball Screw Durability

Two factors that affect the durability of a ball screw are the surface pressure of the screw groove surface and slip friction.

When spacer balls are used, the number of support balls decreases and the load distribution per support ball increases. As with the developed product, if one specer ball is placed after each support ball, the number of support balls will halve. However, the contact between the balls and the screw groove surface becomes contact by curved surfaces therefore if the increase in contacting surface area due to load increase is also taken into account and the load is only borne by the support balls, the maximum surface pressure of the ball screw groove when a load is applied to the developed product will increase by 10% or more (**Fig. 7**).

For this reason the below study was undertaken for the developed product and the design implemented accordingly.

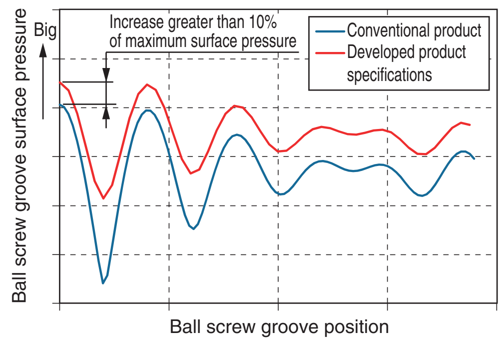

Fig. 7 Surface pressure distribution in ball screw groove

4. 1 Setting of ball diameter difference

The load that a steering gear is subjected to is not constant, but rather decreases when vehicle speed is higher and increases when steering angle is larger. In a similar way, the load that the ball screw is subjected to is also constantly varying.

As already mentioned in **Section 2**, a driver gets a feeling that something is not right when torque variation occurs in the ball screw primarily in situations of repeated small angle steering movements, such as that required when changing lanes, and when the vehicle is traveling at a high speed and the steering angle is small; in other words the load is relative low.

Considering this, on the developed ball screw, we devised the approach of different action for the spacer balls in low-load and high-load areas.

Because drivers can easily sense torque variation in low-load areas, spacer balls are able to fulfill their function completely without being subjected to load, minimize the slip between balls and facilitate smooth operation of the ball screw.

In high-load areas, considering the durability of the ball screw, the spacer balls are included as a portion to which load is distributed in order to minimize a reduction in durability.

We examined the diameter difference between support balls and spacer balls in order to balance these two movements.

First, we determined the steering conditions, travelling conditions, etc. under which torque variation occurs and calculated the load applied to the ball screw under these conditions. From this load, we found the amount of elastic deformation that occurs between the support balls, ball screw shaft and ball screw nut and made this amount the difference in diameters of the support balls and spacer balls.

By establishing this, we could assume that if the total of the elastic deformation between the ball screw shaft and support balls and surface balls and ball screw nut respectively exceeded the diameter difference between the support balls and space balls, then the spacer balls would begin to make contact with the ball screw groove surface, become a portion subjected to load distribution and minimize the reduction in durability.

Figure 8 shows the pressure distribution of the ball screw groove surface during a durability test when the diameter difference is set. It was possible to minimize the increase in maximum surface pressure to around 5% compared to when no spacer balls are used.

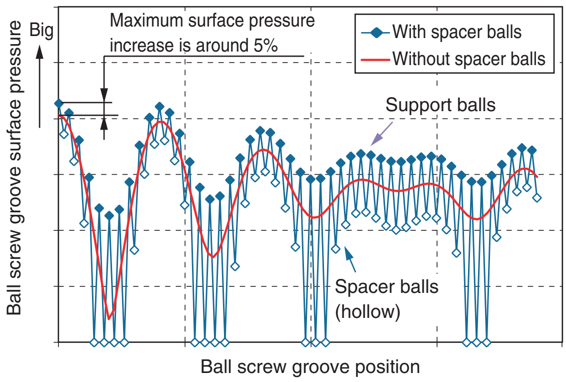

Fig. 8 Surface pressure distribution in ball screw groove with spacer balls

4. 2 The effect of slip friction on ball screw durability

It is already known that slip friction affects ball screw durability.

For the developed product, with consideration towards balancing torque variation and durability, the ball diameter difference discussed in **Section 4. 1** was set therefore load is distributed to both spacer balls and support balls.

However, the distributed load of specer ball is smaller than the support balls. Therefore, for the developed product, even if the balls come in contact with one another during a durability test, the slip friction force that occurs due to multi-point contact is relatively smaller than that of a ball screw which uses support balls only. In other words, when placed under high loads, the spacer balls of the developed product can be thought of as functioning as support balls at the same time as functioning as spacer balls; or in other words, possessing a function to alleviate slip friction.

The slip friction alleviation effect of spacer balls under high load conditions can be contemplated using surface pressure (P) and slip velocity (V) in the below way.

(1) Slip inevitably occurs in ball screws due to the lead angle of the ball screw shaft and ball contact points differing to that of the ball and nut contact points. All ball screws have this type of slip, therefore it is known as "natural slip."
This PV value is around a few MPa m/s with the specifications of the developed product.

(2) Ball-to-ball slip occurs when balls come in contact with one another.
In the developed product, the maximum PV value is the same as (1) at around a few MPa m/s.

(3) When the balls come in contact with one another, a multi-point contact state is established whereby the ball has more than three contact points (ball and ball screw shaft, ball and ball screw nut, ball and ball).
At this time, the PV value of the ball and ball screw shaft and the ball and ball screw nut, despite only being around a few MPa m/s in (1) above, could reach as high as several hundred MPa m/s.

(4) Because the PV value of the ball and ball screw shaft and the ball and ball screw nut becomes extremely large when ball-to-ball slip occurs, minimizing such slip by using spacer balls is extremely effective in improving ball screw durability.

4. 3 Results of a durability test on actual equipment

Figure 9 shows the appearance of support balls after a durability test on actual equipment. The state of the surface is clearly improved when spacer balls are used. The wear of the ball screw groove is considerably smaller than when spacer balls are not used, suggesting that spacer balls are functioning effectively.

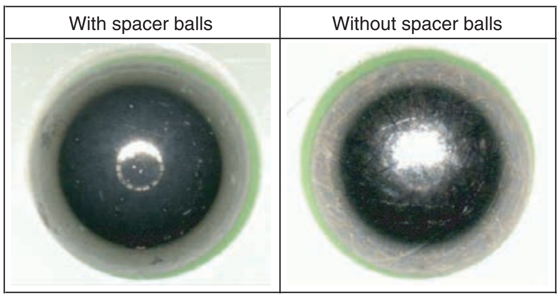

Fig. 9 Ball after durability test

5. Conclusion

On this occasion, JTEKT has developed spacer balls for RP-EPS application and helped to improve RP-EPS performance and ball screw durability. Moving forward, we plan to gradually roll these spacer balls out to RP-EPS, for which the demand is predicted to increase.

*1 RP-EPS is a registered trademark of JTEKT Corporation

Reference

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