Development of a Ball Screw for Electric Brakes

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We have developed a non-circulating ball screw with a simple structure for the actuator of the EMB (Electro Mechanical Brake) which eliminates the need for a complex ball circulating part. Since there is no circulating part, it is necessary to prevent the ball from falling off during stroke. When the load is small, the ball is fixed by an elastic holding, and the spring is contracted by the revolution of the ball during braking, then the ball returns to its original position when the brake is released. This paper introduces the configuration and use of non-recirculating ball screws and demonstrates their effectiveness for use in electric brakes.

Key Words: *EMB, Electro Mechanical Brake, ball screw, non-circulating, spring*

1. Introduction

The electrification of automobiles is rapidly advancing in response to environmental regulations of recent years, and one element of this is predicted to be the expansion of the market for electro mechanical brakes (or EMB). Electro parking brakes (EPB) are already in mass production, and there are cases where the ball screw is applied. The ball screw is promising as a mechanism to efficiently convert the rotational motion of the motor to linear motion, and is suited to EMB. As **Fig. 1** shows, the EMB works by utilizing a linear motion mechanism to trap the disc on both sides with pads pressed by a piston.

Generally speaking, the type of ball screw with a mechanism that circulates balls so as not to fall out of the raceway during stroke is main stream[1)] (**Fig. 2**). There are various types of circulating parts, however the more complicated and larger they are, the greater the disadvantage. This paper introduces a non-circulating ball screw on which the circulating part has been abolished by focusing on the short stroke required when the EMB brakes.

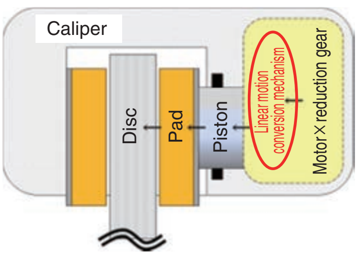

Fig. 1 Configuration of electric caliper EMB

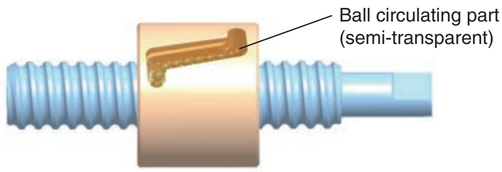

Fig. 2 Circulating ball screw

2. Structure and Issues with the Non-Circulating Ball Screw

On the non-circulating ball screw, there are multiple springs in the nut raceway to substitute the circulating part. The balls are secured with elastic retention in a state where load is small, and when the braking action occurs, the springs shrink due to revolution of the balls, which return to their original positions when the brake is released (**Fig. 3**).

In order to satisfy the stringent requirements demanded of brakes, there is a need to optimize the springs inside the nut, and find a balance between capacity, size, and efficiency. However, because the springs are used in an arc-shape inside the nut, they exhibit behavior different to when used in a regular straight shape, and it is important to grasp this fact. Torque reduction and durability are also issues that need to be addressed.

3. Control of Ball Position Using a Spring

On non-circulating ball screws, as a control mechanism to prevent the balls escaping the raceway upon stroke, there is a spring that encloses the balls on both sides of the nut raceway. With this, the balls revolve while compressing the spring during ball screw due to braking,

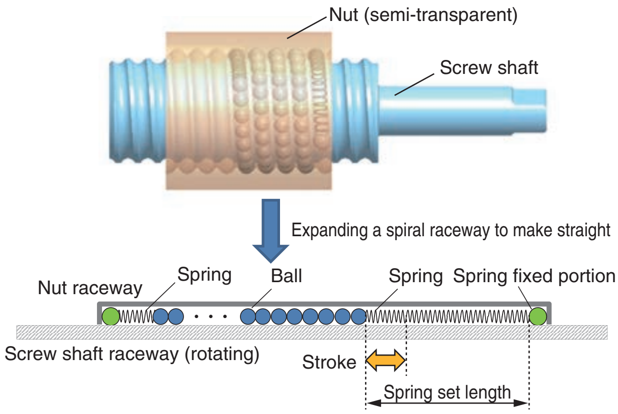

Fig. 3 Non-circulating ball screw

and if there is close to zero load, the initial position is made the position where the spring force balances the balls without revolving them, and it is possible to hold them in place with elastic retention.

Therefore, here, if the balls come away from initial position when there is a zero-load state, the amount of spring compression upon stroke will increase and there is a possibility of damaging the spring. In regards to this, **Section 3. 1** discusses a mechanism to return balls to the initial position.

Next, there is a need to set the spring force and spring allowable stroke to achieve elastic retention of balls in initial position however, because there is friction between the spring's outer diameter and raceway, the spring force and deflection is different to when the spring is straight.

As such, **Section 3. 2** elucidates allowable stroke design based on presuming friction and performing an accurate spring force and fatigue study.

3. 1 Mechanism for Returning Balls to Initial Position

Because the shape of a ball screw is similar to a rolling bearing and raceway, which are subjected to axial load, there are many common aspects. Meanwhile, because ball screws have a lead, there is a sliding element unique to a ball screw in the portion where the balls contact the raceway, and the design is such that the balls penetrate the raceway upon stroke. The direction of travel reverses to suit the stroke direction, therefore balls that make a round trip have a slightly different travel amount[2). Furthermore, because lead/lag occurs in the balls due to ball screw accuracy, the positions of the piston and nut do not change before and after braking, however the minute lead/lag of the ball in relation to the nut raceway cannot be avoided due to the mechanism, and the ball position changes. Hence, one feasible solution to returning displaced balls to the initial position is forcibly moving the balls using spring force and revolving the balls with additional stroke.

When the balls arranged in an arc are moved with spring force, friction with the raceway causes the spring force conveyed to the end of the ball to deteriorate. If there are several rows of balls such as there are in a ball screw, moving all balls by spring force is not a realistic approach. Accordingly, rather than applying a design of moving balls with spring force, JTEKT has assumed adjustment utilizing stroke. When comparing using the same axial force through calculation and actual measurement, it is clear that the load to move the balls as mentioned above is extremely large, while the load to stop the balls from revolving is extremely small. If preload is only lightly applied, the developed ball screw can sufficiently stop ball revolution with a load of only a few N. Therefore, as per **Fig. 4**, if we assume the ball position has only become displaced from the initial position by ⊿S after the axial force has come in close proximity to zero post-stroke, (②→③), it would suffice to pull back the nut slightly and return balls to the initial position. (③→④).

3. 2 Spring Force and Allowable Stroke Considering Friction from Raceway

If a spring is arranged on the raceway, the reaction force from the nut raceway upon spring compression will generate friction force in the spring outer diameter, therefore it is not possible to use calculation results of when the spring is in a straight state (preconditions of general spring calculations). Therefore, JTEKT independently created an estimated formula for spring force considering this friction force and confirmed that the value obtained from the estimation formula and actual measured value were in good agreement (**Fig. 5**).

By studying spring pitch variation in the same way, we discovered that the spring compresses the most on the side that contacts the balls, therefore it would be preferable to study spring fatigue in this area (**Fig. 6**). When we conducted a durability evaluation until the spring broke, we confirmed that the spring broke in this area, as we had predicted (**Fig. 7**). Moreover, the compression amount on the spring on the fixed side gradually decreases, therefore by making it longer than a certain length, there will be wasted space that does not compress. The spring length and stroke are determined by considering the above.

By arranging springs designed in this way, torque increases in the linear direction to suit axial force upon stroke, however torque will be stable as long as the stroke does not go close to full compression of the spring (**Fig. 8**).

If a larger stroke is preferable, it would be effective to enlarge the lead while considering the balance with volume and size.

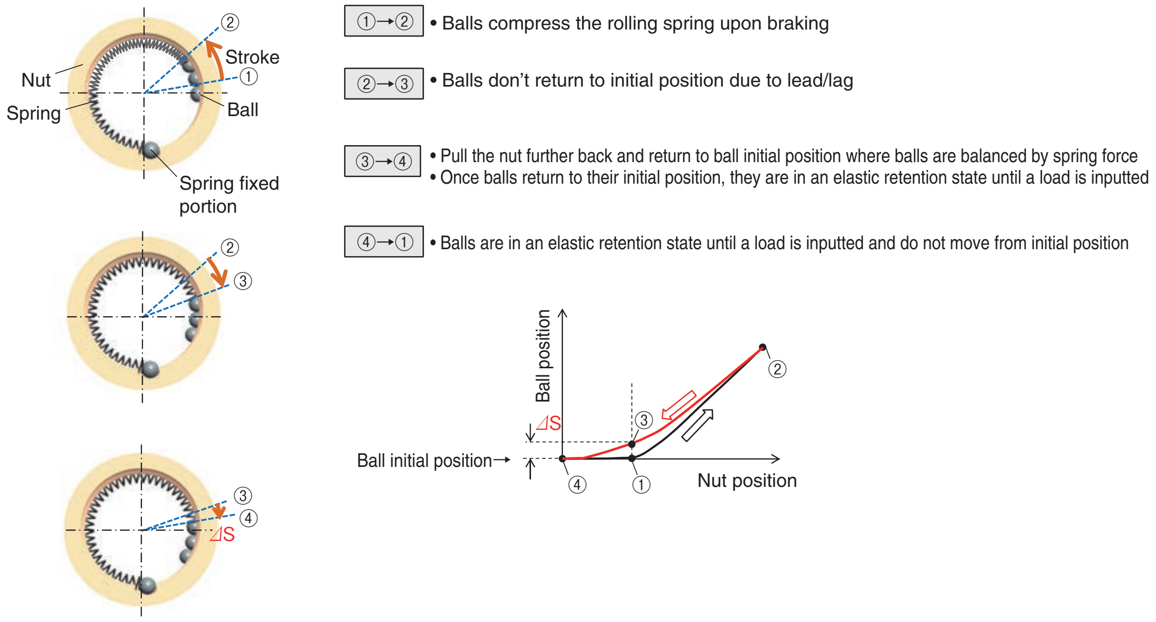

Fig. 4 How to return to the ball initial position by stroke

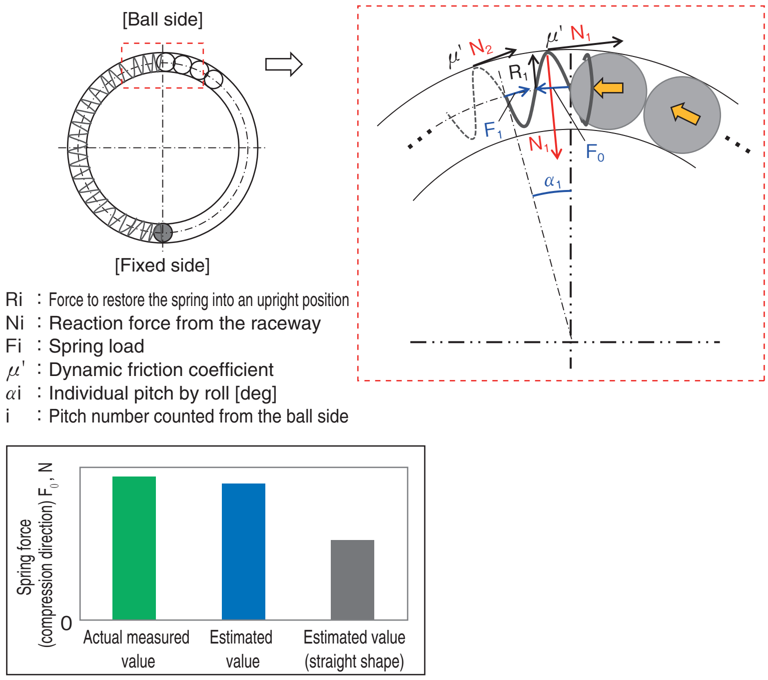

Fig. 5 Spring force with friction from raceway

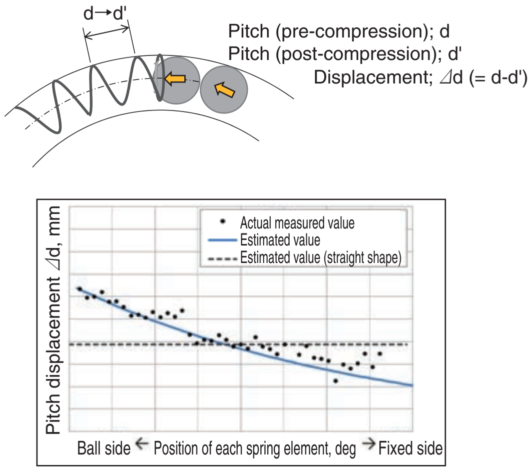

Fig. 6 Pitch change considering friction from raceway

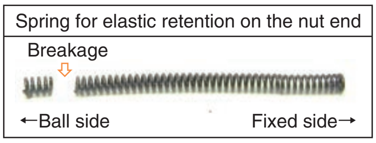

Fig. 7 Confirmation of spring breakage position by durability test

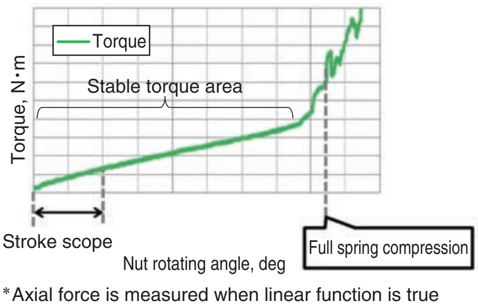

Fig. 8 Confirmation of torque stability according to ball screw stroke

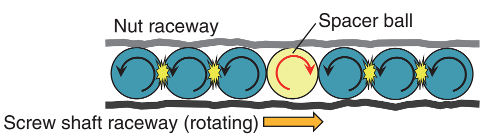

Fig. 9 Friction reduction between balls by spacer balls

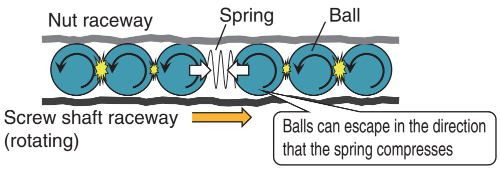

Fig. 10 Friction reduction between balls by spring

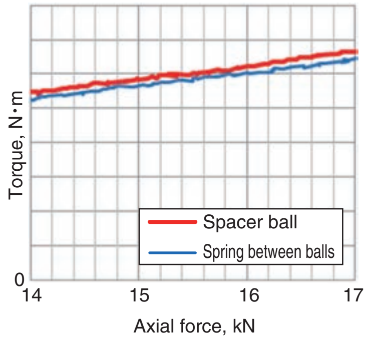

Fig. 11 Comparison of torque values using spacer balls and springs

4. Reduction of Torque Loss

Improving ball screw efficiency is effective in downsizing the motor, which is the power source, however in the case of a non-circulating ball screw, revolution occurs when the ball-to-ball clearance is blocked due to spring force. Hence, reducing friction between balls is of even greater importance than in the case of circulating ball screws. As a way to reduce friction, a common approach is to arrange small spacer balls with a diameter of a few dozen μm to make the rotation direction of the spacer balls the opposite to the balls[1), 3)] (**Fig. 9**).

Moreover, as an alternative to using spacer balls, another feasible method is arranging a spring with a short length of freedom in order to alleviate ball-to-ball blockage (**Fig. 10**). With this structure, the lead/lag can be absorbed in the direction that the spring compresses, therefore we evaluated this option believing it would be possible to further reduce ball-to-ball friction. By comparing with the same number of spacer balls, we confirmed that torque value relative to same axial force was improved (**Fig. 11**). Furthermore, in the case of ball screws for EMB, grease lubrication is assumed as opposed to conventional brake fluid, therefore there is an expectation that arranging a spring between the balls will be effective toward grease retention and supply.

5. Durability

As a result of conducting a durability evaluation under conditions in which this ball screw is predicted to be used on a vehicle, we confirmed there is sufficient durability (**Fig. 12**).

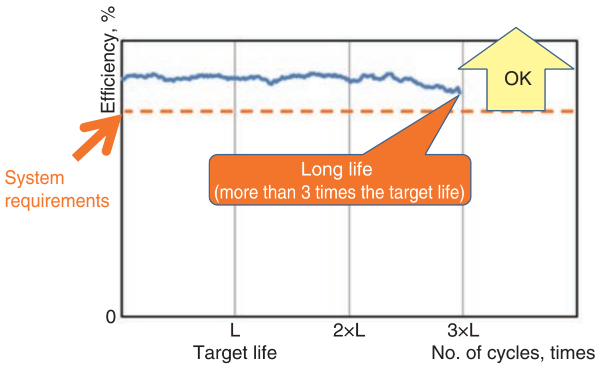

Fig. 12 Durability test result

We used a spring in a straight state, however could not detect any breakage on the exterior of the evaluated part in the same way as a new spring (**Fig. 13**).

This indicates that a non-circulating ball screw would be effective for an electric brake caliper.

Spring between balls	Spring
	

Fig. 13 Spring after normal temperature durability test

6. Conclusion

This paper has examined the application of non-circulating ball screws with no circulating part for use on electric brake calipers. Firstly, after comparing the circulating and non-circulating types of ball screw, we elucidated the ball position control mechanism of the non-circulating ball screw and also studied how to reduce torque loss. Furthermore, we conducted a durability test on the non-circulating ball screw and confirmed that it could sufficiently withstand practical use. Consequently, it was clarified that non-circulating ball screws could be applied to electric brake calipers.

Moving forward, we will optimize raceway shape and spring elements, and proceed with development including improving stroke, load capacity, etc.

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