**Electric Ball Screw Actuators for Automobiles**

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In the automotive market, many new hybrid cars and low-fuel-consuming and low-emission engines have been developed to reduce CO₂ and to produce cleaner exhaust. At the same time, many projects are advancing to achieve more car amenities and safer driving using quicker and more reliable electric motor drives. NTN had already developed a new electric ball screw for use in automatic manual transmission and engine control. Building on this, we have developed an electric ball screw actuator with modularized peripheral parts. This article introduces the structure and the features of this ball screw actuator unit.

1. Introduction

Control-by-wire technologies for automobiles are becoming more commonly adopted with one typical example being the by-wire throttle control system. Recently though, certain cars have adopted brake-by-wire technology. Control-by-wire technologies have been ever evolving in an effort to achieve better comfort and safety in operating vehicles.

Recently, NTN has developed a high-response, high-thrust, electrically driven ballscrew actuator for automobiles (hereinafter referred to as “actuator”) that can be adopted for control-by-wire systems.

This paper hereunder describes the structure and features of this actuator.

2. Structure of the actuator

**Fig. 1** shows the structure of our actuator.

The ballscrew is coupled with an electric motor via an involute spline formed at one end of the ballscrew shaft to transmit torque from the motor.

At the other end of the ballscrew shaft, a double row angular ball bearing is situated securely in an aluminum case. The ballscrew and actuator are synchronized by means of an interlocking arm. Across both ends of the actuating shaft, linear ball bearings and oil seals are arranged symmetrically.

The linear ball bearings support the actuating shaft while developing only minimum friction so that the actuating shaft can slide in the axial direction. The oil seals situated around the linear ball bearings prevent ingress of foreign material into the aluminum case. An actuating wire is connected to the coupling member at the end of the actuating shaft.

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3. Advantages of our actuator

Fig. 2 shows our actuator, and Fig. 3 shows the ballscrew for our actuator.

The actuator has undergone various tests simulating various environmental conditions including water, snow, mud, gravel, and dust along with vibration and impact testing. Through these tests, the actuator has been progressively improved and now boasts a higher degree of reliability. The actuator boasts the following advantages:

1. Highly efficient ballscrew and lower friction moving parts help achieve a higher degree of response and greater thrust force.
2. Sufficient corrosion resistance, and dust-proof & water-proof performance

These advantages are described below:

3.1 Higher efficiency and lower friction

We have set up the specifications for our actuator so that the conversion efficiency of motion of the ballscrew adopted, from both forward and reverse rotation directions, is 90% or greater. The actuating shaft can be readily moved by hand thanks to its low-friction design.

Table 1 provides the specifications for the ballscrew. Fig. 4 graphically plots the theoretical efficiency of the ballscrew. At a lead angle of 4°47’, the efficiency with a benchmark sliding screw is as low as 32%; in contrast, the efficiency of the ballscrew adopted in our actuator is very high, standing at 92%.

Fig. 5 shows the linear ball bearings that support both ends of the actuating shaft. The actuating shaft is supported by the linear ball bearings in rolling contact, thereby the resultant lower friction helps the actuating shaft to move smoothly.

### Table 1 Spec. of ballscrew

<table>
<thead>
<tr>
<th>Shaft diameter</th>
<th>Lead</th>
<th>Lead angle</th>
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<tr>
<td>14.5mm</td>
<td>4mm</td>
<td>4°47’</td>
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### Fig. 4 Efficiency of ballscrew

### Fig. 5 Liner ball bearing

3.2 Corrosion resistance, dust-proof & water-proof performance

Any automotive actuator needs to perform as designed for a prolonged period under various environmental conditions. Our actuator, in particular, has an actuating shaft that is exposed outside the case; therefore, both ends of the shaft are provided with reciprocating motion-capable oil seals to prevent ingress of foreign material.

For enhanced corrosion resistance, the actuating shaft is provided with special plating. Furthermore, the actuating shaft is equipped with a boot and shaft cap so that the shaft is not directly exposed to the ambient air (Fig. 6).
4. Evaluation test

In an effort to develop a highly reliable electromechanical actuator, we have performed various tests to verify that our actuator has sufficient performance and reliability. The major characteristics tested are described below:

4.1 Thrust force test

The load torque on a ballscrew can be determined with the following expression:

\[ T = \frac{P \cdot L}{2 \pi \cdot \eta} \]  

where,

- \( T \) : Load torque (N-m)
- \( P \) : Axial load (N)
- \( L \) : Lead of ballscrew (m)
- \( \eta \) : Efficiency 0.92

Using the result from expression (1), the thrust force can be determined with expression (2) below:

\[ P = \frac{T \cdot 2 \pi \cdot \eta}{L} \]  

For the thrust force test, a load cell was inserted between the coupling member and a fixed part as shown in Fig. 7 to measure the load.

The result of the thrust force measurement is plotted in Fig. 8. We have verified that the theoretical calculated value of 1,200 N is achieved with our ballscrew. The thrust force available from a sliding screw whose size is similar to that of our ballscrew is approximately 1/3 that of our ballscrew.

4.2 Durability test in severe environment

We have subjected the actuator samples to a durability test under severe environmental conditions with a high-temperature ambience while applying a predetermined load to each actuator sample. So that a constant load is applied to an operating actuator, we have fabricated a special durability tester that uses an additional ballscrew responsible for applying a constant load to an actuator sample. Fig. 9 shows a view of this tester. We performed a durability test for a number of loading cycles that is equivalent to the life of a car while applying the maximum expected working load to each actuator sample and, after completion of the durability test, we performed an actuator response test.
Fig. 10 shows results of the response test obtained from actuator samples before and after the durability test. Our actuator having undergone a severe durability test still boasts a higher level of response compared with the pre-test level and its post-test response shows no deterioration.

From these findings we have determined that even after having undergone a durability test under severe environmental conditions the performance of our actuator is as good as the pre-tested level.

Fig. 10 Example of operating time measurement

4.3 Combined cyclic corrosion test

Our actuator was placed in the combined cyclic corrosion tester and each sample was subjected to repeated environmental cycles. Each cycle consisted of a salt water spray, high-temperature drying, and a high-temperature high-humidity condition to verify corrosion resistance of our actuator under severe environmental conditions.

Fig. 11 shows the appearance of our actuator having undergone the combined cyclic corrosion test. The interior of our actuator having undergone the severe test does not show any problems such as rust or water ingress; the characteristics of the post-test actuator do not show any signs of problem.

Fig. 11 Internal condition after cyclic corrosion test

5. Conclusion

We have presented information about our unique, automotive electromechanical ballscrew-driven actuator that adopts various mechanical element-related technologies for realizing higher response and greater thrust force.

With electromechanical moving parts increasingly being used in recent automobile designs, more automobile designers have been considering use of ballscrew-driven mechanisms that can be actuated with smaller electric motors. Thus, our ballscrew actuator products will find a greater market share.

To be able to further improve the lighter-weight and enhanced functionality designs for its automotive electromechanical ballscrew actuator products, NTN is committed to improvements in not only elementary parts such as the ballscrew but also auxiliary components such as sensors and electric motors. Through these efforts, NTN will help expand the scope of applications of its ballscrew actuator products.

References

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