Consideration of Anti-Vibration Performance Improvement of a Servo Motor

Hiroshi Hioki Hideyuki Ishii
Akira Shimizu Satoru Onodera

1. Introduction

To meet the need for motors containing servo motors to become more compact, lightweight and high in response, servo motors find an increasing number of uses under conditions with high vibrations.

Traditional small servo motors are, in general, of a structure that adheres the bearings at a constant pressure to reduce the axial vibration displacement of the shafts. In this case, however, in uses with excessive vibrations, the layer attached to the outer ring of the bearing may peel off.

This paper proposes a motor structure that holds the ends of the bearings at both sides mechanically after adhering them at a constant pressure, thus increasing vibration resistance. The paper then describes how the proposed design is appropriate.

2. Servo motor and vibration

2.1 Issues of traditional motors

A servo motor is, in general, equipped with an optical encoder to detect the rotating position at the reverse output end. Provision must be made to prevent this encoder from malfunctioning due to vibration. If the encoder vibrates excessively due to its axial vibration, a pulse count error may occur. The worst scenario is the possibility of a damaged encoder (rotary disc).

Conventional practice to inhibit the axial vibration of the motor is to attach the bearing that supports the rotation of the motor shaft at a constant pressure. In that case, it is difficult to control the variances in the adhesive dose to fix the bearing. If a motor of such a structure is used in applications subject to excessive vibrations, the bearing may peel off. Of course, in general applications where the motor is subject to relatively small vibrations, the bearing will not peel off even in a traditional motor structure. In recent years, to meet the need for machines incorporating servo motors to become more compact, lightweight, and higher in response, the motor tends to undergo an increasing level of vibrations.

Under these major vibration conditions, to ensure high reliability in the servo motor, the motor vibration resistance must be enhanced. In particular, a motor structure that reduces the vibration displacement due to axial vibrations is in demand. It must be possible to prevent encoder damage in an excessively vibrating environment. This means that, regarding the method of fixing a bearing with an adhesive, too, provision must be made to allow the encoder to be protected even if the adhesive peels off as the worst case scenario.

2.2. Axial rigidity

To quantify the vibration resistance of the motor, this section briefly outlines the axial rigidity of the motor.

Let the rotor mass be m and the axial spring constant as determined by the bearing and its fixed structure be k. The axial characteristic frequency (f) of the motor shaft can be expressed as follows [1] :

$$f = (k / m)^{1/2} /(2\pi) \text{ --------- } (1)$$

The higher the axial spring constant k, the higher the characteristic frequency and the smaller the vibration displacement amplitude and the higher rigidity with regard to the axial vibration.

The next chapter handles the vibration resistance of the motor quantitatively with the aforementioned spring rigidity k.

3. Proposing a motor structure designed to increase axial rigidity

3.1 Structure of the proposed unit

To resolve the inconveniences mentioned above, the authors propose a motor structure that increases vibration resistance by mechanically holding the bearing ends at both sides after attaching the bearing at a constant pressure.

Fig. 1 is a schematic diagram of the proposed motor structure.

This example uses a hollow shaft servo motor with a rated output of 20W, a motor outer diameter of 42mm square, and an rpm rate of 1,000min $^{-1}$.

The structure is based on a fundamental structure where a pressure spring is used to apply a constant pressure and the outer ring of the bearing is attached to the bearing housing, while the bearing is mechanically retained by a hexagon socket set screw. This set screw is applied in the trough in the pressure spring (corrugated spring).

3.2 Considering axial rigidity

This section considers changes in the axial displacement and the axial rigidity of the shaft of the proposed unit with regard to axial loads.

Fig. 2 indicates the measurements of axial load-displacement characteristics when the tightening torque T of the set screw is zero and when it is T = 0.059N (0.6kgf-cm). However, no adhesive has been applied to illustrate a possible case of the adhesive peeling off.

When the tightening torque T of the set screw is 0N, the region where the axial load F is about 40N is within the region where the rigidity of the pressure spring is involved. In the region where F > 40N, the axial rigidity between the inner and outer wheels of the ball bearing determines the load-displacement characteristics. In this region, a great axial displacement arises, suggesting that when the motor is subjected to an excessive axial vibration force and the adhesive layer has peeled off from the outer wheel of the bearing, a great axial displacement occurs in the shaft, resulting in encoder damage.

On the other hand, if the tightening torque T of the set screw is 0.059N (0.6kgf-cm), the set screw has brought about a mechanical locking force. Therefore, even if an excessive axial vibration force is generated, the axial displacement of the shaft is minimized.

The axial spring constants k when the tightening torque T of the set screw is 0N and 0.059N were calculated based on the slope of the load-displacement characteristics.

The results were as follows:

T=0N : k = 3 x 10 ^{6} N/m

T=0.059N : k =12 x 10 ^{6} N/m

Thus, with the proposed motor structure, the axial rigidity k of the motor shaft increases. If the adhesive layer peels off from the outer wheel of the bearing due to an excessive vibration force, the axial displacement can be minimized, thus preventing encoder damage.

The characteristic frequency f calculated on the basis of Equation (1) with the axial spring constant k of 12 x 10 ^{6} N/m when the tightening torque T of the set screw is 0.059N, is about 1.8kHz (provided that m = 0.09kg). The measured characteristic frequency obtained when a real unit is hammered is about 1.6kHz. The authors therefore conclude that the rigidity evaluation given above is appropriate.

Fig. 3 shows the measurements of the axial load-displacement characteristics when the tightening torque T of the set screw is changed. One can see that the axial displacement is minimized as the tightening torque T increases. Note also that, when adhesion is used as well for the outer wheel of the bearing, the tightening torque T of this set screw should be set so that the axial force of the screw will become weaker than the adhesive strength of the adhesive. If the tightening torque is within the range where the axial displacement can be controlled to within the tolerance, it is sufficient for practical use. In the example of the sample unit, the appropriate tightening torque T of the set screw is 0.059N (0.6kgf-cm).

3.3 Effects of the proposed motor structure

The use of the proposed motor structure described above will bring about the effects described below.

① The proposed structure increases the axial rigidity of the motor shaft and reduces the vibration displacement amplitude with regard to the vibration force of the motor. In other words, it increases vibration resistance.

② Even if the adhesive layer peels off from the outer wheel of the bearing due to an excessive vibration, a mechanical locking force can be used to control axial displacement, thus preventing encoder damage. In other words, the proposed structure increases reliability in operating conditions with high vibration levels.

In the development of this motor, the ball bearing is made to a thin wall thickness to reduce size and weight.

4. Conclusion

This paper has proposed a servo motor with a structure that holds the ends of the bearing at both sides mechanically after attaching the bearing at a constant pressure. The paper then stated that a servo motor of this structure achieves high axial rigidity, thus ensuring higher vibration resistance.

This motor structure reduces the axial displacement of the shaft even if exposed to excessive vibrations. This prevents the worsening of the detection precision of the encoder and protects the encoder from damage.

This motor is designed as a direct drive without a deceleration mechanism or similar. The authors consider that it can be used in various applications as a compact, lightweight and reliable motor.

Reference

(1) Tanaka and Saegusa, " Vibration Models and Simulations, " published by Oyo Gijutsu Shuppan, pp. 50–57 (June, 1986)

Hiroshi Hioki
Joined company in 1990
Servo Systems Division, 1st Design Dept.
Worked on design and development of servo motors

Hideyuki Ishii
Joined company in 1989
Servo Systems Division, 1st Design Dept.
Worked on design and development of servo motors and sensors

Akira Shimizu
Joined company in 1982
Servo Systems Division, 1st Design Dept.
Worked on design and development of servo

Satoru Onodera
Joined company in 1986
Servo Systems Division, 1st Design Dept.
Worked on research, development, and design of servo motors
Doctor of Engineering

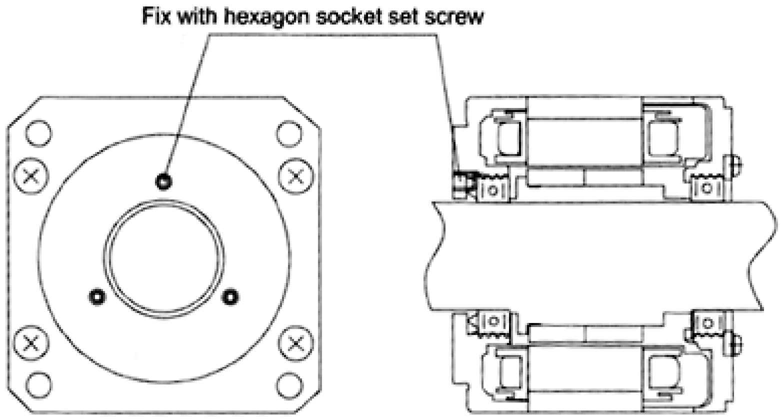

Fig. 1 Motor structure

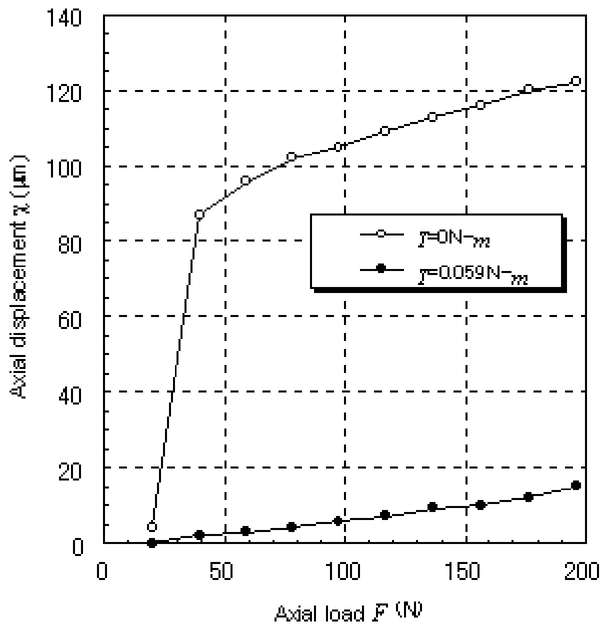

Fig. 2 Axial load-displacement curve

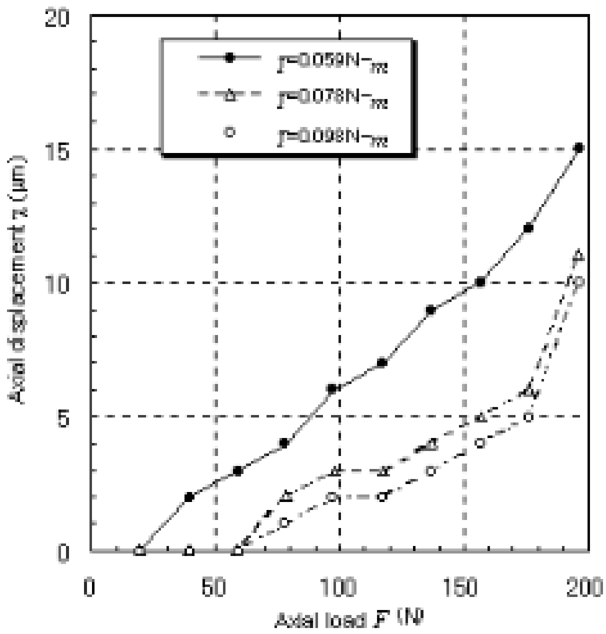

Fig. 3 Axial load-displacement curve
(changes due to the tightening torque of the screw)