Backlash Adjustment Mechanism for Reducer of Electric Power Steering System

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Electric power steering ("EPS") systems, which were first installed on subcompact cars, have been widely adopted even for medium-sized cars. Accordingly, requirements for quietness and good steering feeling of EPS systems have become increasingly severe every year.

Especially, the reducer, a core mechanism in EPS systems that functions to decelerate motor speed in favor of assist torque, has sometimes generated rattling noise when the car is driven on rough roads, thus adversely affecting the driver's feeling of luxury driving, and therefore some solution against this noise has become essential.

In order to respond to this need, a new backlash adjustment mechanism as described herein has been developed for the reducer, which can be comprised in a conventional packaging.

Key Words: reducer, worm gear, electric power steering, rattle noise

1. Introduction

In an electric power steering ("EPS") system, the output of the electric motor, which varies according to the driver's steering wheel maneuvering, is transmitted to the steering output shaft through a reducer. In column type EPS ("C–EPS") and pinion type EPS ("P–EPS"), a worm gear has been adopted as the reducer, and resin has been chosen as the material of the worm wheel thereof in order to reduce rattling noise. Initially EPS was installed only on subcompact cars, but in recent years it has come to be adopted on medium-sized cars as well. When the car is driven on rough roads, worm gear rattling noise occurs, adversely affecting the driver's feeling of luxury driving, and therefore it has become necessary to reduce this noise. In particular because P–EPS is installed in the engine room, strong demands are being made to expand the operating temperature range. However, for EPS incorporating such a resin gear, it is not a simple task to broaden the operating temperature range. Because the resin gear expands at high temperatures and this causes friction to increase, it is necessary to provide the gear with a proper amount of backlash at normal temperature. However, backlash at normal temperature causes rattling noise, creating a trade-off situation that has been extremely difficult to solve. A report is given herein on a backlash adjustment mechanism for EPS reducers that has been developed. This mechanism solves the problems of both friction and rattling noise and can broaden the operating temperature range (it has already been incorporated in mass-production P–EPS).

2. Structure of Reducer

Figure 1 shows the appearance of a P–EPS gear assembly. The structure of this gear assembly's reducer is introduced below.

Fig. 1 Pinion assist type EPS

2.1 Outline of Conventional Structure

The structure of a conventional reducer is shown in Fig. 2. Bearings supporting the worm shaft are fixed and preloaded by a tightening nut so that the worm basically does not move except in the rotating direction. As in the case of any gear, backlash between the worm and worm wheel must be provided in order to enable smooth rotation, but an excessive amount of backlash causes rattling noise, and this creates an inherent trade-off situation. The amount of this backlash is established by the distance between the worm and worm wheel centers, and therefore in the conventional mechanism it is necessary to machine each component with high precision.
2. 2 Outline of Backlash Adjustment Mechanism Structure

The structure of the developed backlash adjustment mechanism is shown in Fig. 3. In this structure, the end bearing is provided with such an inner clearance and raceway curvature as to allow the worm to oscillate around A as a fulcrum, and a special spring is installed in a gap between the bearing and housing. The as-installed state of this spring is shown in Fig. 4. The spring pushes the worm toward the worm wheel in order to eliminate backlash and to serve as a buffer to prevent noise resulting from contact between the bearing and housing. In addition, in order to ensure flexible movement of the worm, a resin coupling (flange and rubber spring shown in Fig. 3) is used for connection between the worm and the electric motor in place of the conventional serration fitting. Although this new internal structure has been adopted, the housing outline has been kept exactly the same as that of the conventional one by means of optimizing the dimensions of each part to accommodate additionally the backlash adjustment mechanism.

3. Selection of Component Materials and Specifications

3. 1 Spring

The worm is pushed by the spring toward the wheel, but excessive spring load can compromise comfortable steering feeling. It is also known from past endurance testing that resin or rubber material cannot retain adequate performance because of its load variation and permanent deformation over time. Therefore, a steel spring was adopted instead of such elastic material as the rubber mentioned above. However, if the steel spring is merely applied as it is, it can lead to new rattling noise due to contact between the spring and housing. Also, because the worm moves minutely in both vertical and horizontal directions, it is very difficult to keep the spring acting on the bearing's entire circumference to prevent noise. However, these problems have been solved by the special spring configuration shown in Fig. 4. While of course the spring must not create rattling noise with the housing, it must have load characteristics favorable for comfortable steering feeling. In the range of low steering torque, a lighter spring load is favored in order to minimize the feeling of friction, whereas in the range of high steering torque, the force separating the worm from the worm wheel is high, and therefore a heavier spring load is desirable. To investigate the load-displacement characteristic of the spring, the load generated by displacing the bearing in the vertical direction was measured as shown in Fig. 5. The result, as shown in Fig. 6, indicates that the spring has the desired characteristics. This two-stepped characteristic is created by the spring protrusion shown in Fig. 4. When the displacement amount is small, this protrusion isn’t in contact with the housing, but when the displacement amount becomes large, contact with the housing occurs, generating the characteristic mentioned above.

![Fig. 2 Conventional structure of reducer](image1)

![Fig. 3 Backlash adjustment mechanism](image2)

![Fig. 4 State of spring as installed](image3)
3.2 Rubber Spring

Although in the conventional product the worm was coupled with the motor by means of a serration fitting, in the developed backlash adjustment mechanism a rubber spring (resin coupling) has been adopted because the worm must be able to move flexibly (Fig. 7). Although the rubber spring must be soft enough to perform its function, a too-soft rubber material may have a large compression rate under torque and cause the part to be broken or deformed. Therefore, a material with appropriate hardness and allowable compression ratio was selected, and the rubber spring surface in contact with the flange was made to form a circular arc shape to enable flexible tilting of the worm. Generally, gears and couplings are not so prone to rattling noise as long as they rotate in one direction only. In the case of steering systems, however, the turning direction changes frequently, at many times the steering wheel is not being turned at all, and it receives reactive force directly from the tires. Because of these factors, requirements concerning noise are severe. In the conventional product, a serration fitting is used, the tolerance levels of which are very severe. In the case of this backlash adjustment mechanism, however, because the worm and motor are connected using a resin coupling, such severe tolerances become unnecessary. This can be regarded as a great advantage of this mechanism.

4. Comparison with Conventional Reducer regarding Performance

A comparison of the conventional and developed reducers was carried out concerning such performance features as rattling noise and rotational torque. Results are as follows.

4.1 Rattling Noise at Different Temperatures

Results of rattling noise measurements at different temperatures are shown in Fig. 8. In the case of the conventional reducer, because resin has a large linear expansion coefficient, the noise level worsened at low temperatures because the resin wheel shrunk. In the case of the developed backlash adjustment mechanism, however, the worm moves to offset such worm wheel shrinkage, and therefore noise level increase was not observed.

4.2 Rotational Torque at Different Temperatures

Because P–EPS often must operate in high-temperature environments, it is necessary to minimize the increase of friction at high temperatures. The measured relationship between temperature and rotational torque is shown in Fig. 9. Rotational torque generally increases with increases in temperature due to expansion of the resin worm wheel. With the developed backlash adjustment mechanism, however, the change of rotational torque at high temperatures is reduced to only half that of the conventional mechanism because of the damping effect of the spring.
4.3 Backlash and Rattling Noise

The relationship between backlash and rattling noise is shown in Fig. 10. In the developed backlash adjustment mechanism, the noise level changes little in relation to backlash changes, while in the conventional one, rattling noise tends to increase as backlash increases, rendering the acceptable backlash range very narrow. The developed backlash adjustment mechanism alleviates the need for severe part and assembly precision.

*The backlash referred herein is the clearance between the worm and the worm wheel expressed in terms of rotation angle of the worm wheel. Since the new backlash adjustment practically does away with the clearance, the values calculated from the dimensions of parts are shown.

4.4 Backlash and Rotational Torque

The relationship between backlash and rotational torque is shown in Fig. 11. Because the developed backlash adjustment mechanism reduces the increase of rotational torque in the small backlash area, the effect on steering feeling when the worm wheel expands at high temperature due to resin gear moisture absorption, etc. is minimized.

5. Example of Application

The structure and performance of the backlash adjustment mechanism have been described in the above sections. Now, an example of actual use on a P–EPS model now under mass-production will be introduced. In the case of reducers, the backlash upper and lower limits are set based on rotational torque and noise. The settings for this particular P–EPS model are shown in Fig. 12.

The light blue area in this figure represents the range actually used during assembling. In the case of the conventional reducer, assembly had to be carried out with extremely high backlash precision, but in the case of the new product with the backlash adjustment mechanism, assembly can be carried out with a wider allowable range of backlash, improving reliability in the assembly process. Also, the allowable limit of resin wear after endurance and the allowable limit of friction at high temperatures or after moisture absorption have been increased. As a result, the new reducer has much greater reliability than the conventional type.
6. Conclusion

EPS initially was installed only in compact and subcompact cars, but demands for EPS applicable to larger vehicles as well grew rapidly because of its environmentally friendly attributes such as energy efficiency and non-use of oil. Today, application of EPS even on luxury vehicles has become necessary because of the need to integrate the steering system into the vehicle control system. Accordingly, EPS with further improved levels of steering feeling and quietness has become necessary. Our efforts to improve this backlash adjustment mechanism will continue in order to meet the demands of customers and the market.