Research of Gear Modification on Noise Optimization of EV Reducer

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Abstract. Based on the simulation software MASTA of gear system, the micro-modification optimization can effectively improve the howling noise. Through gear contact spot test and simulation calibration, the correction model of gear can be established. In order to reduce the transmission error of gear, and optimize the gear contact pattern, the micro modification of gear was researched. It is found that the micro modification of gears can effectively improve the howling noise of gears. The study could improve the ability of independent research and development of gear system.

Keywords: Gear modification, noise optimization, gear contact spot, transmission error.

1. Introduction
Electromagnetic noise of motor and howling noise of gear are common problems in the EV reducer [1]. In this paper, howling noise of gear is studied. The macro parameter adjustment of gear and the improvement of assembly technology level can improve the noise effect, but often not meet the requirements of the noise target, we must use the micro modification of gear to optimize the noise. Through micro modification of gear, can effectively reduce the contact stress and the transmission error [2], the howling noise of gear can be effectively controlled and the NVH quality of the EV reducer can be improved.

2. Establish and calibrate the gear simulation model

2.1. Establish the simulation model of MASTA gear system.
Based on the simulation software of MASTA [3], a refined model of the gear system is established, as shown in Figure 1.

Fig. 1 Refined Model of Gear System
As the shell stiffness of the EV reducer, has great influence on the contact spot and transmission error, the finite element model of the shell is established, and the condensed shell stiffness matrix is introduced into the MASTA simulation model, which can ensure the accuracy of the simulation model.

2.2. Gear contact spot test and simulation calibration.
Affected by the manufacturing error of gear, the manufacturing error of box, the error of bearing and installation position, and the deformation of each component after being loaded, the gear tooth contact will deviate from the ideal state [4]. Therefore, it is necessary to calibrate the contact spot test and simulation model first, and then conduct further micro modification optimization of gear. In order to keep the design condition of the test consistent with the vehicle operating conditions, the contact spot test calibration condition can be divided into two types, driving condition and braking energy recovery condition. According to the highest operating torque, there are three levels of operating conditions, 20% maximum torque, 60% maximum torque and 100% maximum torque. Calibrate the contact spots consistent with the above six working conditions. Take the calibration of a primary gear pair under the condition of 60% peak torque as an example, as shown in FIG. 2, test and simulation comparison of the driving condition of the first gear pair, as shown in FIG. 3, Test and simulation comparison of braking energy recovery condition of first gear pair.

![Fig. 2 Test and simulation comparison of the driving condition](image)

3. Micro parameter optimization design of gear

3.1. Gear micro modification
Based on contact spot simulation and test calibration model, design the micro modification parameters of gear, the micro parameters of tooth lead and tooth profile are designed, using the multi objective optimization method to find a set of optimal solutions, take contact spots and transmission errors as target. The aim of optimizing gear noise is achieved [5]. In this paper, the gear micro modification parameters are shown in Table 1.
Table 1. Gear micro modification parameters

| Parameters               | Driving gear (26 teeth) | Driven gear (75 teeth) |
|--------------------------|-------------------------|------------------------|
|                          | Drive face              | Drag face              | Drive face | Drag face |
| Crowning Relief /µm      | 2                       | 0                      | 2          | 3         |
| Linear Relief /µm        | 8                       | -6                     | 5          | -5        |
| Barrelling Relief /µm    | 4                       | 2                      | 3          | 2         |
| Linear Relief /µm        | 0                       | -5                     | 3          | -5        |
| Parabolic Tip Relief /µm | 2                       | 1                      | 0          | 1         |

After the optimization, the contact spot of the first gear pair is shown in FIG. 4.

(a) Driven gears in driving condition   (b) Driven gears in braking energy recovery condition

Fig. 4 Optimized gear contact spots of the first gear pair.

Comparison of transmission error peak-to-peak values is shown in FIG. 5.

(a) Comparison in driving condition   (b) Comparison in braking energy recovery condition

Fig. 5 Comparison of transmission error peak-to-peak values

For the first gear pair, after the optimization of contact spots, the original partial load and uneven spots were optimized, the uniform spots were distributed in the center of tooth surface, and the contact surface pressure amplitude was also significantly reduced. Under the driving condition, the contact surface pressure was reduced from 1621.8Mpa to 892.8Mpa. Under the braking energy recovery condition, the contact surface pressure was reduced from 1727.5Mpa to 851.5Mpa.

The peak to peak values of the transmission error were significantly improved in the full torque segment. In driving condition, the peak to peak value of transmission error was optimized to less than 0.3µm. In braking energy recovery condition, it is optimized to less than 0.4µm. Both in driving condition and in braking energy recovery condition, all can reach a very stable gear meshing condition.
3.2. The verification results of EV reducer on real car

According to the micro modification parameters of the gear, the sample gear was processed, and the manufacturing error of the gear was detected within the design range. The noise of the real car was tested, and the comparison of Vehicle near field noise test was shown in the FIG. 6.

![Fig. 6 Comparison of Vehicle near field noise test](image1)

![Fig. 7 Comparison of Vehicle near field noise test](image2)

It can be seen that after the noise optimization of gear, the noise test results of real car show that the optimized noise decreases by 15-30dB, which greatly improves the noise quality of real car gear.

4. Summary

Through the calibration between the contact spot test and the simulation model, the accuracy of simulation model can be guaranteed. Based on the simulation model, a set of micro-parameters of gear is adjusted by multi objective optimization, which provides a guarantee for the improvement of gear noise optimization.

Micro parameter optimization was carried out, to improve the original biased load and uneven spots. Then, the contact spots were uniform and were at the center of the contact surface, and the contact surface pressure value was also greatly reduced; The transmission error of gear is also greatly reduced. The noise of gear can be significantly reduced in the full torque segment.

Through the noise test of the real car, the research content of this paper can effectively solve the noise problem of EV reducer, which has a very good guiding significance.

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