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Mechanism of Multi-Source Excitation for Whistling Sound of Gear Teeth in Automotive Electric Drive System

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Abstract: This paper deeply discusses the causes of gear howling noise, the identification and analysis of multi-source excitation, the transmission path of dynamic noise, simulation and experimental research, case analysis, optimization effect, etc., aiming to better provide a certain guideline and reference for relevant researchers.

Keywords: Automotive electric drive system; Whistle of gear teeth; Multi-source excitation mechanism

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1. Introduction

In the development of electric vehicles, silence quality was a subversion of traditional fuel vehicle trademark advantage, when the motor instead of internal combustion engine, had to be covered in the internal combustion engine roar transmission system noise is infinite amplification, the frequency of most mechanical acoustic noise caused by the howling of the gear, this kind of noise exposed the electric drive system defects in the design and manufacture of precision technology. The gear transmission part of the motor drive system mainly includes the drive gear, bearings, housing and lubrication system, and other components [1]. Gear at high speed in electric cars, electric drive system, gear mesh stiffness, transmission error, and tooth surface meshing impact and friction can interact to produce vibration and noise. Based on this, this study aims to comprehensively analyze the multi-source excitation mechanism and control strategy of the whistling sound of the gears in the electric drive system of the vehicle to further improve the comfort of the electric vehicle and provide more professional services for users.

2. The cause of the gear howling noise

2.1. The contact mismatch of the gear tooth surface

Gear may cause different degrees of wear on the tooth surface due to poor lubrication, uneven load distribution, foreign matter mixing, and other reasons. In the area of heavy wear, it will not be able to make good contact between the tooth surfaces, resulting in abnormal contact stress distribution, and the area of contact stress wear is light, and there will be too much pressure in the area, which will cause severe vibration and noise [2]. For example, if a little older gear pitch, another gear pitch smaller, so will appear in the process of meshing impact and collision between tooth and tooth, thus appearing the gear howling noise pitch serious cases, even affects normal equipment operation and service life [3].

2.2. The lack of accuracy of the gear tooth surface

Insufficient manufacturing accuracy will cause tooth profile error, tooth orientation error, and large surface roughness, resulting in poor tooth contact. Among them, the tooth profile error refers to the actual tooth profile and theoretical tooth profile as a result of the deviation between the shock and vibration. The appearance of tooth orientation error will not only affect the smoothness of gear meshing, but also cause vibration and noise. If the surface roughness is too rough, the friction and wear of gear meshing will increase, and the gear will produce high-frequency vibration during operation, and then produce howling noise.

2.3. The influence of dynamic characteristics of the gear transmission system on howling noise

In the process of gear transmission, the meshing of gears and the operation of bearings will generate exciting forces, so as to better act on the system. When the excitation frequency is the same or close to the natural frequency of the system, the system will resonate, so that the vibration amplitude of the gear increases, resulting in strong howling noise. For example, when the motor speed changes, resonance will occur when the excitation frequency coincides with the natural frequency of the gear transmission system, resulting in noise, causing damage to other components, and affecting the service life of the equipment.

2.4. The unreasonable number of gear teeth and transmission ratio

The unreasonable selection of the number of teeth and the transmission ratio will lead to the frequency of the howling noise close to the excitation source frequency, resulting in resonance or noise superposition. For example, when the gear meshing frequency and turn the frequency of the motor or the frequency doubling approaches, the interaction between the two will produce strong vibration and noise; When the gear meshing transmission ratio is not selected properly, it will generate additional vibration and noise during the operation of the gear, thereby enhancing the risk of gear wear and failure [4].

3. Identification and analysis of multi-source excitation

In terms of internal excitation, when the active gear teeth and the driven gear teeth enter or exit the engagement, the stiffness mutation will make the system produce dynamic response, causing vibration and noise; In terms of external excitation, bearing stiffness will change with speed, load and other factors, thus affecting the change of rotation; Electromagnetic excitation is the interaction of the air gap magnetic field between the stator and the rotor when the motor is working, and the frequency is related to the number of motor poles and the frequency of the power supply. Within a specific frequency range, the electromagnetic excitation force will form high-frequency noise, interfere with the normal vibration characteristics of the gear system, and aggravate the problem of howling noise. Together, these factors determine the generation and propagation of gear howling noise in the automotive electric drive system [5].

4. The transmission path of vibration noise

In solving the problem of gear howling noise in the automotive electric drive system, the synergy effect of multi-dimensional optimization measures is significant. Optimizing the gear design is the basis. By improving the gear tooth surface geometry, such as adopting a more reasonable tooth profile curve, the gear can contact more smoothly during meshing, and reduce the impact and vibration caused by the tooth surface shape mismatch. At the same time, improving the processing accuracy and surface finish, high-precision processing can ensure that the gear parameters meet the design requirements, and the improvement of surface finish can reduce the friction and wear between the tooth surfaces, thereby reducing the abnormal vibration and noise caused by friction and wear. The micro modification of the gear is the key. Aiming at the tooth shape error, the deviation between the actual tooth shape and the theoretical tooth shape of the gear is accurately corrected, so that the gear meshing is closer [6]. In addition, gear modification, such as tooth drum and tooth contour modification, can effectively reduce the transmission error, avoid large vibration due to error accumulation, and can also reduce the meshing stiffness fluctuation, so that the gear meshing process is more stable [7]. Dynamic optimization, adjusting the geometric parameters of the gear transmission system and transmission ratio, reasonable layout of the gear position, changes the system's natural frequency, making it avoid gear meshing excitation frequency, and avoid the occurrence of resonance phenomena. Vibration control and isolation as the last line of defense, the use of damping devices such as rubber cushions, spring shock absorber, absorb and dissipate the vibration energy generated by the gear transmission system, while the use of sound insulation materials to wrap the gearbox, reduce the transmission of noise to the car, multi-pron-based, comprehensively reduce the gear noise, improve the vehicle driving comfort [8].

5. Simulation and experimental research

5.1. Simulation of dynamic excitation force

The dynamic excitation force simulation is to thoroughly analyze the dynamic meshing force and acoustic radiation characteristics of gears, and accurately simulate the meshing state of gears in the actual operation process through advanced simulation software and algorithms, and calculate the dynamic meshing force magnitude and direction changes of gears at each meshing position. Dynamic exciting force simulation will also be based on the acoustic theory, analysis of how to stimulate the surrounding air vibration, the dynamic meshing force to produce sound radiation, thus better predict gear in noise levels and frequency distribution under different working conditions, to provide basic data for further research [9].

5.2. The modal analysis

Modal analysis is used to evaluate the dynamic characteristics [10] of the gear transmission system by establishing a finite element model of the system and calculating its natural frequency, damping ratio, and mode shape. Among them, the natural frequency reflects the characteristics of the system in free vibration, and the modal shape directly reflects the vibration form of the system at different frequencies. This can not only understand the resonance frequency of the gear transmission system, but also find the corresponding modal shape, and clarify the vibration weak link of the system in different modes, which provides a certain basis for avoiding resonance and optimizing design.

5.3. Experimental verification

In a controlled experimental environment, researchers applied loads and speeds similar to the actual working conditions to the gear transmission system through bench tests, and measured the vibration and noise response of the system for analysis, so as to obtain real data. In addition, the researchers compared the test results with the simulation data. If the agreement between the two is high, it means that the simulation model is accurate and reliable, and the simulation results have reference value. If there is a deviation, the need to modify the simulation model and optimization to improve the accuracy and practicability of the study [11].

6. Control measures of howling noise

6.1. Optimize the gear design

When dealing with the problem of the howling noise of gears in automotive electric drive systems, a variety of optimization strategies need to be comprehensively applied. Optimizing the gear design is the primary measure, and improving the gear tooth surface geometry can greatly improve the gear meshing performance. For example, an involute gear can optimize the contact state of the tooth surface by reasonably adjusting the displacement coefficient, so that the force of the gear is more uniform in the meshing process and the vibration caused by local stress concentration is reduced. At the same time, it is very important to improve the machining accuracy and surface finish. High-precision machining can ensure that the gear parameters strictly meet the design requirements and reduce the influence of manufacturing errors on gear meshing. And smooth tooth surface can reduce the friction and wear and tear, reduce because of the heat generated by the friction and noise [12].

6.2. Gear micro modification

Gear micro modification is the key to further optimizing the gear performance. Through the tooth shape error optimization, the deviation between the actual tooth shape and the theoretical tooth shape of the gear is accurately corrected, so that the gear meshing is more accurate. Gear modification, such as tooth-to-tooth drum and tooth top edge trimming, can reduce the transmission error, avoid the impact vibration caused by error accumulation, and also reduce the meshing stiffness fluctuation, so that the gear meshing process is more stable.

6.3. Dynamic optimization

Kinetic optimization aims to avoid resonance. The geometric parameters and transmission ratio of the gear drive system are adjusted to change the natural frequency of the system so that it avoids the gear meshing excitation frequency and prevents resonance from occurring [13].

6.4. Vibration control and isolation

Vibration control and isolation as a supplementary means, the use of damping devices such as rubber damping pad to absorb vibration energy, sound insulation materials such as sound-absorbing cotton, sound insulation felt to wrap the gearbox, effectively reduce the spread of noise to the car, multi-pipe, significantly reduce the gear howling noise, improve the vehicle NVH performance.

7. Case study and optimization effect

In the process of working in a certain model, a sharp gear howling noise can be obviously heard, which affects the driver’s experience. Based on this, this case aims to better find the cause of the problem and analyze it in detail. Firstly, through the simulation technology of dynamic excitation force, the researchers found that the dynamic meshing force fluctuated greatly in the process of gear meshing, so that the gear produced periodic vibration and noise. Secondly, when the researchers conducted the simulation analysis, it was found that some modal frequencies of the gear transmission system were close to the frequency of the howling noise, while there was a certain risk. For example, if the gear meshing excitation frequency coincides with the natural frequency of the system, the vibration frequency will become larger, resulting in a large howling noise [14]. Finally, when analyzing the characteristics of sound radiation, the researchers found that the vibration energy generated by gear meshing can be transmitted to the air through the shell and other structures, thus forming a more obvious sound radiation. Based on the above analysis results, the researchers put forward the following optimization scheme: in the gear design, the researchers recalculated the gear parameters by changing the number of teeth and modulus of the gear, so that the gear meshing frequency avoided the resonance frequency range of the system and reduced the possibility of resonance. The researchers reduced the impact of meshing and the error of transmission by trimming the tooth shape and the tooth drum and improving the contact state of gear meshing, so as to reduce the fluctuation of dynamic meshing force. In terms of the shell structure, the researchers increased the shell stiffener to improve the overall stiffness of the shell and reduce the vibration response under the gear meshing excitation. In order to better verify the effectiveness of the optimization measures, the researchers carried out simulations and experiments. The simulation results show that the dynamic meshing force fluctuation of the gear is significantly reduced after optimization, the resonance frequency of the system and the gear meshing frequency no longer coincide, the vibration response of the shell is reduced, and the intensity of acoustic radiation is also greatly weakened. The bench test and vehicle road test further confirmed the optimization effect. Under the same working conditions, the noise of the gear howling in the car was significantly reduced, and the driving comfort was significantly improved, indicating that the proposed optimization measures are effective, which provides a reference for solving similar gear howling problems [15].

8. Conclusion and prospect

In this paper, an in-depth analysis of gear howling noise is carried out to better reveal more multi-source excitation mechanisms, so as to ensure the smooth operation of electric vehicles. The optimized gear design can not only improve the geometry of the tooth surface, improve the machining accuracy but also reduce the transfer error and the meshing stiffness fluctuation, so as to avoid the resonance phenomenon and reduce the noise caused by it. In the future, researchers can explore new noise-reducing materials to better enrich the research methods in the field of electric vehicles, provide some more perfect solutions for gear howling noise control, and promote the development of electric vehicles.

Disclosure statement

The authors declare no conflict of interest.

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