Research on Order Analysis Method of Vibration Signal of Rear Axle Main Reducer

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Abstract. As a key component to increase torque and reduce rotation speed in automobile transmission system, the quality of final drive assembly is related to the working performance of the whole transmission system. As the core component of the rear drive axle of an automobile, the main reducer of the automobile bears the functions of decelerating and increasing the driving torque. Its quality directly affects the safety and comfort of the automobile. The transmission stability and transmission noise of the main drive bevel gear of the main reducer are one of the important factors that affect the performance parameters of the whole system. The order analysis can transform the equal time sampling of vibration signal into equal angle sampling, and transform the non-stationary signal in time domain into the stationary signal in angle domain. Then, the frequency of rotation speed and the position of each harmonic can be determined by spectrum analysis. Starting from the function and structure of the main reducer of the automobile rear axle, this paper explains the necessity of analyzing its vibration signal, and expounds the mechanism and source of the vibration of the main reducer.

1. Introduction

In modern society, as an indispensable means of transportation, automobiles play an extremely important role in the national economy and people's daily life. The rapid development of the automobile industry has driven the development of the upstream and downstream industries, and China's auto parts industry has gradually attracted worldwide attention. The automobile industry is a comprehensive industry of deep processing, with large industrial correlation and high technology intensity. It is a powerful driving force for the development of the national economy [1]. The vibration of the rear axle final drive is one of the important factors that affect the ride comfort of vehicles. Vibration and noise generated during the operation of a car are one of the important indexes for evaluating the performance of the car, and at the same time it directly affects the riding comfort and driving safety of passengers [2]. As a developing country, China has a relatively low share of cars and there is still room for development in the after-sales market. In the production, each manufacturer regards the vibration reduction and noise reduction of the rear axle final drive as an important goal of product quality control. Twenty percent of car accidents are caused by rear axles, so it is necessary to
carry out strict quality inspection before leaving the factory [3]. In the automotive transmission system, the main reducer as an important part is usually produced as a single functional component. As the core component of the rear drive axle of the car, the main speed reducer of the car bears the functions of deceleration and increasing driving torque. Its quality directly affects the safety and comfort of the car [4].

Cars are assembled from thousands of parts, and these parts are produced in series. In order to ensure the performance of the entire vehicle, this requires the entry of raw materials from the raw materials, mechanical processing and heat treatment through automobile inspection technology [5]. The vehicle is a complex vibration system, which is composed of multiple subsystems with inherent vibration characteristics. The drive axle assembly as one of the subsystems is an important excitation source for vehicle vibration and noise. In the process of product manufacturing, quality inspection is the last hurdle before leaving the factory. The final quality of the products leaving the factory is closely related to the implementation of quality inspection [6]. The comprehensive evaluation method of the rear axle main speed reducer of the automobile is used to detect the main performance indicators of the speed reducer and the differential assembly, including the meshing status of the tooth surfaces of the main and passive bevel gears, the noise level, preload and differential speed status. The transmission stability and transmission noise of the main drive bevel gear of the main reducer is one of the important factors that affect the performance parameters of the whole system. In addition to the gear noise and bearing noise, it also stimulates the surface vibration of the drive axle housing and radiates noise [7]. Under normal circumstances, when the main reducer fails, these types of main components have a strong correlation with failures [8]. The order analysis can transform the equal time sampling of vibration signal into equal angle sampling, and transform the non-stationary signal in time domain into the stationary signal in angle domain. Then the frequency spectrum analysis can be done, and the rotational speed frequency and its harmonic position can be determined, so as to avoid frequency ambiguity and get clear frequency spectrum.

2. Vibration Mechanism and Common Faults of Main Reducer

The final drive is located at the rear drive axle of the car. Its function is to receive the motion and torque from the drive shaft, change its direction and size, and then transmit the power to the rear wheels to drive the car forward. Because each part has a certain tolerance, the given tolerance is too small, which will lead to a sharp rise in cost. Therefore, in the design of the automobile main reducer, the adjustment link is reserved to ensure the final accuracy requirement. The final drive assembly consists of the final drive, differential assembly, reducer housing, etc. It is the core component of the rear drive axle. All transmission functions of the rear drive axle are realized through the final drive assembly. Therefore, the performance and quality of the final drive assembly must be guaranteed [9]. The main reducer is mainly composed of a driving bevel gear, a driven bevel gear and a differential, wherein the driving bevel gear and the driven bevel gear are the core components in the main reducer and are also the main sources of vibration reduction signals. The operation status of the main drive unit of the automobile affects the performance of the drive system of the vehicle important meaning.

The gear types of automobile main reducers are generally spiral bevel gears and hypoid gears. These gears have a large overlap coefficient during transmission, and at least two pairs of gear teeth mesh at the same time, so they can withstand a large load and work smoothly. The main reducer assembly in the automobile drive axle is a key component of the automobile transmission system. Its main function is to increase the input torque and reduce the speed, which can change the direction of power transmission and thus distribute the power to the left and right drive wheels. Make the car drive, and make the left and right drive wheels have the differential function required by the car's driving kinematics.

The processing quality of the main and passive gears and the assembly accuracy will directly affect the vibration and noise levels of the main reducer. The driving axle of an automobile may be arranged on the front axle of the automobile, or on the rear axle of the automobile, or both the front and rear axles. The driving wheel is connected to the wheel flange at the outer end of the half shaft through
bolts. The wheels turn with the shaft, which drives the car. In the gear transmission process, due to the influence of factors such as backlash and gear manufacturing errors, it often produces disengagement, which in turn produces gear impact. Gear impact is not only an important source of noise, but also easy to cause damage to the tooth surface and reduce the service life of the gear. In order to ensure the quality of the reducer assembly, it is necessary to conduct a comprehensive performance test after its assembly is completed, as a key guarantee method for product quality, to prevent unqualified products from flowing into the next process, thereby avoiding greater losses. When the layout of the drive axle and the engine are related to each other in the front and rear of the car, they form the layout of the engine front and front axle drive, the engine front and rear axle drive, and the engine rear and rear axle drive, respectively [10]. In the actual operation of the main reducer, the damping force and elastic force of the whistling of the active and passive gears are nonlinear, and the damping force and elastic force of the bearing of the main and driven gears are also nonlinear, so the dynamic model of the main reducer is a very complex non-linear vibration system because the main reducer assembly is a rigid flexible composite system with multiple rotors.

3. Order Analysis Theory and Program Design

3.1. Acquisition and Processing of Speed Signal

The principle of rotational speed pulse measurement is to form a changed pulse signal by proximity switch according to the change of the distance between the groove part of the key phase device on the rotating shaft and the surface of the rotating shaft. Driving the rear axle involves the meshing transmission of five pairs of gears while the applied load is uncertain. At the same time, due to the meshing of many pairs of gears, the load of the whole drive axle becomes more complicated. The signals required for order analysis are equiangular interval signals, so the vibration time domain signals need to be resampled at equiangular increments according to the rotational speed information. When the gears are running together, the number of teeth involved in meshing gradually changes from a smaller number of teeth to a larger number of teeth and simultaneously participates in spraying. After that, the number of teeth involved in whistle-blowing gradually decreased, and then the number of teeth of whistle-blowing wheels increased again.

The system model of linear quadratic optimal control is a system expressed in the form of state space. The objective function is a quadratic function that integrates the state of the object and the control input. Linear optimal control usually includes an optimal problem with feedback. The goal of vibration control is to minimize the following error function:

$$E(k) = \sum_{i=1}^{N_e} e_i^2(k) = \sum_{i=1}^{N_e} \left( p_i(k) + c_i(k) \right)^2$$

(1)

Here $N_e$ is the number of error sensors in the system, and $p_i(k)$ and $c_i(k)$ are the disturbance and control quantities at k time of the ith sensor respectively. The goal can be achieved by adjusting the weight of the neural network through the following gradient descent algorithm:

$$w(k+1) = w(k) - \frac{\partial E(k)}{\partial w(k)}$$

(2)

Where $\mu$ is the convergence coefficient. The control quantity $c_i(k)$ at the ith error sensor is:

$$c_i(k) = \sum_{j=1}^{N_y} x_{ij}(k)^* TF_{ij} = \sum_{j=1}^{N_y} \left( \sum_{i=1}^{N_k} x_{ji}(k) w_{ij} \right)^* TF_{ij}$$

(3)
Where $N_o$ is the number of drivers, $N_h$ is the number of hidden layer nodes, * is the convolution operator, and $TF_{ij}$ is the transfer function between the jth driver and the ith sensor.

Vibration control algorithms include output layer and hidden layer training algorithms.

The training algorithm of the output layer is:

$$
w_{ij}(k+1) = w_{ij}(k) - 2\sum_{i=1}^{N} e_i(k) g_{ij}(k)
$$

(4)

Where $g_{ij}(k)$ is the hidden layer output signal after filtering:

$$
g_{ij}(k) = x_{ih}(k) * TF_{ij} = TF_{ij} * f\left(\sum_{q=1}^{N} x_{qj}(k)w_{iq}\right)
$$

(5)

A complete mechanism needs to be composed of mechanism, force, constraint, motion excitation, etc. Physical constraint is an important component to realize the establishment of virtual prototype, and is the guarantee to realize the real reliability of simulation analysis. The key of calculating order tracking technology is how to apply software method to realize equal angle resampling based on vibration signal and rotational speed signal of rotating machinery. The acquisition process of the rotation speed curve is to input the processed rotation speed pulse data and output the rotation speed at the arrival time of each rotation speed pulse. Ignore the heat generated by friction or collision and the consequences of temperature rise caused by load changes, which may lead to thermal deformation and viscosity drop of lubricating oil in actual operation.

### 3.2. Determination of Resampling Frequency

Amplitude modulation of vibration signal refers to the periodic fluctuation load caused by tooth surface error due to low machining accuracy or low installation accuracy of gear and gear shaft eccentricity, which causes periodic fluctuation of vibration time domain curve. As an elastic mechanical system, gear transmission system will cause vibration and noise in gear meshing under the dynamic excitation of changing gear meshing force. In the transmission design process of hypoid gear, by modifying the geometric surface of the gear, adopting point contact to replace the traditional line contact, and introducing the transmission error function with parabola characteristics, the bearing contact area of the tooth surface is limited to a specific area, so that the gear has good stability in the process of alternate engagement.

The driving axle is located at the end of the transmission system, its basic function is to distribute the torque of the transmission shaft to the left and right driving wheels, and make the left and right driving wheels have the differential function required by the driving kinematics of the vehicle, at the same time, it also bears the vertical force, longitudinal force and transverse force acting on the road surface and between the frame or carriage. When the input and load conditions of the system have been determined, the time-varying meshing stiffness and comprehensive error of the gear mesh determine the action form of the meshing force, that is, the vibration state of the gear mesh [11]. Internal friction of the differential can change the torque distribution of the drive axle, reduce the torque on the side gear with faster rotation and increase the torque on the side gear with slower rotation, which is beneficial to improving the vehicle’s trafficability. Since this modulation is generated when the fault form is relatively light, amplitude modulation forms several groups of sidebands on the spectrum chart, which are separated by the fundamental frequency of the rotation frequency of the gear shaft and its frequency multiplication, around both sides of the fundamental frequency of the meshing frequency.
4. Conclusion
By using the relationship between mechanical noise and vibration, the abnormal noise can be predicted in the design stage of the rear axle, and the number of manufacturing physical prototype can be reduced. Then virtual prototype test can be used instead of physical prototype test. Problems can be found and solved earlier, and reasonable improvement measures can be put forward. As a very important part of the rear axle and even the whole transmission system, the working condition of the final drive directly affects the quality of the whole vehicle. Therefore, when the final drive assembly is assembled, it is very necessary to carry out a comprehensive performance test. In this paper, the fault evaluation method of automobile main reducer assembly is studied, and the characteristic description of typical faults of automobile main reducer assembly is realized by combining amplitude domain characteristic parameters and frequency band energy characteristic parameters of vibration signals. Vehicle vibration has various forms and complicated mechanisms. There is often a complex nonlinear relationship between vibration forms and symptoms. In the design, it is necessary to analyze the dynamic characteristics of the main reducer so that the natural frequency of the main reducer is far away from the operating frequency of each moving part to avoid resonance. The distribution of the region of interest of the existing gear contact imprint image has certain randomness, and the subsequent work can also carry out research on spatial coordinate mapping and image matching.

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