Reliability Optimization Design of Transmission Mechanism of Automotive Mechanical Transmission Based on Feature Extraction

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Abstract

Mechanical transmission is the transmission device that makes the car forward and backward. Its high-efficiency transmission function can not be replaced by other transmissions. The car with mechanical transmission can exercise the driver's coordination and give the driver a better overtaking experience. The strong traction force makes the car have problems such as impact and instability when shifting, which still needs in-depth research and improvement in automobile manufacturing related industries. Based on the reliability analysis of transmission gear extracted from ferrography characteristics of oil, this paper summarizes the reliability optimization design of automobile mechanical transmission gear. The model is solved and calculated by MATLAB programming, and the reliability optimization design result is finally obtained. Under the background of automatic and intelligent automobile science and technology, relevant researchers need to study and analyze it, so as to put forward targeted optimization design scheme.

Keywords*: Feature extraction, Automobile, Mechanical transmission, Transmission mechanism, Reliability*

Ⅰ. Introduction

With the advancement of science and technology, transmissions have been diversified and developed. Although most drivers are still accustomed to traditional mechanical transmissions, the vigorous popularity of automatic transmissions and continuously variable transmissions in the market has brought huge challenges to mechanical transmissions. [1]. The emergence of automatic mechanical transmission (AMT) technology has brought new vitality to mechanical transmissions. As one of the most important means of transportation at present, cars have brought great convenience to people's life and work [2]. Since the internal combustion engine has been used as the power device in the automobile, the automobile's gearbox has become one of the most important components of the automobile's drive mechanism.The use of automotive gearbox not only enlarges the range of wheel distance and speed, changes the drive ratio of the car, but also enables the engine to work within the best industrial and mining range, which has an indispensable important role for the stability and practicability of the overall structure of the vehicle [3].The mechanical transmission of automobiles has the advantages of low cost, long life, good stability, and has been widely used, but it also has some disadvantages, such as large size and large shift impact [4]. Under the new technology application conditions, the research and analysis on the stability of mechanical transmission system can effectively realize the shift transmission operation, reduce the impact effect and improve the vehicle handling and safety [5]. Therefore, it is of practical significance to study the reliability optimization design of the variable speed transmission mechanism of automobile mechanical transmission. Among the traditional methods, the fault detection method of automobile engine mainly adopts the manual experience detection method, which is often influenced by human factors, resulting in poor accuracy and reliability of fault detection [6]. With the development of intelligent fault detection technology, it is intelligent and reliable to use signal detection and fault feature extraction methods to analyze and locate fault causes [7]. In this paper, the reliability optimization design theory is applied to the design of automobile mechanical transmission. According to the requirements of automobile dynamics, the objective function is to minimize the volume of the transmission and maximize the coincidence of the transmission gear under the condition of ensuring the strength and rigidity of the parts. , The mathematical model of the multi-objective reliability optimization design of automobile mechanical transmission is established. The

calculation of the model is realized through MATLAB programming, and finally the reliability optimization design result is obtained. As a key component of the automobile transmission system, the transmission has a direct impact on the power and economy of the automobile, the reliability and portability of the handling, and the stability and efficiency of the transmission. Therefore, this paper proposes the reliability optimization design of the variable speed transmission mechanism of automobile mechanical transmission based on feature extraction to facilitate engineering applications.

Ⅱ. Overview of Automotive Transmission and Reliability Design Principle of Transmission Mechanism

A. Overview of Automotive Gearbox

For more than 100 years, especially since the large-scale production of automobiles and the great development of automotive industry, automobiles have exerted immeasurable and huge influence for the development of the world economy and the entry of human into modern life, made an indelible and huge contribution to the progress of human society, and initiated an epoch-making revolution [8].Since the internal combustion engine has been used as the power unit in automobiles, the transmission has become an important part of automobiles.Reciprocating piston internal combustion engines, widely used in modern automobiles, have the advantages of small size, light weight, reliable operation and convenient use, but their range of torque and speed changes is small, while complex operating conditions require that the traction power and speed of the automobile can vary within a considerable range [9]. Therefore, there is a big contradiction between its performance and the power and economy of automobiles, which cannot be solved by the internal combustion engine of modern automobiles. Therefore, the transmission and main reducer are installed in the automobile transmission system to achieve the purpose of deceleration and torque increase. The main functions of the transmission are as follows: (1) Changing the transmission ratio of the automobile and expanding the range of torque and speed of driving wheels to adapt to the constantly changing driving conditions, and at the same time making the engine work in the most favorable working conditions. ⑵ On the premise that the rotation direction of the engine is unchanged, the automobile can run backwards. ⑶ Realize neutral and temporarily interrupt power transmission so that the engine can start and idle [10]. The transmission is composed of a variable speed transmission mechanism and a control mechanism. According to the change mode of the transmission ratio, the transmission is divided into three types: stepped type, stepless type and integrated type. In 2003, Hyundai Motor’s AT, AMT, DCT, and CVT forums reached the following consensus: In the future development, MT will still be the most widely used automotive transmission, the proportion of AMT application will increase, and AT will also occupy a considerable market. Share, the use of CVT has certain limitations, only due to some small-displacement cars, dual-clutch transmission (DCT) will also sprout. From 2003 to the present, the development of automobile transmission is basically consistent with the consensus reached by the forum [11].

B. Reliability Design Principle of Variable Speed Drive

Transmissions have a direct impact on the safety and maneuverability of the vehicle. For the reliability design of automotive transmissions, not only to achieve the role of gear shifting, but also to ensure the stability and safety during the driving process [12].For a vehicle's mechanical transmission, the optimal design results are determined through analysis and many tests on the materials, dimensions of parts and loads of the transmission.By distributing the reliability of automotive gearbox, the reliability performance of mechanical gearbox in automotive transmission structure is guaranteed. For distributing work, it is often necessary to take into account such factors as cost, technical level, complexity and working environment. In the first step, it is assumed that the components of the transmission are relatively independent when they fail, and that their service life obeys the exponential distribution. Then, the reliability of the transmission mechanism of the near-type transmission needs to be assigned to splines, bearings, transmission shafts and transmission gears respectively. The spline reliability is decomposed into fatigue strength, the transmission shaft reliability is decomposed into fatigue stiffness and shaft fatigue stiffness, and the transmission gear reliability is decomposed into gear contact fatigue strength and gear bending fatigue strength. The spline is

another important part of the transmission. It is very common in mechanical systems. The spline is multi-tooth, and the tooth root is the same and small. The multi-tooth structure enables the spline to have a better load carrying level, and its guidance Both sex and neutrality are better. In the transmission process of the transmission, the shallow tooth root of the spline makes the stress level not high, which can ensure the overall rigidity of the transmission. Therefore, the reliability research of the spline helps to improve the overall reliability of the transmission. Under working conditions, the stress calculation of the spline under extrusion is expressed as:

$$p = \frac{2T}{\phi z h l D m}\left(M p a\right) \quad (1)$$

The spline strength and stress distribution can be obtained by using the normal distribution law, and the joint parameters can be calculated to solve the reliability coefficient of spline structure. In most mechanical equipment, as long as bearings are used, their main function is to provide corresponding support, subject to radial load and transverse load. Although the bearing in the gearbox seems not as important as the bearing structure of the engine and transmission shaft, it is directly related to the overall reliability of the vehicle. Therefore, it is very necessary to carry out reliability analysis in combination with the shape, size and installation mode of the bearing. There are many kinds of transmission bearings, and the bearings used in automobiles are generally radial ball bearings, cylindrical roller bearings, needle bearings, etc. The reliability analysis of bearings is conducive to the development of automobiles in the direction of miniaturization and lightweight, and is also conducive to prolonging the service life of automobiles. In the reliability analysis, it should be considered that there will be contact wear during the use of bearings, which will affect the dynamic load.

Each pair of meshing gears has a reliability constraint on the contact fatigue strength of the tooth surface, and each gear has a reliability constraint on the bending fatigue strength of the tooth root. Therefore, there are four reliability constraints for tooth surface contact fatigue strength and eight reliability constraints for tooth root bending fatigue strength. The meaning and value of each parameter in the gear reliability constraint conditions refer to the national standard GB3480-1997. The fatigue pitting and spalling of the tooth surface is the main damage form of the tooth surface, which is mainly caused by insufficient surface contact fatigue strength. Therefore, higher reliability requirements are put forward for the contact fatigue strength of the tooth surface. In this paper, the reliability is $R'_{cMeet} \geq 0.989$, and the corresponding reliability coefficient is 2.86 according to Table 1.

Table 1 Reliability Coefficient And Reliability Comparison Table

z_R	1.36	1.759	1.89	2.42	2.86	2.84	3.05
R	0.9	0.9456	0.953	0.965	0.989	0.996	0.992

Ⅲ. Mathematical Model and Fault Extraction Algorithm for Optimal Mechanical Design

A. Mathematical Model for Optimal Mechanical Design

Since the optimal design of machinery is to seek the optimal scheme of mechanical design by mathematical method, the corresponding mathematical model must be established first according to the actual mechanical design problems.The mathematical model of mechanical optimal design is the mathematical expression describing the design content, variable relationship, design conditions and optimization intent of the optimization problem.Establishing a mathematical model is the basis of the optimal design. Whether the mathematical model can

closely and accurately reflect the essence of the optimization problem is the key to the success or failure of the optimal design. The mathematical model of optimization design includes three aspects: objective function, design variables and constraints. Usually, the optimization design problem can be described as follows: select the design variables properly, and make the objective function get the optimal value under the condition of satisfying the constraints [13]. The mathematical form of mechanical optimization design problem is usually expressed as follows: find the design variable vector $X = \left[x_1, x_2, \ldots, x_n\right]^T$, and make the objective function f(X)→ the optimal value under the constraint conditions.

$$\begin{cases} h_i\left(X\right) = 0 & \left(i = 1, 2, \ldots, I\right) \\ g_j\left(X\right) \le 0 & \left(j = 1, 2, \ldots, m\right) \end{cases} \quad (2)$$

The optimal value of the objective function has two cases, the maximum value and the minimum value. Since they can be transformed into each other through the reciprocal or the opposite, the optimization mathematical model usually adopts the objective function minimization form. Therefore, the mathematical model can be simplified to:

$$\begin{cases} \min F\left(X\right) \\ X = \left[x_1, x_2, \ldots, x_n\right]^T \\ h_i\left(X\right) = 0 & \left(i = 1, 2, \ldots, I\right) \\ g_j\left(X\right) \le 0 & \left(j = 1, 2, \ldots, m\right) \end{cases} \quad (3)$$

In the optimal design mathematical model, if both the objective function and the constraint function are linear functions of the design variables, the optimization problem belongs to the linear programming problem in mathematical programming.If they are not all linear functions of design variables, they are non-linear programming problems.If all design variables can only take integers, it is an integer programming problem.If there are no constraints, it is called unconstrained optimization problem, otherwise it is called constrained optimization problem.Constraint optimization problems can be divided into equality constraints, inequality constraints and mixed constraints.

B. Fault Feature Extraction Algorithm for Automobile Engine

The first step of automobile engine fault diagnosis is to extract fault features. There are many kinds of fault features, such as vibration signal features, oil state features, image features, etc. [14]. Based on the detection theory of surround wave method, the oil surface wave of automobile engine will form surround wave along the ferromagnetic surface of oil transmission pipe, and its signal expression form is as follows:

$$i = u_1 u_2 = u_{1m} \cos\left[\omega t + \phi_1\left(t\right)\right] u_{2m} \sin\left[\omega t\right] = \frac{1}{2} u_{1m} u_{2m} \sin\left[-\phi_1\left(t\right)\right] + \frac{1}{2} u_{1m} u_{2m} \sin\left[2\omega t - \phi_1\left(t\right)\right] \quad (4)$$

In formula (4), u_1 represents the hydraulic power of the ferrograph under a high gradient magnetic field, u_2 is the total vibration level of the piston gap of the engine, ω is the offset vector of the power spectral density function, and ψ is the ferrograph bandwidth of the piston surface. At this time, the car engine fault signal has a homogeneous attenuation of the surround wave, and the attenuation frequency is:

$$c = \frac{1}{\sqrt{\beta s \rho_0}} (5)$$

The absorption coefficient of oil ferrography of automobile engine is:

$$\alpha_\eta = \omega \sqrt{\frac{\rho_0}{Ks}} \sqrt{\frac{\sqrt{1+\omega^2 H^2}-1}{2\left(1+\omega^2 H^2\right)}} (6)$$

Ⅳ. Optimal Reliability Design of Variable Speed Drive Mechanism of Automotive Mechanical Transmission

A. Distribution of Reliability for Variable Speed Driving Mechanism of Automotive Mechanical Transmission

Reliability allocation is the process of scientifically and reasonably distributing the system reliability index to each subsystem and component in order to achieve the reliability goal of the whole system.The main factors to be considered in the reliability allocation are: the technical level of the unit, the complexity, the importance, the work cycle and its working environment, and the constraints of cost, weight and size.There are many methods to assign reliability, which are based on how much information you have, design goals, and limitations.

Commonly used reliability allocation methods include proportional allocation method, redistribution method and expert scoring method.

According to the assumed conditions, we can choose some reliability allocation method introduced above to allocate the reliability R_s of the whole system to each part R_i . The system reliability R_s of the whole variable speed transmission mechanism is selected according to the transmission design guide. Fig. 1 is an exploded view of the variable transmission mechanism of the mechanical transmission.

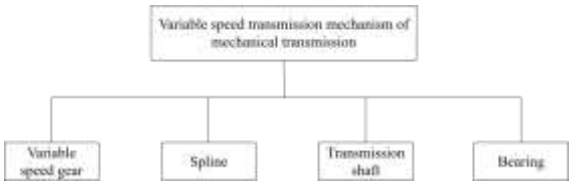

Fig.1 Exploded View of the Variable Speed Transmission Mechanism of a Mechanical Transmission

Bearings are vulnerable parts and can be replaced regularly during work, so they are not considered in the reliability distribution.

The failure modes of gear transmission mainly include tooth root fracture and tooth surface damage. These two types of failure modes correspond to gear bending fatigue strength and gear contact fatigue strength respectively. The reliability of the gear bending fatigue strength is R_{cBend}, and the reliability of the gear contact fatigue strength is R_{cMeet} .

Considering factors such as size, strength and weight of components, reliability experiments are designed with probability statistics, and optimal data are obtained to achieve higher reliability of the system.Fig. 2 shows the algorithm flow of the reliability optimization design model.

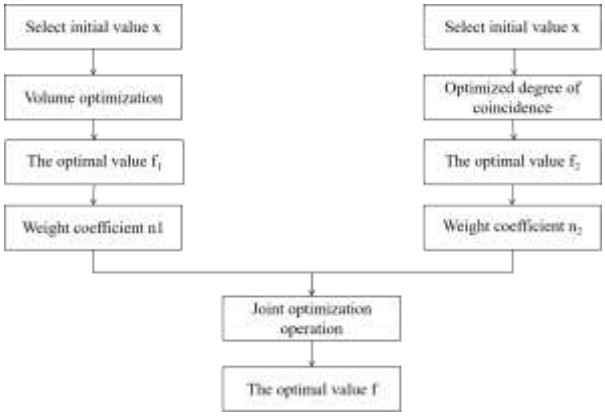

Fig.2 Algorithm Flow of Optimized Design Model

Based on the data of an automobile repair shop, the common faults and causes of the three-axis mechanical transmission shaft are analyzed. See Table 2.

Table 2 Common Failures And Failure Causes of Three-Axis Mechanical Transmission Shafts

Part Name	Function	Failure mode	Failure affects	Cause of the malfunction
First axis	Transmission torque mounting gear	Askew	Out of gear, loud noise	Bearing wear
Second axis	Transmission torque mounting gear	Askew	Out of gear, loud noise	Worn bearing shaft centerline distortion
Intermediate shaft	Transmission torque mounting gear	Askew	Out of gear, loud noise	Bearing wear and shaft bending and deformation
Reverse gear shaft	Transmission torque mounting gear	Askew	Out of gear, loud noise	Bearing wear

According to the analysis in the above table, it is concluded that the main fault cause of transmission shaft is bearing wear, followed by fatigue strength failure and stiffness failure of shafting. The reliability of fatigue strength of shaft is $R_{zStrong}$, and the reliability of shaft stiffness is R_{zJust}. There are almost no failures of the first shaft and the reverse shaft. To simplify the problem, the reliability is not considered when allocating.

The ratio of the gear ratio of each gear of the transmission has a great influence on the performance of the transmission. An excessive ratio will cause difficulty in shifting, and a too small ratio will increase the number of gears and complicate the structure of the transmission. Regarding the relationship between the ratios of the gears of the transmission, it is proposed that the distribution according to the proportional series is beneficial to give full play to the power provided by the engine and improve the dynamic performance of the vehicle. Due to the different operating conditions of the car, the utilization rate of each gear varies greatly, and the number of gear teeth must be an integer, so in fact, it is not strictly distributed according to the proportional series. Table 3 shows the speed ratios of some domestic and foreign auto manufacturers' transmissions.

Table 3 Transmission Ratios Of Some Domestic and Foreign Auto Manufacturers

Transmissions Model	Various speed ratios				
	First gear	Second gear	Third gear	Fourth gear	Five gears
KM130 (Mitsubishi)	4.53	2.46	1.59	1.1	
KM135 (Mitsubishi)	3.65	2.25	1.45	1.1	0.873
R4W63L (Nissan)	4.03	2.49	1.58	1.1	
R4W71B (Nissan)	4.34	2.75	1.76	1.1	
Mercedez Benz	4.38	2.7	1.62	1.1	
TJ6481A travel car	5.76	2.89	1.6	1.1	0.887

B. Multi-Objective Reliability Optimal Design Based on Matlab

MATLAB is a set of scientific computing software introduced by MathWorks in 1984, which is divided into a total package and several toolboxes.The software not only has a good user interface, but also has a strong ability to expand.MATLAB itself has a powerful optimization toolbox, which can accurately and effectively solve linear, non-linear and semi-infinite problems.In order to optimize the reliability of the transmission mechanism of the automotive mechanical transmission, the optimization calculation of single target should be carried out before, the optimal value of volume and coincidence can be obtained, and then the joint optimization calculation can be carried out. The practical results obtained in this way prove that the most efficient and scientific design method is undoubtedly the multi-objective optimization design of helical gears. Because the number of teeth of helical gear must be an integer, the selected gear normal module must meet the international standard value. At the same time, because the number of teeth of a pair of gears can not contain a common factor, and the number of teeth of large gears cannot be an integer multiple of the number of teeth of small gears, it is necessary to carry out the optimization design of gear parameter rounding. However, the problems of insufficient gear receiving strength and insufficient gear bending strength can be solved by gear modification, which can effectively avoid a series of problems caused by the roundness of rabbit gear parameters. The process of debugging the program is: usually do not make any changes to the variables, objective functions and constraints, just change its initial value, the next step is to conduct a comparative analysis, whether the optimization results under different initial values are the same. In addition, without changing the variables and objective function, remove a certain constraint condition, and then compare the optimization results of whether the constraint condition exists, so as to clarify the sensitivity of the optimization analysis to the constraint conditions. By optimizing the program debugging, it is not difficult for us to find that the bending fatigue strength of the first gear pinion is the biggest influence on the optimization result.

Ⅴ. Conclusions

Reliability optimization methods have been used in the field of mechanical structure design for more than 30 years.However, it is seldom used in the design of automotive mechanical transmission, probably because the structure of automotive mechanical transmission is too complex and this part is not a vulnerable part in automobiles.The transmission is one of the key components of a car, and its reliability directly affects the stability and reliability of the whole car quality.Therefore, the reliability of the transmission must be studied, and it must be included in the design. In this paper, combined with mechanical transmission, the application of reliability-based

optimization design is discussed in detail, and the reliability compound optimization model is given, which has certain reference value and significance. Of course, more practical optimization design needs the joint efforts of the technical staff, so that the reliability design and application level of automobile mechanical transmission can be greatly improved. By using MATLAB optimization tool to optimize the results, the related optimization mathematical model is constructed, which can further improve the application level of reliability design of automobile mechanical transmission and effectively promote the steady development of automobile market. This paper proposes an optimization design for the reliability of the transmission mechanism of an automobile mechanical transmission based on the extraction of oil ferrography features. First, the extraction of the oil ferrography features of the automobile engine under fault conditions is carried out, and then the mechanical transmission is analyzed from various aspects. The reliability of the mechanism has been constructed as a transmission reliability model. Of course, there is still a lot of room for improvement awaiting in-depth exploration by automotive researchers to better improve the reliability design level of automotive mechanical transmission transmission mechanisms.

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