

# Reliability Optimization Design of Transmission Structure of Automotive Mechanical Transmission

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**Abstract.** The development of transportation is also driving the progress of the automotive industry in China. The design and manufacture of automotive transmissions has become one of the influencing factors affecting many indicators such as automotive power, operation, economy, energy saving, and environmental protection. The dissertation systematically studies the structural reliability of the variable speed transmission of the automotive mechanical transmission and builds a mathematical reliability model based on MATLAB. The optimization measures are combined with examples to expect rapid progress and long-term development of the automotive industry in China.

**Keywords:** Automotive Mechanical Transmission; Transmission Structure; MATLAB; Example Analysis

## 1. Introduction

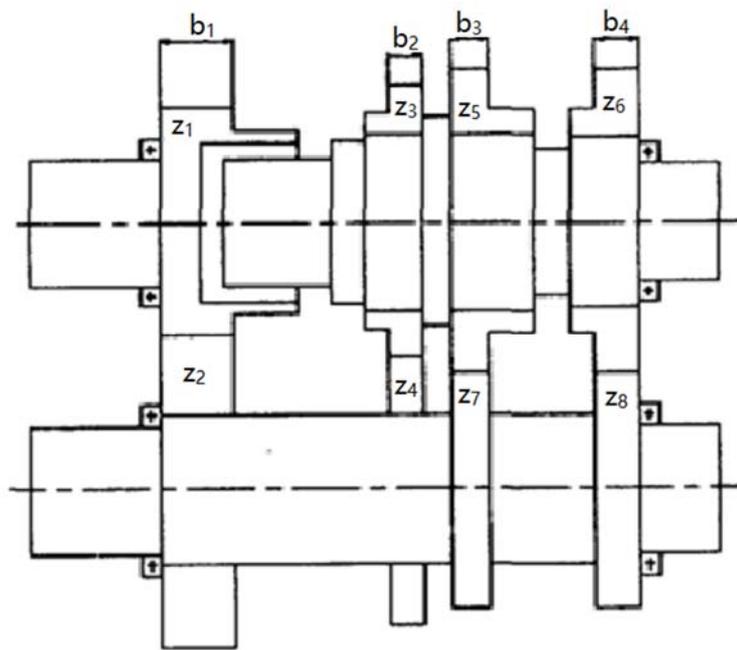
Starting from the use of internal combustion engines as power devices, transmissions have become an important component of automotive transmission systems. Its main functions are: changing the transmission ratio of automobiles and making the engine work within the most favorable working conditions; temporarily interrupting power transmission and achieving Neutral; In the premise of the same engine rotation direction, realize the reverse driving of the car. Therefore, the transmission has an important influence on the economical, reliability, power, and stability of the vehicle [1]. With the rapid development of the automotive industry and the advancement of vehicle technology, automobiles have been widely used in people's lives, and people are increasingly demanding the design of automobile transmissions.

## 2. Car Transmission Overview and Principle Analysis

The transmission consists of a variable speed transmission and an operating mechanism. According to the change of transmission ratio, the transmission is divided into three types: stepless, stepless and integrated. Progressive transmissions are the most widely used. It uses a gear drive and has several fixed gear ratios. The transmission ratio of a continuously variable transmission can be changed in an unlimited number of levels within a certain range [2]. Commonly, there are electric type and hydraulic type (hydraulic type). Continuously variable transmission is the ultimate goal of the development of the transmission, because only it can make the engine in the most economical working conditions, in order to provide the best fuel economy and optimal dynamic performance for the vehicle, giving people the



most comfortable ride. The typical representatives of today's continuously variable transmissions are CVTs and IVTs. However, the development is not very good because of the problems of poor working reliability, non-durable materials, and high cost. The integrated transmission refers to a hydromechanical transmission consisting of a torque converter and a mechanically-variable transmission, and the transmission ratio thereof can be varied sleeplessly within several breaks between the maximum value and the minimum value, but it's the transmission efficiency is significantly lower than the gearing efficiency[3]. According to the operating mode, the transmission can be divided into three types: forced operation, automatic operation and semi-automatic operation.



**Fig. 1** Forward position of a three-axle and four-speed mechanical transmission

Maneuverable transmissions rely on the driver to directly manipulate the shift lever, which is used by most cars, also known as manual transmissions. Transmission ratio selection (shifting) of automatic transmission is automatic. The driver can control the speed by simply operating the accelerator pedal, also called an automatic transmission. Semi-automatically operated transmissions come in two forms. One is that several common gears are automatically operated, and the rest of the gears are operated by the driver; the other is pre-selection, in which the driver pre-selects the gear position, and when the clutch pedal is depressed or the accelerator pedal is released, the change is performed. Withdraw an electromagnetic or hydraulic device for shifting. In recent years, with the advancement of vehicle technology and the increase of vehicle density on the road, the performance requirements for transmissions have become higher and higher. Transmission technology has been rapidly developed. The emergence of AT, AMT, DCT, CVT and IVT has been obtained through comparative analysis. The traditional mechanical transmission is still the most widely used automobile transmission at present [4]. If it can improve the above-mentioned shortcomings of the mechanical transmission, it still has a lot of room for development.

### 3. Multi-objective reliability optimization design mathematical model of transmission gear train

#### 3.1. design objective function

When the transmission satisfies reliability and automotive power requirements, it should minimize the size and save material to reduce costs. Therefore, minimizing the transmission volume is selected as the

first design goal. Since the overall size of an automotive mechanical transmission depends mainly on its gear train, the minimization of the sum of the transmission gear volumes is used as the first objective function.

The speed change gear is hollow and its size is determined by the shaft diameter of the transmission. This paper temporarily considers the speed change gear as solid when designing the reliability of the gear train, because the comparison between the optimization result and the original value is relative. Therefore, optimizing it as a solid gear has little effect on the optimization result. After the design of the shaft diameter of the transmission is completed, the actual volume of the speed change gear can be obtained by subtracting the volume of the hole from the solid volume. The volumetric formula of solid helical gears.

$$V = \pi \left( \frac{m_n z}{2 \cos \beta} \right)^2 \cdot b$$

Among them,  $m_n$  is the normal modulus of the helical gear,  $z$  is the number of helical gear teeth,  $\beta$  is the helical gear helix angle, and  $b$  is the helical gear normal tooth width.

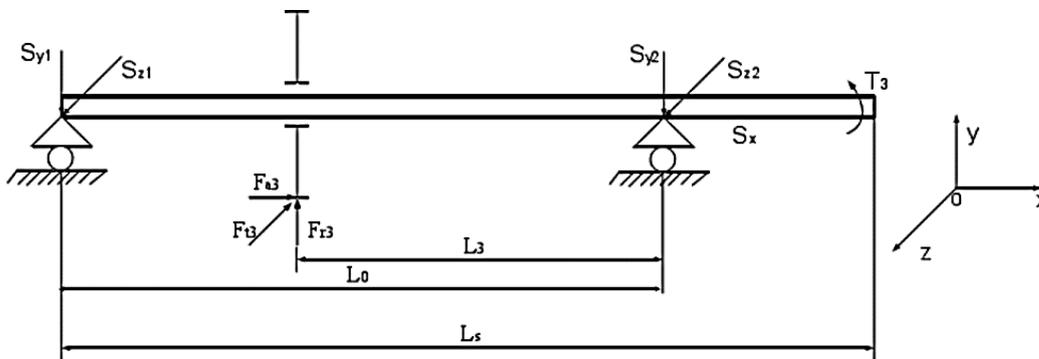
### 3.2. Selection of Design Variables

The design of the mechanical transmission gear system involves many design parameters, such as gear ratio, number of teeth, gear module, tooth width, helix angle, pressure angle, gear displacement coefficient, and tooth top height coefficient. In order to simplify the design problem, this paper only takes five variables: constant meshing gear teeth number, helix angle, gear ratio, tooth width and each pair of meshing gear module as design variables in the optimization design. There are function expressions as follows.

$$X = [x_1, x_2, x_3, x_4, x_5]^T$$

$$= [i_1, i_2, i_3, z_1, z_2 z_1, m_{n1}, m_{n2}, m_{n3}, m_{n4}, \beta_1, \beta_2, \beta_3, \beta_4, b_1, b_2, b_3, b_4]^T$$

The normal modules of each pair of meshing gears:  $m_{n1}$  for constant mesh gear pair,  $m_{n2}$  for three gear pair,  $m_{n3}$  for second gear pair,  $m_{n4}$  for first gear pair; each pair of meshing gear helix angles:  $\beta_1$  for constant mesh gear pair,  $\beta_2$  for three gear pair,  $\beta_3$  for Second-gear gear pair,  $\beta_4$  for first-gear gear pair; each pair of meshing gear tooth widths:  $b_1$  for constant mesh gear pair,  $b_2$  for three gear pair,  $b_3$  for second gear pair,  $b_4$  for first gear pair.



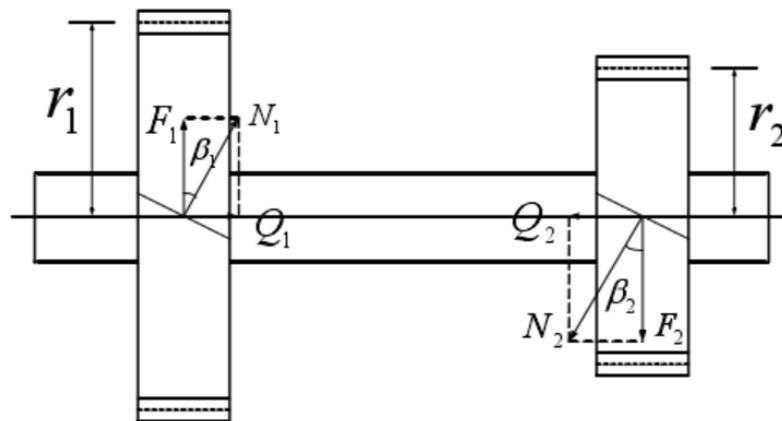
**Fig. 2** Schematic diagram of force analysis of transmission power output shaft

### 3.3. Determination of Constraints

The constraint conditions identified in this paper are the following six: First, the reliability constraints of the transmission gear. Each gear has the reliability constraint of the bending fatigue strength of the tooth root, and each pair of meshing gear has the reliability constraint of the tooth surface contact fatigue strength. Second, the maximum gear ratio of the transmission is constrained. The maximum transmission ratio of the transmission is the opportunity for the transmission ratio of the transmission and the gear ratio of the final drive. This parameter is limited by the maximum grade of the car and the adhesion of the road surface. Third, the ratio of transmission gear ratios is constrained. The ratio of gear ratios of the transmissions has a great influence on the performance of the transmission. Due to the different operating conditions of automobiles, the ratios of the gear ratios of the transmissions of domestic and foreign automobile manufacturers are also different. Therefore, in the actual design, it is necessary to reasonably allocate the speed ratio of each gear according to the actual situation so as to maximize the power of the engine. Generally, the value is between 1.5 and 1.8. Fourth, the transmission center distance constraints. The center distance of the transmission has a great influence on the quality and volume of the transmission, so it is a key indicator of the transmission. To ensure that the transmission has sufficient strength, maximum transmission ratio and maximum torque, the center distance should be reduced as much as possible. Fifth, the intermediate shaft axial force balance constraint. When the helical cylinder is designed in the transmission, if the helical angle of the helical gear is large, a large axial force will be generated. In order to reduce the force of the transmission case, the helical angle of the helical gear should be selected appropriately. Sixth, boundary constraints. Boundary constraints include modulus constraints, helix angle constraints, tooth width constraints, and gear undercut constraints.

### 3.4. Reliability Design of Transmission Shaft

Because the axis of the transmission is composed of a shoulder, a journal, a transition section of the undercut, and a mounting gear segment, the structure of the transmission is complex. When designing the reliability, the first step is to save material as much as possible while satisfying the strength and reliability. The small shaft diameter provides enough space for the improvement of bearing, hub and spline performance. This article only studies the second shaft with the most complex structure and poor working conditions. 1 power output shaft static strength reliability design. Due to the complex structure of the transmission shaft, in order to simplify the analysis process, the stepped shaft is simplified into an equal section shaft, and it is considered that the strength distribution and stress distribution of the shaft at the dangerous section obey the normal distribution, and the static strength reliability design process of the power output shaft is performed. : First draw the sketch of the shaft structure, then analyze the shaft force, and then determine the intensity distribution and stress distribution of the shaft at the dangerous section. Finally, determine the shaft diameter according to the given reliability. 2 power output shaft stiffness reliability design. The reliability design of the power output shaft stiffness includes three aspects of deflection, shaft section deflection angle and shaft twist angle. Assume that the deflection, deflection angle and shaft twist angle are all random variables that follow the normal distribution.



**Fig.3** Balance diagram of the axial force of the intermediate shaft

#### 4. Multi-objective reliability optimization design based on MATLAB

In this paper, we use the MATLAB tool with friendly user interface and powerful expansion ability as the tool to carry out the reliability optimization design of the transmission mechanism of automobile mechanical transmission.

##### 4.1. MATLAB Toolbox

MATLAB has a powerful optimization toolbox that can solve linear, nonlinear minimization, maximization, semi-infinite problems, etc. In this paper, the functions in the MATLAB optimization toolbox are used to solve nonlinear minimization problems under constraint conditions. When optimizing the transmission mechanism of automotive mechanical transmissions, the single-objective optimization calculation is performed first to obtain the optimal value of the total degree of convergence and the optimal volume value, and then the joint optimization calculation is performed. The result of optimization design shows that multi-objective optimization design of helical gears is the most efficient design method.

##### 4.2. Round gear parameters

Since the number of teeth of the helical gear must be an integer, the normal modulus of the gear must also meet the values specified in international standards. The number of teeth of a pair of meshed gears must not contain the common factor or the number of teeth of the large gear cannot be an integer multiple of the number of teeth of the pinion. The gear structure rounding must be performed on the optimized structure. Due to gear parameter rounding caused by the lack of gear contact strength, lack of bending strength, the center of each pair of meshing gear is not the same as the problem and other issues can be resolved through gear displacement.

##### 4.3. Tuning of Optimizer

In order to verify the optimization function of the multi-objective reliability optimization design program under various input conditions and find out the sensitivity degree of each constraint condition in the optimization analysis, this paper has debugged the program. The debugging process is as follows: 1 Do not change the constraint condition and target the function and design variables only change the initial values and compare and analyze whether the optimization results are the same under different initial values. 2 does not change the objective function and design variables, just remove a constraint, re-optimization analysis, contrast analysis of the optimization results when the constraints exist, so as to determine the sensitivity of the optimization analysis of the constraints. In this paper, through the debugging of the above process, the bending fatigue strength of the first gear pinion has the greatest influence on the optimization result.

#### 4.4. Simulation Results

Compared with the general 4WS yaw rate feedback control algorithm, the 4WS control algorithm proposed in this paper makes the time domain performance of each state quantity greatly improved when the car is running at high speed. The oscillation is relatively slow, the reaction time is reduced, and the rise time is basically unchanged. In steady state, the steady-state values are basically unchanged. Therefore, the control sensitivity of the vehicle is maintained, and the consistency is not excessive, which not only reduces the difficulty of the driver's operation, but also significantly improves the steering stability of the vehicle.

#### 5. Conclusion

Through the discussion of the evaluation index of the steering stability, the comparison of the relationship between the side-off angle, the yaw rate, the lateral acceleration and the front-wheel rotation angle of the main index affecting the steering stability is carried out. The simulation results show that the four-wheel-steering vehicle adopting the yaw rate tracking control algorithm proposed in this paper can have a relatively smaller center-of-mass declination angle of the car during the steering process when steering at various vehicle speeds. The vehicle declination remains zero. At low speeds, the turning radius of the car is reduced and the mobility of the car is improved. At higher speeds, the 4WS Steering Vehicle improves the steering lag of the front-wheel steering vehicle, allowing it to better follow the driver's manipulation commands, with good trackability and excellent handling stability.

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