Matching and Analysis of Ethanol Engine and Transmission System of Light Passenger Car

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Abstract—In the process of the matching of ethanol engine and transmission system with a new light passenger car, it is found that the traditional theory formula is complex, and with long time of debugging process and low accuracy. By using Cruise software, the performance simulation model of passenger car is built, simulation tasks are established. Different matching scheme is set up and the simulation calculation of power performance and fuel economy are carried on. The comprehensive evaluation system of index weight is established by analyzing the simulation results. According to the index weight and the simulation result, a better set of combining scheme for vehicle with comprehensive performance indicators can be obtained.

1. Introduction
With the continuous growth of car ownership, the shortage of petroleum resources and the increase of oil prices, the engines with ethanol, butanol and other new energy fuels with low fuel consumption and low emissions mixed with gasoline in different proportions have become one of the main targets for automobile enterprises to develop. The engine displacement, engine operating characteristics, transmission ratio and efficiency of the transmission system have the greatest impact on the power performance and fuel economy of the automobile [1]. Reasonable matching engine and transmission system is a typical optimization design process, which can rely on the professional software CRUISE to build the model for the system and key components, by filling in each of the proposed system and the detailed specification of key components and design parameters [2-3], such as engine, gearboxes and main reducer, according to the simulation and analysis of the matching of the optional power performance and fuel economy, a relatively comprehensive performance combination schemes can be found, which will be a better reference for researchers.
2. Establish the whole vehicle model and match the dynamic parameters
The front front-wheel-drive arrangement form is selected for this whole vehicle, and analysis for the chosen type is selected for the model library, including the whole vehicle, cab, engine, mechanical friction clutch, mechanical manual gearboxes, drive axles, wheels and mechanical brake module [3-4].

2.1. The main parameters of whole vehicle
The main parameters of the vehicle include vehicle curb weight: 900 kg; full load weight: 1250kg; windward area: 2.0880m²; wind resistance coefficient: 0.32; no-load barycenter height: 552mm; height of gravity center with full load: 530mm; wheelbase: 2335 mm; tire model: 165/65 R13, tire static and dynamic radius: 272.35&277.35mm.

2.2. The matching engine type and main parameters
The main parameters of the two engines E1 and E2 matching for the light passenger car are shown in table 1.

2.3. The matching type and main parameters of gearboxes and main reducer
Four kinds of gearboxes and four kinds of main reducer will be chosen for this light passenger car. The transmission ratio and efficiency of each transmission block are shown in table 2. The four main reducer types are ST1, ST2, ST3 and ST4. The transmission ratio is 4.388, 5.125, 4.105 and 3.789 respectively, and the transmission efficiency is 0.97.

2.4. Matching scheme
Considering of two engines, four gearboxes and four main reducers, there is a total of 32 combination schemes for the selection of the passenger car, the specific combination schemes are shown in table 3.

3. Simulation analyses
The simulation analysis mainly includes the power performance and fuel economy analysis.

3.1. Power performance analysis
Power performance analysis is mainly focus on the top speed, climbing performance, standing start (0~100 km/h) acceleration time and overtaking acceleration time [3].
3.1.1. Top speed analysis:
Under the condition of full load with the fifth block, a top speed of the simulation results are shown in figure 1. It is can be seen that the matching schemes with a top speed of the fifth block under 145 km/h are the three combinations of main reducer ST2 and gearboxes G2, G4 (respectively schemes 6, 14, 22), the three schemes of top speed is low which cannot be adopted. The main reason is the excessive transmission ratio of the main reducer ST2 which is 5.125, resulting in the total transmission ratio is relatively large.

![Figure 1. Simulation results of maximum speed in block 5 under full load for different design schemes.](image1)

3.1.2. Climbing performance analysis:
Under the condition of full load, the simulation results of the maximum gradability with block 1 are shown in figure 2. It is can be seen that the number of the scheme which the maximum gradability is lower than 45% are a total of 10. The matching schemes of main reducer ST4 (respectively schemes 4, 8, 12, 16, 20, 24, 28, 32) are all less than 45%, along with two other schemes which are the matching with main reducer ST3 and gearboxes G1 (respectively schemes 3, 19), the maximum gradability of which is low, which should be abandoned. The main reasons are that the transmission ratio of main reducer ST4 which is 3.789 is too small, leading to the total transmission ratio of main reducer ST3 and gearbox G1 is relatively small.

![Figure 2. Simulation results of maximum gradability of block 1 under full load for different design schemes.](image2)

3.1.3. Standing start (0–100 km/h) acceleration time and overtaking acceleration time:
Standing start shift (0–100 km/h) acceleration time and overtaking acceleration time are shown in Fig.3. It can be seen that the acceleration time of each scheme from 0 to 100km/h is about 15.63-18.62s, which is similar to each other. The trend of the fourth block (60-100 km/h) acceleration time and the fifth block (80-120 km/h) acceleration time are basically close, but the overtaking acceleration time is slightly longer. The acceleration time of the matching schemes with the main reducer ST4 (respectively schemes 4, 8, 12, 16, 20, 24, 28, 32) and the main reducer ST3 (respectively schemes 3,
11, 15, 19, 27, 31) are too long, which is not acceptable. The main reason of which is that the total transmission ratio of the fourth block and the fifth block is smaller, resulting in a weaker power performance.

Figure 3. Simulation results of standing start shift (0~100km/h) acceleration time and overtaking acceleration time for different design schemes.

3.2 Fuel economy simulation analysis

The fuel economy simulation analysis is mainly focused on the fuel economy under the cyclic working condition and the constant speed condition. The cycle conditions mainly include UDC (1.013km, 195s) in urban areas, EUDC (6.955km, 400s) in suburb areas and NEDC (11.007km, 1180s) in comprehensive of urban and suburb areas [5] [6] [7].

3.2.1 Fuel economy analysis under cycle conditions

In the case of full load, the fuel consumption of 100 kilometers in UDC, EUDC and NEDC under cycle driving condition is shown in Fig. 4. It can be concluded that in the same design scheme, the rank of the fuel consumption is UDC, NEDC, and EUDC. The main reason is that the idle time of the whole cycle is different, UDC idle time accounted for 30% of the entire cycle (60s), the NEDC idle time accounted for 24% of the entire cycle (280s), the EUDC idle time accounted for 10% of the entire cycle (40s), as a result, the reasonable control of the oil-saving measures, such as the driving condition and idle, will be conducive to reduce hundred kilometers fuel consumption. From the simulation results, it can also be seen in figure 4 that the trend of three kinds of working conditions is consistent. The fuel economy of matching design schemes for engine E1 under cycle conditions are relatively poor because of larger displacement, especially the design schemes of 2, 6, 9, 10, 13, 14 and 15 are much larger, which should not be adopted, while the fuel economy of matching design schemes for engine E2 under cycle conditions are relatively good.

Figure 4. Simulation results of fuel consumption of 100 km under full load for different design schemes.
3.2.2. Fuel consumption analysis under constant speed:
In the case of the reference mass (no load+100kg), the fuel consumption of 100km (L/100km) at the same speed of 60, 90 and 120km/h under the fifth block are shown in Fig. 5. From the simulation results in the figure, it can be seen that the fuel consumption of the matching design scheme with main reducer ST2 is basically on the high side, which cannot be adopted. The main reason is that the transmission ratio of main reducer ST2 is 5.125, which is too large.

![Figure 5. Simulation results of fuel consumption of 100 km at constant speed under full load for different design schemes.](image)

4. Establish comprehensive evaluation index weight system and evaluation of comprehensive index weight
In order to prevent the optimization of one index, leading to the decline of other indicators, the comprehensive evaluation system of the power performance and economy for the whole vehicle is established [8]. A comprehensive evaluation index $\Delta$, vehicle power performance evaluation index $P$ and economy evaluation indexes $F$ are introduced. Comprehensive evaluation index $\Delta$ is made of vehicle power performance evaluation index weights (0.5$P$) and economic evaluation index (0.5$F$).

In terms of fuel economy, according to the national standard test method of passenger car fuel consumption (GB/T 12545.1-2001), the main indexes include five weight indexes, such as UDC, EUDC, NEDC, fuel consumption of 100km under driving cycle conditions and fuel consumption of 100km under the fifth block at the constant speed of 50km/h and 120km/h, the weight coefficients of which are 0.2.

In terms of power performance, the indexes to be considered mainly include 5 weight indexes, which are the maximum gradability under the first block, the maximum speed, the standing start shift (0~100km/h) acceleration time, the overtaking acceleration time under the fourth block(60~100km/h) and the overtaking acceleration time under the fifth block(80~120km/h), the weight coefficients of which are 0.2.

To facilitate the mutual comparison, a representative value of design scheme as a reference need to be chosen, design scheme 1 is to be selected as basic configuration scheme for reference benchmark values, of which each index as the benchmark design weight value is 0.2, each design scheme of dynamic weight index $P$, economy weight index $F$ and comprehensive evaluation index $\Delta$ can be obtained as follow.

$$P_j = \sum_{j=1}^{32} \sum_{i=1}^{5} P_{ij} = \sum_{j=1}^{32} \sum_{i=1}^{5} \left( \frac{P_{ij} - P_{ni}}{P_{ni}} \times 0.2 + 0.2 \right)$$  \hspace{1cm} (1)

$$F_j = \sum_{j=1}^{32} \sum_{i=1}^{5} F_{ij} = \sum_{j=1}^{32} \sum_{i=1}^{5} \left( \frac{F_{ij} - F_{ni}}{F_{ni}} \times 0.2 + 0.2 \right)$$  \hspace{1cm} (2)
\[ \Delta_j = 0.5P_j + 0.5F_j \]  

(3)

Where, \( P_j \) - The whole vehicle power performance index of design scheme \( j \); \( P_{ij} \) - The i-th power performance index of the design scheme \( j \); \( P_r \) - Power performance index of reference benchmark; \( F_j \) - Fuel economy index of design scheme \( j \); \( F_{ij} \) - The i-th fuel economy index of the design scheme \( j \); \( F_r \) - Fuel economy index of reference benchmark.

It can be seen from the figure 6, the design scheme which the power performance weight index \( P \) and economy index weights \( F \) is not less than 0.5, and the comprehensive evaluation index \( \Delta \) is not less than 1 are respectively 1, 7, 21, 25, 29, meaning that the power performance, economy and comprehensive performance is relatively good, where other schemes can't meet this requirements.

5. Conclusions

- The whole vehicle modeling and simulation analysis for manual transmission light passenger car is carried on, the power performance and fuel economy for light passenger car are studied through CRUISE software, as a result the development time is greatly shorten, and the simulation results is easy to read intuitively. The method can predict the performance of the car in the early stages for the product development and bring a lot of help to automotive research work.

- In order to balance the comprehensive performance for light passenger car, 32 kinds of combination of two engines, 4 kinds of gearboxes and four kinds of main reducer are introduced. The comprehensive evaluation index weight system and the comprehensive evaluation index \( \Delta \) are established, which is used for selecting the perfect schemes. There are three kinds of scheme are appropriate for the 1.1 L engine, which are the main reducer transmission ratio 4.388 is appropriate, gearboxes are all appropriate except G1. There are two right solutions for the 1.3 L engine, which are the transmission ratio of the main reducer is more appropriate to choose 4.388 and 4.105, while the transmission of G3 and G4 schemes is not suitable because of large transmission, so the transmission of G1 and G2 schemes are matched respectively.

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