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A Method for Measuring Power Loss Distribution of Mini-car Driveline

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Abstract: How to quickly diagnose has always been a difficulty of chassis engineers when optimizing automobile driveline. In order to make the main direction of optimization work more clearly, it is required to determine exactly the power loss distribution of automobile driveline. In this study, a method used for measuring power loss distribution of mini-car driveline was proposed based on detailed research of the structure and working principle of mini-car driveline. Through measuring the internal resistance of mini-car driveline on a chassis dynamometer in different conditions, the power loss of each driveline component can be quantified combined with mathematical model proposed by us for power loss and the complete feature of the whole driveline can be obtained with this method. And best of all, the components that have potential to improve become evident which has very important theoretical and practical significance to optimization work for mini-car driveline. The research we have done suggests that this method used in our study is simple and effective and can greatly enhance the efficiency of optimization work for mini-car driveline.

Key words: Method, mini-car, driveline, power loss, efficiency, resistance

INTRODUCTION

As the world energy demand has been increasing year by year, the problem of global warming caused by fossil energy consumption makes the human face more and more severe challenges. In the international climate of energy conservation and emissions reduction, the Chinese government timely introduces new fuel consumption regulations which makes many auto companies operate under great pressure due to the tightened standard limit.

As far as most vehicles are concerned, the fuel consumption mainly depends on the technical conditions of engine system and driveline. As for driveline, the most direct measurement index of total energy consumption is the size of power loss. In order to reduce energy consumption and enhance the efficiency of automobile driveline, it is necessary to acquire exactly power loss distribution of automobile driveline, namely the quantity and proportion of power consumption in different components which is extremely useful to improve the performance of automobile driveline. When the automobile driveline needs to be optimized, resources can be allocated appropriately and targeted solutions will be given to optimize driveline. To explore the power loss allocation is of great significance for guiding the development of automobile driveline.

Many domestic and foreign scholars have achieved a lot on the transmission efficiency of automobile driveline (Kirk *et al*., 2013; Celli, 2011; Lloyd, 2012; Worner *et al*., 2011) but they rarely paid little attention to the internal power losses of automobile driveline. A simple model is proposed for calculating the overall transmission efficiency of passenger cars by using a chassis dynamometer (Irimescu *et al*., 2011). A simple method is developed that will allow reasonable estimates of fuel consumption for 4WD vehicles to be made from single axle dynamometer testing (Shimizu *et al*., 2008). A test bench was developed on the basis of adequate study on the properties of the structure of automobile driveline (Vantsevich, 2008; Zhang and Mo, 2013; De Klerk and Rixen, 2010). A simple method is developed that will derive the relation between the rolling resistance coefficient, the air resistance coefficient and initial velocity by solving differential equations (Han and Li, 2002). Another method is developed that will derive the rolling resistance coefficient and the air resistance by taking advantage of global searching and implicit parallelism of genetic algorithms (Liu *et al*., 2003). Coasting tests has been carried out under conditions of no load, semi- load and full load and the motion differential equation of coasting resistance calculation model has equated based on testing data (Gao *et al*., 2008). But all of these studies are aimed at the entire driveline, the internal resistance or power loss distribution of the driveline is not involved.

Based on fully study of the composition and working principle of chassis dynamometer, a new research method

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for measuring power loss distribution of mini-car driveline is proposed in this study. It is verified that this method can be easily used in practical application which provides new technical method for research of mini-car driveline.

PROBLEM FORMULATION

Automobile driveline is a type of power transmission device arranged between the engine and driving wheels and its main task is transferring power to the drive wheels effectively and guaranteeing the driving force required under all kinds of conditions.

The arrangement type of automobile driveline is mainly related with the drive type and the position of the engine. Most of mini-car adopts the arrangement type of front-engine and rear-drive. As for mini-car, the main components of driveline are clutch, transmission, universal joints and drive axle. The overall structure of mini-car driveline is shown in Fig. 1.

As an important technical index for automobile driveline, the size of power loss has notable influence on dynamical performance, efficiency and reliability of automobile. Excessive power loss can not only result in the decrease of transmission efficiency but also cause the premature deterioration of lubricating oil.

It was validated that the relationship between the power loss of driveline and the internal resistance of driveline can be expressed as:

$$P = F \times V \quad (1)$$

where, P is the power loss of driveline and F is the internal resistance of driveline and V is the linear velocity of the driving wheels.

The internal resistance of driveline refers to the mechanical loss from the engine flywheel to the wheels bearing. It is well known that the internal resistance has relationship with lubricant viscosity and temperature, tooth surface machining accuracy and status of running-in. It is proportional to the rotational speed growth and can be given as:

$$F = F_0 + C \times V \quad (2)$$

where, F_0 is the internal resistance due to the friction between bearings and gears and C is the velocity coefficient of the driveline resistance and V is the linear velocity of the driving wheel.

TYPES OF POWER LOSS IN MINI-CAR DRIVELINE

For the convenience of research, the power loss of mini-car driveline is divided into the following four categories according to the arrangement type of driveline.

Power loss of braking system: Drum brake is commonly used in mini-car. When braking system begin to work, it exerts brake torque on brake drum and makes its rolling velocity slow down and even stops the car. However, friction always exists between brake drum and brake shoe because of the low-level manufacturing accuracy or unaccepted assembled components which will cause the loss of power, the decline of automobile dynamic performance and the reduction of transmission efficiency.

Power loss of transmission: To adapt to the changing driving conditions, transmission is used to change the transmission ratio so as to enlarge the range of drive wheel's torque and rolling speed. The loss of transmission's power consists (1) Churning losses because of the stir of rolling parts in lubricating oil, (2) Friction power loss between sealing rings and gear shafts, (3) power loss of gear meshing and (4) Friction power loss of bearings.

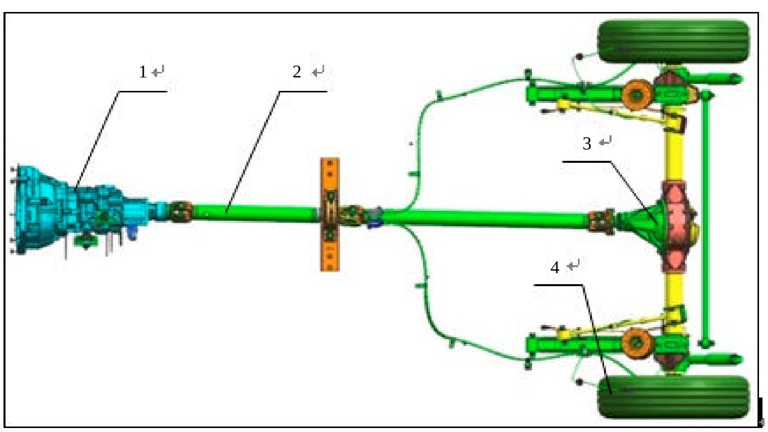

Fig. 1: overall structure of mini-car driveline. (1) Transmission, (2) Universal joints, (3) Drive axle and (4) Driving wheels

Power loss of main reducer: Main reducer is mainly used to increase the input torsion and correspondingly reduce rolling speed. The loss of main reducer's power consists (1) Power loss of hypoid gears meshing, (2) Churning loss, (3) Friction power loss between sealing rings and shafts and (4) Friction power loss of tapered roller bearings.

Power losses of differential assembly and axle shaft assembly: Power losses in this part mainly consist of friction power loss in the running processes of differential bearings and axle shaft bearings.

DESIGN OF MEASURING METHOD

Chassis dynamometer is the equipment that widely used in scientific research, product development and quality supervision of automobile. Chassis dynamometer can accurately simulate the working condition of automobile road or the actual driving resistance, so it is an ideal tool for vehicle performance testing such as dynamical performance, reliability and vehicle emission pollutants detection. The schematic diagram of measuring is shown in Fig. 2.

The vehicle shall be ballasted to target weights as specified. This is normally same as the one used for road load test. To provide a procedure to measure mechanical losses using a chassis dynamometer, the internal resistance of driveline is selected as measuring object, because the internal resistance is just the embodiment of driveline power loss.

Before testing, the following work should be carried out in advance:

- Replace driveline fluids after running-in of vehicle (typical 5,000-10,000 km)
- Make sure that wheel alignment and wheel balancing is done before the test
- Set the cold tire pressure as specified

The power loss of each components of driveline can be determined by the method of anti-dragging. The so-called anti-dragging completes the testing through dragging the vehicle by the chassis dynamometer when the vehicle is put in neutral state. The testing of mechanical loss should be repeated as follows:

Step 1: Rear wheels on chassis dynamometer:

- Put the car in neutral state
- Run at 70 km h^{-1} for 30 min to warm up: (or till axle oil is stable)
- Start with 130 km h^{-1}, maintain 5 min, measure force on dynamometer
- Repeat in decreasing speeds of 10 km h^{-1}

Note the resistance and represent it by F_1:

Step 2: Rear wheels on chassis dynamometer and brake shoe removed

Repeat procedure in (1). Note the resistance and represent it by F_2

Step 3: Rear wheels on chassis dynamometer and brake shoe removed and propeller shaft removed

Repeat procedure in (1). Note the resistance and represent it by F_3

Step 4: Rear wheels on chassis dynamometer without hypoid gear meshing and brake shoe removed and propeller shaft removed

Repeat procedure in (1). Note the resistance and represent it by F_4

ANALYSIS OF EXPERIMENT RESULT

Taking two kinds of mini-car for examples, the power losses of driveline can be tested according to the above method.

The arrangement types of these two mini-cars are all front-engine and rear-drive. In addition, these two kinds of mini-cars are equipped with three-shaft and five-speed gearbox and constant drive axle.

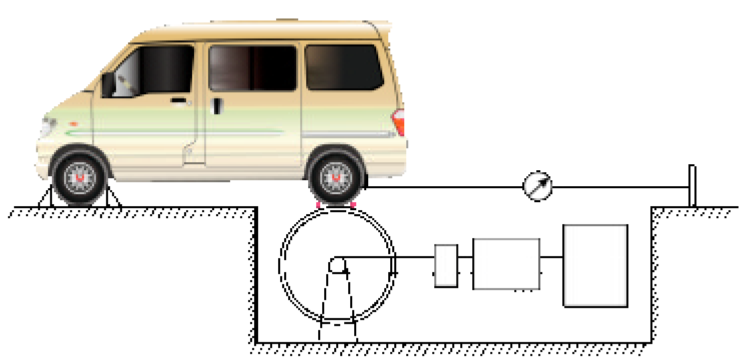

Fig. 2: Schematic diagram of measuring

Table 1: Testing results of mini-car A

Velocity ($km\ h^{-1}$)	F1(N)	F2(N)	F3(N)	F4(N)	ΔF1(N)	ΔF2(N)	ΔF3(N)
30	81.3	77.9	57.6	53.8	3.4	20.3	3.4
40	89.4	86.1	62.4	58.6	3.3	23.7	3.8
50	94.1	90.9	63.8	59.7	3.2	27.1	4.1
60	98.3	96.2	70.0	65.4	2.1	25.5	4.6
70	101.3	99.5	72.6	67.4	1.8	26.1	5.2
80	103.0	101.5	73.9	67.8	1.5	27.0	6.1
90	104.4	103.2	77.4	70.2	1.2	25.3	7.2
100	105.1	104.1	80.3	72.5	1.0	23.2	7.8
110	105.9	105.1	81.5	73.4	0.8	23.6	8.1
120	106.5	106.0	83.3	74.4	0.5	22.7	8.9

Table 2: Testing results of mini-car B

Velocity ($km\ h^{-1}$)	F1(N)	F2(N)	F3(N)	F4(N)	ΔF1(N)	ΔF2(N)	ΔF3(N)
30	104.7	96.1	76.5	72.6	8.6	19.6	3.9
40	111.4	103.9	80.7	76.4	7.5	23.2	4.3
50	117.9	112.5	86.7	82.0	5.4	25.8	4.7
60	124.4	120.6	91.4	86.5	3.8	29.2	4.9
70	129.6	126.7	94.0	88.2	2.9	32.7	5.8
80	133.9	131.3	96.7	88.8	2.6	34.6	7.9
90	137.9	135.5	99.0	90.7	2.4	36.5	8.3
100	140.6	138.6	100.9	91.5	2.0	37.7	9.4
110	144.4	142.6	104.2	94.4	1.8	38.4	9.8
120	148.6	147.3	107.6	97.3	1.3	39.7	10.3

In this article, the power losses are only taken into consideration when vehicles run in a straight way steadily and the power loss of clutch is ignored. The specific test results are obtained as shown in the Table 1 and 2.

It is obvious that the power loss of braking system has direct relationship with the internal resistance of braking system. The power loss of braking system can be expressed as:

$$P1 = \Delta F_1 \times V = (F_1\text{-}F_2) \times V \qquad (3)$$

where, ΔF_1 is the internal resistance of braking system, F1 is the testing value obtained in procedure (1), F_2 is the testing value obtained in procedure (2) and V is the linear velocity of the driving wheel.

As shown in Fig. 3, there is no abnormal brake drag in the braking system of mini-car A but the situation of mini-car B is completely opposite, there may be friction power loss between the brake drum and brake shoe in the non-braking state, because the gap between the brake drum and brake shoe is too small. As far as mini-car B is concerned, the braking system has obvious flaw and needs to be further optimized, especially the brake drum and brake shoe.

Similarly, the power loss of transmission has direct relationship with the internal resistance of transmission and can be expressed as:

$$P2 = \Delta F_2 \times V = (F_2\text{-}F_3) \times V \qquad (4)$$

where, ΔF_2 is the internal resistance of transmission, F_2 is the testing value obtained in procedure (2), F_3 is the testing value obtained in procedure (3) and V is the linear velocity of the driving wheel.

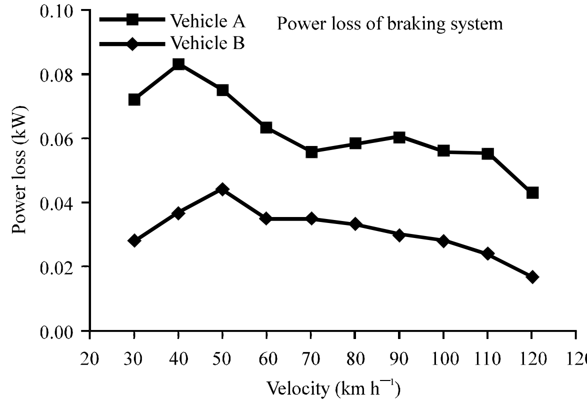

Fig. 3: Power loss of braking system

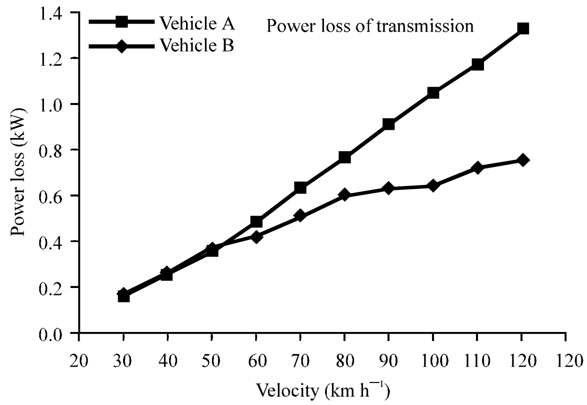

Fig. 4: Power loss of transmission

As shown in Fig. 4, There is not too much difference in mini-car A and mini-car B's power loss of transmission at low speed but the power loss of transmission of mini-car B is much bigger than mini-car A under the condition of high speed. This is probably because the performance of the bearings is not good enough or the precision of gear machining precision is not accurate enough.

Likewise, the power loss of main reducer has direct relationship with the internal resistance of main reducer and can be expressed as:

$$P_3 = \Delta F_3 \times V = (F_3\text{-}F_4)^* \qquad (3)$$

where, ΔF_3 is the resistance of transmission, F_3 is the testing value obtained in procedure (2), F_4 is the testing value obtained in procedure (3) and V is the linear velocity of the driving wheel.

As shown in Fig. 5, There is no difference in mini-car A and mini-car B's power loss of main reducer When the speed under 70 $km\ h^{-1}$ but difference gradually become obvious When the speed beyond 70 $km\ h^{-1}$.

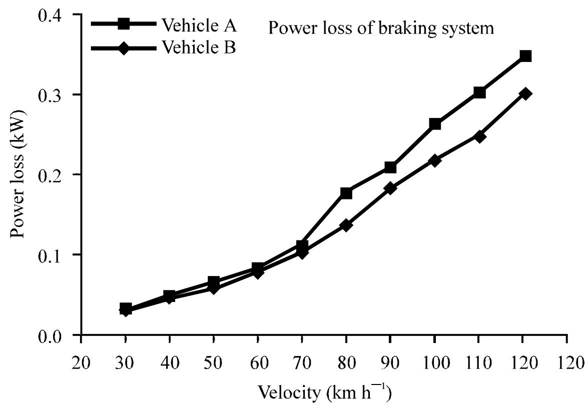

Fig. 5: Power loss of main reducer

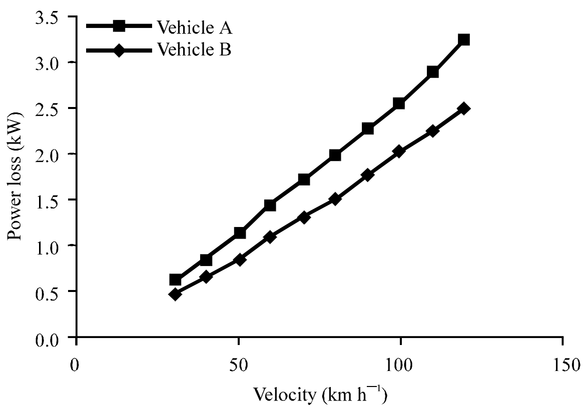

Fig. 6: Power losses of differential assembly and axle shaft assembly

In the same way, the power loss of differential assembly and axle shaft assembly has direct relationship with the internal resistance of differential assembly and axle shaft assembly. It can be expressed as:

$$P_4 = F_4 \times V \tag{4}$$

where, F_4 is the internal resistance of differential assembly and axle shaft assembly and V is the linear velocity of the driving wheel.

After testing, the power loss of all driveline components can be calculated and the proportion of respective parts will become very clear. Most important of all, the component that has the greatest potential to improve can be found.

As shown in Fig. 6, there is a huge difference between mini-car A and mini-car B, This is probably because the performance of the bearings is not good enough.

CONCLUSION

This study presented a method used for measuring power loss distribution of mini-car driveline. This method can not only quantify power loss distribution of different parts in driveline but also can find whole features of mini-car driveline at the least expense of testing time. As the component that has the greatest potential to improve is obvious after testing, the best solution to improve driveline will be developed very easily.

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