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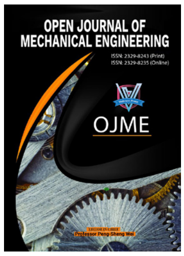

ARTICLE

DISCUSSION ON NEDC POWER CALCULATION AND ANALYSIS METHOD OF WET DCT ACTUATOR

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ABSTRACT

This paper analyzes the key factors affecting the power consumption of the oil pump based on the background of analyzing the selection and power consumption calculation of a certain DCT transmission oil pump. Combined with NEDC working conditions, the analysis and calculation are carried out, and the calculation method of NEDC power consumption is studied. The calculation method and analysis results in this paper have certain reference significance for the selection of the oil pump of the DCT hydraulic system and the calculation and evaluation of the power consumption of the hydraulic system.

KEYWORDS

DCT, power consumption, calculation.

1. INTRODUCTION

Energy saving and emission reduction has always been an eternal topic in the automotive industry. The hydraulic system is usually used as the executive control system in the wet DCT. Conventional DCTs usually employ mechanical pumps. For the traditional DCT, the energy consumption of the oil pump accounts for a relatively large proportion of the entire energy consumption of the gearbox. As the power source of the hydraulic system, the oil pump is used to provide the pressure and flow required by the system [1, 2]. The current mainstream solution is a solution using a mechanical pump + an electronic pump. By further reducing the mechanical pump displacement, the electronic pump is activated on demand, which can further reduce the energy consumption of the system [3]. Therefore, how to reasonably determine the displacement of the oil pump is of great significance to further improve the efficiency of the gearbox [4]. On this basis, it is also important to find an appropriate calculation method for quantitative analysis of system power consumption.

2. PUMP SIZING CALCULATION

Before calculating the power consumption of the oil pump, it is usually necessary to first determine the displacement of the oil pump. Oil pump displacement determination requires consideration of numerous system factors such as engine speed, system leakage, clutch and fork action, clutch and pinion lubrication. The general requirement is that the oil pump must meet the total flow requirements of engine speed & torque, system leakage, clutch and shift fork action, clutch and pinion lubrication and cooling under high temperature and low speed (engine) conditions. As shown in the following formula:

$$V_{mech}n_{engine}\eta_{v1} + V_{eletric}n_{eletric}\eta_{v2} \ge \max(Q_{shift} + Q_{clutch} + Q_{clutchcooling} + Q_{lubrication} + Q_{leakage})$$

V_{mech} and $V_{electric}$ are the corresponding mechanical pump and electronic pump displacements, respectively. n_{engine} and $\eta_{electric}$ are engine speed and electronic pump speed. Q is the flow required by each part. η_v is the corresponding volumetric efficiency.

According to the above calculation principles, the displacement of the original mechanical pump is reduced, and the addition of an auxiliary electronic pump can also meet the flow requirements of the original DCT.

3. NEDC WORKING CONDITION INTRODUCTION

The NEDC operating condition is shown in the figure below, consisting of 4 repeated urban cycles and one outer suburban cycle. Among them, the urban operation cycle is composed of four small urban operation cycle units. The unit test time of each cycle is 195s, including several stages such as idling, starting, accelerating and decelerating to stop. The maximum speed is 50km/h. The average speed is l8.35km/h. Maximum acceleration 1.042m/s. The average acceleration is 0.599m/s2. Suburban operation cycle time is 400s. The maximum speed is 120km/h. The average speed is 62km/h. The maximum acceleration is 0.833m/s2. The average acceleration is 0.354m/s. The total cycle time is about 1220s, and the NEDC condition is a common test method for the current vehicle fuel economy index. At present, my country also adopts this working condition as the standard working condition for testing.

Actuator power consumption is a key indicator in current hydraulic system design. In the whole hydraulic system, according to the power consumption of the actuator, it is mainly divided into the power

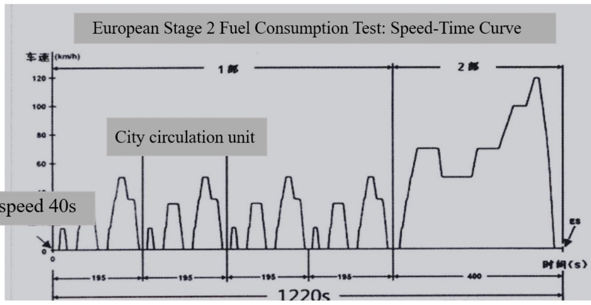

Figure 1: NEDC cycle

consumption of the oil pump and the power consumption of the electrical components. Among them, the power consumption of the oil pump accounts for a large proportion, and the current peak value (<1.2A) and resistance value (about 522) of electrical components such as solenoid valves, etc., the power consumption is small. The electronic pump is used as an auxiliary oil pump and is only activated on demand under certain operating conditions. Therefore, the corresponding power consumption is also relatively small. The power consumption of the actuator mainly needs to consider the energy consumption of the mechanical pump.

4. CALCULATION AND ANALYSIS OF NEDC POWER CONSUMPTION OF OIL PUMP

4.1 Calculation formula of oil pump trumpet

The formula for calculating the corresponding power of the oil pump:

$$P_{pump}=\frac{P_{main}Q}{\eta*600}=\frac{P_{main}nV_P}{\eta*600} \tag{1}$$

In the formula, P_{min} is the main oil circuit pressure (bar). η is the mechanical efficiency of the oil pump. Q is the output flow of the oil pump (corresponding to temperature and pressure), L/min. n is the oil pump speed, rmp. V_P is the oil pump displacement cm^3/rev. P is the oil pump power W.

According to formula (1), the power consumption of the oil pump mainly depends on the main oil circuit pressure, flow and engine speed. Usually mechanical pumps are driven by an engine. Therefore, the oil pump flow mainly depends on the engine speed and oil pump displacement, as well as the main oil circuit pressure. The main oil circuit pressure is the output pressure of the oil pump. As the power source of the system, the oil pump is used to provide the pressure and flow required by the system. Mainly used to perform the following functions: ①Clutch control. ②Fork control. ③Gear shaft lubrication and high clutch lubrication and cooling.

In the NEDC cycle, the number of shifts for the entire vehicle is small and the shift time is very short (<300 ms). In addition, it is closely related to the shift control strategy. Ignore the fork control process. During driving, the main oil circuit pressure is based on the clutch control pressure. Usually the main oil circuit pressure is 2-3bar higher than the clutch control pressure. The lubricating and cooling oil circuit pressure is low. Therefore, the system main oil pressure mainly depends on the clutch control oil pressure during the NEDC power consumption calculation process. As shown in Figures 2 and 3 below, the relationship between the clutch transmission torque and the clutch control pressure after the kiss point is approximately a straight line. The corresponding slope is called torque gain. The vehicle parameters in the NEDC cycle are known. During acceleration and deceleration, it is mainly controlled by the transmission torque worker. The control torque target and main oil pressure can be properly linked by delivering torque gain.

4.2 Introduction to related concepts of TP curve

The TP curves of the two clutches are shown in Figures 2 and 3.

The relationship between torque gain and main oil circuit pressure and clutch control torque is

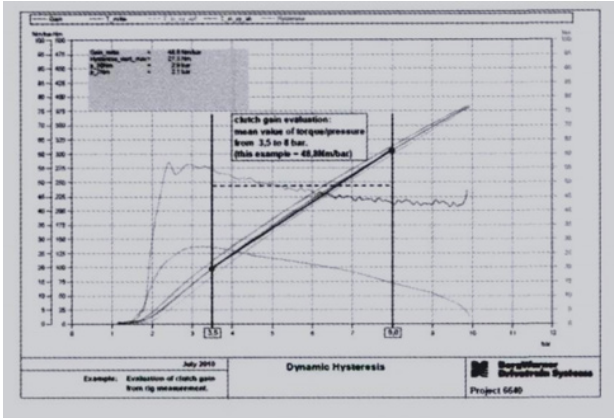

Figure 2: Clutch 1 T-P curve

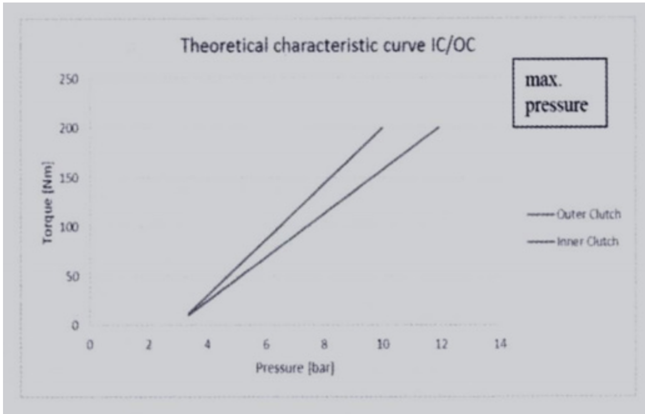

Figure 3: Clutch 2 T-P curve

$$\frac{P-P_{kisspo\,\mathrm{int}}}{T-0}=\frac{1}{k} \tag{2}$$

The parameters of the whole vehicle in the NEDC cycle are known, the clutch transmission torque T is mainly controlled during the acceleration and deceleration process, and the control torque target and the main oil pressure P can be properly linked through the transmission torque gain k.

The fixed system clutch control pressure is P. The torque corresponding to kiss point is 0. The relationship between system pressure and clutch transmission torque can then be calculated. The relationship between clutch control pressure, control torque and kisspoint pressure is

$$P=\frac{T}{k}+P_{kisspo\,\mathrm{int}} \tag{3}$$

The relationship between main oil circuit pressure, control torque and kiss point pressure is:

$$P_{main}=\frac{T}{k}+P_{kisspo\,\mathrm{int}}+\Delta P \tag{4}$$

According to equation (4), it can be known that the larger k is, that is, the steeper the torque gain, the lower the corresponding main oil pressure. However, the smaller the k value, the better the clutch control stability. In the NEDC cycle comparison process, because the cycle time is fixed, the average power consumption is usually used to compare the energy consumption.

4.3 Average power consumption

The above introduces the calculation formula of oil pump power and the calculation formula of main oil circuit pressure and torque gain.

Quantitative analysis of the power consumption of the entire process, usually expressed in terms of average power consumption. The relationship between NEDC power consumption and average power is shown in equation (5). t is the NEDC cycle time is a fixed value

$$w = \sum_{i=1}^{n} P_{pump} \Delta t_i = \overline{P}_{pump} t \qquad (5)$$

5. APPLE—APPLE ANALYSIS

NEDC power consumption is closely related to vehicle parameters and control systems. Therefore, it only makes sense to compare within a specific range. In the analysis of this paper, it is assumed that a DCT pure mechanical pump is changed to the form of a reduced displacement mechanical pump + an electronic pump. The whole vehicle adopts the original DCT gearbox. And in the NEDC condition, the electronic pump does not start. Different clutch torque gains have different effects on main oil pressure. Considering the influence of the clutch, the comparative analysis of NEDC power consumption is divided into the following two categories:

Assume that this is the same car, the same engine, the same gearbox body, different clutches, and the same actuator. The mechanical efficiency of the following formula takes the same value, and only considers the mechanical pump. DCT pure mechanical pump changed to reduced displacement mechanical pump + electronic pump.

$$\frac{w_1}{w_2} = \frac{\overline{P}_{main1}}{\overline{P}_{main2}} = \frac{\dfrac{(\frac{T_1}{k_1} + P_{kisspo\mathrm{int}} + \Delta P_1) n_{engine} \frac{n_{pump1}}{n_{clutch1}} V_{P1}}{\eta_1 * 600}}{\dfrac{(\frac{T_2}{k_2} + P_{kisspo\mathrm{int}} + \Delta P_2) n_{engine} \frac{n_{pump2}}{n_{clutch2}} V_{P2}}{\eta_2 * 600}} \qquad (6)$$

From formula (6), it can be calculated that the power consumption of the actuator mainly depends on the clutch torque gain, the pressure value at kp point, the difference between the main oil circuit pressure and the clutch oil circuit pressure, the ratio between the oil pump teeth and the clutch oil pump teeth, and the displacement of the oil pump. The mechanical efficiency corresponding to the oil pump. Substitute several torque parameters for calculation. Before the analysis, the corresponding engine torque value during the NEDC cycle is analyzed. The following is an analysis and calculation based on the NEDC real vehicle data of a certain DCT model.

As can be seen from Figure 4, the corresponding engine torque under NEDC conditions is usually in the range of 0-170 N m. It can be seen from Fig. 6 that in the case of using different clutches (clutch 1 and clutch 2), in the torque section below 60 N m, the use of mechanical oil pump + electronic oil pump with reduced displacement can reduce the energy consumption of the system. But the reduction is not very noticeable. When the mechanical efficiency of the mechanical pump with reduced

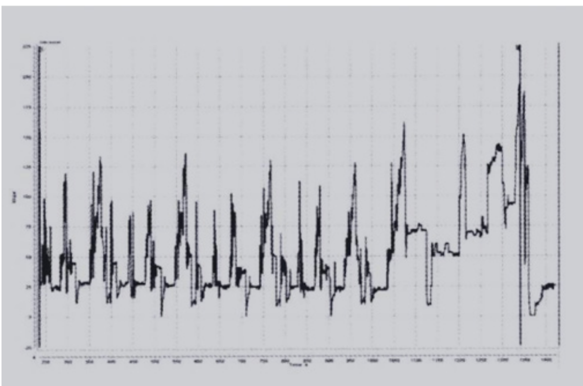

Figure 4: Corresponds to the engine torque

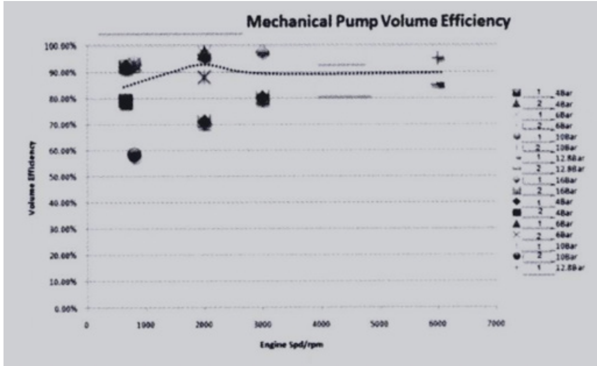

Figure 5: Mechanical pump mechanical efficiency

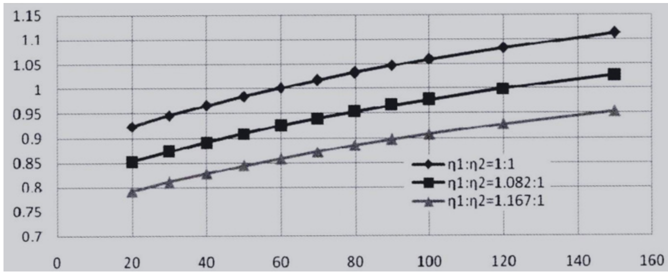

Figure 6: Power consumption ratio

displacement is higher than that of the original mechanical pump, the energy consumption ratio will decrease. However, the overall energy consumption of the execution system using clutch 2 is larger than that of clutch 1 as the torque increases. Analyze the reason that the torque gains of clutch 1 is larger than that of clutch 2. And clutch 1 kiss point is lower than clutch 2. When the mechanical efficiency of the mechanical pump with reduced displacement is higher than that of the original mechanical pump, the energy consumption ratio is slightly reduced. But the energy consumption ratio will increase with the increase of torque.

Assume that the car is the same, the engine is the same, the clutch is the same, the actuator is the same, and only the oil pump is different.

$$\frac{w_1}{w_2} = \frac{\overline{P}_{main1}}{\overline{P}_{main2}} = \frac{\dfrac{(\frac{T_1}{k_1} + P_{kisspo\mathrm{int}} + \Delta P_1) n_{engine} \frac{n_{pump1}}{n_{clutch1}} V_{P1}}{\eta_1 * 600}}{\dfrac{(\frac{T_2}{k_2} + P_{kisspo\mathrm{int}} + \Delta P_2) n_{engine} \frac{n_{pump2}}{n_{clutch2}} V_{P2}}{\eta_2 * 600}} \qquad (7)$$

From equation (7), it can be calculated that the power consumption of the actuator mainly depends on the displacement of the oil pump, the mechanical efficiency corresponding to the oil pump, and several parameters are substituted for the calculation.

It can be found from Figure 7 that if the clutch is the same, only the mechanical pump is different, the power consumption of the oil pump is significantly reduced after the displacement of the oil pump is reduced. And the power consumption ratio decreases obviously with the increase of the mechanical efficiency ratio. When the two mechanical efficiencies are equal, the power consumption ratio is about O. 7. The energy consumption of the execution system is significantly reduced. Through the analysis of two different situations (using different clutches and the same clutch), it can be seen that the clutch torque gain and the kiss point pressure value have a great influence on the energy consumption of the system. There is also the effect of the mechanical efficiency of the mechanical pump itself. But the efficiency usually doesn't vary much. Therefore, the main factors affecting the power consumption of the system are summarized as clutch torque gain, kiss point pressure value and oil pump displacement, and hydraulic system design (including lubrication and cooling control strategy).

Table 1: Power consumption comparison (=0.7)

Oil pump and clutch combination	Crude oil pump + clutch 1	Lower displacement oil pump + clutch 2	Lower displacement oil pump + clutch 1
NEDC power consumption	287W	249W	217W

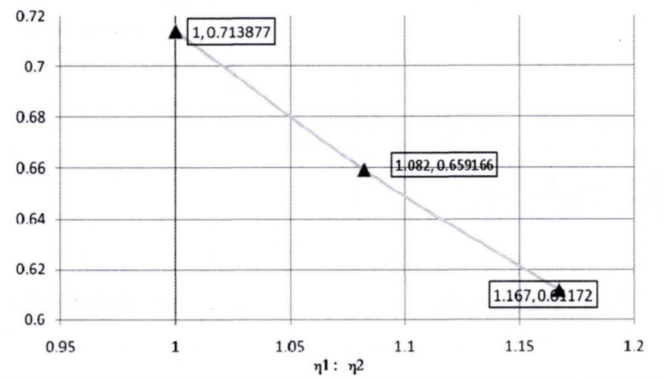

Figure 7: Power consumption ratio

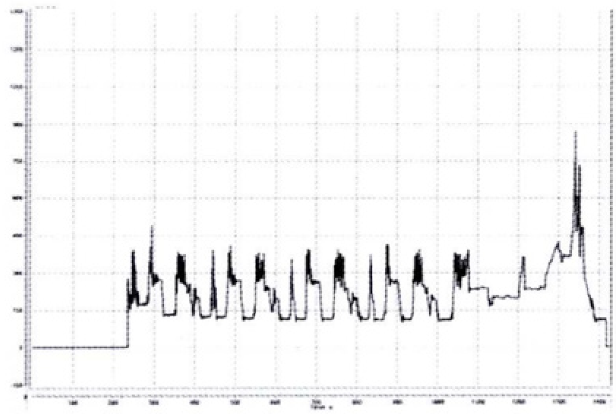

Figure 9: Lower Displacement Oil Pump + Clutch 2

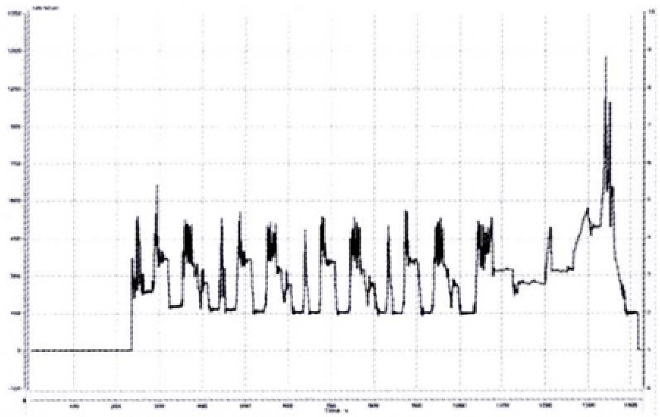

Figure 8: Crude oil pump + clutch 1

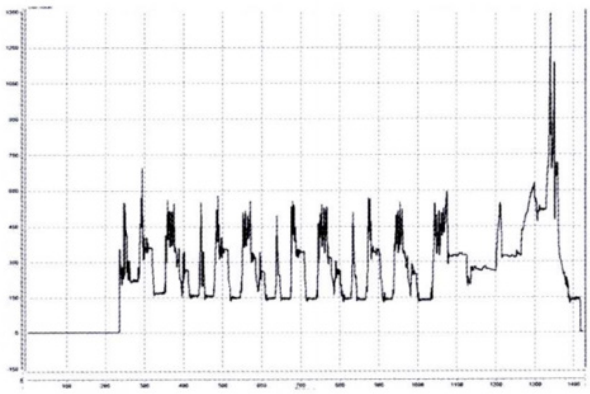

Figure 10: Lower Displacement Oil Pump + Clutch 1

Average power consumption comparison

The analysis and calculation are carried out with the NEDC real vehicle data of a certain DCT model as a reference. The following is the collected NEDC working condition data. Using engine torque and engine speed, the mechanical pump parameters and clutch-related parameters before optimization and after displacement reduction are respectively substituted. According to formulas (5) and (6), the power consumption curve of the oil pump can be obtained. Time integration of the power consumption gives the total energy consumed by the NEDC cycle. Then divide by the time to get the corresponding average power consumption. Figure 8, Figure 9, Figure 10, and Table 1 are the power consumption curves corresponding to different oil pump and clutch combinations.

6. CONCLUSIONS

This paper discusses a calculation method for calculating the NEDC power consumption of a hydraulic system. A detailed comparison and analysis are carried out in combination with the two hypothetical situations. The average power consumption was calculated according to the formula. The quantitative analysis and qualitative analysis of this paper have certain reference value. In the future, it can be considered to establish a corresponding more accurate matlab/Simulink model including the parameters of the whole vehicle, and consider the influence of temperature, throttle opening, mechanical efficiency of the oil pump and gear shifting, and design a more accurate calculation method.

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