Research on the Relationship between Engine Drag Torque and Cylinder Compression Pressure Based on Regression Analysis

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Abstract. This paper first proposes that cylinder tightness is an important factor affecting engine performance, which can directly reflect engine technical conditions. Cylinder tightness directly affects cylinder compression pressure, and cylinder compression pressure directly affects engine drag torque. Then, based on the test of real engine, the formula of the relation between the drag torque and the compression pressure is obtained by using the method of linear regression analysis, which provides a real and effective new method and means for inspecting the cylinder sealing. Data is obtained by preliminary analysis was carried out on the data of the basic characteristics, contact, and then use regression model to establish correlation between variables, with the method of mathematical model to describe the relation between resistance torque and compression pressure, through the relationship to provide scientific and effective in sealing cylinder detection method, make forecasting data more real and effective, More guidance for cylinder maintenance and state detection.

Keywords. Cylinder tightness; compression pressure; drag torque; engine test; regression analysis.

1. Introduction
Cylinder compression pressure is always an important comprehensive performance index of engine, and it is also one of the acceptance criteria of engine repair work. Relevant departments of the state also issued corresponding standards, that is, the compression pressure of each cylinder, gasoline engine should not exceed 8% of the average pressure of each cylinder, diesel engine should not exceed 10%. Therefore, how to quickly and accurately detect cylinder compression pressure is of great significance for detecting engine repair quality and improving repair efficiency after overhaul.

2. Commonly Used Cylinder Compression Pressure Measurement Method [1]

2.1. Cylinder Pressure Gauge Method
During the measurement, unload the fuel injector or spark plug of each cylinder, connect the pressure gauge with the cylinder through the pipe, and reverse drag the engine to measure the compression pressure of each cylinder respectively, which is simple and reliable, and is the most commonly used method by engine users. But because the cylinder compression process, the higher temperature in cylinder, cannot be directly connected to the cylinder pressure gauges, often through the pipeline connection, pipe has certain volume, pressure gauge by actual measured pressure value is less than
cylinder compression pressure, the measurement results, there are some error and measurement must remove the nozzle or the spark plug, complex operation, time-consuming.

### 2.2. Indicator Diagram Method

This method can accurately determine the pressure value and its variation law in the cylinder of diesel engine, as well as the compressibility index. However, expensive instruments and equipment are needed to obtain the engine indicator diagram, and sensors are set in the engine, so the test cost is high and the workload is heavy.

The method is to measure and record the current waveform of the starter under the starting condition and determine the relative compressibility of each cylinder according to the corresponding relationship between the current waveform and each cylinder stroke. But this method cannot determine the absolute value of the compression pressure of each cylinder.

### 2.3. Instantaneous Speed Method

Engine instantaneous speed change and the change of the engine crankshaft by close moment have determined, the relation between instantaneous rotation speed change within a circular curve by the number of peaks and troughs and corresponding of diesel engine cylinder number, comparing the difference between the corresponding waveform each cylinder, usually can be qualitative discriminant each cylinder work performance difference, but the operation of the instantaneous speed sensor must be installed, requires high accuracy of measurement.

### 3. Analysis of Relationship between Reverse-Drive Torque and Compression Pressure

#### 3.1. Analysis of Engine Drag Process

When the engine is reverse driving on the bench, the reverse-drive torque depends on the reverse-drive of the engine acting on the drag motor. Taking the crankshaft axis as the research object, when the cylinder head is covered, the drag moment mainly includes the mechanical loss moment and the gas compression loss moment, while when the cylinder head is removed, the drag moment mainly consists of the mechanical loss moment [2], as shown in the following figure 1.

![Figure 1](image)

**Figure 1.** The relationship between the backward drag loss pressure and the speed of a diesel engine

It can be seen from figure 1, the loss torque when the cylinder head is covered is much larger than that when the cylinder head is not covered, that is, the gas compression loss torque accounts for a relatively large proportion of the total torque of the cylinder head.

#### 3.1.1. Mechanical Loss Resistance Moment

When the engine is dragged, the mechanical lost power is mainly consumed in the friction work of each friction pair, the energy consumption of each accessory and the mass inertia moment of each cylinder in reciprocating motion, whose friction work of the friction pair and the drive attachment are only related to the speed and temperature. When the speed and temperature are constant, its influence on the reverse-drive torque remains the same, that is, in the
compression process of each cylinder, its influence is the same, forming the same resistance moment waveform with regular changes. However, the inertial force of complex moving parts only affects the shape of the torque curve and does not consume any work [3]. The drag moment generated is related to the rotation speed. In addition, when the rotating speed is low, the torque is not large. When the rotating speed is dragged backwards, its influence on the dragging torque remains unchanged.

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3.1.2. Gas Compression Loss Resistance Moment. In the process of cylinder compression, the electric energy of the motor is converted into the pressure energy of the gas in the cylinder. If there are no air leakage and heat transfer in the cylinder, this energy will be released during the expansion of the cylinder. In the actual situation, there are air leakage and heat transfer loss of cylinder wall, which causes the energy released in the expansion process to be less than the work consumed in the compression process, and the torque generated will form the resistance moment of the gas compression loss. Compared with air leakage, the loss caused by heat transfer is relatively large, which is because the pressure and temperature inside the cylinder are higher at the end of compression, and the temperature difference between the cylinder and the cooling water of the engine jacket is larger, and the heat dissipation is greater, resulting in a greater energy loss.

The pressure and temperature after compression can be calculated by the following formula:

\[ P_c = P_a e^n \]  \hspace{1cm} (1)
\[ T_c = T_a e^{n-1} \]  \hspace{1cm} (2)

In the formula, \( P_c \) - compression end pressure, \( P_a \) - inlet end pressure, \( T_c \) - compression end temperature, \( T_a \) - end of intake temperature, \( n \)- average compression polytropic index.

Value range of gasoline engine \( n \) (7 ~ 10), diesel engine \( n \) (14 ~ 22), supercharged diesel Engine \( n \) (12 ~ 15). The \( n \) value range of diesel engine (1.38 ~ 1.4) and supercharged diesel engine (1.35 ~ 1.37). When the cylinder tightness is poor, high temperature and high pressure gas leakage, so that the compression end temperature and pressure is low, and the cooling water temperature difference with the jacket is small, less heat dissipation, small energy loss, so that the gas compression loss torque and reverse-drive torque become smaller.

3.2. Relationship between Reverse-Drive Torque and Cylinder Compression Pressure
It can be seen from the analysis of engine reverse-drive resistant torque on the top side that the reverse-drive torque of gas compression loss accounts for a large proportion in the drag torque. The influence of mechanical loss moment on drag resistance moment of each cylinder at a certain speed is the same and varies regularly. The main reason for the different drag moment of each cylinder during the compression process is the resistance moment of cylinder compression loss, and the sealing property of cylinder directly affects the resistance moment of gas compression loss. Therefore, as long as the relationship between cylinder compression pressure and reverse-drive torque is found out, the cylinder compression pressure can be indirectly determined by engine reverse-drive torque, so as to achieve the purpose of cylinder compression pressure detection.

4. Test the Relation between Back Towing Moment and Compression Pressure
4.1. Laboratory Equipment
The relationship between engine cylinder compression pressure and reverse-drive torque was tested on the engine cold grinding and hot test bench designed and developed by our research group, as shown in the following figure 2.
4.2. Main Performance Parameters of Test Engine

The heat and cold run-in and power measurement of Steyr WD615.64/74 diesel engine were carried out on the test bench. Performance parameters of Steyr WD615.64/74 diesel engine are shown in Table 1.

### Table 1. Main performance parameters of Steyr WD615.64/74 diesel engine.

| Performance parameters | Meaning Performance indicators |
|------------------------|--------------------------------|
| Air inlet              | Booster                        |
| Number of cylinders    | 6                               |
| Rated power/speed (kW/r-min^{-1}) | 175/2200                   |
| Compression ratio      | 15.5: 1                         |

4.3. Test Speed Determination, Test Preparation and Data Acquisition

4.3.1. Determination of Test Speed [4, 5]. In order to accurately detect cylinder sealing, the pressure at the end of cylinder compression should be increased as much as possible. As can be seen from equation (1), when n increases, the cylinder compression end pressure increases, while N increases with the increase of the engine speed. This is because when the engine speed increases, the heat exchange time shortens and the heat dissipated to the cylinder wall decreases. However, the rotational speed should not be too high, because with the increase of rotational speed, the mass inertia of the reciprocating motion of each cylinder also increases rapidly. Although the influence on the compression process of each cylinder is the same, the increase of the resistance moment value is relatively large relative to the compression pressure change, which cannot highlight the change of compression pressure of each cylinder. At the same time, the increase of the rotating speed will lead to the decrease of the aeration coefficient and the high rotating speed, which, on the contrary, will lead to the decrease of the cylinder end compression pressure.

Therefore, while increasing the compression pressure in the cylinder, the influence of the mass inertia moment of each reciprocating movement on the dragging moment and the inflation coefficient on the final compression pressure in the cylinder is minimized. The test speed is set at 450 RPM. At this speed, the mass inertia moment of the reciprocating movement is not big and has little influence on the inflation coefficient.
4.3.2. Test Preparation. According to the national standards, after the overhaul of the engine running-in, the maximum power and maximum torque must not be less than 90% of the original design. Only after the engine meets the power detection requirements, can the test be carried out. At the same time, the temperature of cooling water after power measurement fully meets the test requirements (the temperature of cooling water is 75~85°C). On this basis, the engine oil supply pipeline is cut off, the motor is controlled by frequency conversion governor, and the engine is driven backward.

4.3.3. Data Acquisition Equipment and Data Acquisition. In order to accurately detect the engine cylinder compression pressure, the high-temperature pressure sensor of Beijing Starry Sky Sensor Co., Ltd. is installed directly in the installation hole of the fuel injector through a self-made connection sleeve (the highest operating temperature is 580 °C). At the same time, the pressure signal acquisition and analysis software was made by Qinhuangdao Xinheng Electronic Technology, and the acquisition channel was set as 6 channels with the acquisition frequency of 10000HZ. The amount and density of data acquisition met the analysis requirements. The signal acquisition results are shown in figure 3.

![Figure 3. Pressure signal acquisition.](image)

In order to make the torque data collected reflect the reverse torque change during each cylinder compression process and to collect the instant torque, jW-3 microcomputer torque meter and supporting software of Xiangyi Dynamic Testing Instrument Co., LTD were selected. According to the performance of the instrument, the collection method was set as instantaneous collection with an interval of 2 milliseconds. The data quantity and density fully met the needs of analysis. The data acquisition results of the torque tester are shown in figure 4 below.
In order to distinguish the compression pressure of each cylinder and its corresponding reverse-drive resistant torque data, the cylinder was positioned at the engine output by contact sensor before the backhaul, that is, the maximum torque point of the reverse-drive torque waveform collected when the piston compression process of a cylinder is about to reach the upper dead point is taken as the maximum reverse-drive torque corresponding to the cylinder compression.

4.4. Test and Data Correlation Analysis
The experimental team collected compression pressure and reverse-drive resistant torque data of a Steyr WD615.64/74 engine, and intercepted some data at random. Table 2 shows random interception of data.

Table 2. Compression pressure and reverse-drive torque measured in real car.

| Tank no. | Compression pressure | reverse-drive torque |
|----------|----------------------|----------------------|
| 1        | 4.732                | 165                  |
| 2        | 4.875                | 166                  |
| 3        | 4.903                | 172                  |
| 4        | 5.124                | 183                  |
| 5        | 5.302                | 184                  |

According to the least square principle, linear regression was carried out for cylinder compression pressure and reverse-drive torque, and the regression equation was obtained:

\[ P = 0.0229N + 0.9969 \]  \hspace{1cm} (3)

Table 3 shows the error between the cylinder compression pressure calculated according to the regression equation and the actual measurement.

Table 3. Error of measured compression pressure and calculated compression pressure.

| Tank no. | Compression pressure | Reverse-drive torque | Value | Dispersion | Error |
|----------|----------------------|----------------------|-------|------------|-------|
| 1        | 4.8961               | 172                  | 4.9357| 0.0396     | 0.81  |
| 2        | 4.9823               | 175                  | 5.0044| 0.0221     | 0.44  |
| 3        | 4.8401               | 170                  | 4.8899| 0.0498     | 1.02  |
| 4        | 5.2721               | 186                  | 5.2563| -0.0158    | 0.30  |
| 5        | 5.0899               | 176                  | 5.0273| -0.0626    | 1.22  |
| 6        | 4.8205               | 170                  | 4.8899| 0.0694     | 1.43  |
It can be seen from the table that the data calculated by the regression equation has little error with the data measured by the real car, which can meet the requirements of cylinder compression pressure detection.

5. Test Validation
In order to verify the accuracy and applicability of the regression equation, tests were carried out on the same type of engine after overhaul, and the results are shown in table 4.

Table 4. Compression pressure measured in real vehicle and calculated.

| Tank no. | Compression pressure | Reverse-drive torque | Value | Dispersion | Error |
|----------|----------------------|----------------------|-------|------------|-------|
| 1        | 4.8961               | 172                  | 4.9357| 0.0396     | 0.81  |
| 2        | 4.9823               | 175                  | 5.0044| 0.0221     | 0.44  |
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It can be seen from the table that the data calculated by the regression equation has little error with the data measured by the real car, which can meet the requirements of cylinder compression pressure detection.

6. Conclusion
The test method is to test the cylinder compression pressure and the reverse-drive torque of a certain engine on the bench at the same time. The linear regression analysis is carried out on the data of the two and the relation equation is obtained. The detection method is simple and high precision, which is of great significance to the rapid detection of engine technology.

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