Analysis of Engine Exhaust Pressure Wave Performance

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Abstract: By analyzing the form of pressure wave within automotive exhaust system and relationship between propagation process and working condition of engine, simulate a work cycle for purpose of timely diagnosing troubles, thus presenting exhaust stroke of four cylinders through pressure wave; modifying of the speed of engine will affect the amplitude of pressure wave, harmonic components, phase position and other parameters; at the end of the exhaust stroke, exhaust pressure wave generates interference, superposition and negative effect, which is of great importance for analysis and diagnosis of engine troubles by using exhaust pressure wave.

Keywords: Exhaust pressure wave; Exhaust system; Model of exhaust system; The simulation

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1.Introduction

The automobile engine is a very complicated system with machine, electricity and liquid, whose working condition directly affect safety, economy, dynamic performance, emission pollution and other indexes. The dynamic characteristics of the engine exhaust gas directly reflect the changes of the boundary conditions of the piping system, thus reflecting the running state of the engine.

1.1 Research on the Exhaust Pressure Wave

Create a model using the exhaust pressure wave to predict volumetric efficiency of the four-stroke diesel engine through relevant software, under the situation of effect-free engine work, analyze inhomogeneity of each cylinder filling quantity[1], through the measurement of the exhaust pressure wave of the diesel engine, the cause of temperature inhomogeneity of each cylinder can be found, thus making exhaust temperature comply with the relevant standard by taking measures[2].

2. Construction and Working Principle of Automobile Exhaust System

Automobile exhaust system, the whole exhaust gas passage from cylinder exhaust outlet to exhaust pipe outlet of automobile, is mainly made up of exhaust manifold, muffler, exhaust pipe, catalytic converter, tail pipe and other components. Exhaust gas goes to the following exhaust pipe after exhaust integration of each cylinder by exhaust manifold. Temperature of high-speed exhaust flow erupted from the cylinder can reach up to 888K, pressure of which can reach up to 100MPa[3]. Well-designed exhaust manifold uses pressure wave interference principle of each cylinder and negative effect generated by exhaust pressure wave, then erase remaining exhaust gas in exhaust stroke and overlapping phase of intake stroke, and absorb fresh mixed gas, thus improving working performance and efficiency. Catalytic converters convert harmful waste gases into non-toxic gases to meet the regulated vehicle emissions standards. Now the three-way catalytic converter generally uses aluminium magnesium silicate or metal as the carrier, in which there are tens of thousands of small holes, and coated with aluminium oxide in its surface, which greatly increase the contact area. The catalyst is made from platinum and rhodium, which can convert CO, HC and NO_X into CO_2, H_2O and N_2. The main function of muffler is to reduce combustion noise of engine. In a working cycle, the important factors that directly affect combustion noise of combustion engines are the gas dynamic load caused by the combustion process and the high frequency combustion pressure oscillation, etc.[4]. The interior of the muffler is divided into several reflective Chambers, which can reflect and dissipate the sound energy of sound. The reflection chamber is connected by a perforated pipe that can disperse and smoothen the flow of the exhaust gases. The entire muffler tube wall is a porous material with silencing function, such as asbestos, ceramic, etc., which can absorb high frequency noise and convert them to friction heat. The low-frequency part of the exhaust noise will be eliminated in the process of detouring through the connecting pipe between the reflection chambers. Each engine cylinder on the exhaust stroke in turn opens the discharge valve, after combustion exhaust gas gets out of the cylinder, it flows through the exhaust manifold, the front exhaust pipe, catalytic converter, muffler and tail pipe in turn, and then goes into the atmosphere. After the exhaust gas flow passes through the exhaust system, the temperature and pressure of the exhaust pipe are reduced to the same level as the surrounding atmosphere.

3.The Form of Pressure Wave and Propagation of the Exhaust System

3.1 Pressure Wave in the Exhaust Pipe

Before the end of each of the engine's working stroke, the exhaust valve opens, releases the high temperature, high-pressure combustion exhaust going into the exhaust pipe. Due to the intermittent opening and closing of the exhaust door of the engine, the high temperature and high pressure exhaust from the cylinder is transmitted along the exhaust pipe in the form of compression wave pulse. The compression wave pulse increases the pressure of the gas, and the pressure wave passes through the exhaust gas in turn and converts the pressure into the kinetic energy of the exhaust in front of it. At the same time, the high temperature and high pressure exhaust gas suddenly expand in the exhaust pipe, and soon replace the previous gas filled in the exhaust pipe. The exhaust gas concentration at the back of the expansion wave is diluted, resulting in a decrease in the pressure of the gas. The speed of pressure wave pulse propagation greatly exceeds the exhaust flow speed within the exhaust pipe, when the piston reaches the upper dead point, namely at the of the end of the exhaust stroke and at the beginning of intake stroke respectively, the compression wave reaches the terminal exhaust pipe. The average speed of the exhaust gas flow in the exhaust pipe can be calculated by formula[5].

$$V_g = \frac{SN}{30000}\left(\frac{D}{d}\right)^2$$

In the formula: Vg—Exhaust gas average velocity,m/s; D - piston diameter, mm; d - diameter of exhaust pipe, mm; S-piston travel, mm; N - crankshaft rotation speed, r/min pressure wave is transmitted by the sound velocity of exhaust gas, the sound velocity in exhaust gas can be expressed as: C= γpρ(2) : C - exhaust sound velocity, m/s; γ - molar specific heat capacity (γ = 114 of air); P - exhaust pressure, N/m^2; ρ - exhaust gas density, kg/m^3 combined with the pressure of the gas in the gas laws of thermodynamics relation P = mRTV, C $\propto$ T (3) can be deduced, propagation speed of the pressure wave in exhaust pipe is in direct proportion to the exhaust gas temperature.

3.2 Pressure Wave at the Opening End of the Pipe

The exhaust compression wave propagates in the exhaust pipe and produces reflected pressure waves at the outlet end of the exhaust pipe in the end.

Due to the restriction of pipe wall, the compression wave in the pipe section cannot be passed around. When it reaches the pipe end, however, the pressure spreads in all directions, the exit section of exhaust gas layer vibration amplitude is very big, due to the effect of inertia in the meantime, exhaust gas flows to cross section, leaving a thin zone between the pipe and the cross section of exit thin zone (depressurization).

The pressure drop is propagated backward along the tube, so the pressure wave is reflected in a negative pressure wave. When the depressurization zone reaches the end of the pipe, the exhaust gas from all directions will rush into the low pressure zone. Therefore, the rarefied (low density) area is reflected as a pressure wave from right to left. When the reflection pressure wave pulse reaches to the front row, it is passed to the outlet of the exhaust pipe by a positive pressure wave, and after arriving at the outlet of the exhaust pipe, the pressure wave rebounces back to the exhaust pipe. The cycle continues and occurs multiple times, but the amplitude attenuates, and if time is sufficient, it will continue until the next exhaust phase occurs.

3.3 Exhaust Interference of Exhaust Manifold

Since the exhaust outlet of the engine's various cylinders is connected by the exhaust manifold, the compressed wave pulse from each cylinder will be interfered at the junction. In terms of a four-cylinder engine, one exhaust stroke is completed every time the crankshaft turns 180 degrees. Theoretically, the engine completes a journey before starting the next journey. However, the actual upper intake valve opens at the upper end (10-25 degrees), which means that the intake gate overlaps open near the upper stop. In the same way, as the exhaust valve is closed after the upper stop, there is a certain exhaust gate overlap between the cylinders. Therefore, when a cylinder starts to exhaust, the second cylinder starts to enter the air intake, but the exhaust door remains open. Because the exhaust valve overlap between cylinder opens, when a cylinder exhaust stroke starts exhausting (the high pressure gas goes into the exhaust manifold), it interferes the adjacent cylinder which will be in the intake phase as the exhaust stroke will soon end. The cylinder has low filling pressure and low residual gas pressure in the exhaust manifold. As a result, the high pressure gas in the cylinder of the early exhaust process not only flows into the exhaust manifold, but also attempts to flow into the exhaust manifold of the adjacent cylinder, resulting in the exhaust gas from the cylinder goes back into the cylinder.

4. Simulation Analysis of Exhaust Pressure Wave

In order to study the relationship between the formation of pressure wave in the exhaust system as well as its propagation process and the working condition of the engine, build a model a four-cylinder and four-cylinder gasoline engine by a certain software. The four cylinders of the engine alternately carry out stroke in a certain order. During each period (180 - degree angle of crankshaft), one cylinder is in the exhaust stroke while another cylinder is in the intake stroke, at the end of exhaust stroke, the inlet valve opens, and then it forms the cylinder itself and the overlapping between the intake valve and the exhaust valve, so the exhaust pressure causes interference and overlap within the exhaust pipe. In a certain software environment, set the engine speed as 750 RPM. Under this condition, the engine is simulated and the crankshaft turns around 720 degrees, goes through four strokes, which is called a working cycle of the engine. During a working cycle of the engine, the pressure waves appears in four peaks and troughs, corresponding to the exhaust stroke of four cylinders. Cylinder No.1 begins compression stroke, and Cylinder No.3 is undergoing transition from the exhaust stroke to the intake stroke, the intake and exhaust valves open overlap, this time there was a trough slightly lower than the atmospheric pressure, this is due to the negative pressure produced by the reflected wave from the tail pipe port and other cylinders' interference effect, negative pressure wave is helpful to cleaning of the cylinder exhaust gas and inhaling of fresh gas mixture; Afterwards, the positive pressure wave pulse of the exhaust stroke of Cylinder No.4 takes up the mainstream, and the pressure rises rapidly. When Cylinder No.4 is transitioned from the exhaust stroke to the intake stroke, the pressure reaches its peak and then falls sharply to form the next trough, and the pressure wave enters the next cycle. Therefore, the waveform corresponding to the four cylinder in the rotation angle of Cylinder No.1 of 180-0 degrees is the same as Cylinder No.4 of the other wave forms. Thus, during a working cycle of the engine, there is a pressure wave of four cycles. When the exhaust gas is propagated in the exhaust system, on the one hand, the pressure peak decreases gradually; meanwhile, the wave trough of the pressure wave has increased slightly. This means the continuous decrease of the amplitude of the pressure wave, which is absorbed and converted into heat energy by the components of the exhaust system. On the other hand, because the pressure wave in exhaust system transmits as gas velocity, though gas transmission process cools gradually, resulting in decreases in the pressure wave propagation speed, in general, phase shift of pressure wave from the vent of the cylinder to the exit of exhaust pipe can be estimated according to the average speed. It can be seen that as the engine speed increases, the amplitude of the exhaust pressure wave accordingly (energy increases), harmonic wave decreases, phase position delays, reduced harmonic components, and phase delay.

5. Conclusion

The exhaust pressure wave of the engine can reflect the running state of the engine. By simulation, it is found that exhaust pressure wave of the engine has interference, superposition and negative pressure effect at the end of the exhaust stroke. The engine speed can affect the amplitude, harmonic components, phase position and other parameters. A solid foundation has been laid for the analysis of the exhaust pressure wave spectrum.

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