Data study on influence of high altitude on dynamic performance of supercharged diesel engine

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Abstract. In this paper, the dynamic performance of turbocharged diesel engine is studied comprehensively and systematically by using a high altitude diesel engine simulation test-bed to simulate different altitudes. The influence of altitude change on the dynamic performance of turbocharged diesel engine is analyzed, which provides an important basis for further improving and enhancing the performance of turbocharged diesel engine at high altitude.

1. Introduction
China has a vast territory and is the country with the largest plateau area in the world. The plateau area above 1000m above sea level accounts for more than 65% of the total land area of China. In particular, the Qinghai-Tibet Plateau, known as the "roof of the world", covers an area of 2.3 million square kilometers with an average elevation of over 4000m meters. Not only the altitude here is high, but also the drop is large and the slope is long, which brings great difficulties to transportation.
When a car is driving on plateau, the change of altitude has obvious influence on engine performance. With the increase of altitude, the engine has some problems, such as decreased power performance, deteriorated economy and serious emission pollution. The reason is mainly due to the influence of high altitude (low pressure) atmospheric conditions.
The main influencing factors of high altitude atmospheric conditions on the performance of internal combustion engines include atmospheric pressure, atmospheric temperature and air relative humidity. Among them, the influence of atmospheric pressure and atmospheric temperature is very significant. China's plateau is vast, and the temperature varies greatly in different seasons, on day and night, and under different weather. It is of no practical significance to take the annual average statistical temperature as the representative. Table 1 shows the meteorological data of China's plateau [1].

| altitude(m) | Atmospheric pressure(kPa) |
|------------|---------------------------|
| 0          | 101.33                    |
| 1000       | 89.87                     |
| 2000       | 79.49                     |
| 3000       | 70.10                     |
| 4000       | 61.63                     |
| 5000       | 54.00                     |

Table 1. Plateau pressure data in China.
The data listed in Table 1 can be approximated by the following formula.

\[ p_A = p_0(1-0.02257H) \]  

(1)

Where:

- \( p_0 \) — atmospheric pressure at sea level (kPa)
- \( p_A \) — atmospheric pressure at any altitude (kPa)
- \( H \) — altitude (km)

According to the standard, when the engine is tested at high altitude (low pressure), the environmental conditions at each simulated altitude shall meet the requirements in Table 2. At each simulated altitude, the engine exhaust backpressure should be 0.7 ~ 3.5 kPa higher than the intake pressure.

| Table 2. Environmental conditions of high altitude (low pressure) operation test [2]. |
| --- |
| serial number | Simulated altitude(m) | intake pressure(kPa) | Minimum ambient temperature |
| --- | --- | --- | --- |
| 1 | 2000 | 79.5 | 30 |
| 2 | 3000 | 70.1 | 24 |
| 3 | 4000 | 61.7 | 17 |
| 4 | 5000 | 54.0 | 11 |

The highest highway in China is Qinghai-Tibet Highway, and the highest road section is near Tanggula Pass, with an altitude of 5230m m. In this paper, the highest test simulation height is 5000m, which can basically cover the altitude of most highways in China. According to the regulations, the atmospheric pressure conditions of high altitude (low pressure) simulation test of internal combustion engine are worked out with reference to the plateau meteorological data in Table 1, as shown in Table 3.

| Table 3. Atmospheric pressure of high altitude (low pressure) simulation test. |
| --- |
| Simulated altitude(m) | intake pressure(kPa) | exhaust back pressure(mmHg) |
| --- | --- | --- |
| 0 | 101.33 | 760.0 |
| 1000 | 89.87 | 674.1 |
| 2000 | 79.50 | 596.3 |
| 3000 | 70.13 | 526.0 |
| 4000 | 61.70 | 462.8 |
| 5000 | 54.00 | 405.0 |

The diesel engine tested in this paper is a BF8L413FC air-cooled turbocharged diesel engine produced by Hebei Huabei Diesel Engine Factory, which is an advanced diesel engine in the early 1990s. In 1997, North China Diesel Engine Factory exclusively introduced this series of diesel engine models, which are the matching diesel engine models of Mercedes-Benz heavy military vehicles in North China [3].
Table 4. Main technical parameters of BF8L413FC turbocharged diesel engine.

| Engine model       | BF8L413FC |
|--------------------|-----------|
| Number of cylinders| 8         |
| Cylinder diameter/stroke(mm) | 125/130 |
| the volume of work(L)   | 12.763    |
| Compression ratio      | 16.5      |
| maximum speed(r/min)   | 2700      |
| Calibration power/calibration speed(kW / r/min) | 235.4/2500 |
| maximum torque(N·m / r/min) | 1000-1100 |
| Rated fuel consumption rate(g/kW·h) | Not more than 240 |

The main measured and monitored parameters in the test are shown in Table 5.

Table 5. Main measured parameters and monitoring parameters.

| Measured parameters (unit) | Monitoring parameters (unit) |
|----------------------------|------------------------------|
| Engine torque Ttq(N·m)     | Temperature of lubricating oil(℃) |
| Engine speed n(r/min)      | Lubricating oil pressure(kPa)   |
| Fuel consumption B(kg/h)   | Temperature after turbocharging T(℃) |
| Pressure difference of air flowmeterΔp(mmH2O) | atmospheric pressure p(kPa) |

According to QC / T524-1999 Automobile Engine Performance Test Method, the effective torque, power and fuel consumption rate are corrected. The main calculation formula is as follows:

\[ Ttq_0 = \alpha_d \cdot Ttq \]  
\[ Pe_0 = \alpha_d \cdot Pe \]  
\[ be_0 = \alpha_d \cdot be \]  

In which:
- \( Ttq_0 \) — corrected effective torque(N·m)
- \( Pe_0 \) — corrected effective power (kW)
- \( be_0 \) — corrected effective fuel consumption rate (g/kW·h)
- \( Ttq \) — effective torque(N·m)
- \( Pe \) — effective power (kW)
- \( be \) — effective fuel consumption rate(g/kW·h)
- \( \alpha_d \) — correction coefficient

In which the correction coefficient \( \alpha_d \):

\[ \alpha_d = f \cdot a \]  

After the simulation operation of the simulation platform, the data are shown in Tables 6 and 7:
Table 6. Percentage decrease of effective power of turbocharged diesel engine at different altitudes.

| (m) | 1000 | 2000 | 3000 | 4000 | 5000 |
|-----|------|------|------|------|------|
| r/min |      |      |      |      |      |
| 2500 | 0.58% | 0.77% | 1.15% | 1.91% | 3.50% |
| 2000 | 0.65% | 0.98% | 1.93% | 2.60% | 4.07% |
| 1500 | 1.23% | 2.26% | 4.18% | 6.27% | 11.81% |
| 1300 | 3.91% | 8.34% | 14.20% | 18.68% | 24.59% |
| 1000 | 4.84% | 9.26% | 14.88% | 18.91% | 25.25% |

Table 7. Percentage decrease of effective power of turbocharged diesel engine for every 1000m elevation.

| (m) | 1000 | 2000 | 3000 | 4000 | 5000 |
|-----|------|------|------|------|------|
| r/min |      |      |      |      |      |
| 2500 | 0.55% | 0.23% | 0.41% | 0.81% | 1.68% |
| 2000 | 0.65% | 0.36% | 1.01% | 0.71% | 1.57% |
| 1500 | 1.24% | 1.08% | 2.04% | 2.26% | 6.31% |
| 1300 | 4.07% | 4.86% | 6.86% | 5.54% | 7.86% |
| 1000 | 5.08% | 4.90% | 6.63% | 5.01% | 8.51% |

It can be seen from the above table that the change trend of diesel engine output torque and power is basically the same at different altitudes: when the diesel engine speed increases from low speed, the output torque and power increase with the increase of speed. With the increase of altitude, the power performance of turbocharged diesel engine mainly has the following characteristics:

2. With the increase of altitude, the overall power performance of turbocharged diesel engine decreases

With the increase of altitude, the output torque and power of diesel engine decrease as a whole; after the altitude exceeds 2000m, the torque and power decrease significantly. The effective power reduction percentage of diesel engines at different altitudes is shown in Tables 6 and 7. According to the table:

(1) When the altitude is below 2000m, the effective power of turbocharged diesel engine does not decrease obviously, and the decrease range does not exceed 10%.

(2) The effective power of turbocharged diesel engine decreases by 1% ~ 5% on average when the altitude rises by 1 000 m. Compared with naturally aspirated diesel engine's power decline at high altitude [4-5], the power performance of turbocharged diesel engine at high altitude has obviously recovered and improved, and the decline range has been reduced by more than 50%.

3. The power performance of turbocharged diesel engine decreases significantly with the increase of altitude at low speed

At low speed, the power performance of diesel engine is significantly affected by altitude, and the output torque and power decrease greatly with the increase of altitude; At high speed, however, the power performance of diesel engine is less obvious.

It can be seen from Tables 6 and 7 that with the increase of altitude, the power of turbocharged diesel engine decreases slightly at high speed, but decreases rapidly at low speed. At high altitude and low speed, the power of turbocharged diesel engine decreases by 25%.
Therefore, at high speed, the power of diesel engine changes little with altitude, and the lower the speed, the greater the decrease of power with altitude. At low speed, the power drops rapidly after the altitude exceeds 2000m.

The main reason why the dynamic performance of turbocharged diesel engine drops sharply at low speed is that with the increase of altitude, although the air density decreases, the intake air of diesel engine decreases, but at the same time, the back pressure of turbine also decreases, and the expansion ratio increases, which makes the turbocharger function relatively improve and plays the role of air compensation. At high speed, the compensation effect of turbocharger is better, while at low speed, the exhaust energy of diesel engine is insufficient, and the working capacity of turbocharger drops rapidly, so the dynamic performance of diesel engine drops rapidly. It can be clearly seen that in the low speed region, the higher the altitude, the faster the diesel engine output torque decreases from the maximum value.

4. The high-altitude torque characteristics of turbocharged diesel engines deterioration
With the increase of altitude, the maximum torque value of turbocharged diesel engine torque output decreases in turn; at the same time, the rotational speed of diesel engine increases in turn when it outputs the maximum torque. This change of torque characteristics seriously affects the torque reserve coefficient of turbocharged diesel engine at high altitude, which is very unfavorable for automotive diesel engine.

5. Conclusions
By analyzing the change law of dynamic performance of turbocharged diesel engine at different altitudes, the following main conclusions are drawn:
(1) With the increase of altitude, the atmospheric pressure decreases, the intake charge decreases, and the combustion process deteriorates, which leads to the decrease of the power performance of turbocharged diesel engine. Although the turbocharger has a certain recovery and compensation function, the performance of turbocharged diesel engine still decreases greatly after the altitude exceeds 2000 m.
(2) The effective power of turbocharged diesel engine decreases by 1% ~ 5% on average when the altitude increases by 1000 m.
(3) The change of altitude has a significant impact on the turbocharged diesel engine at low speed. Because with the increase of altitude the turbocharger’s working capacity decreases at low speed, the diesel engine's power performance deteriorates rapidly.

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