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# Free Acceleration Smoke Control Method of Non-Road Mobile Machinery

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**Abstract.** The free-acceleration smoke test method is widely used in diesel-powered vehicles or machinery to visually represent the level of particulate emissions from non-road mobile machinery. By controlling freely accelerated smoke emissions, particulate emissions from non-road mobile machinery can be effectively controlled. Based on the analysis of the working condition characteristics and particle generation principle of non-road mobile machinery, this paper has developed a method to optimize the non-road mobile machinery gear switching time to reduce the free acceleration smoke of the machine and achieved good results.

## 1. Introduction

Non-road mobile machinery is widely used as an important equipment for engineering construction in urban construction and road and bridge construction. However, due to the fact that its working place is far from the residential area and the working environment is poor, people have relatively little knowledge of non-road mobile machinery emissions. Due to the large amount of non-road mobile machinery and the relatively low level of emission control technology, coupled with the complex working conditions of non-road mobile machinery, exhaust emissions are much worse than road vehicles. The exhaust pollution of non-road mobile machinery has become one of the major sources of pollution to the atmosphere and harm human health. With the acceleration of urban construction in recent years, the total amount of non-road mobile machinery has increased sharply, and particulate matter discharged from non-road mobile machinery has become the major source of air pollution in major cities. The non-road mobile machinery is powered by a diesel engine. The particle size of the particulates discharged from the diesel engine is usually between 10-1000 nanometers, and contains a variety of toxic substances, which seriously harm human health.

In recent years, countries of the world attach great importance to the pollution of diesel particulate matter and its impact on human health, and have developed stricter particulate emission standards. However, limited to the diversity and complexity of non-road mobile machinery, the standards of various countries are based on the engine. It is difficult to quickly and effectively evaluate the emission of the non-road mobile machinery. Therefore, in order to quickly and effectively evaluate the level of particulate emissions in non-road mobile machinery, major cities in China have used the method of measuring the free acceleration of non-road mobile machinery to measure the level of particulate emissions in non-road mobile machinery. The free-acceleration smoke test method is responsive, quick-responding, and intuitive in results, and can realize the continuous measurement of



instantaneous smoke under transient conditions. It is very suitable for the detection and enforcement of non-road mobile machinery particle emissions. It has now become the main method for rapid assessment of particulate emissions levels in non-road mobile machinery.

## **2. Principle of soot formation in non-road mobile machinery**

The main driving force for non-road mobile machinery is the diesel engine. When the diesel engine is working, the injector quickly injects high-pressure liquid diesel into the combustion chamber through small holes. The droplets passing through the small holes at high speed are strongly rubbed against the air taken in by the intake system, heated and vaporized, and thoroughly mixed with the air. When the piston moves near the top dead center, the temperature in the combustion chamber has reached the combustion temperature, and some of the mixture with the proper concentration starts to burn. The small droplets of fuel sprayed from the injector are difficult to be very uniform when mixed with the air in the cylinder, and it is easy to cause the local air-fuel ratio to be less than the theoretical air-fuel ratio. The fuel that fails to be mixed is not fully combusted due to lack of sufficient air, and is rapidly cracked into a hydrocarbon chain at a high temperature, and the hydrocarbon chain is further dehydrogenated to form small-sized carbon particles having a diameter of nanometers. These small particles accumulate together to form soot with the exhaust gas.

When the diesel engine accelerates or increases the load, it needs to spray more diesel in order to achieve the target speed and load. However, the response time of the intake and exhaust system can not increase the intake air synchronously, resulting in low instantaneous air-fuel combustion and easier formation of soot. Moreover, the diesel engine is often equipped with a turbocharger, and the response time is further lengthened. This is because the energy of the turbocharger operation comes from the energy of the exhaust gas discharged from the cylinder. The energy of the exhaust gas comes from the kinetic energy and residual heat of the exhaust gas discharged from the cylinder after combustion. It is necessary to provide more energy after more fuel is burned, which causes the response of the entire intake and exhaust system to be slower. Therefore, when the non-road mobile machinery has a large change in the rotational speed or load during the work, smoke is likely to occur. In addition, the choice of the phase angle of the valve and the intake and exhaust resistance will also have a greater impact on the particle generation of the diesel engine. This is mainly related to the single-cylinder exhaust interference and whether the exhaust gas is discharged smoothly. Exhaust back pressure is the basis of diesel engine design, so it will not be described here.

The condition required in the free acceleration smoke test is to manipulate the diesel fuel injection amount to a maximum in a short time (the pedal is 1s to the end). Under this condition, the oil quantity changes the most severely and the response time to the intake and exhaust system is the least, so it can be considered as the worst case. Therefore, the smoke value in the free accelerated smoke test can be considered as the maximum smoke emitted by the non-road mobile machine during actual use. Therefore, the method of freely accelerating smoke can effectively evaluate the soot or even particulate emissions of non-road mobile machinery.

## **3. Measures and methods for reducing free acceleration smoke**

From the above analysis, we can see that the main reason for the formation of exhaust smoke in non-road mobile machinery is the excessive supply of fuel, insufficient supply of fresh air, and insufficient mixing of fuel air. Therefore, the corresponding solution is: Reduce the instantaneous supply of fuel; Reduce the booster response time (or give enough reaction time); Provide a suitable vortex ratio and fuel injection pressure.

The third point is that the vortex ratio of the intake port and the injection pressure of the fuel system have been determined in the diesel engine design selection stage, it is very difficult to adjust and verify. So it is not the main means to reduce the free acceleration smoke of non-road mobile machinery. Reducing the instantaneous fuel supply and reducing the booster response time (or increasing the fuel supply transition time) can be achieved by adjusting the fuel system calibration data or optimizing the booster configuration. At present, the technical route of the third stage of

domestic non-road mobile machinery mostly adopts electronically controlled high pressure common rail technology, so optimizing fuel injection parameters becomes the main means to reduce the free acceleration smoke of non-road mobile machinery. The research objects selected in this study are two Dynapac road rollers. The relevant parameters of non-road mobile machinery are:

**Table 1.** Main parameters of non-road mobile machinery for testing

Production Year	2017	2017
Type	CC6200	CC5200
Rated Power	113kW	93Kw
Rated Speed	2200r/min	2200r/min
Emission route	Common rail+ Turbocharger	
Emission Stage	China III	

The smoke measuring device is the MEXA-600S portable opaque smoke meter, manufactured by HORIBA, Japan.

The road roller is compacted in the actual work by using two heavy mills before and after the asphalt paver is paved on the road surface. The actual working condition of the road roller is close to the constant speed variable load, and the running speed of the whole machine is basically unchanged during operation. Therefore, the design of the roller in the operation mode uses a multi-position electronic switch to set the three speeds of idle speed, working speed and rated speed. By setting different gear positions, the roller machine can make the roller work at a constant speed under the set gear speed.

The measurement standard of this test is based on Beijing local standard DB11/184-2013 "Limited emission limits and measurement methods for non-road diesel machinery". Before the test prototype, there was a problem of free acceleration and smoke, which did not meet the requirements of the DB11/184 standard. The test plan reduces the maximum single-cylinder fuel supply of diesel by changing the time that idle speed to the rated speed, thereby achieving the purpose of reducing the free acceleration smoke.

**Table 2.** Calibration time is 1s smoke measurement result

Times	Result(unit: $\text{m}^{-1}$ )	
	CC5200	CC6200
1	1.160	1.001
2	1.048	0.976
3	0.991	0.927
4	0.876	0.890
5	0.945	0.832
6	0.942	0.827

After the calibration data is changed, the roller shift position is changed to 2s, and then tested again:

**Table 3.** Calibration time is 2s smoke measurement result

Times	Result(unit: $\text{m}^{-1}$ )	
	CC5200	CC6200
1	0.782	0.688
2	0.694	0.597
3	0.688	0.588
4	0.682	0.583
5	0.671	0.585
6	0.670	0.578

It can be seen from the data that the free acceleration smoke value of the roller has dropped significantly after increasing the gear shifting time, but still higher than the Class III limit requirement of the DB11/184-2013 standard. Therefore, it is necessary to further optimize the gear switching time to meet the regulatory limit requirements. The test results when the gear shifting time is set to 3s are as follows: Therefore, it is necessary to further optimize the gear switching time to meet the regulatory limit requirements. The test results when the gear shifting time is set to 3s are as follows:

**Table 4.** Calibration time is 3s smoke measurement result

Times	Result(unit: $\text{m}^{-1}$ )	
	CC5200	CC6200
1	0.318	0.321
2	0.255	0.214
3	0.257	0.188
4	0.252	0.183
5	0.224	0.178
6	0.224	0.183

The free acceleration smoke at the calibration time has already met the regulatory requirements, and the reduction effect is obvious. In order to further study its role in reducing smoke, it is necessary to continue to increase the gear switching time and test it. The results are as follows:

**Table 5.** Calibration time is 4s smoke measurement result

Times	Result(unit: $\text{m}^{-1}$ )	
	CC5200	CC6200
1	0.292	0.336
2	0.258	0.226
3	0.237	0.186
4	0.233	0.184
5	0.227	0.178
6	0.225	0.178

As can be seen from the above table, continuing to increase the calibration time does not further reduce the free acceleration smoke of non-road mobile machinery.

**Table 6.** Free Accelerated Smoke (mean) at different calibration times

NO.	Calibration time	Result(unit: $\text{m}^{-1}$ )	
		CC5200	CC6200
1	1s	0.921	0.850
2	2s	0.674	0.582
3	3s	0.233	0.181
4	4s	0.228	0.180

By increasing the gear shifting time by calibration, the free acceleration smoke value of the non-road mobile machinery can be effectively controlled, with a reduction of 75.2%. However, continuing to increase the gear shifting time after reaching a certain boundary time cannot further reduce the free acceleration smoke of the non-road mobile machinery.

#### 4. Conclusion

The test aims to reduce the free acceleration smoke value of non-road mobile machinery by increasing the gear switching time. The calibration time of gear shifting was increased from 1s to 3s, and the smoke value (mean) was reduced from 0.921 to 0.233. Continue to increase the calibration time smoke value is not further reduced.

According to the previous analysis, when the diesel engine oil quantity suddenly increases, the turbocharger will cause the air-fuel ratio to be lower than the steady-state working air-fuel ratio due to the untimely response, resulting in a large smoke. The free acceleration test requires that the speed of the diesel engine be rapidly increased from the idle speed to the rated speed. The diesel engine is required to quickly add fuel to the cylinder to increase the speed. Increasing the gear shifting time actually reduces the single maximum fuel supply and the total fuel supply during the acceleration process. At the same time, the longer rotation speed change time gives the supercharger sufficient reaction time, and the boost pressure follow ability is better. It can supply enough fresh air in the cylinder to meet the combustion requirements, so that the cylinder is in oxygen-rich combustion and lower smoke. Since the maximum oil supply is reduced, the fuel injection continuous angle is reduced, the oil jet spray to the combustion chamber may be reduced, which reduces the probability of particle formation. Increasing the gear shifting time during the test can reduce the free acceleration smoke, but after a certain period of time, even if the gear shifting time is increased, the free acceleration smoke cannot be further reduced. This is because by increasing the gear switching time, the follow-up of the intake pressure has been met, and there is enough fresh air to support the combustion, and the air-fuel ratio cannot be further increased. At this time, in the case where there is sufficient fresh air in the combustion chamber, the formation of the smoke is only related to the vortex ratio, the valve timing, the fuel injection parameters, and the like. Further increasing the gear shifting time has no benefit in reducing the smoke of the non-road mobile machinery, but will affect the power performance.

Since the working speed of the roller is basically constant, there is no high demand for the gear switching time. After the operator's own test, changing the gear switching time to 3s has no effect on operation and power. Therefore, the method of adjusting the diesel engine speed switching time is a fast and efficient method for reducing the smoke of the non-road mobile machinery for the constant speed non-road mobile machinery working in the multi-speed gear position.

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