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DIAGNOSTICS OF INTERNAL COMBUSTION DIESEL ENGINES OPERATED IN CONSTRUCTION AND MINING

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Abstract

Mining machinery and equipment belong to the group of special machines working in extreme conditions. Mining machines are used in difficult conditions such as limited supplies of fresh air, heat from the rock, in places with high humidity and heavy dust. In other specifics related to the extraction process is brine, harmful compounds such as sulphur dioxide, or rock debris raining down.

The machines are operated in continuous mode, the clock. Working in mining conditions machines are exposed to frequent breakdowns and malfunctions.

Identifying of failure diesel engines can be cumbersome in these conditions and time-consuming, leading to longer downtime, thereby reducing operating efficiency and increased cost.

Therefore, in the paper was a review and analysis methods for the diagnosis of internal combustion diesel engines used in machines built and used to power machines in underground mining. On the basis of diagnostic testing was performed analysis of cases occurring malfunctions and failures.

***Keywords**: engine diagnostics, construction machines, mining machinery vehicle operation, SI engine*

1. Introduction

Internal combustion engines, particularly these with compression-ignition (CI) are currently the most widely used source of power in construction and mining machines, both from a technical point of view and as regards possible applications.

Compared to the spark-ignition engine, this engine operates longer, is characterized by better energy balance and it results in lower fuel consumption. Another advantage of the diesel engine is fairly low sensitivity to changing physical and chemical properties of fuels. In addition, this engine adapts easily to all kinds of recharging systems, as a result, we can improve engine output without increasing its capacity and without major obstacles. The diesel engine, while working with an excess of air, causes better combustion of the fuel mixture, and thus reduces the share of toxic emissions to the air in the form of exhaust gases (carbon monoxide, aromatic hydrocarbons, etc.) [1, 2]. These are some of the most important reasons supporting the usage of diesel engines in modern construction machinery and mining as well as in automotive industry.

The development of diesel engines, stimulated by constantly increasing demand for power, economic and environmental aspects of work, aims at developing new, innovative technologies and control systems concerning injection and combustion.

Unfortunately, newer and newer designs and technologies used in diesel engines bear greater operational problems as well. The older generation engines with compression-ignition, fitted with mechanically controlled fuel injection system have not presented major problems when handling and during diagnostics. Unfortunately, the exacerbation of regulations on exhaust emissions in particular resulted in increasing use of electronically controlled injection systems. Introducing electronics into an engine have also resulted in the emergence of increasingly sophisticated and complex diagnostic issues that so far have been connected only to the gasoline engine [3, 4].

2. Construction machines and mining

Construction equipment constitutes an entire group of specialized, heavy equipment mainly for earthworks. The machines are used in construction work, transport and mining.

The main tasks of such machines include:

- loosening (separation) substrates – excavated,
- trenching,
- moving ore,
- compaction of excavated material,
- mining and material transport.

These machines are commonly used in every place where such processes have to be performed.

In the mining industry they operate in particularly difficult conditions posed by underground excavations, therefore, it is safe to say that these are special machines. Each of these machines is designed to work on a specific process at the exploitation site, pavement or during tunnelling.

The simplest method of distribution of these types of machines is dividing them into the machine stall, which participates directly in the extraction of minerals and machines outside the stall so called auxiliary machines, which are used, in various types of work outside the excavation site [3, 5].

Due to the environment in which they operate and the continuous nature of the work Self Mining Machinery (SMG) is prone to frequent failures. An additional disadvantage affecting the operation of these machines is the high turnover of operators of the vehicle.

Below there is a graph presenting the incidence of failure concerning most important systems of mining machines in underground workings [6].

Failures of engines with accessories represent the most significant share, reaching 28%. This is consistent with the harsh conditions engines in mining machinery have to deal with [6].

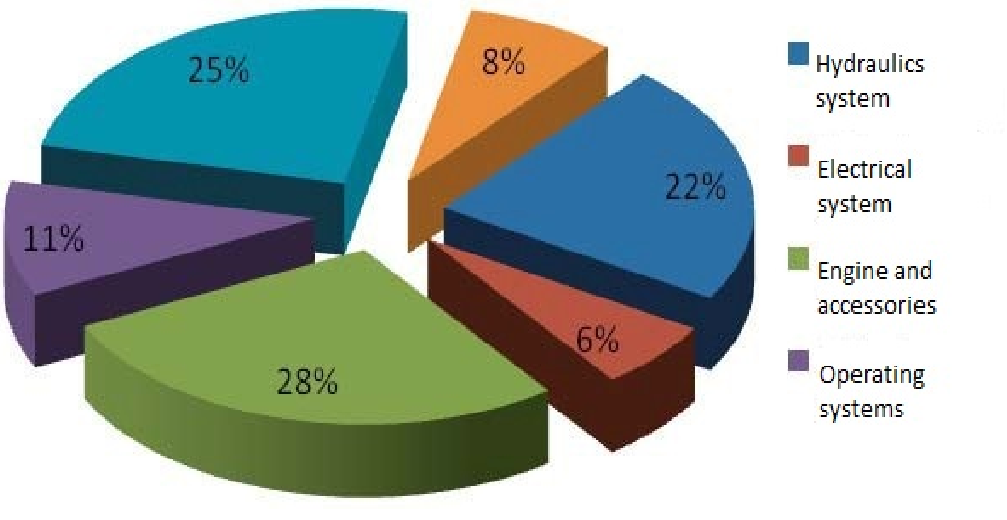

Fig. 1. Failure most important systems of mining machines [6]

3. Principles of diagnosis of diesel engines

Diagnostic tests of an engine constitute a group of tests including assessment of the technical condition of the engine and its components without disassembly or after partial disassembly, which does not affect the main legitimate operation of the item.

Evaluation of technical condition of the engine is done on the basis of the results:

- external inspection of the engine and its components,
- engine management,
- analysis of diagnostic parameters [4].

Nearly every irregularity during operation of the diesel engine is indicated in more or less specific way, the symptoms of which are apparent on the outside, such as noise (knocking, rattling, rumbling), overheating, or smoking.

Usually the symptoms described above are detected quite quickly. Faults which symptoms are not observed right away worsen with the passage of time and consequently can lead to serious engine failure, hence the importance of rapid and accurate diagnosis. Some faults can be detected only by using special diagnostic tools, but this happens quite rarely. It is important for any new symptoms and those different from the most common ones to be perceived as disturbing. Detecting any disturbing symptom should also lead to rapid and accurate recognition of the cause. One should adopt the principle the sooner the failure is detected the simpler and less expensive it will be to remove the cause and potential effect.

While recognizing irregularities it is worth using materials provided by the manufacturer, or the technical manual and the instructions for engine repairs.

The first step is an inspection consisting mainly on visual inspection: the outer completeness of the engine, the components necessary for its proper operation, external damage, to measure the levels and quality of service fluids used and the possible detection of leaks in power systems, cooling and lubrication.

The next step of the comprehensive diagnosis is to control the engine operation, which mainly involves checking the engine during start-up, vulnerability to run, stability in the required useful engine speed range and the susceptibility to varying the speed (acceleration, deceleration). During this test signs of irregularities frequently, appear concerning the engine, which allows us to determine further diagnostic or repair procedure.

Based on the aforementioned methods, one can pre-define ailments concerning the diesel engine. For a detailed analysis of faults, one must take measurements of diagnostic parameters of the engine.

The first measurement helpful in the diagnostic of the engine condition is measuring the compression pressure. This measurement is used to evaluate the degree of wear of the engine and its components affecting the tightness of the cylinder, for example, a cylinder sleeve, rings, valves, and outlets of the seat, the head gasket.

Another important measurement is the measurement of lubrication pressure. Inspections are carried out to determine the degree of wear of bearings (sliding) of the crankshaft as well as the timing and checking the performance of the oil pump.

Another method often used to determine the state of the diesel engine is to measure the opacity.

The colour of exhaust, their degree of density and amount of pollutants emitted into the environment in the exhaust gases allows us, with fairly good accuracy, to determine engine condition or determine the type of failures. For these measurements, special exhaust gas analyser called the opacimeter is used.

Introducing electronics into combustion engine with CI, particularly in the area of injection, results in the above-mentioned methods of diagnosis being currently insufficient for carrying out a full diagnosis. The main task of computerization of engines is their adjustability, easiness of checking and such a selection the operating parameters to make the work most efficient. These systems are additionally equipped with the option of self-diagnosis, which helps the operator or diagnosticians to identify malfunction, which are difficult to detect. This is possible thanks to computer systems, data exchange and memory controllers, which store the majority of fault codes and engine malfunctions in electronic form. Any defect, especially those related to a malfunctioning of the exhaust system (ecology) must be stored in the engine computer and additionally displayed on the notice board. Most commonly is a yellow engine icon or the sign "CHECK ENGINE". Saved (registered) fault code can be read using special diagnostic computers, so-called code readers or in case of the older generation of engines using light (LED) flash. Computers used to read errors of the engine currently have a number of other applications; one of the most important ones is the possibility of diagnosing the electronics of the engine. They can read the parameters of the engine based on a series of electronic sensors located on the engine and compare them with ranges established by engine manufacturers. Based on this information, one can conduct monitoring and diagnostics of almost any engine system.

4. Diagnosis and analysis of the shortcomings selected engines

Many reported and repaired failures are not always documented in photographs and described in detail. This is due to the fact that very often the user can cope with the repair himself/herself or it is done by external engines or machines services. Another aspect is that in case of major engine repairs it is necessary to transport the engine or the entire machine to the service because the user does not always have the appropriate technical equipment to carry out a professional repair. 1000 meters underground in mining repair chamber where air dust is so immense that it is not possible to maintain the necessary purity conditions for engine repairs.

Considering the cases of engine failures reported by users of the machines operating on the surface (construction machines) and underground (mining) it is difficult to clearly determine the typical symptoms that occur when working on engines. The average repair mileage for diesel engine is 15000 mth for construction machines and 10000 mth for mining machinery, these data depend on many factors, such as: motor model, the type of machine or device inside of which it is built and the conditions of operating.

4.1. Analysis Engine no. 1 − loss of power, excessive oil consumption and coolant consumption

The failure that occurred in the machine working underground, the operator reported a decrease of power under load and excessive engine oil consumption in the amount of 2-3 litters per 10 mth and coolant consumption. After the initial diagnosis, high oil in the intake and exhaust systems was reported. The first element to be subjected to a more detailed assessment was turbocharger, which, as it turned out, was not worn on the housing, and bore no signs of damage on the shoulders, but had excessive axial and radial clearance on the rotor resulting in oil escaping into the intake and exhaust system. Due to damage, the turbine could be replaced, but the damage was not large enough for the engine to lose power and consume much oil. The next step undertaken by mechanics was to measure the compression pressure using the tool SPCS-50, which gave the result in a form of very large, almost 50%, decrease in pressure on the cylinder number 4. It was decided that the engine must be removed from the machine and verified by the unit dealing with reconditioning engines. After dismantling the engine and removing the head, microcracks were found in the head as well as large amounts of carbon and the remains of a burned coolant on the head, valves, pistons and cylinder liner number 4.

During further verification of the damaged engine, the crack in the cylinder liner was found as well as numerous traces of seizing on the crankshaft, camshaft, and connecting rod bearing shells and key. Due to the large extent of the damage engine recognized as suitable for an overhaul.

The probable cause of the engine failure was overheating or low level of engine oil during operation, but one could not rule out the fatigue of head material and cylinder liner. Prior to installation of the reconditioned engine cooling systems of the engine oil were checked as well as coolant in the machine and very heavily soiled coolers were observed, which confirmed that the engine was overheated due to insufficient cooling.

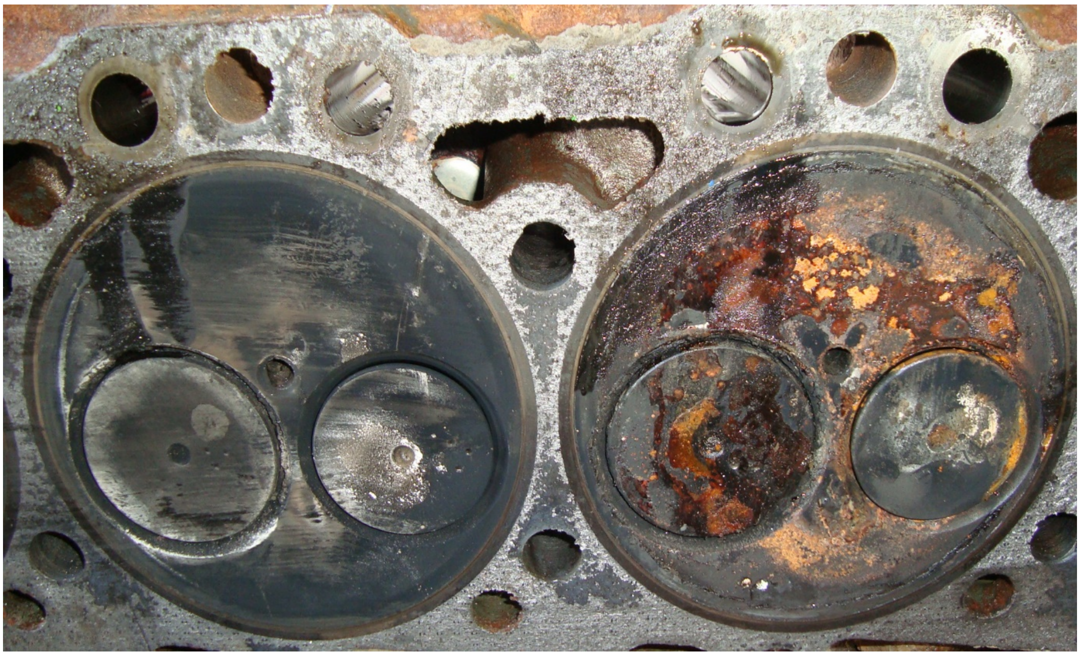

Fig. 2. Engine No. 1 − damaged head

Fig. 3. Engine No. 1 − damaged number 4 cylinder sleeve and piston

4.2. Analysis Engine No. 2 − safe mode, led lit DPF

The first failure reported by the operator were the problems with combustion of the particulate filter (DPF), the engine has not always been able to complete the burnout procedure and periodically a light signalling pollution filter lit. The service was called when the machine began to get into emergency mode limiting power and warning yellow light signalling engine failure lit permanently. The mechanic began diagnostics from connecting the diagnostic computer. After the failed test, it was found that the cause of problems with the filter DPF and the control diode was the damage of engine exhaust gas temperature sensor or the fault in the electrical system.

After the control of the DPF filter, very high amount of impurities (3-5 cm layer of dry mud) on the filter housing was detected as shown in Fig. 4.9. This layer isolated heat dissipation from the filter, it could cause a fire of the machine with catastrophic consequences of and could be the cause of defects associated with engine control. Removing and cleaning the filter and re-diagnosis did not eliminate engine fault. Additional computer diagnostics and control of electrical installation were launched. All connections with temperature sensor with control units were checked. On one engine computer, connector there was a signal from the sensor, but it had much lower voltage than what the manufacturer recommended.

Fig. 4. Engine No. 2 − view of the particulate filter

Electrical wire was inspected centimetre by centimetre and in one place (Fig. 5) the cable had damaged insulation and clenched to ground. Faulty wire was isolated and mounted in a way that prevents another abrasion.

Fig. 5. Engine No. 2 − damaged loom

After the final computer-based test, all the failures disappeared and the machine started operating again. This failure was caused by the negligence of the machine operator who did not control the DPF filter and routed wires in a faulty manner.

4.3. Analysis Engine No. 3 – loud engine while operating, metallic rattles

In the engine there was a failure while working at the mining forefront, the engine started to operate loudly and then stopped working work could not be resumed. Computer diagnostics showed no irregularities, it was not possible to rotate the crankshaft. The valve cover was dismantled for inspection of the valve and valve timing. At the beginning of the diagnosis, it was noted that the single valve lacked the valve spring and the lever of the valve was blocked, and valve fell into the cylinder (Fig. 6).

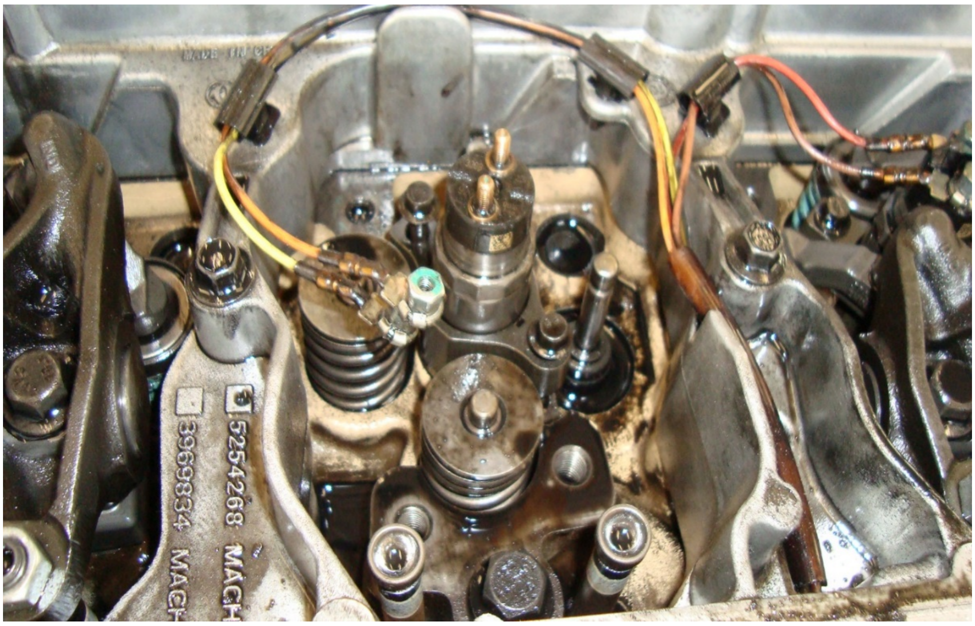

Fig. 6. Engine No. 3 − damaged head with electromagnetic injector

Further inspection revealed that the valve spring was damaged, resulting in subsequent engine failures. In the picture below, one can see the broken spring and bent push rods.

Fig. 7. Engine No. 3 − broken valve spring

In sum, there were a large number of damaged elements of the head, valves, pistons and the injector. The following pictures show the scale of damage of the engine.

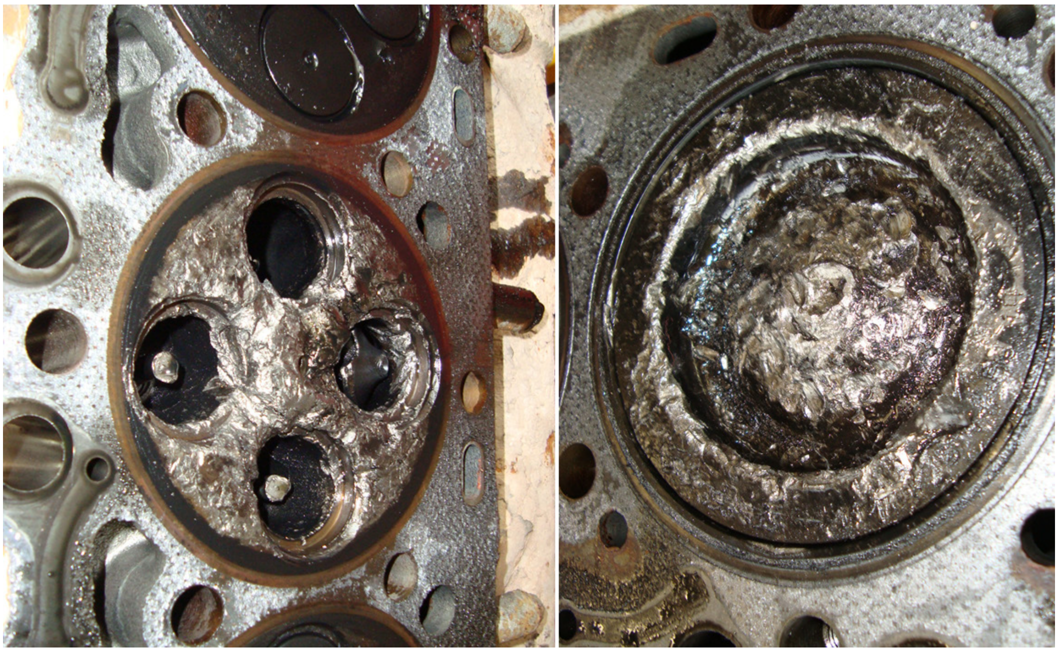

Fig. 8. Engine No. 3 − damaged head, valves and piston

Broken pieces of valve switches caused damage to the valve of Common Rail injector.

Fig. 9. Engine No. 3 − faulty injector

The main cause of the failure was most likely the crack of the valve spring due to fatigue. The lack of pulling the valve during engine operation resulted in contact of the valve with the piston in the upper position. Another possible cause of failure could be a valve switch rupture causing further damage to the valves on this cylinder and an engine failure described above.

5. Conclusions

On the basis of the diagnosis and analysis of diesel combustion engines used as the main power source for construction and mining the following conclusions could be drown up:

1. One of the decisive factors influencing of the failure rate and lowering operating life of engines is specific conditions in which they are used. The high temperature is one of the main causes of overheating and engine failures mining machinery.

2. Extremely strong dusty work environment and brine greatly influence the failure and false readings of all kinds of electronic devices mounted on the machine and engine. Reduced visibility caused by dust lead to strokes machine with a side of work and a block of rock, which damage the low-contained engine parts, such as sump.
3. The next factor causing engine malfunction are negligence and mistakes, which is made during the operation of machines and engines. The most important include compliance with the Guidelines service engines by users of machines. It should be added that are not always negligence caused not reliable service operators, and often a lack of training and knowledge required.
4. Another cause of failure is the use of low cost and often low-quality materials and operating fluids.
5. Delays in inspections because of the continuous operation of the machine or try to carry out repairs on their own.
6. Large companies are working in multi-shift, where one machine falls greater number of operators. In such situations, not all of them apply the adequate attention to maintain the engine in the correct state.

On the basis of engine diagnostics it can be found that, the greater the intensity of the failure concerns the engines working in mining machinery. Presented the results of analyses are worrying and confirm the significant impact of the specific conditions in which they are used.

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