

CAUSAL INVESTIGATION

# Catastrophic engine failure in an underground coal mine



**Planning &  
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## Document control

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# Executive summary

While operating in an underground coal mine at Wongawilli Colliery near Wollongong on 4 July 2017, a catastrophic failure of a diesel engine system occurred. This resulted in internal engine components being ejected from a cylinder block and being exposed to the mine atmosphere. The temperature of the ejected components created an ignition source which had the potential to cause an explosion. However, no person was injured as a result of the incident.

Diesel engine systems used at underground coal mines are explosion-protected to ensure they do not create an ignition source in methane-rich atmospheres. The catastrophic failure of a diesel engine system, where the products of internal combustion are potentially exposed to a methane-rich environment, presents a significant risk of initiating an explosion.

Incidents of this type and magnitude are rare, and the NSW Resources Regulator has not had any previous reports of similar incidents in recent years.

Accordingly, the regulator determined to undertake a [causal investigation](#) into the incident to enable the quick and full understanding of the causes of the incident and publication of the corresponding lessons to reduce the likelihood of recurrence.

Relevant stakeholders were invited to participate and a team was subsequently formed comprising representatives from WesTrac, Delta SBD, Wongawilli and the regulator. The machine in the incident was a Bucyrus FBL10 and was moved to WesTrac so that the explosion-protected diesel engine system could be tested, disassembled and examined.

The causal investigation team considered engine examination findings, maintenance and other circumstances as part of the investigation.

The investigation found that the likely cause of the catastrophic engine failure was a lack of oil quality or quantity (termed marginal lubrication) at the No 6 big end bearing. As a result, the excessive heat created a failure of the bearing and connecting rod. Once the connecting rod failed, further contact of broken components with the rotating crank shaft caused the parts to punch a hole in both sides of the engine block. It was this which ultimately led to the catastrophic engine failure.

Key leanings from this investigation are:

- mine operators or workers in control of explosion-protected diesel engine systems should ensure maintenance, inspection and testing is carried out in accordance with the vehicle and engine manufacturers' recommendation, and thorough inspection and testing is undertaken before commissioning plant.

More specifically:

- engine oil should be maintained at the correct level
- engine oil and filter changes should occur at a frequency recommended by the engine manufacturer
- engine oil should be used to the engine manufacturer's specifications and suited for the ambient temperature range of the environment
- engine oil should be stored and decanted to prevent contamination by dirt or water
- regular oil sampling and analysis should be conducted
- ensure correct operation of automatic engine shutdown systems (loss of engine oil pressure).

This is an event which in all likelihood could have been prevented – and demonstrates that catastrophic failures and significant risks that can eventuate when appropriate maintenance, testing and inspection is not carried out.

# 1. Introduction

Diesel engine systems used in underground coal mines present a number of hazards including the potential to ignite an explosive atmosphere, catch fire and expose workers to toxic emissions. As such, diesel engine systems in underground coal mines are modified so they possess explosion-protected properties, meaning the engine (if operated as designed) will not ignite a methane-enriched atmosphere.

Another key hazard with diesel engine systems is that the effect of a methane-rich atmosphere can cause the engine to run on methane alone, even if the diesel fuel is shut off. This is known as an abnormal combustion event, leading to an engine running faster than it is designed to run, to the point of destruction (an over-speed event).

A catastrophic failure of a diesel engine system occurred in the Wongawilli underground coal mine. This resulted in hot metal components being ejected through the engine block where they were then exposed to the mine atmosphere. The atmosphere in an underground coal mine may contain methane gas. Methane gas is in the explosive range when the methane volume in the air is between 5% and 15%. The engine's catastrophic failure and the parts that came into contact with the mine atmosphere had the potential to become an ignition source for an explosive mixture of methane gas.

The NSW Resources Regulator has facilitated a causal investigation into this incident to determine the cause of the failure and investigate the risk to worker health and safety.

The vehicle involved in the incident was a Bucyrus FBL10 plant number 130 (FBL10) and it was owned by a hire company, Delta SBD. As a hire machine, it was routinely moved between various mine sites. The FBL10 was serviced by Delta SBD and mine site personnel. At the time of the incident, it had been at Wongawilli Colliery for less than a month. It was at a previous mine site for about 18 months.

A key objective of this report is to provide timely communication about the likely cause of this safety incident and disseminate learnings about it to the broader mining community.

# 2. The incident

In the early hours of 4 July 2017, the Caterpillar 3126 DITA engine in the FBL10 (the engine) catastrophically failed in the main intake airway of the mine. The failure caused internal engine components, including the connecting rod end cap and fragments of the piston skirt to be ejected from both sides of the engine block (adjacent to No 6 cylinder bore).

**Figure 1: The hole in left rear of cylinder block (circled below) after the parts were ejected from it.**



The engine is identified by design registration number MDR 084131 DES - 1 and item registration number MIR 10115.

The location where the incident occurred was relatively flat. The FBL10 was towing an unloaded sled into the mine at the time. The operator heard a 'flapping sound' followed by a loud bang. He stopped the vehicle. The operator got out of the cabin and walked to the rear of the FBL10. Through the grill, the operator could see that the engine was covered with oil. A decision was made to tow the FBL10 onto a sled and it was towed a short distance so that it was not blocking the roadway.

A fitter with engine-building experience arrived later that morning. The fitter was tasked with entering the Wongawilli underground workings to determine why the engine was covered in oil and fix it. During the inspection of the engine, the fitter found the engine wet with oil but he could see no damage to the sump or a reason for the oil to be there. The fitter checked the engine oil level, which was very low.

Fourteen litres of engine oil were then poured into the engine. The engine was restarted and shortly thereafter was stopped because oil was leaking out of the engine through a broken pipe. It is not clear how or when the pipe was damaged but it may have occurred when the engine failed. The fitter then returned to the surface to obtain a new pipe for the engine. The new pipe was fitted and the engine was restarted. The engine was 'running rough' and again was stopped. It is now understood that the engine was at that time running on five cylinders.

The FBL10 was then dragged out of the underground workings to the surface.

No person was injured as a result of the incident.

The Resources Regulator was informed of the incident on 5 July 2017 at 8.41am.

### **3. Explosion-protected diesel engine systems**

Diesel engine systems used at underground coal mines are explosion protected to ensure they do not create an ignition source in methane rich atmospheres.

Explosion-protected diesel engine systems (ExDES) must comply with design standards. The standards for design registration in NSW are [MDG 43](#) and AS/NZS3584.2:2008. The purpose of design standards is to prevent an engine system from becoming an ignition source. A key way this is achieved is by limiting external surface temperatures of an ExDES to a maximum of 150°C and eliminating the transmission of sparks or flames to the mine atmosphere.

When designing an ExDES, the designer must consider and identify potential ignition hazards that are reasonably foreseeable in the lifecycle of the ExDES. Among other things, the designer's assessment must consider:

- all reasonably foreseeable misuse
- reasonably foreseeable human error
- whether potential ignition sources could occur during normal operation, expected malfunctions and rare malfunctions.

This catastrophic engine failure is considered to be an uncommon malfunction for underground coal mines in NSW.

## 4. The investigation

A preliminary investigation and assessment of the incident was carried out by the regulator which did not identify any material breaches of the work health and safety laws. Following this assessment the regulator determined that an investigation under the regulator's [causal investigation policy](#) was the most appropriate way forward to enable the quick and full understanding of the causes of the incident and publication of the corresponding lessons to reduce the likelihood of recurrence.

Notably, a causal investigation is an investigation into a safety incident notified to the regulator under the work health and safety laws, not to obtain evidence for a prosecution but rather to identify the causal factors of safety incidents, the effectiveness of the controls being used and what factors may have contributed to the failure of the controls. Timely communication helps ensure that duty holders under the work health and safety laws are able to better understand the risks they must manage, and the necessary controls to prevent reoccurrences of similar safety incidents.

The regulator invited relevant stakeholders to participate in the causal investigation process. Not all invited parties accepted the invitation. Out of the nominated participants, a causal investigation team was formed. The causal investigation team included representatives of Wongawilli Colliery, the Resources Regulator and the FBL10 owner, Delta SBD. The intention to conduct a causal investigation was announced to industry on 11 August 2017.

The FBL10 was delivered to the WesTrac service facility in Tomago, NSW.

### 4.1. Review of records for FBL10

Documents were provided to the causal investigation team by Wongawilli Colliery and the mine operator who had used the FBL10 before it went to Wongawilli Colliery. Documents that were reviewed for this investigation included:

- plant information dossier
- maintenance and service records
- in service dates.

Interviews were also conducted with people who had relevant knowledge of the FBL10 (further on this below).

### 4.2. Inspection and testing of FBL10

The engine features a SEMS II electronic shutdown system. The original equipment manufacturer was Setco Australia. The emergency shutdown system is a manually activated strangler valve. The examination of the engine found that this was not activated at the time of the incident.

As part of the investigation, the causal investigation team tested the shutdown systems of the FBL10. These tests simulated the engine running and applied various triggers in order to be able to witness the response of the shutdown systems so that they could be evaluated. The purpose of this was to gain an understanding of whether the automatic engine shutdown system was working effectively at the time of the incident.

The WesTrac testing of FBL10 included the:

- engine oil sensor
- engine exhaust temperature sensors
- engine coolant level and temperature sensors
- engine scrubber water level float sensors
- vehicle hydraulic oil level and temperature sensors.

The testing simulated the operation of the engine by using compressed air to trip the ‘SEMS start initiate switch’ that in turn activated the ‘SEMS run solenoid’ piloting the ‘safe start valve’ and the ‘shutdown cylinder’. This ‘tricks’ the automatic engine shutdown system into thinking that the engine is running.

The tests activated each sensor separately by applying temperature, removing pressure or changing the state of a level indicator to test which sensor caused the energised ‘SEMS run solenoid’ to deactivate and shut the engine down.

At the completion of the testing, the tests were conclusive in showing that the SEMS II electronic shutdown system was functioning correctly at the time of the incident.

At the third visit to WesTrac on 4 September 2017, the causal investigation team watched the disassembly of the FBL10 engine at WesTrac. Before the arrival of the investigation team, WesTrac workshop personnel had carefully removed the engine covers and ancillary components and placed the engine block on a stand ready for disassembly. During this visit, the exhaust valve was found to have a bent valve stem. This was caused by contact between the valve head and the piston as a result of the No 6 conrod and bearing failure.

The following photographs show the stages of disassembly.

**Figure 2: Engine from FBL10.**





**Figure 3: Rocker cover removed to access valves and fuel injectors.**



**Figure 4: Valve head from No 6 is not seated indicating bent valve shaft.**



Figure 5: Valve second from left shorter than others due to bent shaft.



Figure 6: Debris found in sump (fragments of the piston skirt and conrod bolts).



**Figure 7: Crankshaft, main bearings caps and pistons complete with conrods (1-5) on bench. Can see No 6 blackened bearing journal.**



Refer to figure 11

### 4.3. Wear to bearings and what it indicates

#### No 4 upper connecting rod bearing:

Smearing is adhesive wear and smearing on bearings indicates that there has been a system problem at some time that produced marginal lubrication to the bearing. The No 4 rod bearing showed signs of adhesive wear with corresponding discoloration on the crankshaft journal. This typically is a lubrication-related issue.

**Figure 8: No 4 upper rod bearing showing smearing (adhesive wear).**



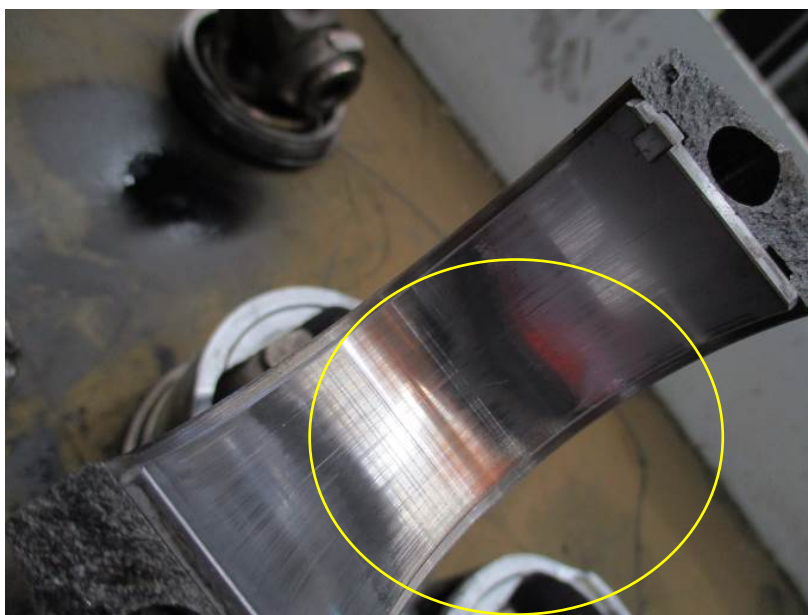
Inspection of the remaining five upper rod bearings showed that the copper bonding layer was visible, which is typically indicative of fine debris wear.

**No 5 upper connecting rod bearing:**

WesTrac advised the causal investigation team that there was a copper bond layer underneath the tin flash layer and lead tin layer of the engine bearing.

WesTrac advised the causal investigation team that the lead-tin overlay on the bearings was 1/1000 of an inch thick. The copper bond layer was 1/10,000 of an inch thick. It is only when abnormal abrasive wear occurs that the lead tin overlay bearing will display a copper color. This could indicate there has been abnormal abrasive wear created by oil with debris in it. The copper bond layer that can be seen in figure 9 indicates that the top two layers have been worn through.

**Figure 9: Upper rod bearing No 5 showing a copper bonding layer often associated with fine debris damage.**



The recovered No 6 rod bearing cap was found to be black in color indicating excessive heat.

**Figure 10: No 6 conrod bearing cap (rectangle) and blackened, destroyed No 6 bearing shell (oval).**



**Figure 11: No 6 rod journal became so hot that impact with the connecting rod caused material flow and left an imprint of rod profile on the crankshaft.**



## 4.4. Interviews and records

Members of the causal investigation team conducted interviews with the:

- worker who was operating the machine at the time of the incident
- fitter who recovered the FBL10 after the incident
- mechanical engineering manager from Wongawilli at the time
- relevant persons who were in control of the FBL10 at the previous mine site.

The interviews and records revealed the following points:

- there were extended periods (of approximately seven months) where oil changes cannot be verified (700-plus hours of operation)
- engine oil analysis had not been conducted
- daily inspection documents (PITS) at Wongawilli were unable to be located
- at the time of the incident, the number of hours on the engine was 7907 as indicated on the hour meter.

## 4.5. Technical findings

A WesTrac failure analysis technician with more than 20 years' experience was present during the strip down of the FBL10 engine. The technician prepared a failure analysis report and relevant sections are excerpted below:

*Possible root cause of the damage above (assumption/experience):*

*Failure of the No 6 rod bearing is typical of a marginal lubrication failure. Marginal lubrication can be classed as an oil quality or oil quantity related failure. The extent of the damage to the No 6 rod and bearing components makes it impossible to determine the cause. Observation of the remaining bearings did note fine debris damage to the upper rod bearings and some adhesive wear on the No 4 rod bearings. The adhesive*

*wear on No 4 rod bearings may indicate the root cause of the failure of No 6 rod bearings, as adhesive wear is a precursor to bearing failure.*

## 5. Contributing factors

The following points can be made about the engine and the failure:

- after the FBL10 engine catastrophically failed, 14 litres of oil were poured into the engine and an attempt was made to restart the engine
- inspection of the remaining five upper rod bearings showed that the copper bonding layer was visible, which is typically indicative of fine debris wear
- the No 4 rod bearing showed signs of adhesive wear with corresponding discoloration on the crankshaft journal, which is typically a lubrication-related issue
- the recovered No 6 rod bearing cap was found to be black in color indicating excessive heat
- the manually activated strangler valve had not been used
- the automatic engine shutdown system was functioning correctly at the time of the incident
- the oil pressure sensor could not detect oil pressure loss to a single bearing, only the supply to all bearings
- the engine oil pump was found undamaged during engine disassembly
- sample records indicate a daily check of oil level had been conducted at the previous mine
- no engine oil analysis has been conducted in the previous two years of operation
- fine debris wear was evident on upper con-rod bearings and adhesive wear was evident on No 4 con-rod bearing
- no evidence could be found to indicate that the catastrophic engine failure was a result of an abnormal combustion event caused by methane or engine oil ingestion
- no evidence could be found to indicate that the catastrophic engine failure was a result of an engine over-temperature event
- no evidence could be found to indicate that the catastrophic engine failure was the result of an engine hydraulic lock event
- no evidence could be found to indicate that the catastrophic engine failure was a result of an engine over-speed event
- molten metal flow does indicate that extreme temperatures were reached, which were clearly above the hot surface ignition temperature of an explosive range methane.

## 6. Lessons learned

The most likely cause of the No 6 conrod bearing failure was a lack of oil, and/or poor oil condition. As a result, the excessive heat created a failure of the bearing and connecting rod. Once the connecting rod failed, further contact of broken components with the rotating crank shaft caused the parts to punch a hole in both sides of the engine block. It was this which ultimately led to the catastrophic engine failure.

This incident and the investigation highlights the importance of engine oil in ensuring the function of the engine and preventing the engine from catastrophically failing.

The investigation is inconclusive in identifying the exact failure event because the oil had been replenished so a sample of the original oil could not be accurately taken and there were insufficient records regarding the engine oil and its condition.

There is sufficient evidence to demonstrate this event would have ignited an explosive methane mixture had it been present in the mine atmosphere at the time that the incident occurred.

**Figure 12: Piston and wrist pin with remainder of conrod attached (other part never found).**



# 7. Recommendations

When oil is not registered on the dipstick or there is evidence that the engine is wet with oil or oil has leaked into the engine compartment, **do not refill it** with oil or restart it before diagnosing the cause of the oil loss.

Operators of ExDES should:

- ensure engine oil is maintained to the correct level
- ensure engine oil and filter changes occur at a frequency as recommended by the engine manufacturer
- use engine oil to the engine manufacturer’s specifications and suited for the ambient temperature range of the environment
- store and decant engine oil preventing contamination by dirt or water
- ensure correct operation of automatic engine shutdown systems (loss of engine oil pressure).

Operators should also consider:

- engine oil filter analysis technologies for a predictive warning of catastrophic engine failure
- conducting regular oil sampling and analysis to report on abnormal wear, breakdown of lubrication properties over time, contamination level and correct application of lubricant
- reviewing engine oil change frequency as a result of oil analysis, filter analysis or changes in environmental or ambient conditions
- recording engine oil top up quantities and review maintenance records to recognise trends in oil consumption
- thorough inspection and testing before commissioning plant.

Manufacturers of explosion-protected diesel engine systems should:

- position engine oil filters in a location that promotes ease of filter changes
- position and orientate filters in such a way to prevent ingress of contaminants when changing the filter
- provide oil drain facilities to assist the oil change process
- provide suitable oil sampling facilities
- have information decals in a prominent location for oil and filter specifications and part number details
- provide access panels for inspection of engine block and sumps as far as is reasonably practicable.

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