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SURFACE VEHICLE INFORMATION REPORT

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Power Cylinder Blow-by: Problem Solving

RATIONALE

Not applicable.

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1. SCOPE

This document describes methodologies to determine the causes blow-by oil consumption caused by the power cylinder.

1.1 Purpose

During the combustion event, the intent of the engine design is to contain the combustion gases in the combustion chamber to load the piston and drive the piston to turn the crankshaft. It is the intent of the power cylinder system to seal the gases and to control the oil film on the power cylinder parts. The gas that escapes around the rings and piston is referred to as blow-by gases or just blow-by. The power cylinder system and individual components are designed to seal the gases. The understanding associated with which features affect blow-by is important in the engine design and development process.

When diagnosing blow-by problems the engineer must be aware that other engine systems can affect blow-by. These systems are as follows:

- Power cylinder system (piston, rings, liner)
- Head gasket
- Cylinder head system (valves, valve stem guides and seals, etc.)
- Turbocharger
- Supercharger
- Air compressors

This document describes general methods for determining the causes of high blow-by so that it might be corrected.

2. REFERENCES

There are no referenced publications specified herein.

3. DEFINITIONS

There are no unique definitions.

4. LIST OF METHODS

The following is a list of the basic methods for determining the causes of high blow-by:

- Check the History of the Engine
- Eliminate the Simple Possibilities
- Eliminate the Mistakes
- High Blow-by as a Result of a Failure
- Modeling and Mapping
- Component Swapping and Variation Techniques
- System Separation

5. CHECK THE HISTORY OF THE ENGINE

High blow-by may be a result of how the engine was operating. Make sure that the engine was run properly. Some of the areas to check on engine operation are:

- Check for sudden changes in the blow-by. This might indicate a problem in the engine.
- Check the history for changes in temperatures and/or pressures that might indicate incorrect engine operation or problems:
  - Oil
  - Coolant
  - Intake
  - Exhaust
- Check for incorrect engine operation.
  - Speed
  - Load
- Check warranty data to determine if the engine has a history of problems and under what conditions.
- Check the history of past engine test done on the same engine configuration. Have things changed? Was the engine run differently?

6. ELIMINATE THE SIMPLE POSSIBILITIES (BEFORE ENGINE TEARDOWN)

When there is a problem with high blow-by of an engine, it is important to eliminate the simple potential causes first. These are the things that are done prior to any engine teardown.

6.1 Check for Malfunctioning Blow-by Measurement Transducer

Investigate the blow-by measurement transducer for indications that it is malfunctioning. It is common for some transducers to be affected by oil that gets trapped in the device. Check to make sure the calibration of the device is correct.

6.2 Check for Malfunctioning External Components

Components other than the power cylinder may contribute to high blow-by. Check these components for potential problems that may result in blow-by problems.

Turbocharger/Supercharger – Can often be isolated from the main engine to determine the turbocharger/supercharger contribution to blow-by.

Valve Guides – Gases may flow around the valve stems. Replace the valve stem seals if possible.

6.3 Check for Coolant in the Oil

Coolant in the cylinder will vaporize causing high blow-by. Also it will affect lubricity of the oil and result in high wear of the cylinder walls that will affect blow-by.

6.4 Check for Fuel in the Oil

Fuel in the oil will affect the lubricity of the oil and result in high wear of the cylinder walls that will affect blow-by.

6.5 Compression Check

A compression check can help to determine if there is a problem with the rings, valves, gaskets, cylinder head, or pistons that might be resulting in high blow-by.

6.6 Leak Down Test

A leak down test can follow a compression check to identify the source of the leak. Look for signs of leaking in the intake ports, exhaust ports, crankcase, or coolant. Signs for leaks may be leakage noise in the ports and crankcase, or gas bubbles in the coolant. This test makes it possible to better understand whether the power cylinder (piston and rings) is the source of the blow-by.

6.7 Cracked Head or Block

Investigate the engine for signs of a cracked head or block which will cause high blow-by. Signs of this might include water in the oil and gases in the coolant.

6.8 Borescope the Engine

A borescope of the cylinder will help to identify if there has been scuffing or piston damage, valve burning damage, or other in-cylinder damage that has occurred that might explain the cause of high blow-by.

6.9 Examine the Color of the Exhaust

The color of the exhaust gases might indicate problems:

- Excessive white smoke might indicate coolant in the cylinder
- Excessive black smoke might indicate excessive fuel.

7. ELIMINATE THE POTENTIAL MISTAKES (AFTER ENGINE TEARDOWN)

7.1 Incorrect, Missing, or Misassembled Components

- Have the correct pistons been used?
- Are all the correct piston rings on the piston?
- Are there any missing piston rings?
- Are all the rings orientated correctly with the proper side up?

7.1.1 Broken Parts

Check all the piston rings for breakage. Piston rings may have been broken during operation or during assembly. Rings that were broken on assembly can often be identified by damage to the piston.

Check for valve damage that may result in lack of sealing. Look for cracks on the cylinder head and also for damage on the head gasket.

7.1.2 Abnormal Marks

Installation Errors: Check the pistons and rings for abnormal markings. This could be an indication of assembly damage.

Look for manufacturing issues such as signs of waviness in the piston rings.

FIGURE 1 - EXAMPLE OF DAMAGED TO THE THIRD LAND DUE TO INSTALLATION DAMAGE

7.1.3 Improperly Handled Rings

A piston ring that is overextended or excessively twisted during installation might break in operation or show abnormal marks on the face of the ring.

8. HIGH BLOW-BY AS A RESULT OF A FAILURE

High blow-by will be caused by failure of components. This must be determined when investigating the cause of high blow-by. In the subsequent sections there are a few examples of failures that may result in high blow-by.

8.1 Broken Rings

A broken piston ring can easily be found and can result in high oil consumption and high blow-by.

FIGURE 2 - EXAMPLE OF BROKEN PISTON RING

8.2 Face Coating Failure

Failure of the top ring face coating will result in high blow-by.

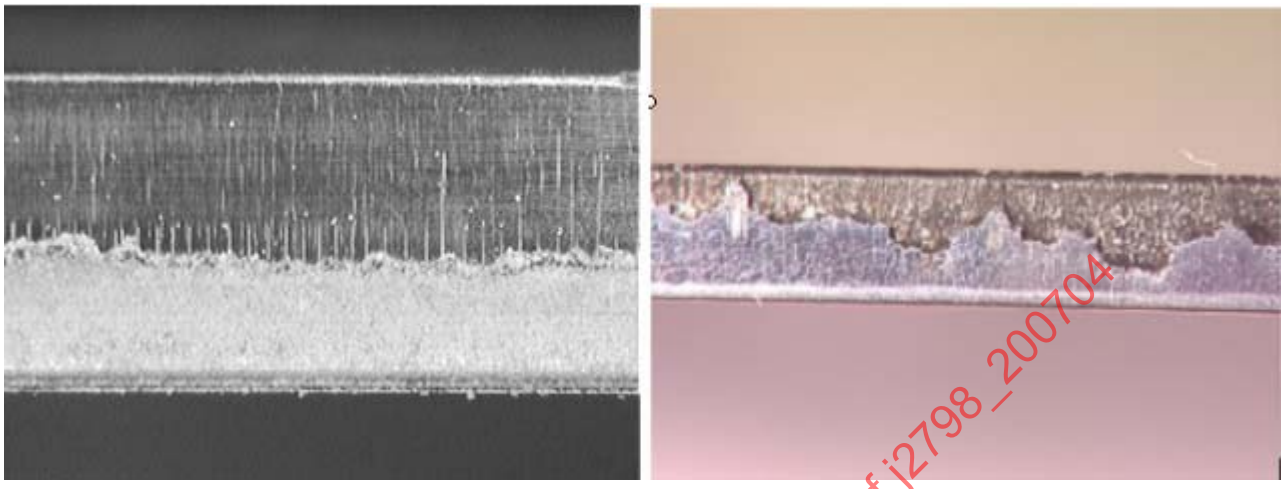

FIGURE 3 - EXAMPLE OF FAILED RING FACE COATINGS

8.3 Scuffed Power Cylinder

Blow-by will be high if the cylinder is scuffed. Scuffing will be an obvious failure.

FIGURE 4 - EXAMPLE OF PISTON SCUFF

8.4 Carbon Deposits on the Piston Top Land and Top Ring Groove

8.4.1 Carbon Buildup on the Top Land

Excessive carbon deposits on the top land are a sign that the ring pack is not effectively sealing the oil. Problems with carbon build-up include:

- Polishing of the cylinder walls.
- Scraping oil upward from the carbon that is built up.
- Potential lack of ability to energize the top ring because the carbon blocks the pressure build-up.

FIGURE 5 - EXAMPLE OF CARBON POLISHING

Inspect the top ring groove for excessive carbon deposits which can cause the top ring to be stuck and ineffective. Carbon in the top ring groove which makes the top ring ineffective is typically accompanied by high blow-by.

8.4.2 Carbon Buildup in the Top Ring Groove

Excessive carbon packing in the ring groove may decrease its effectiveness to seal the gases and oil because:

- The ring may stick in the groove.
- There may be interference between the ring and the carbon in the groove.

8.4.3 Carbon Tracking

Carbon tracking around a piston ring might be a sign of a leakage path for the blow-by gases that needs to be investigated.

FIGURE 6 - EXAMPLE OF CARBON TRACKING CAUSED BY EXCESSIVE BORE DISTORTION

8.5 Excessive Wear

Excessively worn rings can result in high blow-by. If the wear is very high and at low mileage, it might be caused by dust in the engine. This could occur if the proper air filter is not used.

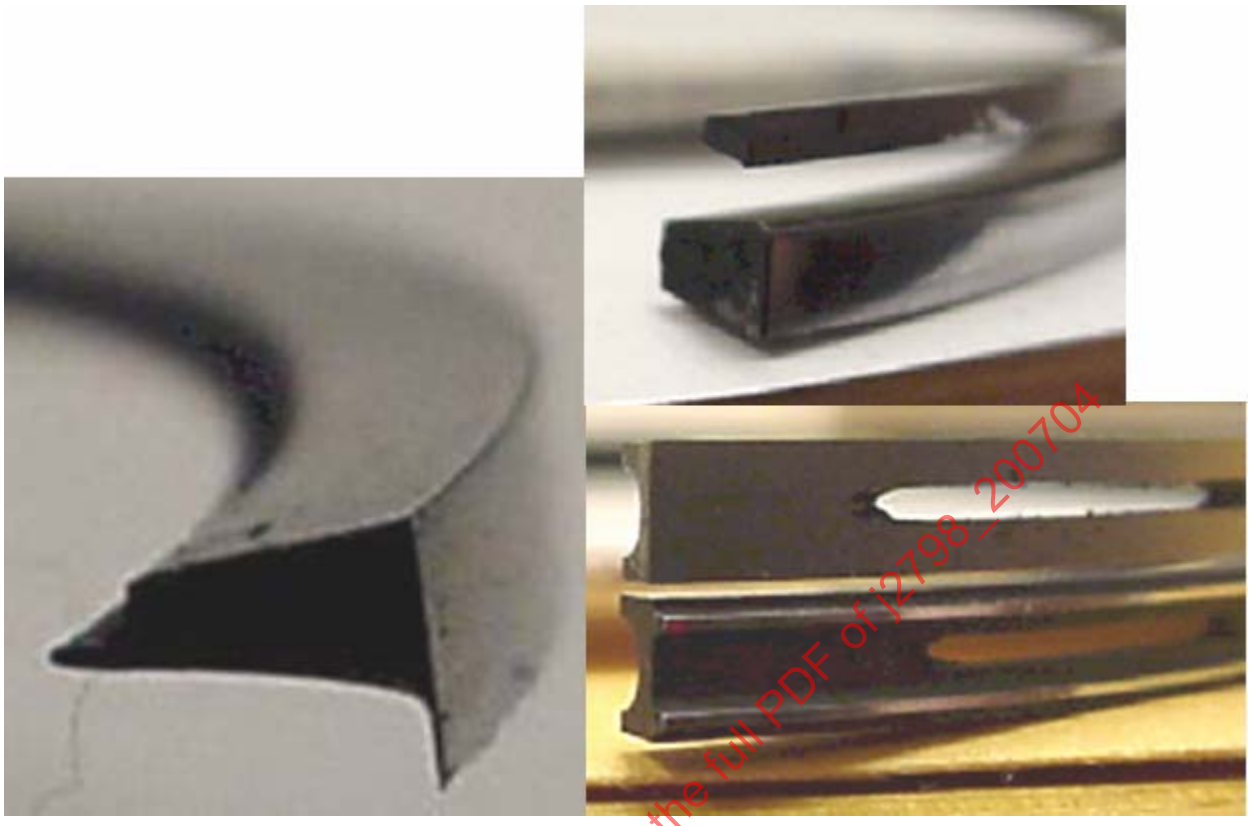

FIGURE 7 - EXAMPLES OF EXCESSIVELY WORN RINGS

8.6 Debris

Examine the engine for damage. Excessive vertical scratching on the bore walls, piston skirts, and piston ring face might indicate a problem. Also, examine the intake manifold for signs of debris or sediment, some of which might have been ingested by the engine. Bearings often will show scratching from debris.

8.7 Lack of Lubrication

Examine the engine for signs that the engine might have lost lubrication which caused problems in the power cylinder. Main and/or connecting rod bearings, when worn down to the copper, are an indicator of loss of oil pressure during operation. Scuff pistons with a bright metallic appearance and little evidence of burned oil around the scuffed zone is an indication of a lack of lubrication.

8.8 Bore Washing from the Fuel

Getting fuel on the cylinder walls may result in excessive polishing and wear which will result in high blow-by. Polishing that corresponds to spray plumes of an injector might be an indication of bore wall washing with fuel.

8.9 Oil Burning from the Cylinder Wall

When the combustion gets too close to the cylinder wall, the oil may evaporate. The rings will not be lubricated in that region causing high wear. The wear may occur in regions that correspond to the spray plumes of an injector.

FIGURE 8 - EXAMPLE OF EXCESSIVE POLISH DUE TO BORE WASHING OR OIL BURNING

8.10 Valve Damage

Burned valves, cracked valves, or valves with a chipped or broken deposit layer on the seat surface can result in leak paths to cause high blow-by.

9. CHECK FOR PROPER DESIGN

The power cylinder components may not be designed properly and as a result will have high blow-by. SAE Standard J2797 describes the design parameters that will affect blow-by. These parameters should be carefully considered to ensure a low blow-by engine design.

10. MODELING AND MAPPING

Blow-by can be affected by the pressure balance of the ring pack and the motion of the rings.

10.1 Cylinder Kit Dynamics

Cylinder kit dynamics model or experimental measurements can be used to determine the build up of gas pressures, determine how the gases and oils flow through the ring pack, and determine how the rings move. The motion of the rings and the pressure built up between the rings significantly affects blow-by.

In many cases, as blow-by increases, oil consumption will go down. However, there are conditions where blow-by and oil consumption can be reduced at the same time. The models can also predict how the gases flow upward into the combustion chamber. This is called blow-back. Increased blow-back will tend to increase oil consumption but potentially lower blow-by.

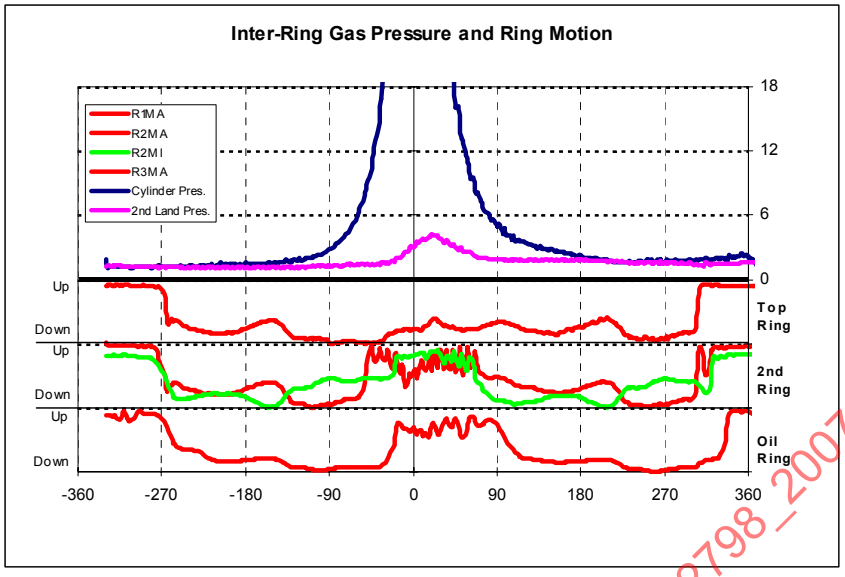

FIGURE 9 - EXAMPLE OF INTER-RING GAS PRESSURE AND RING MOTION

10.2 Engine Blow-by Steady State Mapping

Blow-by mapping of the effects of speed and load might show where there are regions of high blow-by. This might indicate a condition with non-optimal ring pack dynamics. Some conditions that have been prone to having high blow-by are:

- High Speed and Load
- High Speed and Light Load (High Idle)

11. COMPONENT SWAPPING AND VARIATION TECHNIQUES

When trying to find the component that is causing high blow-by a swapping or variation technique might help. However, in both of these cases, for the testing to be effective a good repeatable method for measuring blow-by needs to be utilized. Otherwise the results will be confounded with variation in the measurement system.

11.1 Swapping Technique

This technique works when you have a known high blow-by engine and a different engine of the same configuration with low blow-by. The concept is to take the known high blow-by engine configuration and swap parts into the engine from the good configuration. After each swap of parts, measure the blow-by. If the blow-by goes low then the cause for the high blow-by has been determined.

Once the component or components causing the high blow-by has been determined, it will be necessary to compare detailed measurements of the parts. The differences in measurements will determine the feature of that component that is causing the high blow-by.

11.2 Variation Technique

In this case, variations of various design parameters might be tested. For example, variations in the end gaps of the rings might be tested. Often there are multiple design parameters that could be tested. Therefore, a Design of Experiments might be useful to process the results of the test.

It is very important in this type of testing that all the power cylinder components are measured before tests. Then it is important that all the key dimensions that affect blow-by are controlled as appropriate so that they do not confound the results of the main variation that is being tested.

12. SYSTEM SEPARATION

In searching for the causes of high blow-by, it is often not known which systems are contributing. Therefore it is common to try to separate the various systems to isolate the system that is causing the problem. The systems that might be contributing to high blow-by are as follows:

- The Power Cylinder (piston, rings, liner)
- The Overhead (valves, valve stem guides and seals, etc.)
- The Turbocharger/Supercharger
- Head Gasket

12.1 Isolating the Overhead

The overhead will be difficult to isolate. The alternative might be to replace parts in the overhead that might contribute to blow-by to evaluate their effect. For example the valves, valve stem seals, lifters, or cam shaft may be replaced.

12.2 Isolating the Turbocharger/Supercharger

The performance of the turbocharger/supercharger should be checked to ensure that it is delivering the proper boost pressure for the power cylinder.

To isolate the turbocharger/supercharger, the lube oil to the turbocharger/supercharger is isolated from the engine. Then blow-by is measured from the main engine using the standard techniques. The difference between the total engine blow-by and the base engine blow-by is the blow-by from the turbocharger/supercharger.

12.3 Isolating the Crankcase Ventilation Systems

If a component in the crankcase ventilation system (e.g. PCV Valve, Breather) is malfunctioning, it will affect the blow-by. Make sure that there are no issues with these systems. An example might be plugging of the PCV valve or breather.

12.4 Isolating the External Components

There are other external components that might be causing high blow-by. An example might be an air compressor. The lubrication to these components must be isolated or the component removed directly from the engine to determine their contribution.

13. BLOW-BY PROBLEM SOLVING SEQUENCE – BLOW-BY HAS BECOME BAD

This is the sequence of steps that are followed when an engine that was running with acceptable blow-by has suddenly developed high blow-by.

13.1 Before Disassembly of the Engine

The following steps should be followed before the engine is disassembled:

13.1.1 Check the History

Check the engine history for potential causes of the change in blow-by as described in the preceding sections. Have there been any changes in how the engine was operating (loss of pressure, increase in temperature, ...)

13.1.2 Investigate the Source

Check for the source of the high blow-by.

- Are the crankcase ventilation systems working properly? (Air breather, PCV valve)
- What is the blow-by from other components? (Turbocharger, Supercharger, Air Compressor)
- Separate the systems if possible to determine the source. (Turbocharger, Overhead)

13.1.3 Check for Problems

- Are there any problems with the blow-by measuring equipment?
- Did anything change in the installation of the engine during service checks? Did anything break?
- Are there signs of coolant in the oil?
- Are there signs of fuel in the oil?
- Are there gas bubbles in the coolant? Is coolant becoming over-pressurized due to combustion pressures leaking into the coolant passageways?

13.2 Minimal Disassembly of the Engine

Look for potential signs of the cause of the problem by:

- Using a borescope to inspect the cylinder walls and internal components. Do you see signs of scuffing? Has anything broken? These will result in high blow-by.
- Do a compression test to check if a piston ring has broken, a valve is damaged, or a gasket may not be sealing.
- Do a leak down test to identify the source of the leak.

13.3 Remove the Head

With the head removed from the engine check the following:

- Evaluate the cylinder walls for signs of scuffing or debris damage that might have caused the high blow-by.
- Check the piston for signs of cracking, debonding, contact with the valves, debris damage, melting.
- Evaluate the head for signs of damage to the valves.
- Check the intake manifold for signs of water or debris entering the cylinder.
- Review the exhaust system for signs of damage or debris that went through the engine.

13.4 Remove the Power Cylinder Components

Once the power cylinder components are removed then check the following:

13.4.1 Check for Incorrect Installation Issues

- Most installations problems will manifest themselves from the very beginning of the test. If the blow-by was good originally, then there was probably not an installation problem.

13.4.2 Check for Damage

- Check for broken components (piston rings, pistons)
- Check for chipping or delamination of the ring coatings
- Check for damage to the cylinder bore from:
  - Scuffing
  - Scratching from debris
  - Carbon Polishing causing bore polishing
  - Bore washing and excessive polishing from fuel
  - Bore washing and excessive polishing from coolant

13.4.3 Evaluate the Components

It is sometimes possible to look at the components to determine how oil and gases are flowing through the ring pack. This will give an indication of potential problems that can be resolved. Indications may be seen:

- In the carbon marks on the pistons and/or rings showing how blow-by gases flow past the rings.
- Polishing of the components showing signs of sealing. Non-polished regions might indication a flow path.