SURFACE VEHICLE INFORMATION REPORT

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Power Cylinder Oil Consumption: Problem Solving

RATIONALE

New engineers or engineers that are not experienced in power cylinder development may not always have the necessary background to develop the optimum engines or solve problems that are experienced. This document gives basic background information that will help engineers working with power cylinders with the knowledge that they need to help them be more effective.

TABLE OF CONTENTS

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1. SCOPE

This document describes methodologies to determine the causes of high oil consumption caused by primarily the power cylinder system.

1.1 Purpose

The oil consumption of an internal combustion engine is a significant performance attribute. The loss of engine oil through the combustion chamber is critical because it impacts the emissions signature of the engine and potentially poisons any exhaust gas after treatment devices. To the operator of the engine, the consumption of oil is an unnecessary and excessive cost of engine operation. While solving oil consumption problems, it is important to have a systematic way of determining the cause of the high oil consumption. Not all of the oil consumption problems are due to the power cylinder system. Other engine subsystems can contribute to the oil consumption of an engine which means that isolation of contributing systems is essential for diagnosing and eliminating the source of oil consumption. The purpose of this document is to review the various possible systematic methods for solving oil consumption problems.

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 oil consumption:

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

5. CHECK THE HISTORY OF THE ENGINE

High oil consumption 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 changes to 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 the condition of the oil for signs of potential problems. Example of lubrication conditions to analyze are:
  - Oxidation parameters
  - Viscosity
  - Wear Metals
  - Contaminants
- Check for incorrect engine operation:
  - Speed
  - Load

6. ELIMINATE THE SIMPLE POSSIBILITIES (BEFORE ENGINE TEARDOWN)

When there is a problem with high oil consumption 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 Leaks

In any case where there is high oil consumption, an examination of leaks should be made. Look for oil on the ground or oil on the engine. The magnitude of the leak might be determined by catching the oil leaked over a period of time and measuring the final quantity.

6.2 Check for Excessive Oil Carry Over

Oil may exit through the crank case breather. In an open system, the oil may then accumulate on the ground. In a closed system there may be oil in the intake system. Excessive oil through the breather might be an indication of various problems:

Design Issues

- Poorly Designed Breather
- Incorrectly Positioned Breather
- Plugged Breather or Valve (PCV)
- Missing Breather or Valve (PCV)

Problems

- Might indicate excessively high blow-by that results from a power cylinder problem

6.3 Check for Malfunctioning External Components

Components other than the power cylinder may contribute to high oil consumption. Check these components for signs of oil consumption problems.

Turbocharger/Supercharger – Can often be isolated from the main engine to determine the turbocharger/supercharger contribution to oil consumption. Oil tracks might also be seen in the outlet if there is a broken seal.

Air compressor – Might be able to remove from the engine to check for its contribution to oil consumption.

Valve Guides – There may be oil leaking down the valve stems. Replace the valve stem seals if possible.

Fuel Pump – The fuel pump or fuel injectors may leak oil into the fuel. The oil will then be burnt with the fuel.

6.4 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 and oil consumption. Coolant in the oil could also indicate a failed cylinder head gasket which could cause high blow-by and / or oil consumption.

6.5 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.

6.6 Measure Blow-by

Measure blow-by in the problem solving efforts. High blow-by might be an indicator of power cylinder issues that might result in high oil consumption also. These issues could include:

- Broken Ring
- Broken Piston
- Scuffed Cylinder

6.7 Compression Check

A compression check can help to determine if there is a problem with the rings or pistons that might be resulting in high oil consumption.

6.8 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 blow-by that might be affecting oil consumption.

6.9 Borescope the Engine

A borescope of the cylinder will help to identify if there has been scuffing or piston damage that might explain the cause of high oil consumption.

6.10 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.

6.11 Complete an Oil Analysis

Analyze the oil for signs of potential problems. Analyze viscosity change and base number change for oil degradation. Check for wear metals (iron, chrome, etc.) in the oil for indications of failures occurring within the engine. The oil should also be analyzed for contaminates such as fuel and coolant. Excessive fuel or coolant in the oil may diminish the lubricity which will cause excessive wear or scuffing of the cylinder. This can result in high oil consumption.

7. ELIMINATE THE POTENTIAL MISTAKES (AFTER ENGINE TEARDOWN)

7.1 Incorrect or Missing Components

Verify that there are no incorrect or missing components in the engine.

7.1.1 Piston Rings

Check each ring. Have all the rings been installed on each piston? Have the correct piston rings been used. Make sure that the oil rings are installed with all the pieces. A missing piece can be detrimental to oil consumption.

7.1.2 Incorrect Dip-stick

An incorrect dip-stick may result in the engine being overfilled with oil. This might result in high oil consumption.

7.2 Misassembled Power Cylinder Parts

7.2.1 Piston Rings

Make sure that all the rings have been installed with the proper side up. An asymmetric ring that is installed upside down will scrape oil upward causing high oil consumption.

7.2.2 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. The broken ends of the rings become polished against the cylinder bore and / or against each other during running if they were broken at assembly or during running. If they were broken during or after tear-down, the broken ends are not polished.

Broken ring lands on the piston would also be a cause of high oil consumption and blow-by. It may be necessary to remove the rings to determine whether any ring lands are cracked or broken.

Look for cracks on the cylinder head and also for damage on the head gasket.

7.2.3 Abnormal Marks

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

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

7.2.4 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. OIL CONSUMPTION AS A RESULT OF A FAILURE

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

8.1 Broken Rings

A broken piston ring can be 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 oil consumption.

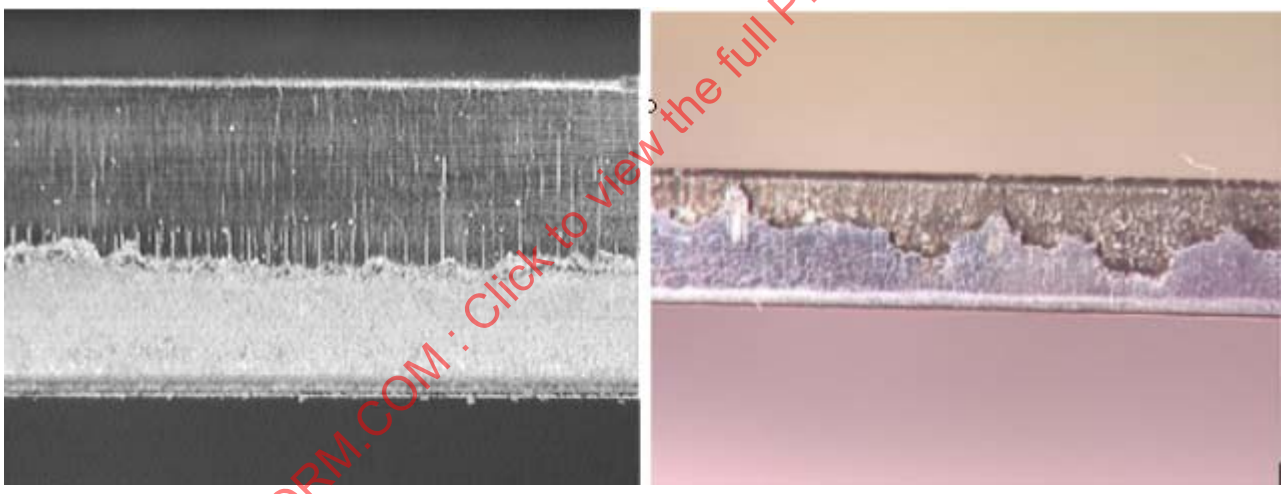

FIGURE 3 - EXAMPLE OF FAILED RING FACE COATINGS

8.3 Scuffed Power Cylinder

Oil consumption 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 oil consumption. 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 or if there is a leak path for dirty air to enter the clean side of the intake system e.g., cracked air duct or loose clamp.

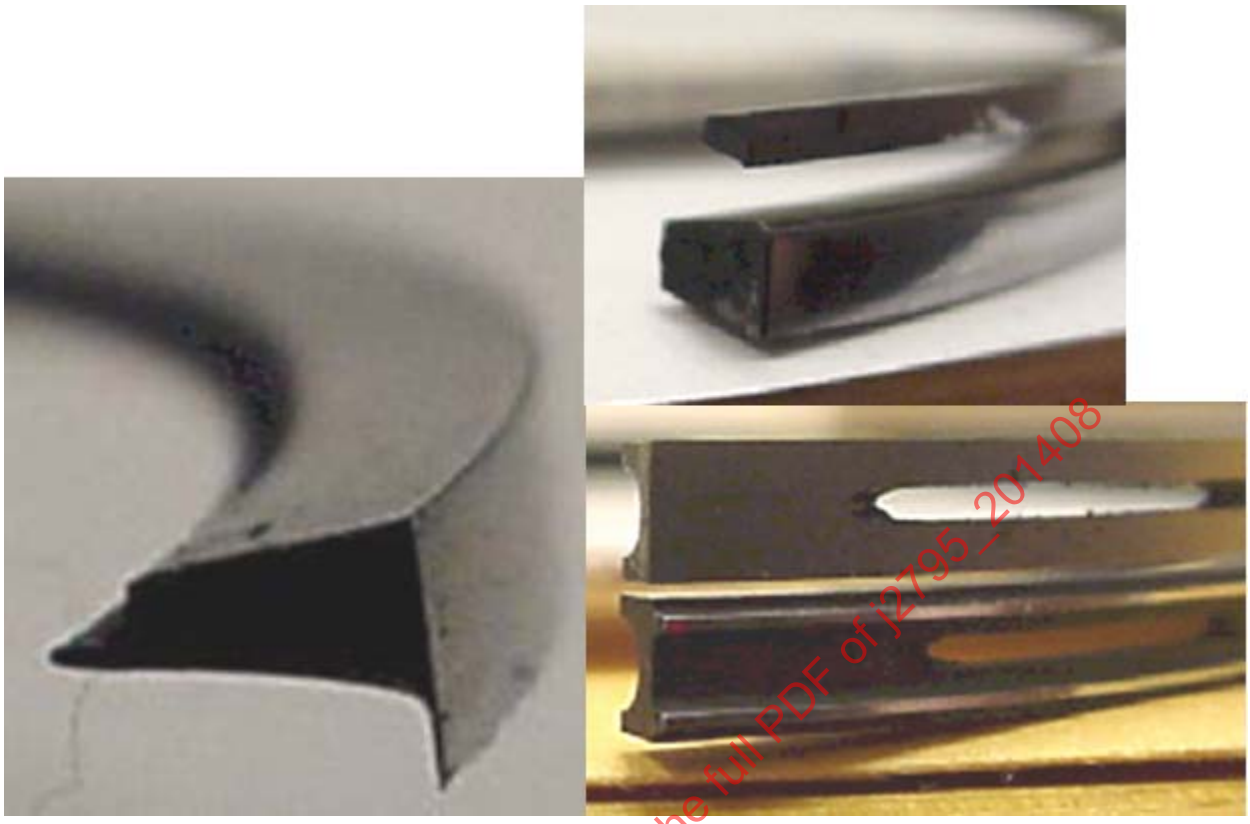

FIGURE 7 - EXAMPLES OF EXCESSIVELY WORN RINGS

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. Scuffed 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

Liquid fuel impinging on the cylinder walls may result in excessive polishing and wear which will result in high oil consumption. 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

9. CHECK FOR PROPER DESIGN

The power cylinder components may not be designed properly and as a result will have high oil consumption. SAE Standard J2794 describes the design parameters that will affect oil consumption. These parameters should be carefully considered to ensure a low oil consumption engine design.

10. MODELING AND MAPPING

Oil consumption 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. This can help diagnose the causes of high oil consumption and also predict high levels of 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 increase oil consumption.

Models are available to predict oil consumption directly. However, caution should be exercised because the modeling of oil consumption is very difficult and subject to interpretation and potential errors.

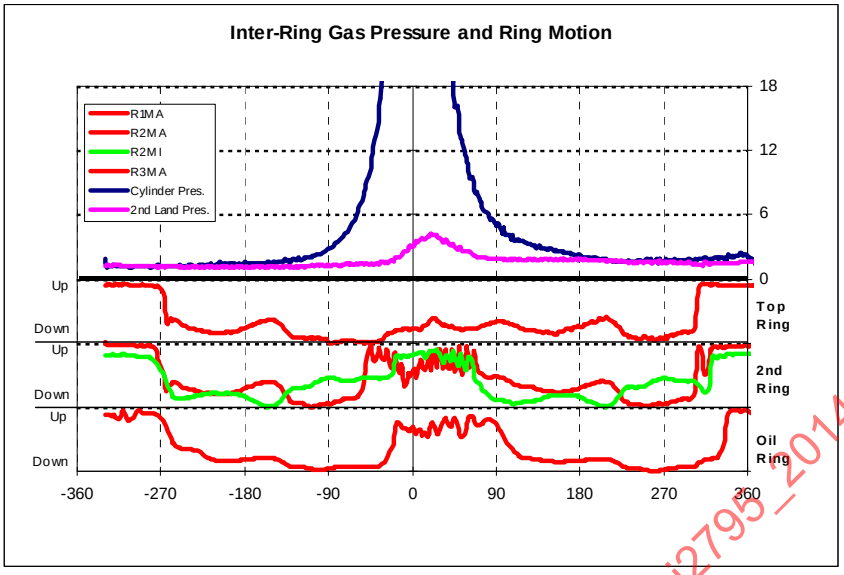

FIGURE 9 - EXAMPLE OF INTER-RING GAS PRESSURE AND RING MOTION

10.2 Engine Oil Consumption Steady State Mapping

Oil consumption mapping of the effects of speed and load might show where there are regions of high oil consumption and blow-by. This might indicate a condition with non-optimal ring pack dynamics.

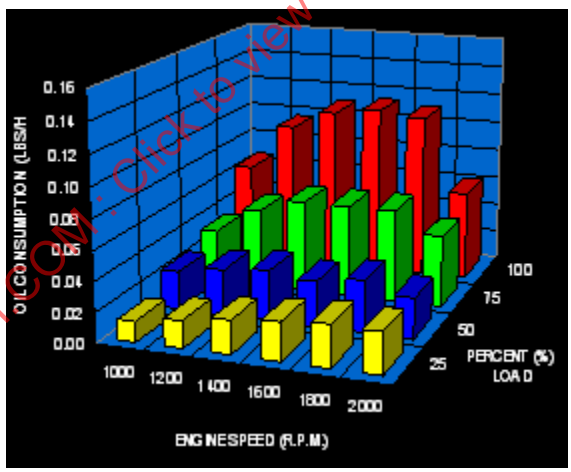

FIGURE 10 - EXAMPLE OF OIL CONSUMPTION MAPPING

11. COMPONENT SWAPPING AND VARIATION TECHNIQUES

When trying to find the component that is causing high oil consumption 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 oil consumption 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 oil consumption engine and a different engine of the same configuration with low oil consumption. The concept is to take the known bad oil consumption engine configuration and swap parts into the engine from the good configuration. After each swap of parts, measure the oil consumption. If the oil consumption goes low then the cause for the high oil consumption has been determined.

Once the component or components causing the high oil consumption have 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 oil consumption.

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 oil consumption 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 oil consumption, 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 high oil consumption. The systems that might be contributing to oil consumption are as follows:

- The Power Cylinder (piston, rings, liner)
- The Overhead (valves, valve stem guides and seals)
- The Turbocharger/Supercharger
- The Fuel Pump
- Other External Components

12.1 Isolating the Overhead

This can be a difficult task to accomplish. This requires that the lube system in the head be separated from the lube system in the block. Therefore each are run as separate systems. The next step is to measure the oil consumption from both systems. To do this, it is possible to use a lube oil tracer system where the tracer element in the exhaust is measured to determine oil consumption. The other way to do this is to measure the oil consumption from the main engine (not the overhead) and subtract this from the total engine oil consumption to determine the overhead contribution.

12.2 Isolating the Turbocharger/Supercharger

Isolating the turbocharger/supercharger is not uncommon. In this, the lube oil to the turbocharger/supercharger is isolated from the engine. Then oil consumption is measured from the main engine using the standard techniques. The difference between the total engine oil consumption and the base engine oil consumption is the oil consumption from the turbocharger/supercharger.

12.3 Isolating the Fuel Pump

Oil might be entering the fuel through the fuel pump. To separate this effect, the lube system to the pump must be separated from the base engine to determine the contribution of the fuel pump. Another sign of oil getting into the fuel from the fuel pump will be when the fuel in the fuel tank turns black from sooty oil.

12.4 Isolating the Crankcase Ventilation Systems

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

12.5 Isolating the External Components

There are other external components that might be causing high oil consumption. 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. OTHER POSSIBLE FACTORS

13.1 Customer Duty Cycle

Oil consumption of an engine might be subject to the variation of the customer duty cycle or to the application in which the engine is placed. An engine put in one type of vehicle might have completely different oil consumption than if it was placed in another vehicle.

14. OIL CONSUMPTION PROBLEM SOLVING SEQUENCE – OIL CONSUMPTION HAS BECOME BAD

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

14.1 Before Disassembly of the Engine

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

14.1.1 Check the History

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

14.1.2 Investigate the Source

Check for the source of the high oil consumption.

- Are there any leaks?
- Are the crankcase ventilation systems working properly? (Air breather, PCV valve)
- What is the oil consumption from other components (Turbocharger, Supercharger, Air Compressor, Fuel Pump)
- Separate the systems if possible to determine the source (Turbocharger, Overhead)

14.1.3 Check for Problems

- Are there any problems with the oil consumption 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?

14.2 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 or scoring of the bore walls? Has anything broken? These will result in high oil consumption.
- Do a compression tests to check if a piston ring has broken, valves are not sealing or a gasket may not be sealing.

Do a leak down test to identify the source of the leak.

14.3 Remove the Cylinder Head

With the head removed from the engine check the following:

- Evaluate the cylinder walls for signs of scuffing, scoring or debris damage that might have caused the high oil consumption.
- Check the piston for signs of cracking, debonding of the ring carrier insert (if present), contact with the valves or cylinder head,debris damage,and melting.
- Evaluate the cylinder 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.

14.4 Remove the Power Cylinder Components

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

14.4.1 Check for Incorrect Installation Issues

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

14.4.2 Check for Damage

- Check for broken components (piston rings, pistons)
- Check for chipping or delamination of the ring coatings
- Check for rings that have been stuck in the grooves. Rings may be stuck in the grooves because of:
  - Carbon packing
  - Micro-welding of the ring to the groove
  - Scuffing
  - Impact damage to the piston
- Check for damage to the cylinder bore from
  - Scuffing
  - Scratching from debris
  - Dust in the cylinder causing excessive wear. This can most commonly be seen on the piston ring faces and bottom side.
  - Carbon Polishing causing bore polishing
  - Bore washing and excessive polishing from fuel
  - Bore washing and excessive polishing from coolant