



# SURFACE VEHICLE INFORMATION REPORT

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Power Cylinder Oil Consumption: Transport Mechanisms

## 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.

### 1. SCOPE

This document covers oil transport mechanisms from the power cylinder system which might affect oil consumption. It will not discuss in detail the oil consumption mechanisms from other systems or engine components.

#### 1.1 Purpose

The oil consumption of an internal combustion engine is a significant performance and emissions attribute. The loss of engine oil through the combustion chamber is critical because it impacts the warranty life, as well as the emissions signature, of the engine and potentially poisons any exhaust gas after treatment devices. In addition, oil consumption is an attribute that directly affects the operator of a vehicle. The durability of an engine is defined, in many cases, as the point at which oil consumption becomes excessive.

This document addresses the oil consumption transport mechanisms for the power cylinder. Other sources for oil consumption which will not be covered in this document are the turbocharger, the crankcase ventilation system, leaks, and the valve train. The material covered is appropriate for all compression cylinders including spark ignition and compression ignition engines and air compressors.

The intent of this document is not to be a comprehensive oil consumption handbook. It is an introduction to the oil consumption mechanisms. Since every engine is unique, this document handles oil consumption mechanisms in a general way, leaving the specific dimensions, surface finishes, end gaps, and angles to be detailed by the power cylinder engineer for each individual engine. Consequently, the document evaluates each feature in a qualitative manner. Each source of oil consumption is evaluated by the qualitative parameters of Major, Medium, and Minor. For example, the unit pressure of the oil piston ring is categorized as a major effect on in-cylinder oil consumption. In solving oil consumption problems, this feature should be explored before the piston skirt surface finish since skirt finish is categorized with a minor rating. In addition, if a new engine is being designed, specifying the unit pressure of the oil piston ring will be a significant step in ensuring that a new engine design will have acceptable oil control.

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This document does not emphasize the effect of wear on oil consumption. It applies to essentially new power cylinder components whose dimensions will change as the result of wear processes. Experience with each individual engine will determine how significantly the power cylinder oil consumption is impacted by wear. This document is an introduction to understanding power cylinder oil transport mechanisms. The specific details of each individual engine will remain with the power cylinder development engineer.

## 2. REFERENCES

### 2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

#### 2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

SAE J2612 Internal Combustion Engines—Piston Vocabulary

#### 2.1.2 ISO Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

ISO 6621-1 Internal Combustion Engines – Piston rings – Vocabulary

## 3. DEFINITIONS

Refer to SAE J2612 for the piston nomenclature, and ISO 6621-1 for the piston rings vocabulary.

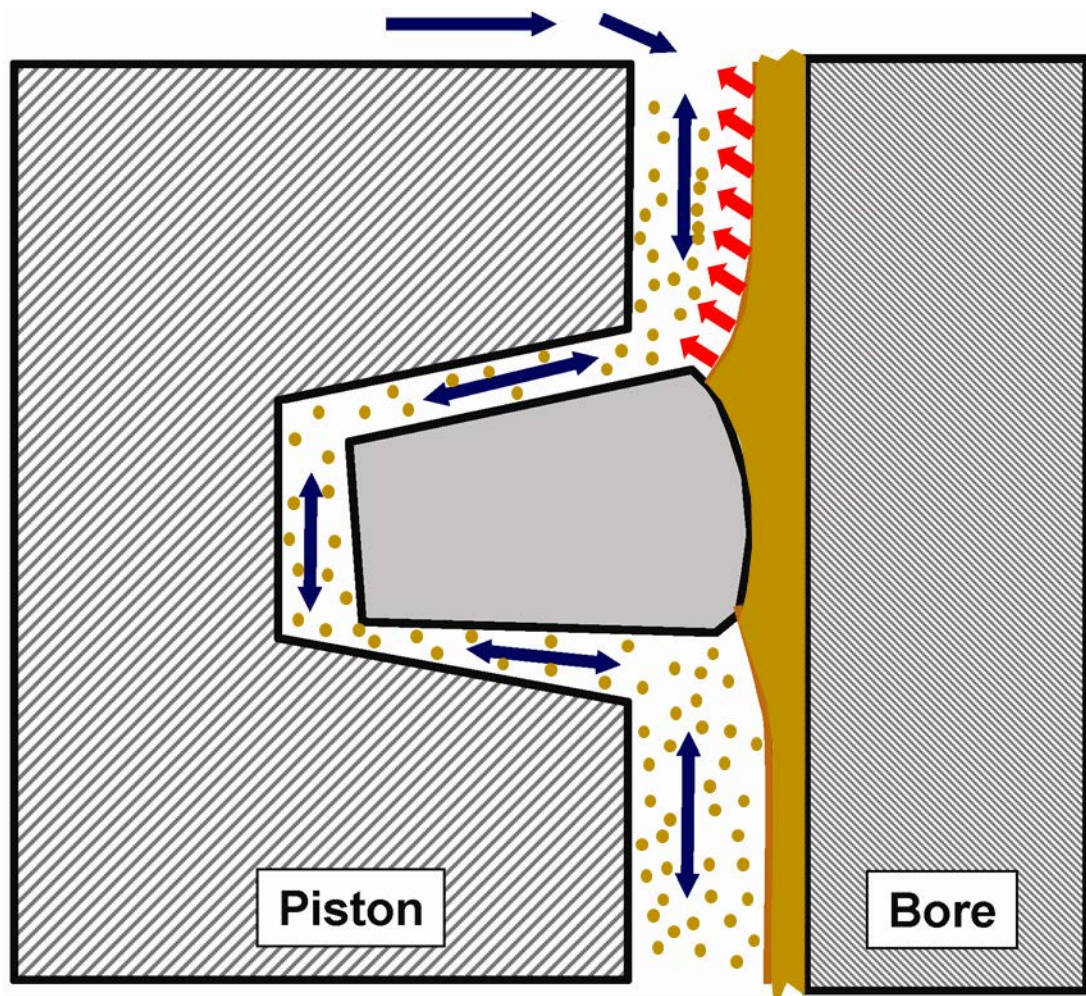
## 4. PISTON RING

### 4.1 Piston Ring Basics of Oil Transport for Consumption

Fundamentally, any oil that migrates past the top piston ring into the combustion chamber can be lost and contribute to the oil consumption of an engine. The purpose for the power cylinder design is to seal gases and to control the oil, allowing it to lubricate the piston rings without losing it into the combustion chamber. The phase of the oil migrating past the top piston ring into the combustion chamber can be liquid, vapor, or mist (or bubble, which is liquid + vapor).

Oil Phases are:

- a. Liquid: Liquid oil can be scraped, flow, and be squeezed around the piston ring.
- b. Vapor: The oil can vaporize or evaporate. This can occur while the oil is on the piston, on the liner, or in the piston ring-pack. In the vapor form, the oil can be burned or transported by gases or coalesce or condensate into another phase.
- c. Mist (or bubble): Due to the motion of the piston and piston rings, and the gas flow, the oil can become a mist or aerosol. This mist can be carried in the gases that flow through the piston ring-pack.



Double arrows (blue) represent the gas or oil vapor/mist transport path.

Single arrows (red) represent evaporation.

Brown area represents the power cylinder lubrication wall film being scraped.

**Figure 1 – Flow of oil and gases past a piston ring**

## 5. POWER CYLINDER COMPONENT - EFFECTS ON OIL CONTROL

The following power cylinder components each can contribute to oil consumption. These effects will be described in subsequent sections.

### 5.1 Components

#### 5.1.1 Piston

#### 5.1.2 Piston rings

##### 5.1.2.1 Top compression piston ring

##### 5.1.2.2 Second compression piston ring

##### 5.1.2.3 Oil control piston ring

#### 5.1.3 Cylinder bore

#### 5.1.4 Oils

#### 5.1.5 Oil jets

##### 5.1.5.1 Under-crown spraying

##### 5.1.5.2 Gallery cooling sprays

#### 5.1.6 Piston pin

##### 5.1.6.1 Wrist pin

##### 5.1.6.2 Lock rings

#### 5.1.7 Connecting Rod

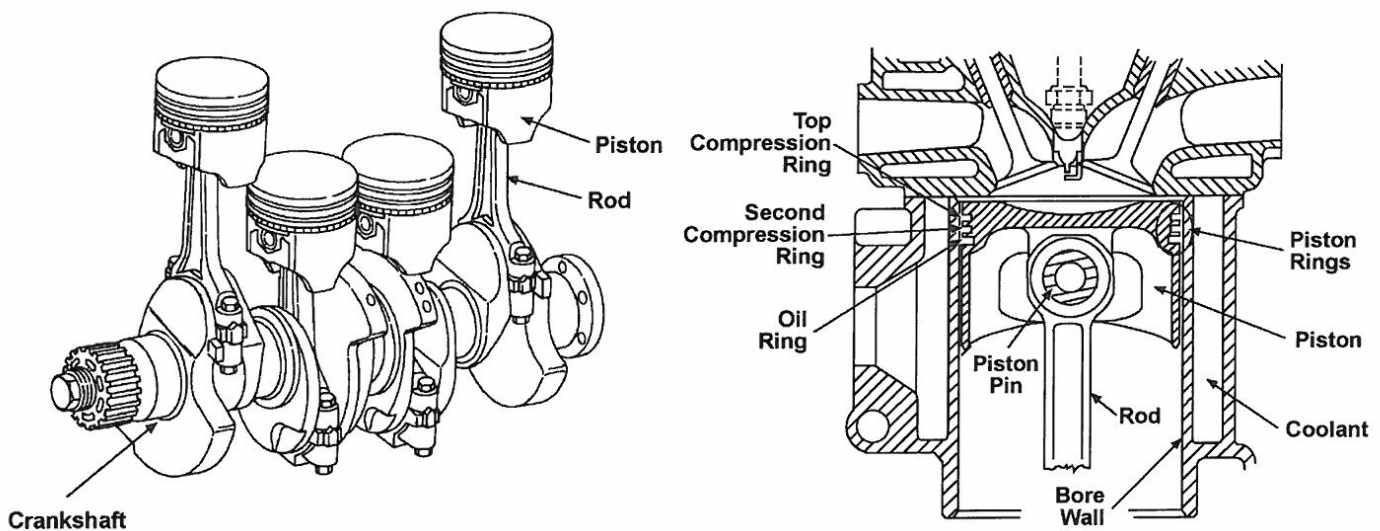


Figure 2 - Power cylinder

## 5.2 Piston

The total volume of oil flowing past all of the piston contributes to the oil consumption of the engine. The piston must provide for accumulation and drainage of excess oil. The grooves and lands should be designed to control the gas and oil flow around the piston rings and through the piston ring gaps.

The piston top land can scrape oil into the combustion chamber if not designed properly, or if it has excessive carbon that builds up during engine operation. The design of the piston skirt will also influence oil consumption by shape, clearances, and surface finish. The secondary motion of the piston must be controlled in order to allow the piston rings to perform their function.

## 5.3 Top Piston Ring

The top piston ring is the primary seal for the combustion gases and as a result has the most significant effect on blow-by. However, the top piston ring is the final obstacle before the oil is transported into an area where it can be consumed. Thus the top piston ring is also important for oil control.

## 5.4 Second Piston Ring

The second piston ring primarily scrapes the excess oil off the bore surface that passes by the oil piston ring. As a result it is very important for good control of oil consumption. Also, the second piston ring seals the gases that flow past the top piston ring. Therefore, it has an effect on both oil consumption and blow-by.

## 5.5 Oil Piston Ring

The oil piston ring scrapes oil from the cylinder wall to prevent excessive amounts from reaching the upper compression rings. The oil that is scraped by the oil ring must be able to drain back so the piston will typically have oil drain slots or holes in the oil ring groove.

## 5.6 Cylinder Bore

The interaction of the piston and piston rings with the bore surface affects the gas and oil sealing of the cylinder. As a result, it is the function of the cylinder bore to provide a good sealing surface with sufficient but not excessive oil retention for the lubrication of the piston and piston rings. The conditions of the bore (temperatures, distortion, surface finish, etc.) also need to be optimized for proper oil control.

## 5.7 Oil Properties

The properties of the oil play a significant role in oil consumption. The properties must be optimized to lubricate the cylinder sufficiently, but minimize oil consumption. Factors that will affect the oil consumption are viscosity, volatility, misting characteristics, surface tension, and additive package. While the engine designer does not have control of these properties, he or she must be aware of them so that an accurate specification can be stated for optimum operation of the engine.

## 6. OTHER EFFECTS ON OIL CONTROL

There are other components and factors that can also significantly affect oil consumption which are listed below. These are not discussed in detail in this document, but it is important to understand their influence when diagnosing oil consumption problems or optimizing the oil control of an engine. These other systems must be isolated in order to optimize or determine the oil consumption contribution by the power cylinder system.

- Valve train (valves, valve guides, valve stem seals)
- Turbocharger
- Air compressors

- Breather systems (PCV, CCV, breather tubes)
- Internal leaks (intake manifold gasket, head gasket, cracked intake manifold, etc.)
- External leaks (oil pan, covers, crankshaft seals, etc.)

## 7. PISTON EFFECTS ON OIL CONTROL

### 7.1 Piston Ring Grooves

#### 7.1.1 Groove Type (Medium Effect)

Conventional wisdom is that rectangular piston ring grooves are better for oil and blow-by control. However, in some cases, keystone piston ring grooves are needed to prevent piston ring sticking, especially in diesel and 2-stroke engines. If piston rings stick, they will lose their sealing and oil control capability.

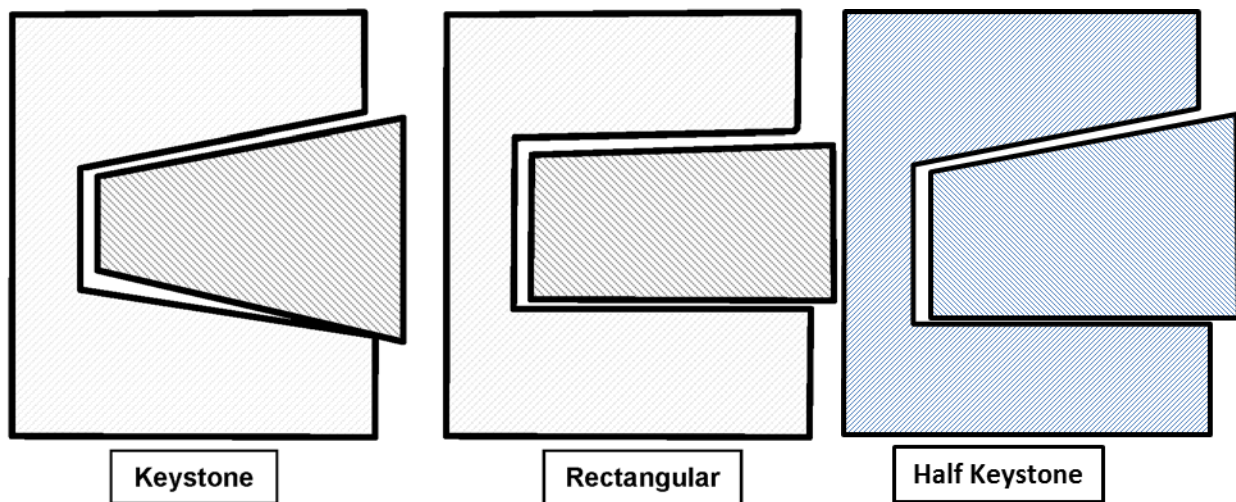


**Figure 3 – Angles of piston rings and grooves**

#### 7.1.2 Waviness and Flatness (Major Effect)

Circumferential waviness and radial flatness will affect how the piston ring will seal with the piston ring groove. Excessive circumferential waviness or radial flatness will create flow paths for oil and/or gases to pass by the piston ring. The circumferential length and the height of a wavy portion determine whether there is a leak path.

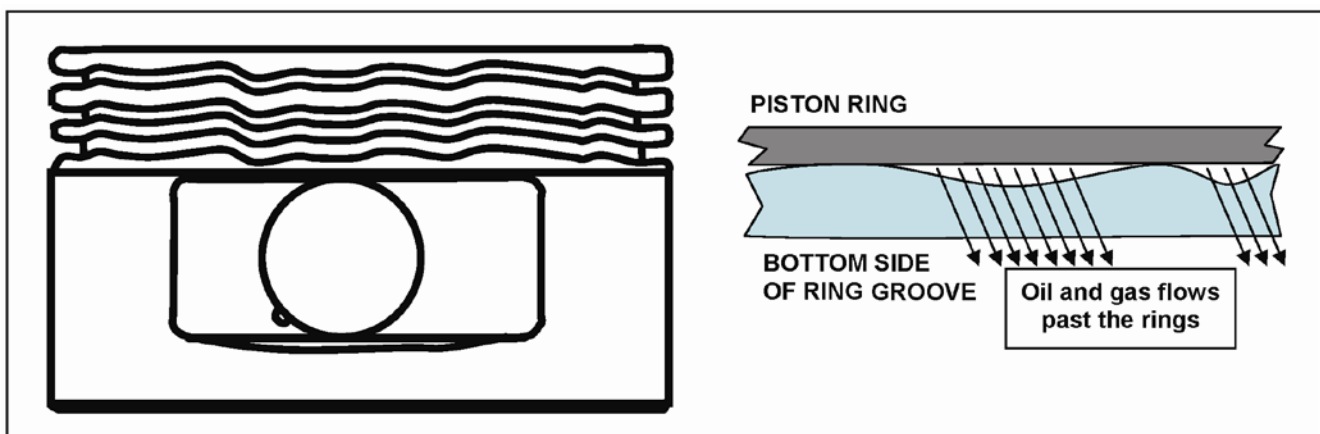


**Figure 4 – Piston groove waviness**

### 7.1.3 Surface Conditions (Medium Effect)

If the surface roughness or waviness is excessive, the piston ring will not seal properly with the groove. This will create passages through which oil might flow.

The method in which a piston ring groove is machined can affect blow-by and oil consumption. It will affect how the oil and gases may flow around the side of the piston ring.

Tool chatter produces peaks and valleys on the groove sides. Valleys interrupt the seal of the piston ring face to the groove face, creating gas and fluid transport paths.

Coarse surface finish reduces piston ring/piston effective sealing area thereby reducing the transport pressure resistance of gases and fluids.

### 7.1.4 Tilt (Major Effect)

The uptilt of the piston ring groove is defined by the deviation in angle that a symmetrical piston ring groove will have relative to the horizontal.

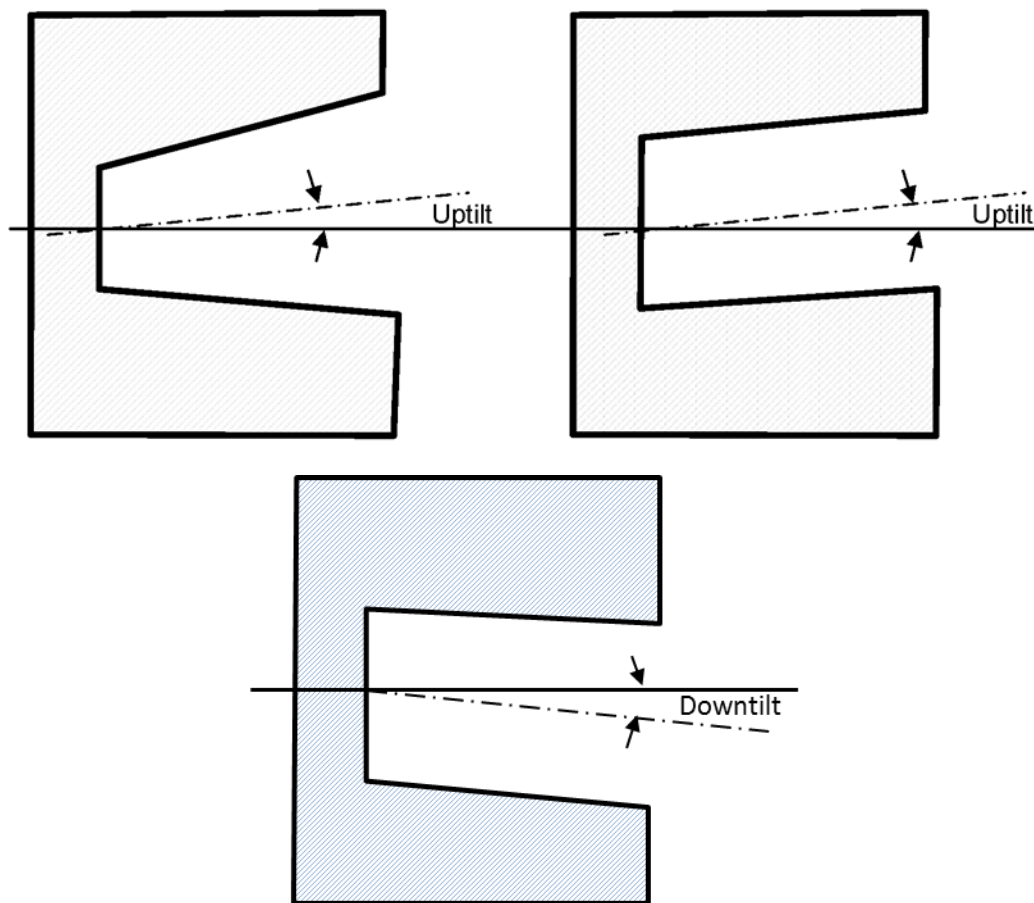


**Figure 5 – Groove tilt**

Due to high temperature and pressures, it is possible that the piston ring groove will rotate downward. This arching effect will be more pronounced on the first piston ring groove. It is common to give the piston ring grooves a positive uptilt to compensate for this arching of the piston. Finite element models can be used to determine the extent of the piston arching so that the uptilt can be specified appropriately. To verify the prediction, the top piston ring face should have a wear track that is centered on the piston ring face after the engine has been run under high stress load: mechanical or thermal conditions.

A negative tilting of the piston ring groove can cause piston ring to bore contact at the upper edge of the piston ring face. This contact can result in upward scraping of oil and increased oil consumption.

Groove tilt and/or piston ring twist can be used to cause inner edge contact of the piston ring to groove to give a better gas seal, but may have higher wear. Outer edge contact can allow gas under the lower side face of the piston ring and reduce the tendency to seal.

#### 7.1.5 Concentricity (Minor Effect)

Ring groove and lands should be concentric to each other and the piston axis. Deviations from concentricity can contribute to sealing issues contributing to gas and fluid transport paths.

#### 7.1.6 System Effects (Major Effect)

The interaction of the groove with the piston ring is very important. How the piston ring seats with the groove and how it moves within the groove can have a large effect on the performance of the power cylinder system.

The clearances between the piston, piston rings, and bore can all significantly affect oil consumption. These should be designed to provide the optimum dynamic control for the piston rings. But the system should be designed to allow reservoirs where oil and gases can collect in appropriate areas (e.g., the second land) to minimize oil consumption and blow-by. However, there are inappropriate reservoir locations (e.g., volume behind the top piston ring) that should be minimized to prevent excessive oil consumption or blow-by.

#### 7.1.7 Piston Ring Groove Material (Medium Effect)

The groove material or coatings on the groove can affect the wear of the groove. High groove side wear and piston ring side wear can increase oil consumption.

### 7.2 Piston Lands

#### 7.2.1 Diameters (Major Effect)

The regions between the piston rings determine volumes into which gases and oil flow in and out. The volumes in these regions will be affected by the diameters of the lands and the profiles on the land.

The interface between the land and the piston ring end gap will determine the gas flow path through the piston rings. Therefore, the diameter of the lands will affect the amount of gases flowing through the piston ring-pack.

Also, if the clearance is too small, the land might scrape oil upward and result in high oil consumption. In some cases, carbon will build up on the top lands when the clearance is too small. This could scrape oil upward and/or cause bore polishing which will increase oil consumption.

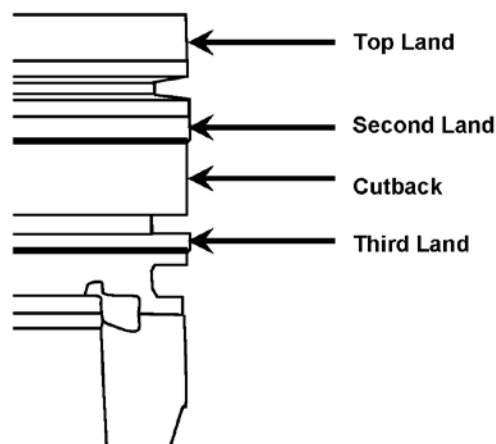


Figure 6 – Land diameters

### 7.2.2 Piston Land Lengths (Medium Effect)

The length of the piston land will affect the crevice volume between or below the piston rings for accumulating oil and gases. Therefore the length can affect oil consumption and blow-by.

### 7.2.3 Piston Land Axial Profiles (Major Effect)

The profiles of the piston lands will affect the oil drainage and gas flows. Typically the top of the piston will have higher temperatures than the lower regions. Therefore, the piston lands are typically profiled where the upper lands are cut back more than the lower lands to compensate for thermal expansion at higher temperatures. Excessive thermal growth of a land may cause upward scraping of the oil by the land and result in oil consumption.

Land profile can be cylindrical, tapered, balcony, or barrel shaped.

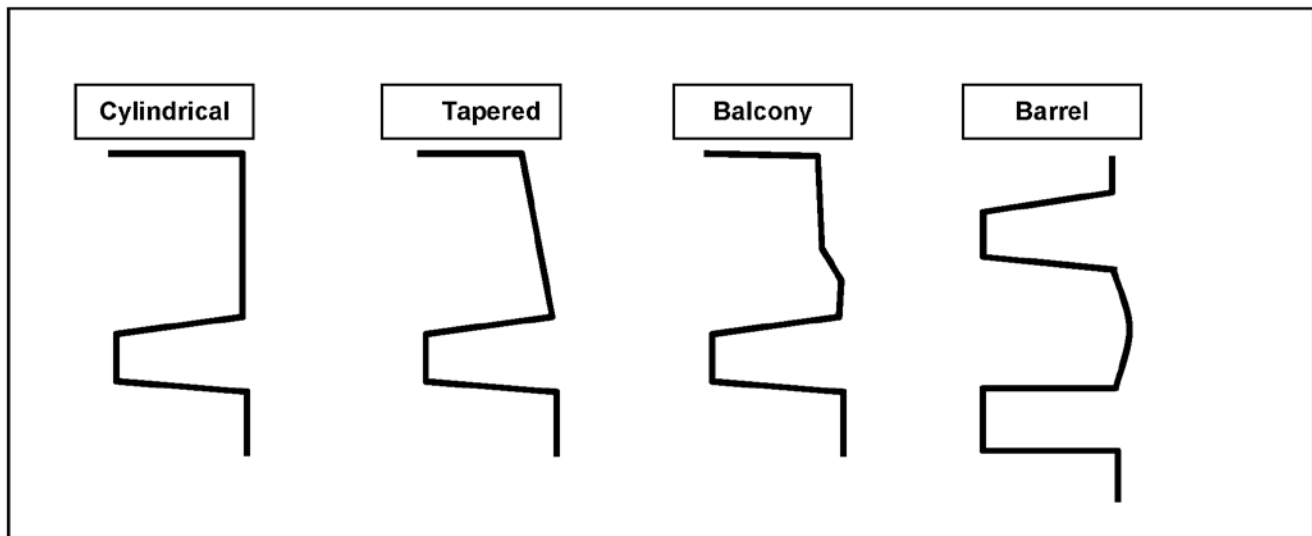


*Figure 7 – Land profiles*

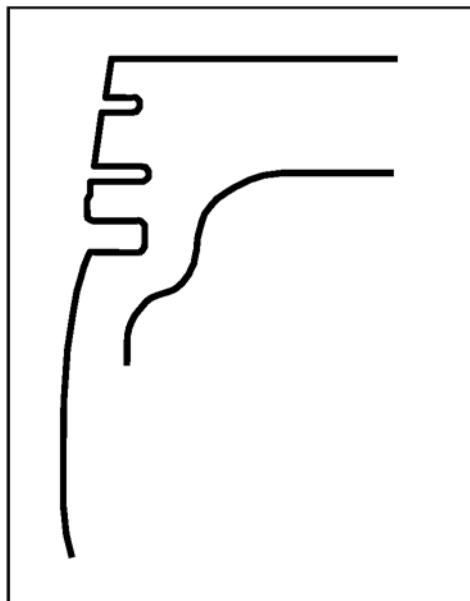


*Figure 8 - Land and skirt profile example*

#### 7.2.4 Piston Land Circumferential Profiles (Minor Effect)

At times, ovality is necessary on the piston lands to compensate for the thermo-mechanical deformations of the piston and to enhance such things as scraped oil drainage and inter-ring gas pressure.

The cylinder bore will also deform into an oval shape during operation. The ovality of the piston should be chosen to help stabilize the piston in the oval bore. On an articulated piston, the second land is the guiding land and should have the appropriate ovality to stabilize the piston.

#### 7.2.5 Piston Land Pressurization (Major Effect)

The top land will affect the pressure balance of the top piston ring. A tight clearance or a non-optimum profile might restrict the gas flow which seats and energizes the top piston ring. If the gas pressures cannot seat and energize the top piston ring adequately, then the piston ring will flutter or collapse radially inward, lose sealing, initiate pumping, and thereby cause high blow-by and oil consumption.

Excessive pressure build up on the second land might force gases upward. If there is oil in the land region, this will cause high oil consumption and affect blow-by.

#### 7.2.6 Chamfers (Major Effect for the Top Groove Bottom Side, Medium Effect for Other Groove Chamfers)

The outside diameter edge break on the bottom side of the piston ring groove can significantly affect blow-by and oil consumption (see Figure 9). If the edge break is too large, the gas flow area at the gap will be increased and affect the pressure balance of the piston ring-pack. Also, the piston ring might twist down, causing the piston ring to ride on the upper edge of the face.

Chamfers too large create an accumulation/reservoir for fluids build up. Achieving a sufficient volume and pressure, fluids can be forced between the piston ring and groove mating faces or be forced between the piston ring and cylinder contact surfaces.

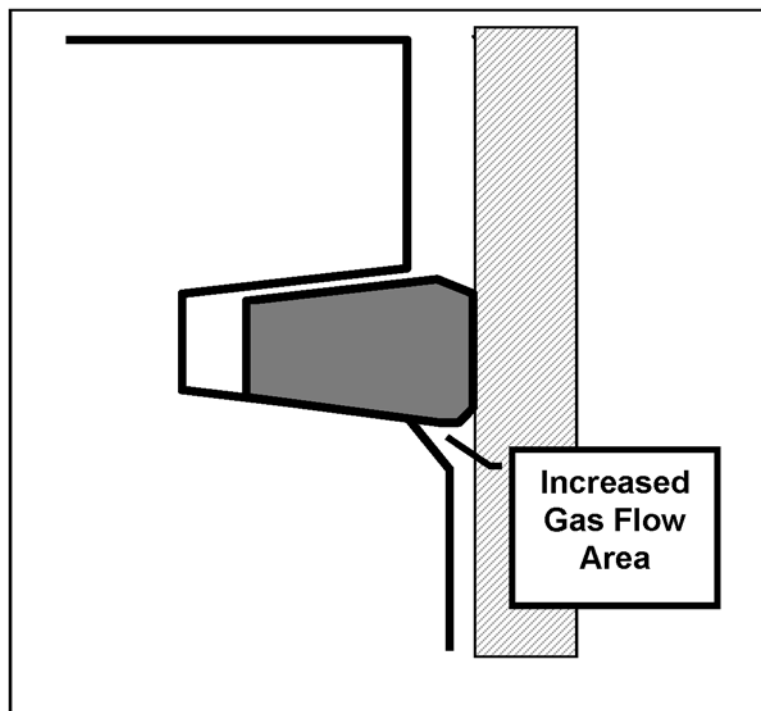


**Figure 9 - Effect of the large outside diameter edge break**

### 7.2.7 Accumulator Grooves (Major Effect)

Some engines will have a large land diameter directly under the piston ring to restrict the gas flow. This is followed by cutback area or accumulator volume. Oil and gases can then accumulate in this region rather than migrate upward to the top piston ring. A large second land volume may decrease the second land pressure, enhancing the sealing of the top piston ring. Typically, it will also reduce blow-by.

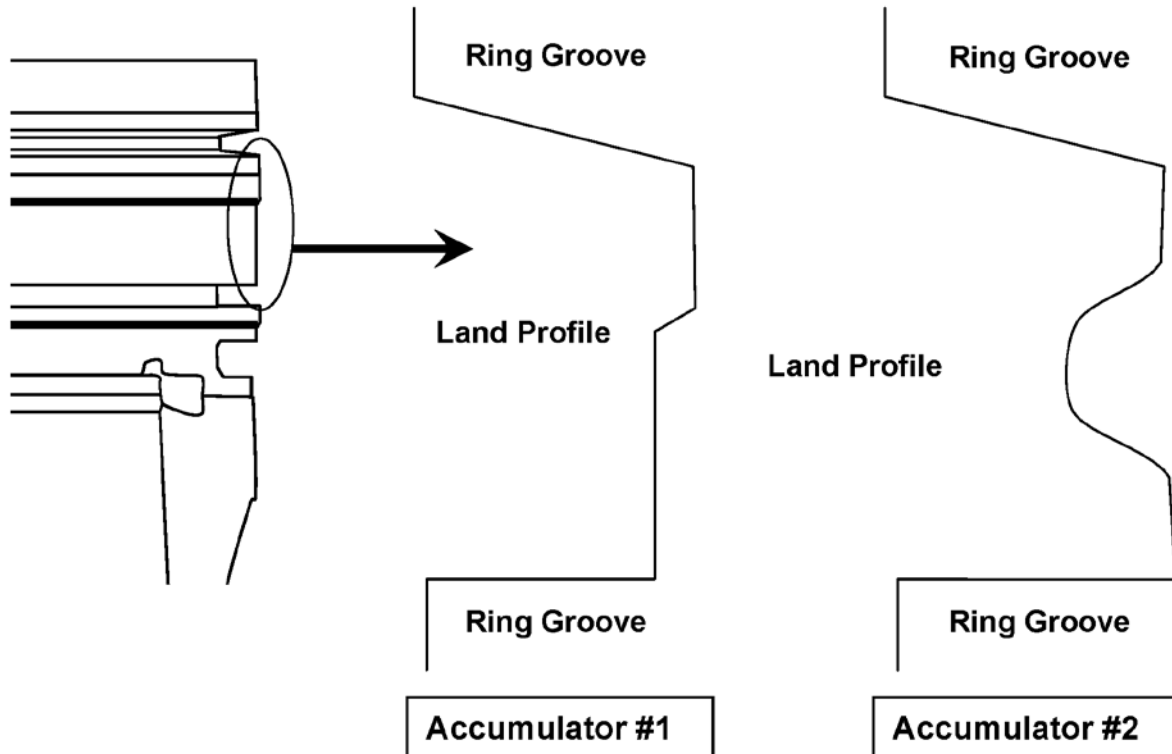


**Figure 10 - Land accumulator grooves**

### 7.2.8 Piston Guidance by a Land (Minor Effect)

The piston may be guided by one of the lands depending on the piston design. An articulated piston will have one guiding land because of its design. The one-piece piston is typically guided by the skirt but can at times have a contribution from a land. The profile of this land is important because it will interact with the oil film. Land profile can be cylindrical, tapered, balcony, or barrel shaped.

## 7.3 Oil Drain Features (Major Effect)

### 7.3.1 Oil Drain Holes (Major Effect)

Oil drain holes are typically placed in the back of the oil piston ring groove to allow for oil that is being scraped by the oil piston ring to drain back to the sump. This can be very effective for reducing oil consumption. However, if positioned in the wrong place (avoid the piston cooling nozzle spray), oil that is splashed or sprayed on the bottom side of the piston may flow upward through these grooves and increase oil consumption.

### 7.3.2 Oil Drain Slots (Major Effect)

Slots may be located directly under the oil piston ring to enhance the oil drainage rather than oil drain holes. The slots will typically extend to the back of the oil piston ring groove. The slots are typically located in the window regions of the piston. This allows oil then to drain down the sides of the piston.

For a three-piece oil piston ring, care must be taken in the use of drain back grooves. The rails of the piston rings may rotate to expose the piston ring gap to a slot and subsequently lock up in the drain back grooves.

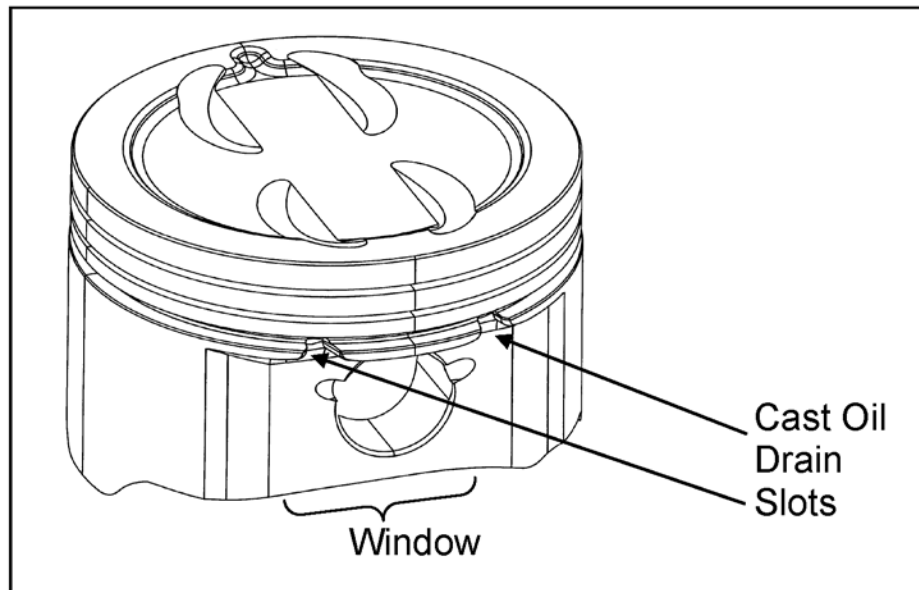


**Figure 11 - Oil drain trans slots**

#### 7.3.3 Trans Slots (Major Effect)

Trans slots may be located at the back of the oil piston ring groove as shown in the figure below. These slots can also be used to drain oil. Many of the new modern engines that are being designed will not have trans slots. This is because modern engines typically produce higher cylinder pressures and the trans slots tend to reduce the strength of the piston.

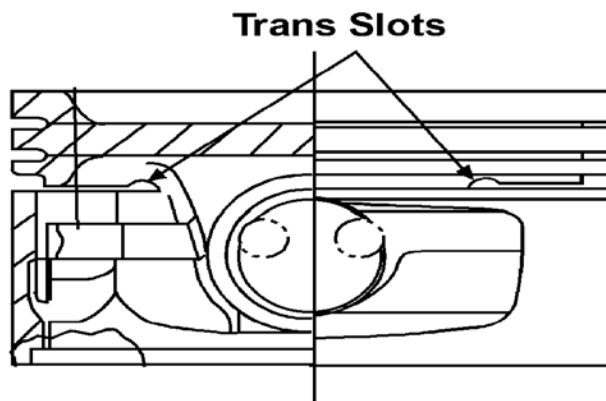


**Figure 12 - Oil drain slots**

#### 7.3.4 Drain Along Sides of the Piston (Medium Effect)

In some cases, there are no oil drain holes or slots. Oil that is scraped by the oil piston ring then must drain past the piston. To enhance this flow, it may be possible to increase the ovality of the piston or create windows on the sides of the piston in the pin axis to promote oil flow along the sides of the piston. Restricted flow along the side of the piston can adversely affect oil consumption.

#### 7.3.5 Oil Drain to the Pin Bore

Some pistons have oil drain holes that are meant to help lubricate the pin bore. However, it is possible to get oil to pump upwards through these holes into the piston ring pack and increase oil consumption.

## 7.4 Piston Skirt

### 7.4.1 Piston Guidance or Piston Secondary Motion (Major Effect)

The skirt will guide the piston in the bore. The stability of the piston and the resultant oil consumption may be affected by how well the piston is guided by the skirt.

The stability of the piston is determined by the piston secondary motion or lateral/tilting motion in the cylinder bore. There are analytical models for this type of motion.

If the piston moves such that the top land scrapes the cylinder wall, resulting in loss of contact of piston ring sealing with the cylinder wall, then high oil consumption might result.

#### 7.4.1.1 Piston Pin Offsets (Medium Effect)

A piston pin offset can significantly affect how the piston moves within the cylinder bore and as a result may affect oil consumption. Pin offset determines the amount of motion and force the piston exerts in the power cylinder – excessive or extensive motion may result in loss of piston ring sealing contributing to high oil consumption.

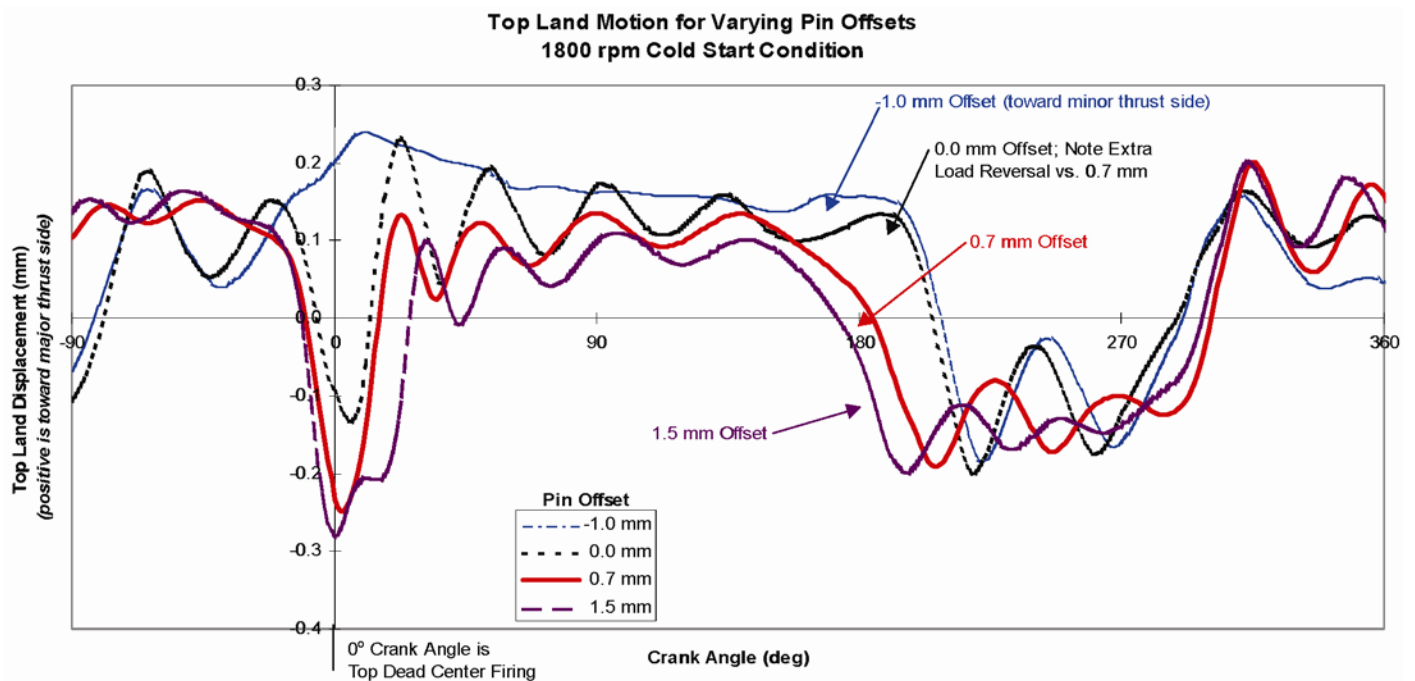


**Figure 13 - Example of the effect of pin offset on piston motion**