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(R) Power Cylinder Blow-By: Blow-By 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.

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1. SCOPE

This document covers the mechanisms associated with the power cylinder system which might affect blow-by. It will not discuss in detail the blow-by mechanisms from other systems or engine subsystems.

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 piston 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
- Head gasket
- Cylinder head system (valve stem guides and seals)
- Turbocharger
- Supercharger
- Air compressors

To solve an excessive blow-by problem, these systems must be isolated so that the system causing the problem can be identified. If the power cylinder system is identified as the cause of the blow-by problem, this document will provide guidance as to which design feature has made the greatest contribution to the excessive blow-by. The guidance provided by this document will also help the development engineer to optimize the blow-by and oil consumption of the engine. In addition to the design, it must also be recognized that the quality and cleanliness of the power cylinder components as well as the assembly practices can have a major influence on the blow-by of an engine. There is not very much detail on the influence of quality of the components on blow-by. In addition, there is no mention of how blow-by is measured because it is typically engine specific and company specific. This document will provide guidance for solving and preventing blow-by problems from the design viewpoint.

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 724-776-4970 (outside USA), www.sae.org.

SAE J2612 Internal Combustion Engines - Piston Vocabulary

2.1.2 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, Tel: 212-642-4900, www.ansi.org.

ISO 6621-1 Internal Combustion Engines - Piston Rings - Vocabulary

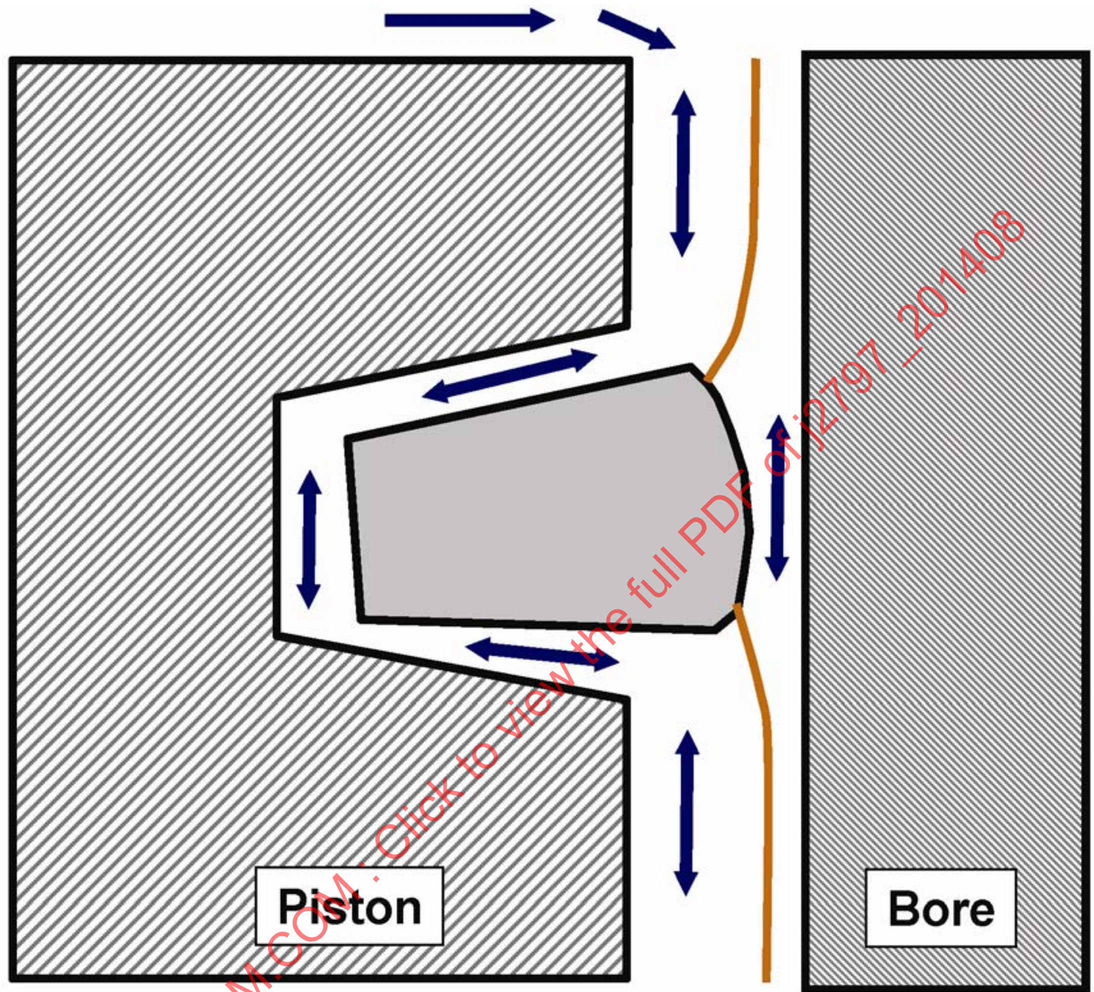
3. DEFINITIONS

See SAE J2612, Piston Vocabulary for the piston nomenclature.

ISO 6621-1 Internal Combustion Engines - Piston Rings - Vocabulary

4. BASICS OF MECHANISMS OF BLOW-BY

Fundamentally, any combustion gas that flows past the piston into the oil pan is considered blow-by of an engine. The power cylinder design is established to seal combustion gases and to control the oil.



(DOUBLE ARROW (BLUE LINES) = TRANSPORT PATH)

(RED SOLID LINE = POWER CYLINDER LUBRICATION WALL FILM)

FIGURE 1 - FLOW OF OIL AND GASES PAST A PISTON RING

5. POWER CYLINDER COMPONENT - EFFECTS ON BLOW-BY

The following power cylinder components each can contribute to blow-by. These effects will be described in subsequent sections.

Components

- Piston
- Piston Rings
  - Top Compression Ring
  - Second Compression Ring
  - Oil Control Ring
- Cylinder Bore
- Oils
- Oil Jets
  - Under-crown Spraying
  - Gallery Cooling Sprays
- Piston Pin
  - Wrist PinLock Rings
- Connecting Rod

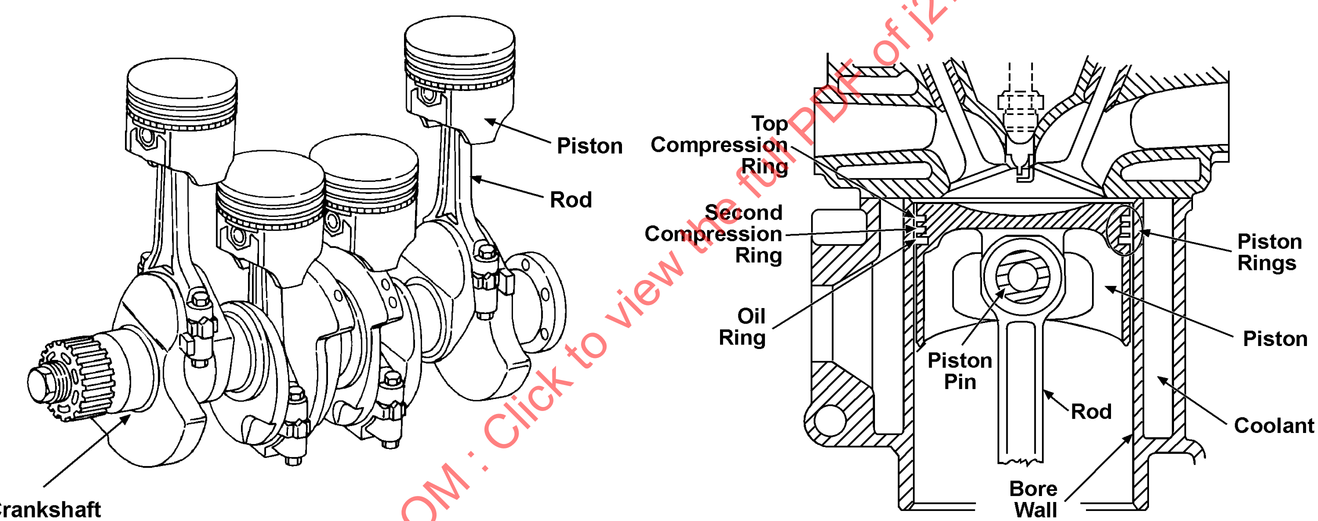


FIGURE 2 - POWER CYLINDER

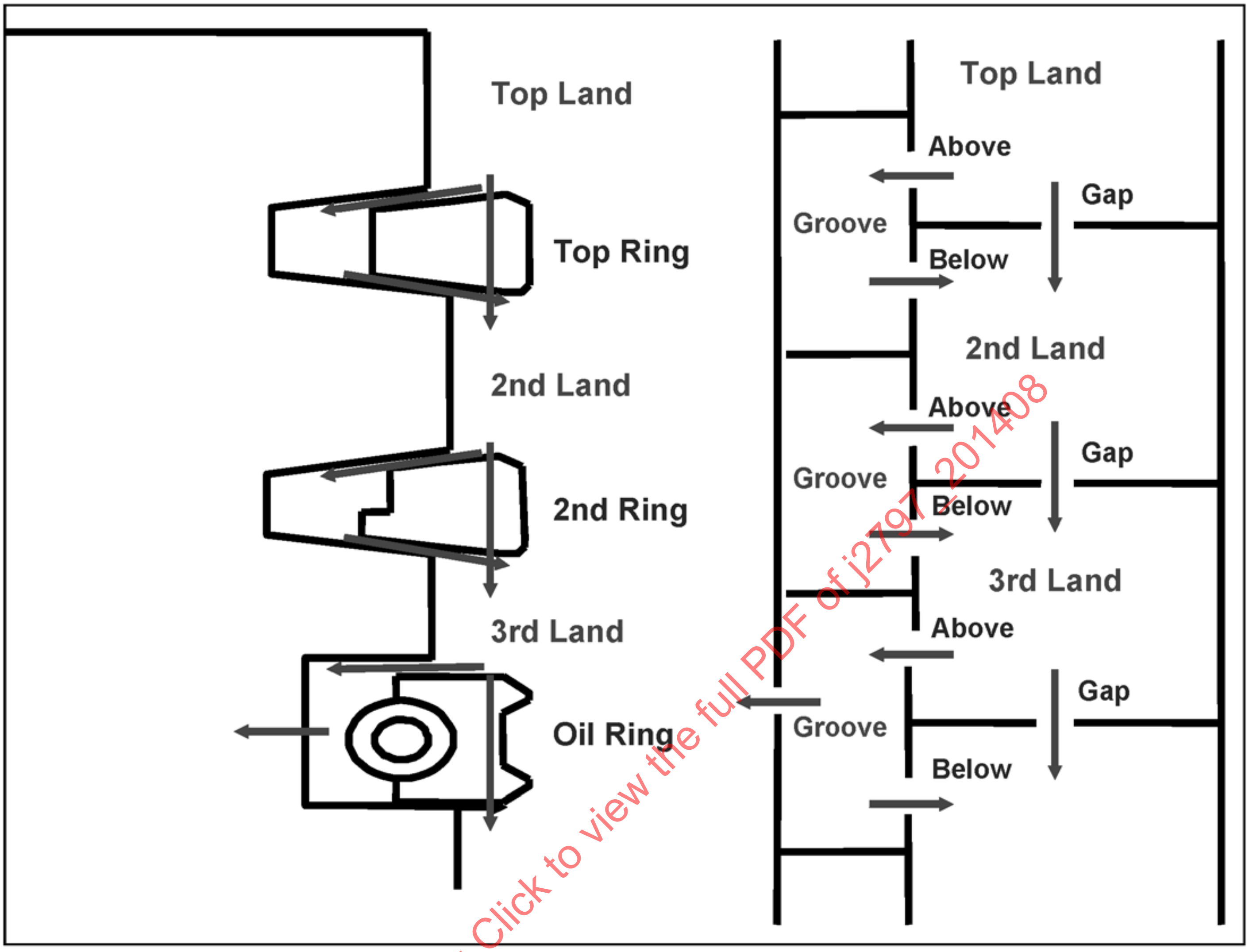


FIGURE 3 - PISTON RING PACK - ORIFICE/VOLUME MODEL

5.1 Piston and Piston Ring Pack

The piston and piston ring pack can be characterized as a series of volumes connected by orifices or flow channels through which the blow-by gases flow (See Figure 3). The gases from the combustion chamber are restricted by the piston rings. Gases accumulate between and behind the piston rings. The net gas flow past the bottom of the piston is called blow-by.

5.2 Piston

The total volume of gases flowing past all of the pistons is the blow-by of the engine. The piston, in combination with the piston rings, must provide a seal to block the flow of gases. The grooves and lands form locations where gases can accumulate. This accumulation will affect how the gases flow past the piston ring.

5.3 Top Ring

The top ring is the primary seal for the combustion gases and as a result has the most significant effect on blow-by. Combustion gasses passing this ring will either exit as reverse blow-by past the top ring, back up to the combustion chamber or as blow-by to the crankcase.

5.4 Second Ring

The primary function of the second ring is to scrape the excess oil off the bore surface that passes by the oil ring. However, the second ring also seals the gases that flow past the top ring. Therefore, it has an effect on both oil consumption and blow-by.

5.5 Oil Ring

The oil ring is not typically considered to have a significant effect on blow-by. However, gases must flow past the oil ring to enter the crankcase and it can restrict the flow. Therefore it is possible for the oil ring to affect, but not control blow-by.

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. The conditions of the bore (temperatures, distortion, surface finish, etc.) need to be optimized for proper blow-by control.

6. OTHER EFFECTS ON BLOW-BY

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

- Turbocharger
- Supercharger
- Cylinder Head Gasket
- Cylinder Head System (valve stem seals, seats, and guides)
- Air compressors

7. PISTON EFFECTS ON BLOW-BY

7.1 Piston Ring Grooves

7.1.1 Groove Type (Medium Effect)

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

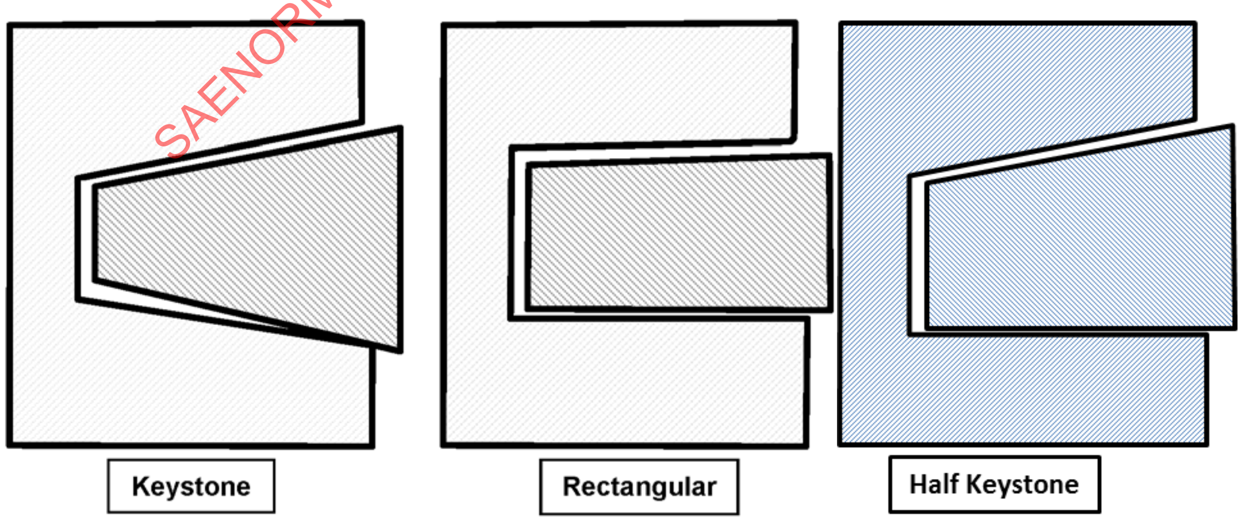


FIGURE 4 - TYPES OF RINGS AND GROOVES

7.1.2 Waviness (Major Effect)

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

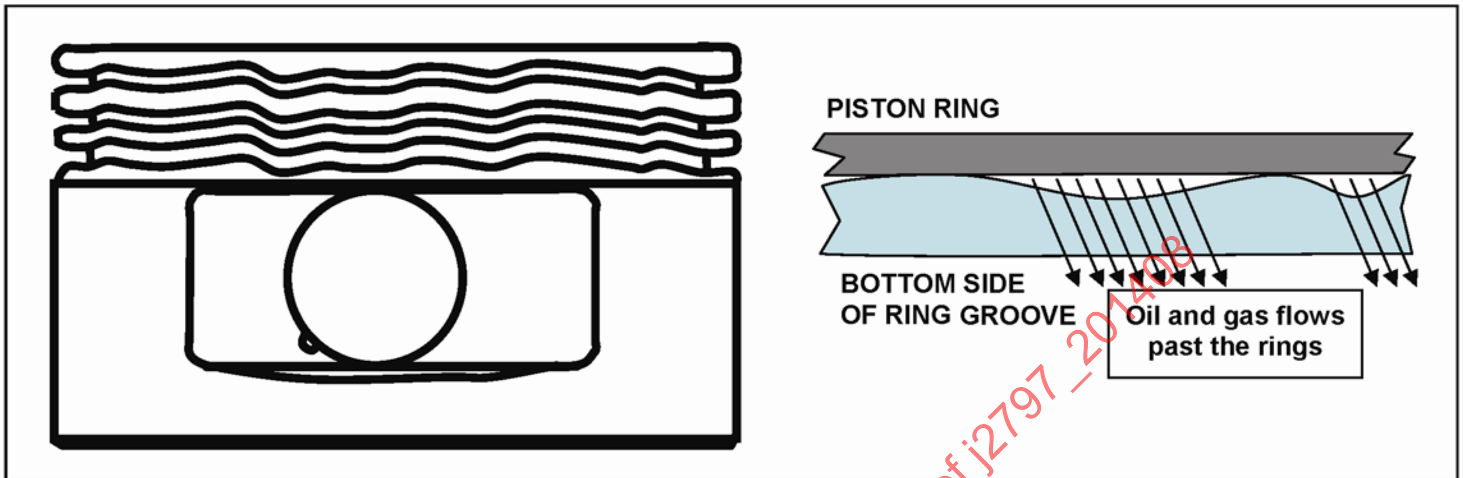


FIGURE 5 - PISTON GROOVE WAVINESS

7.1.3 Surface Conditions (Major Effect)

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

The method in which a piston ring groove is machined can affect blow-by. It will affect how the 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 side face to the piston groove face creating gas and fluid transport paths.

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

7.1.4 Tilt (Minor Effect)

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

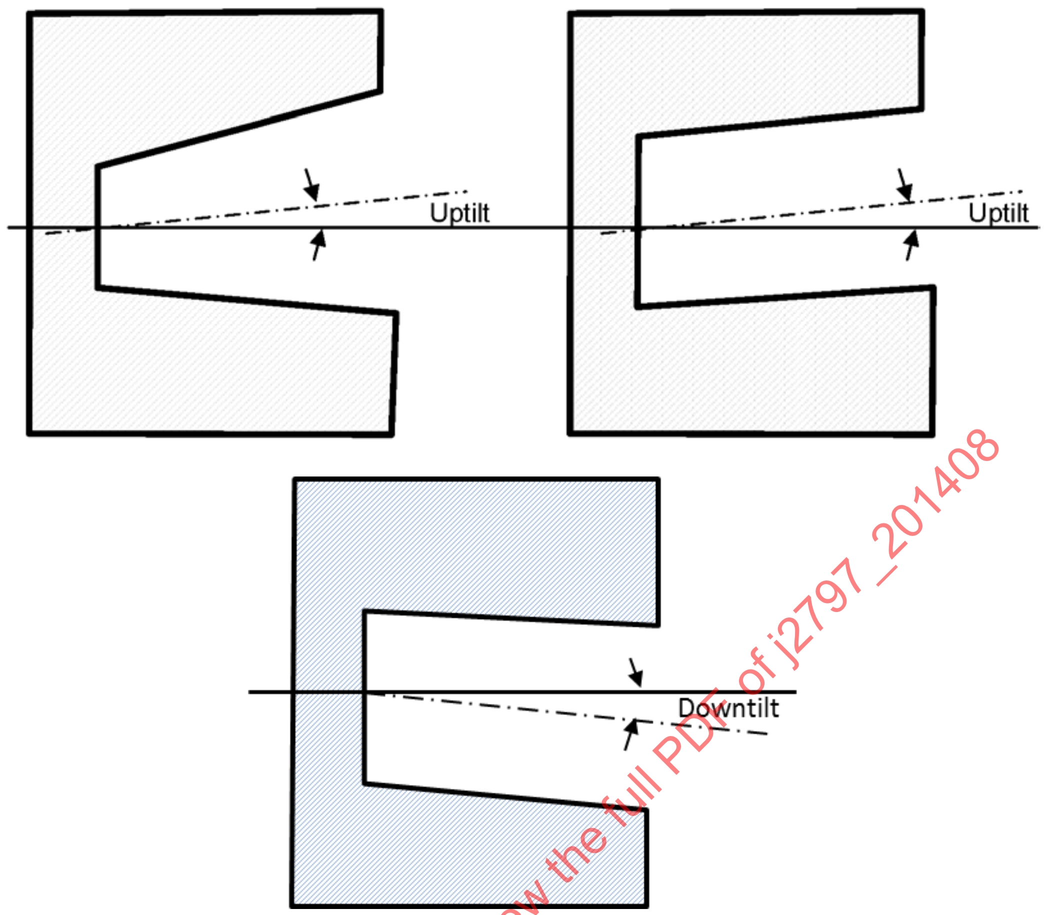


FIGURE 6 - GROOVE UPTILT

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 top 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 predict the extent of the piston arching so that the uptilt can be specified appropriately. To verify the prediction, the top piston ring periphery 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 bore contact at the upper edge of the piston ring periphery. This contact can result in increased blow-by.

Groove tilt and/or piston ring twist can be used to cause inner edge contact of the piston ring to groove to give 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 System Effects (Major Effect)

The interaction of the groove with the ring is very important. How the 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, rings, and bore can all significantly affect blow-by. These should be designed to provide the optimum dynamic control for the 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 blow-by and oil consumption. However there are inappropriate reservoir locations (e.g., volume behind the top ring) that should be minimized to prevent excessive blow-by or oil consumption. .

7.1.6 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 ring side wear can increase blow-by.

7.2 Piston Lands

7.2.1 Diameters (Major Effect)

The regions between the piston rings determine volumes into which gases flow in and out. The volumes in these regions will be affected by the diameters of the lands. 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 ring-pack.

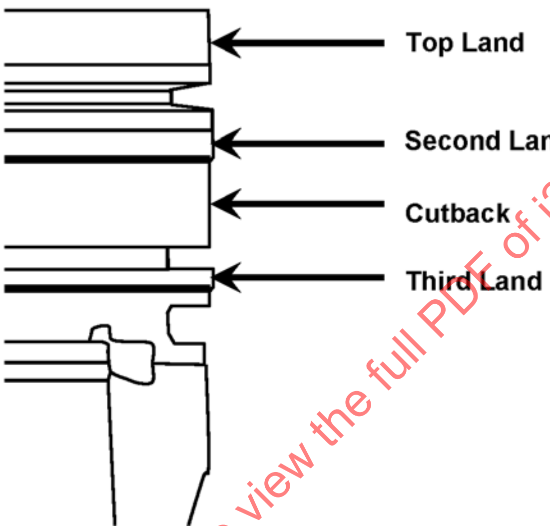


FIGURE 7 - PISTON LAND DIAMETERS

7.2.2 Piston Land Lengths (Medium Effect)

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

7.2.3 Piston Land Profiles (Major Effect)

The profiles of the piston lands will affect how the blow-by gases flow and accumulate within the ring pack. 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.

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

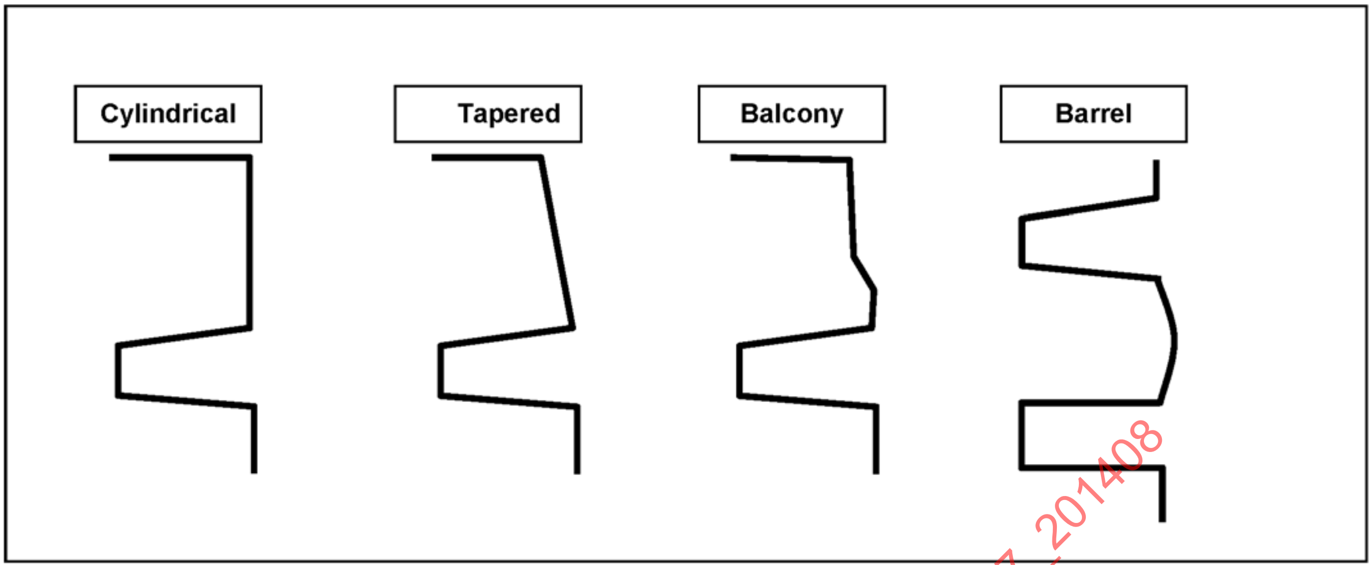


FIGURE 8 - PISTON LAND PROFILES

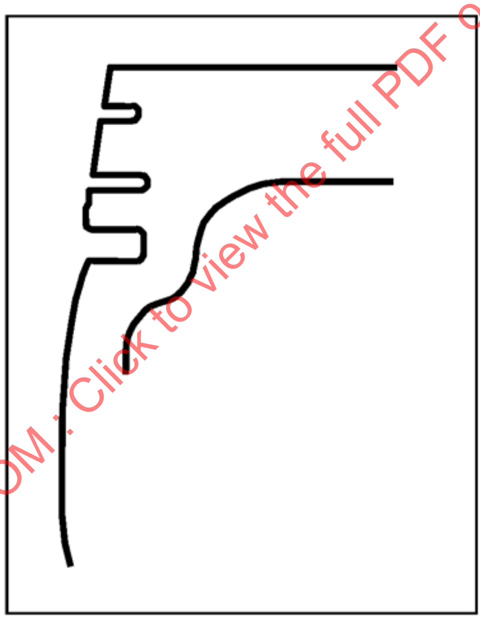


FIGURE 9 - PISTON LAND AND SKIRT PROFILE EXAMPLE

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 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 thus causing high blow-by.

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 (Medium Effect)

The piston land edge break on the bottom side of the piston ring groove can significantly affect blow-by(See Figure 7). If the edge break is too large, the gas flow area at the gap will be increased and affect the pressure balance of the ring-pack. Also the piston ring might twist down causing the piston ring to ride on the upper edge of the periphery.

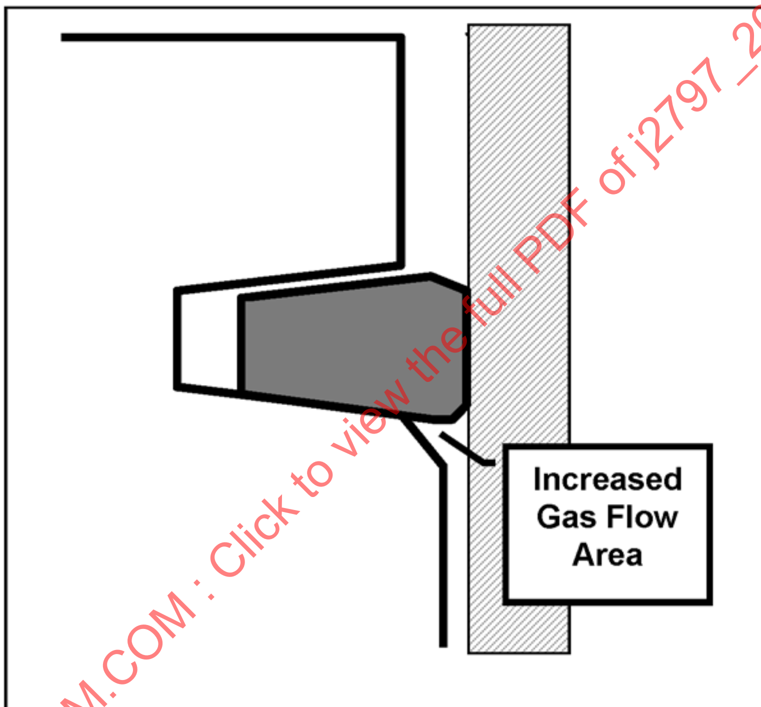


FIGURE 10 - EFFECT OF A LARGE PISTON LAND EDGE BREAK

7.2.7 Accumulator Grooves (Medium 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. Gases can then accumulate in this region rather than migrate upward to the top piston ring and/or cause the top ring to unseat. A large second land volume may decrease the second land pressure, enhancing the seating of the top piston ring helping to prevent the top ring to unseat. Typically, it will also reduce blow-by.

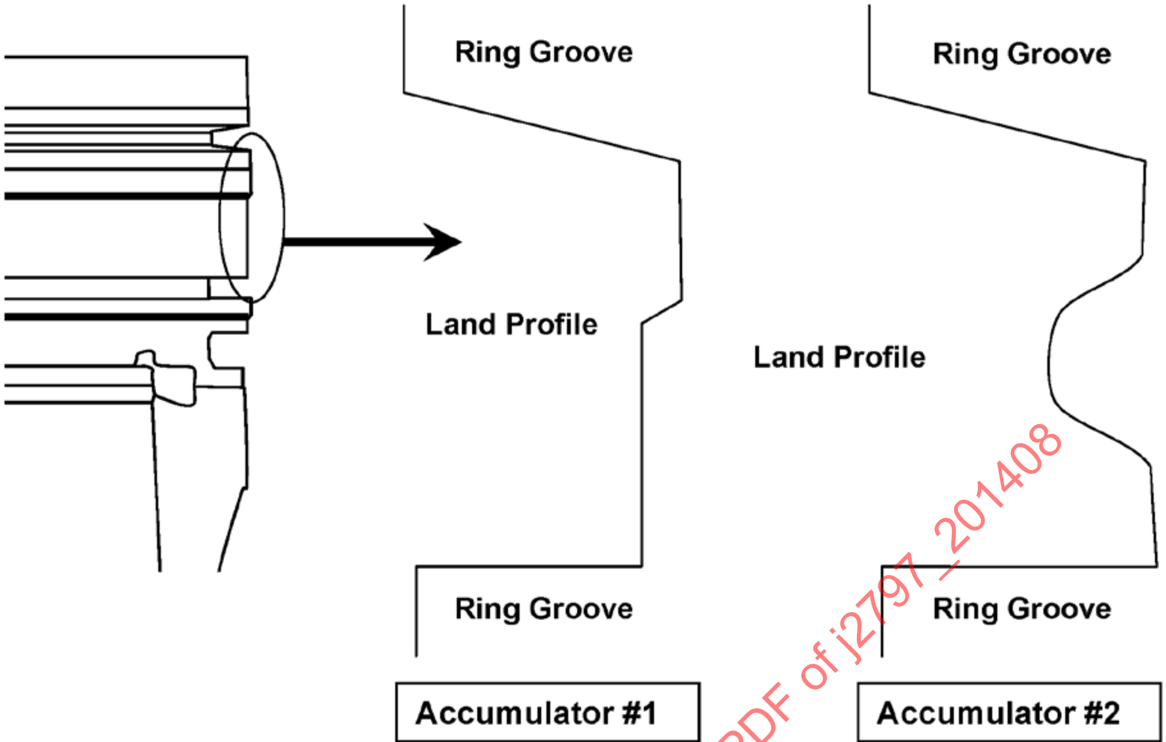


FIGURE 11 - PISTON LAND ACCUMULATOR GROOVES

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.

7.3 Oil Drain Features (Minor Effect)

Oil drain features on the piston may cause an increase in blow-by. Oil Drain features include oil drain holes, oil drain slots, and trans-slots.

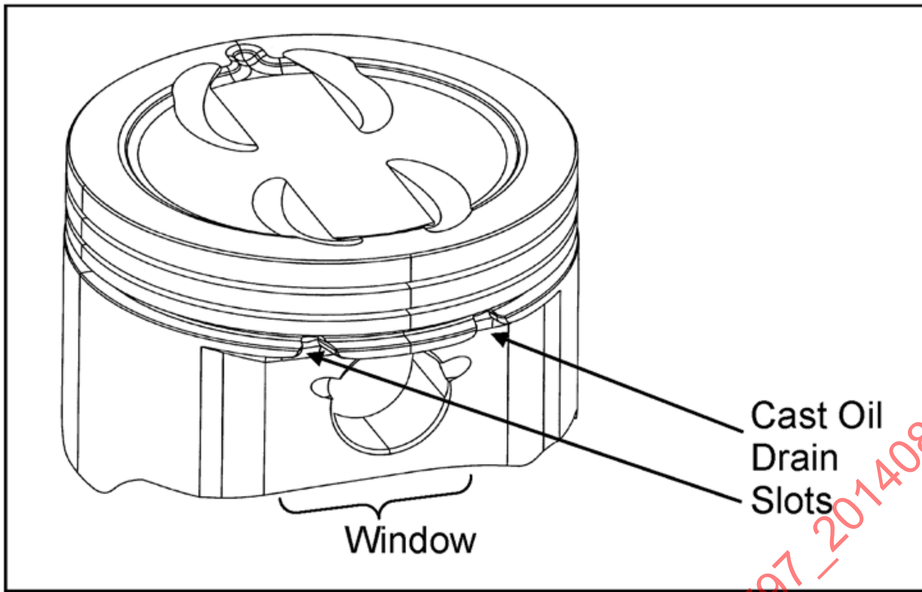


FIGURE 12 - PISTON OIL DRAIN SLOTS

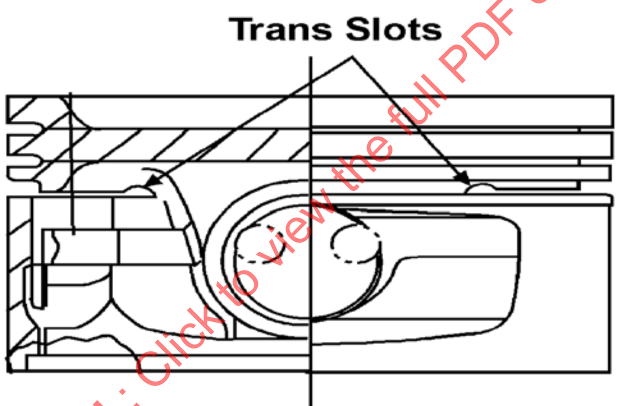


FIGURE 13 - PISTON OIL DRAIN TRANS SLOTS

7.4 Piston Skirt

7.4.1 Piston Guidance or Piston Secondary Motion (Minor Effect)

The skirt will guide the piston in the bore. The stability of the piston and the resultant blow-by 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.

7.4.1.1 Piston Pin Offsets (Minor Effect)

A piston pin offset can significantly affect how the piston moves within the cylinder bore.

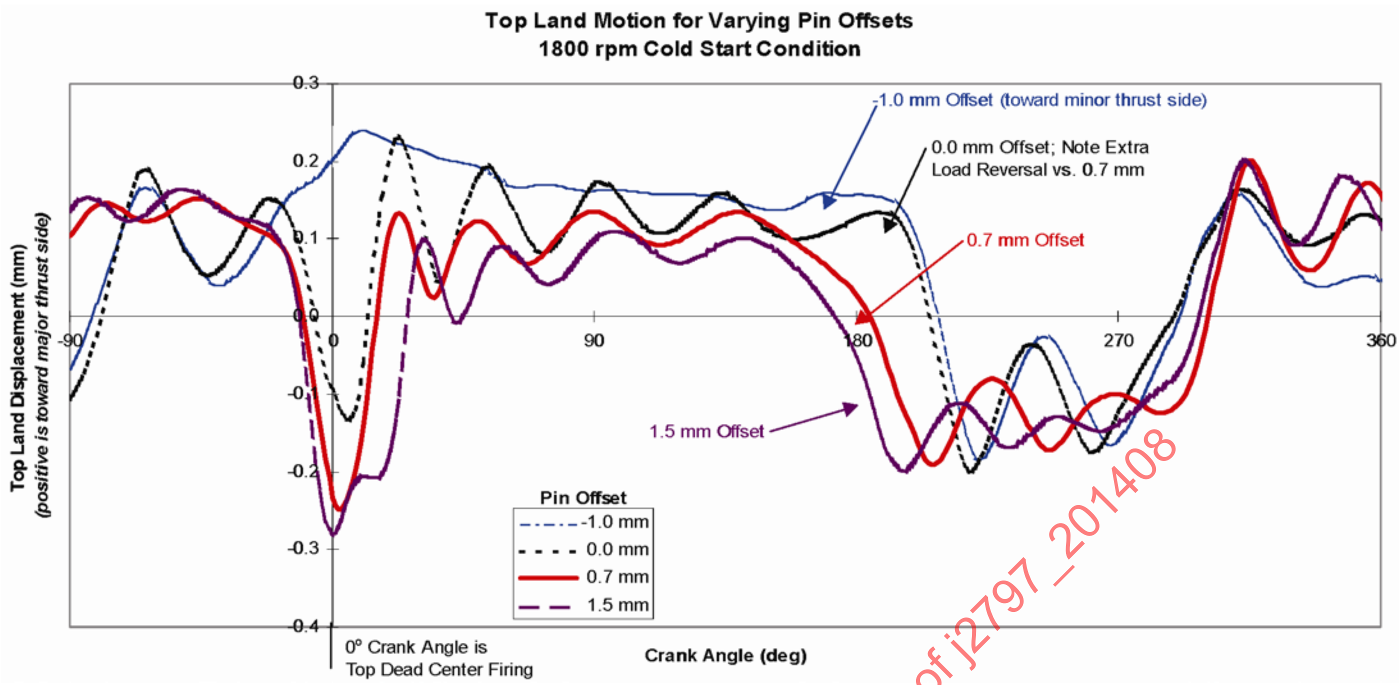


FIGURE 14 - EXAMPLE OF THE EFFECT OF PISTON PIN OFFSET ON PISTON MOTION

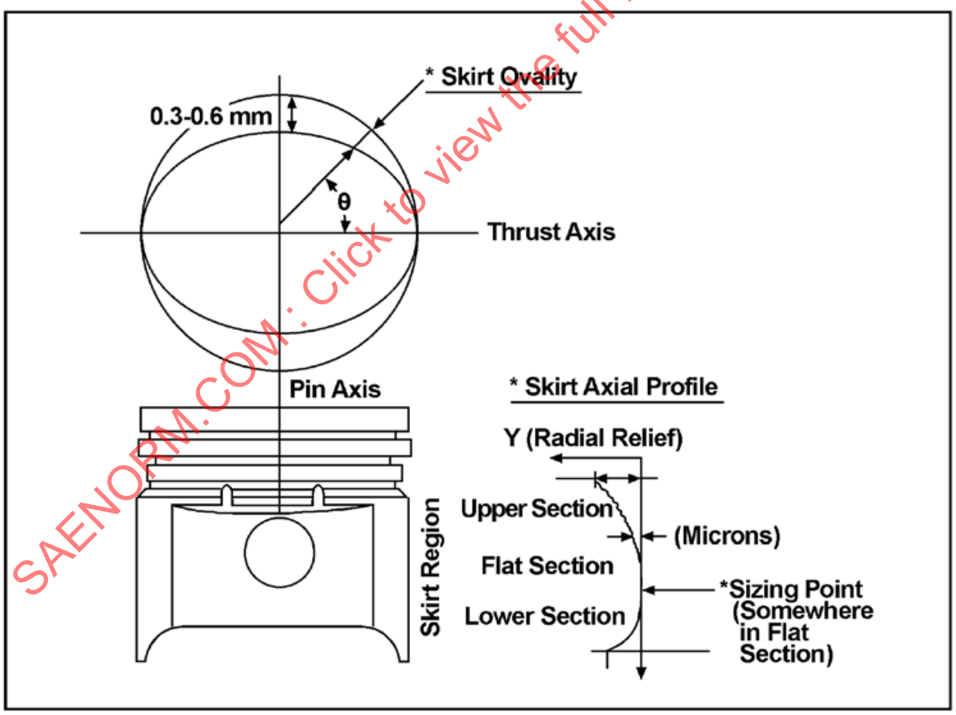


FIGURE 15 - PISTON PROFILES

7.4.1.2 Skirt Axial Profile (Barrel) (Minor Effect)

The axial profile of the skirt is designed to create good hydrodynamic lubrication with the bore to minimize contact wear while providing guidance for the piston to minimize secondary motion.

The piston will typically be designed with an axial profile so that the diameter is larger in the lower regions of the skirt than at the top. This is done primarily to allow thermal expansion.

Theoretically, if the skirt profile provides inadequate piston guidance, piston ring sealing can be adversely affected and increase blow-by. Therefore, the profile needs to be designed for good piston stability

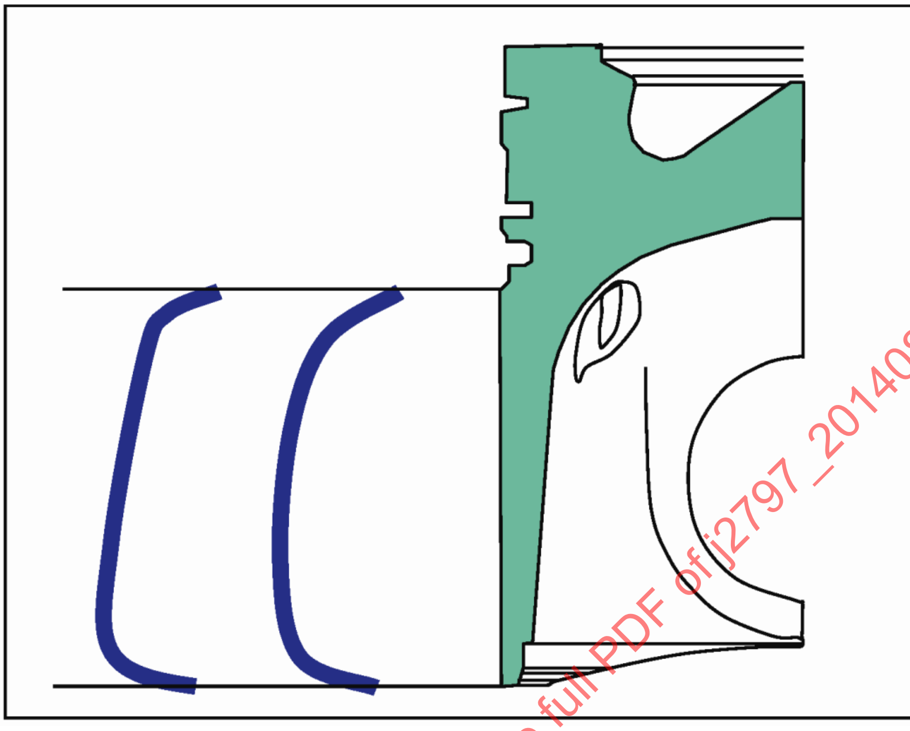


FIGURE 16 - PISTON SKIRT AXIAL PROFILES

7.5 Piston Cooling (Minor Effect)

7.5.1 Piston Cooling (Minor Effect)

The piston may have a cooling spray under the crown of the piston or from the connecting rod. It also may have a cooling gallery. The way a piston is cooled will have a significant effect on the piston temperatures and as a result may have an effect on blow-by.

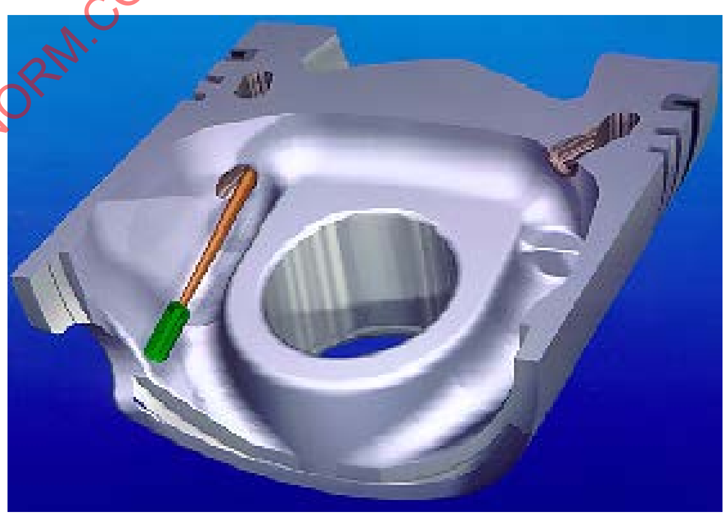


FIGURE 17 - GALLERY COOLED PISTON

7.6 Piston Temperatures (Minor Effect)

Blow-by can be affected by piston temperatures in the following ways.

7.6.1 Piston Thermal Distribution

The piston thermal distribution should be addressed as a system to reduce incidences and effects of incorrect clearances, excessive wear or friction, carbon build up, and piston ring performance.

7.6.2 Carbon Build Up

Carbon can build up on the piston lands. This can cause polishing of the bore surface if the carbon bridges between the piston and bore. Excessive polishing will affect the piston ring periphery sealing and possibly blow-by.

Buildup of carbon in the piston ring grooves can cause the piston rings to stick in the grooves resulting in oil transport around the piston rings into the combustion chamber or combustion gas pressure transport into the engine crankcase further contributing to blow by.

7.6.3 Thermal Expansion

Piston ring end gap and piston to bore clearance are temperature dependent. Better control of piston temperature permits the use of smaller clearances, resulting in lower blow-by.

8. PISTON RING EFFECTS ON BLOW-BY

8.1 General Piston Rings

8.1.1 Conformability (Major Effect)

The conformability of a piston ring (compression or oil ring) can have a significant effect on blow-by. The piston ring must create a seal with both the cylinder wall and the piston ring groove. In the engine the cylinder walls will not be perfectly cylindrical because of machining imperfections, thermal distortion, and mechanical distortion. The piston grooves and also the piston ring itself will not be perfectly flat. Conformability is the ability of the piston ring to conform to distortions between itself and the mating surfaces.

8.1.1.1 Elastic Circumferential Conformability (Major Effect)

Conformability of the piston ring to the cylinder wall will be strongly influenced by the radial wall thickness of the piston ring and its circumferential shape. The circumferential conformability due to the elastic tension of the piston ring may be estimated by determining the elastic conformability factor of the piston ring:

$$k = \frac{F_t d_1^2}{4EI} \quad \text{(Eq. 1)}$$

Where:

k = Elastic Conformability Factor

F_t = Tangential Tension

d_1 = Bore Diameter

E = Young's Modulus

I = Moment of Inertia of the Cross-section

The higher the Elastic Conformability Factor (*k*), the greater ability of the piston ring to conform to the distortions of the cylinder wall. The oil ring is typically designed with the most conformability so that it can effectively scrape oil off the cylinder walls. Compression rings need to seal the combustion gases primarily and also provide oil sealing.

8.1.1.2 Conformability to the Groove (Major Effect)

The conformability of the piston ring to the piston ring groove will be strongly affected by the axial width of the piston ring. A thinner piston ring will be able to conform better to the circumferential distortions of a piston ring groove when pressure is acting axially on the piston ring. . Too narrow an axial piston ring width could initiate undesirable distortion and flutter interrupting piston ring sealing to the piston ring groove further contributing to oil consumption.

8.1.1.3 Conformability to Axial Distortion in the Cylinder Wall (Minor Effect)

The piston rings must also conform to the axial distortions of the cylinder wall. If there is an axial “bump” in the cylinder, the piston ring must travel over the “bump” and maintain contact at all times. If the piston ring is moving too fast and the tension of the piston ring is not sufficient then the piston ring might not be able to react and it could create a “jumping” effect of the piston ring. This may cause a temporary loss of sealing to the piston ring periphery.

8.1.2 Surface Conditions (Major Effect)

The surface conditions of both the side face and periphery of the piston ring can significantly affect how well the piston ring will seal. Surface finishes that are too rough may result in high oil consumption especially on the sides of the piston rings. Sometimes a rough periphery is chosen for oil retention to improve scuff resistance. Unusual waviness or bumps may also cause the piston ring to lose its sealing ability.

8.2 Compression Rings

8.2.1 Twist (Major Effect)

The twist of the piston ring affects its seating to the groove (Figure 18). A positive twist piston ring will promote back edge contact on the bottom side and is very effective at sealing gases. A negative twist piston ring will promote a front edge contact on the bottom side. This enhances the flow around the back of the piston ring and will reduce the axial force created by the gas pressure. This, in turn, will generally increase blow-by.

The seating of the piston ring caused by the twist will have a major effect on blow-by. The negative twist second ring will have a tendency to flutter since the gas pressure force is reduced. This flutter will cause high blow-by, but conversely can lower oil consumption. Oil consumption is reduced since the downward flow is enhanced with the increased blow-by.

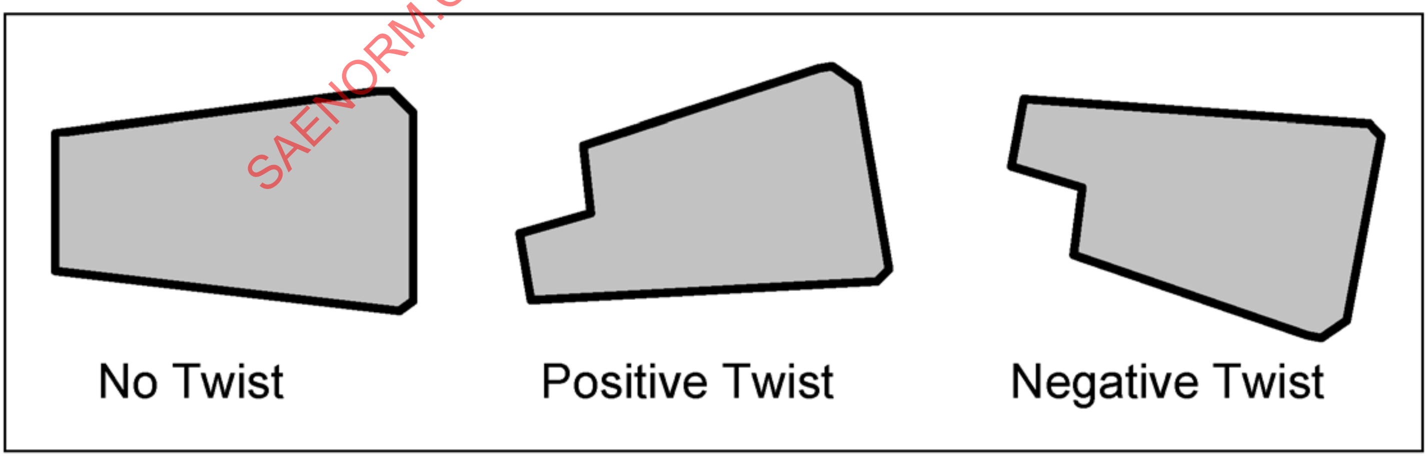


FIGURE 18 - PISTON RING TWIST TERMINOLOGY

8.2.2 Closed Gap (Major Effect)

The closed gap of the piston ring form the main orifices through which the gases flow through the ring pack. This flow can be both up (reverse blow-by) and down (blow-by) depending on the relative pressures above and below the piston ring. As a result this will significantly affect the blow-by.

8.2.3 Gap Ratios (Major Effect)

The ratio of the second ring gas flow area (including end gap) to the top ring gas flow area (including end gap) can significantly affect the performance and stability of the ring pack. As a result both blow-by and oil consumption will be affected. A proper balance between the two gaps needs to be determined to balance the effects on both blow-by and oil consumption. In general, the ratio of the second ring end gap to the top ring end gap is often two (2).

In normal operation, combustion pressure during the compression and power strokes will force the piston ring against the bottom side of the piston groove. It should stay there until the piston reaches top dead center during the exhaust stroke, The inertia forces in the piston ring may cause it to lift and plant itself against the top of the piston groove. If pressure builds up between the top and second rings, the piston ring will “float” or rapidly move up and down between the top and bottom of the piston groove. This is known as piston ring flutter. When a piston ring flutters, a large leak path is created around the piston ring whenever one of the side faces are not contacting the piston groove. This will result in very high blow-by but may lower oil consumption.

8.2.4 End Gap Chamfer (Major Effect)

Like the closed gap, the end gap chamfers help to form the orifice through which gases flow. Therefore this can affect the build-up of pressures between the piston rings and thus affect blow-by.

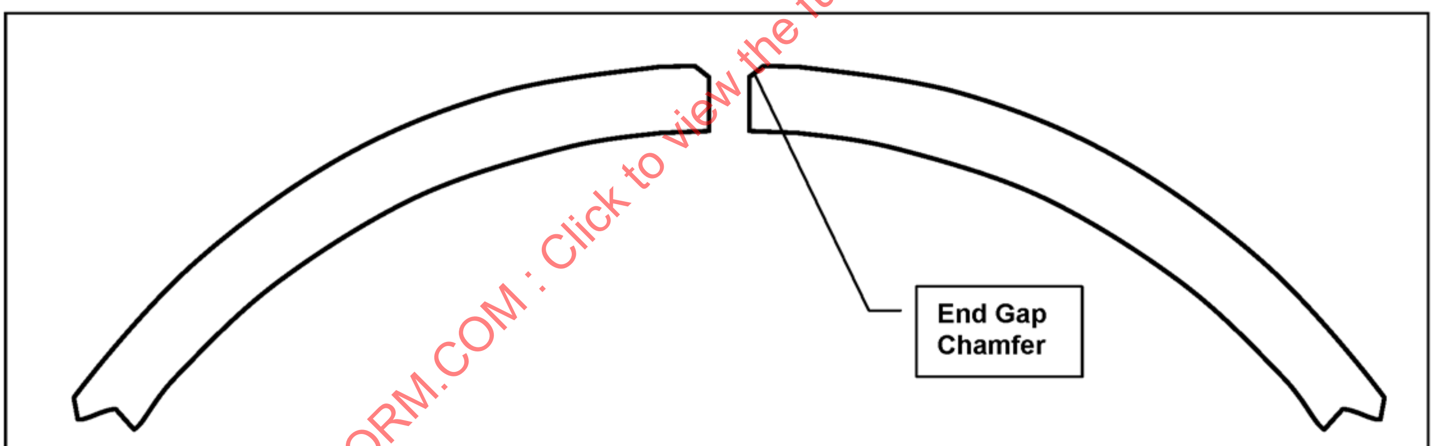


FIGURE 19 - END GAP CHAMFER

8.2.5 Axial Width (Major Effect)

The axial width of the piston ring affects its mass. In high speed engines this becomes a critical factor for top ring stability. In high speed operation, inertial forces may cause the top ring to lift early in the cycle. This will cause the top ring to flutter and will result in very high blow-by. Automotive engines which have high speeds and low cylinder pressures are more susceptible to this problem than diesel engines.

Reduced axial width will increase axial conformability. Higher axial conformability will improve the piston ring seal with the piston groove and reduce blow-by.

8.2.6 Ring Mass (Major Effect)

The mass of the rings is significant for the inertial forces acting on the rings. The mass of the rings will determine if the rings lift and flutter which can significantly affect blow-by and oil consumption. This effect is more significant with high speed engines.

8.2.7 Waviness (Chatter) (Major Effect)

Circumferential side face waviness affects how the piston ring seals with the piston ring groove. Excessive waviness 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. Waviness may be caused by chatter distortion of the piston during the machining operation of the grooves. Chatter is caused by vibration or stick-slip during machining.

Rings too thin can induce a waviness effect in piston ring sealing by piston ring deformation through excessive piston ring motion, high tangential load, and deformation.

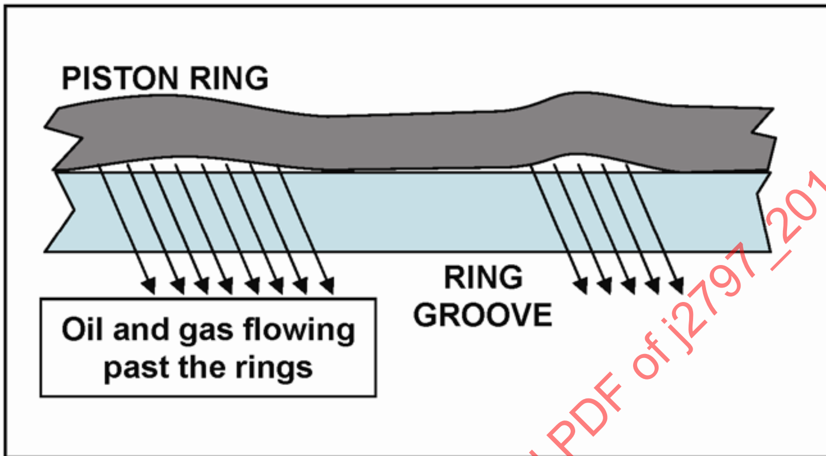


FIGURE 20 - WAVY PISTON RING EXAMPLE

8.2.8 Straightness (Medium Effect)

If the bottom side is not straight, oil and gas leakage flow paths may be formed.

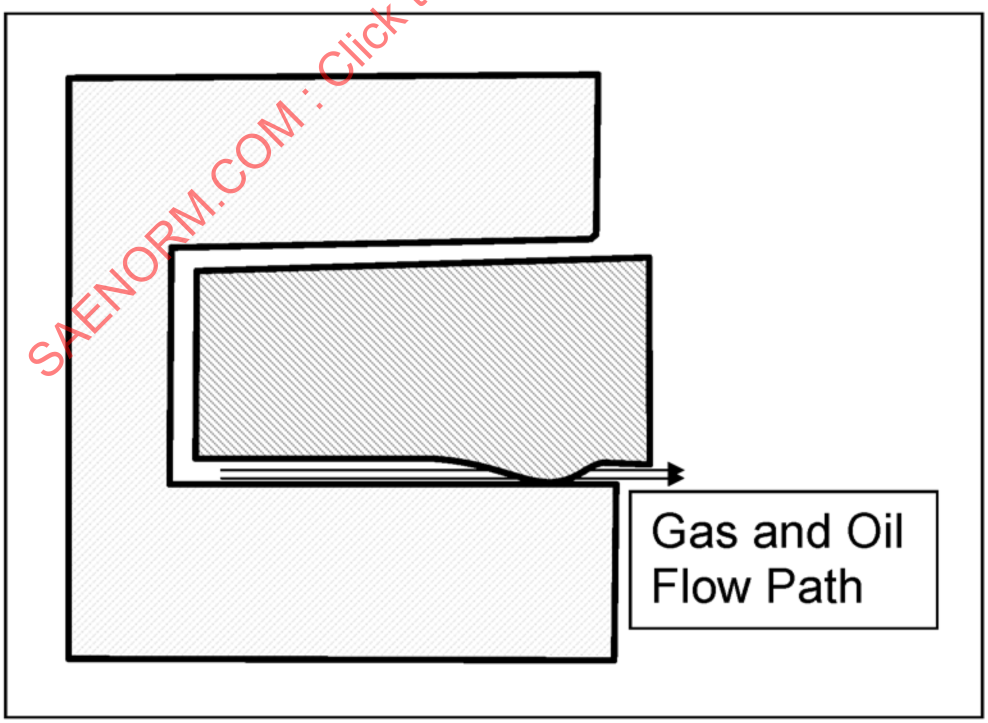


FIGURE 21 - PISTON RING STRAIGHTNESS EXAMPLE

8.2.9 Roughness (Medium Effect)

If the surface roughness or waviness is excessive, the piston ring will not seat properly with the piston groove. This will create passages through which blow-by gases might flow.

8.2.10 Periphery Profile

The profile of the piston ring periphery will determine the oil film that is built up between the piston ring and the liner. Each piston ring will have different profiles for different purposes.

8.2.10.1 Top Ring Periphery Profile (Medium Effect)

The top ring periphery will typically be barrel shaped. The top ring bears the high cylinder pressure and must be designed to develop an adequate oil film to not have excessive wear. A piston ring with a large barrel drop will tend to build larger oil films at mid-stroke but these films will break down easier at the ends of the stroke. Conversely, a piston ring with a small barrel drop will shear and scrape more oil from the cylinder bore at the mid-stroke. There will be thicker oil films at the ends of the stroke because of the squeeze film effect.

An offset barrel towards the bottom side of the piston ring periphery is sometimes used to promote oil scraping downward. Also, the higher barrel drop on the top side will allow high pressures to act on the periphery of the piston ring and counteract some of the net pressure acting on the piston ring. Therefore the wear will be reduced while benefiting blow-by.

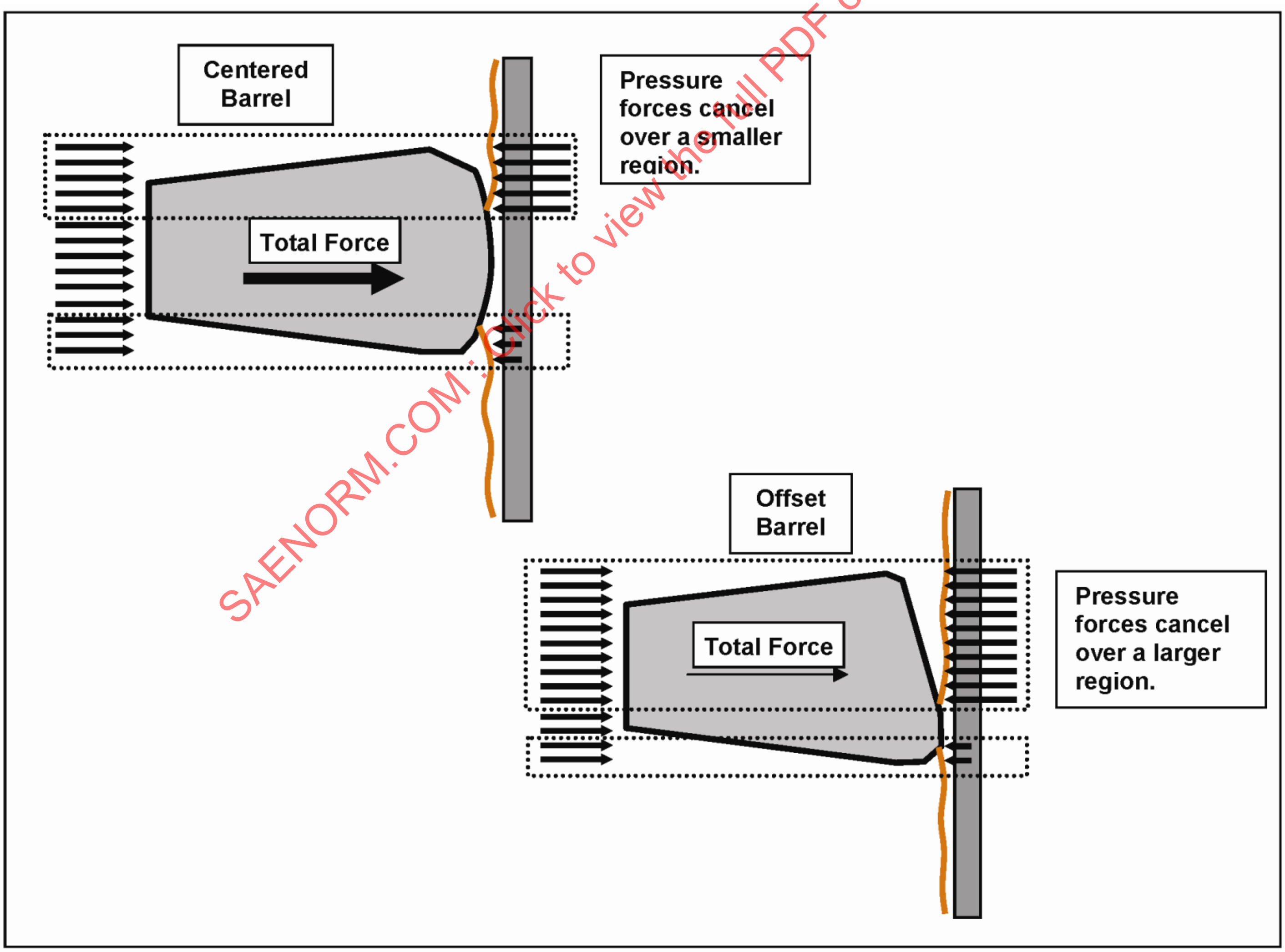


FIGURE 22 - EFFECT OF PERIPHERY PROFILE ON NET FORCE ACTING ON THE PISTON RING

8.2.10.2 Second Ring Periphery Profile (Major Effect)

The second ring is not exposed to the high cylinder pressure so a piston ring with a more aggressive oil scraping role can be used.

A stepped or napier periphery piston ring will have higher blow-by because of the increased circumferential gas flow area between the piston ring and piston ring groove at the piston ring gap. It is possible to use an “interrupted” cut design so that there is no cut-out at the gap. This will maintain low blow-by with the enhanced scraping ability of the piston ring periphery.

Another alternative in the stepped or napier periphery design is to make a very small cut out region. This “micro napier” design will minimize the circumferential gas flow area caused by the cut out.

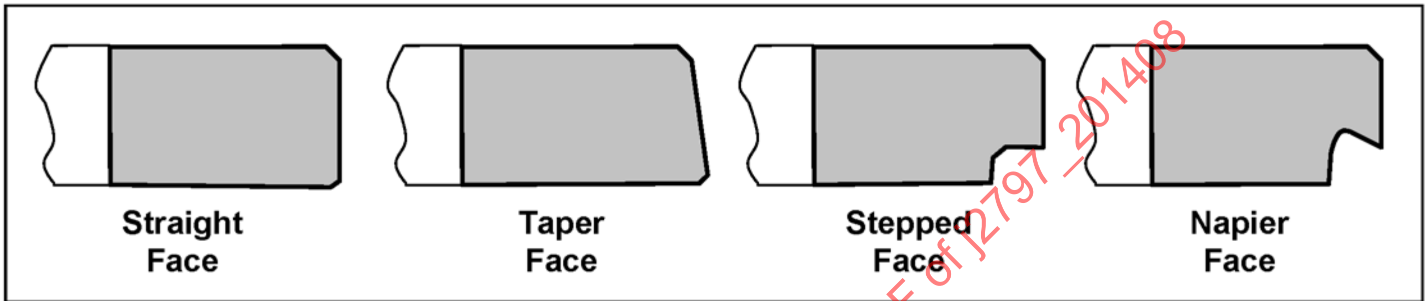


FIGURE 23 - SECOND RING PERIPHERY PROFILES

8.2.11 Material (Medium Effect)

The material or coatings can affect the wear on the sides of the piston ring. High side wear can increase blow-by. Angles (Minor Effect)

8.2.12 Angles (Medium Effect)

Conventional wisdom is that rectangular piston rings are better for blow-by control. However in some cases keystone piston rings are needed to prevent piston ring sticking, especially in diesel engines. Stuck piston rings will not conform to the bore and will allow leak paths for blow-by.

8.2.13 Piston Ring Circumferential Shape (Minor Effect)

Piston rings in the free shape are not round. The circumferential shape is designed to give specific contact pressures around the piston ring periphery. This pressure pattern will affect how a piston ring will seal the gases that might pass by it.

In some cases at room temperature, piston rings are designed with very low contact pressure near the end gaps. This is done so that at operating temperatures, there is uniform contact during operation.

Very simply, it is thought that the pressure exerted by piston ring on the cylinder should be constant around the piston ring periphery during operation. However, some suppliers will design the piston rings with a region of higher pressure in the region of 30° on either side of the end gap to promote “piston ring stability” and better blow-by control.

An example of the calculated circumferential pressure pattern can be seen in Figure 24.

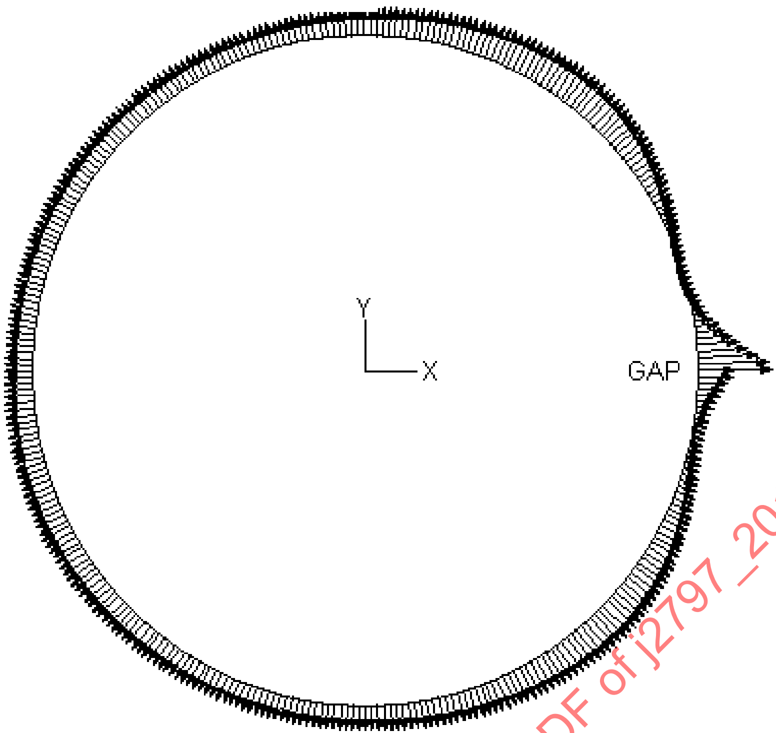


FIGURE 24 - EXAMPLE OF CALCULATED PISTON RING PRESSURE PATTERN

8.2.14 Tension (Minor Effect)

The tension of the piston ring is the force required to close a piston ring down to the bore diameter or gage diameter for the engine (See Figure 25). This represents the force exerted on the cylinder bore. The piston ring tension affects the friction on the periphery and as a result can affect its motion. The friction forces caused by tension of a compression ring are fairly small. However anything that can affect piston ring motion may also affect blow-by.

With some engine configurations, When the tension is not high enough, the piston ring might radially collapse inward. This will result in a loss of sealing on the piston ring periphery.

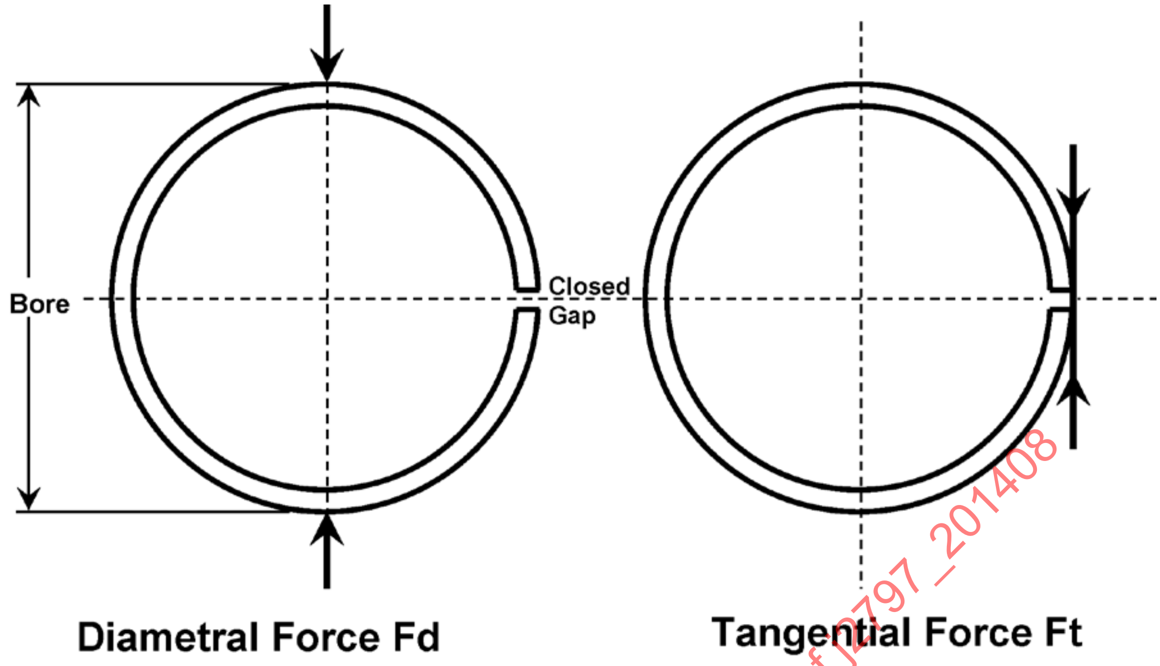


FIGURE 25 - ILLUSTRATION OF PISTON RING TENSION MEASUREMENTS

8.2.15 OD Chamfers (Minor Effect)

The bottom outside diameter chamfer on the piston ring periphery also affects blow-by. It is important that the chamfer be kept as small as possible.

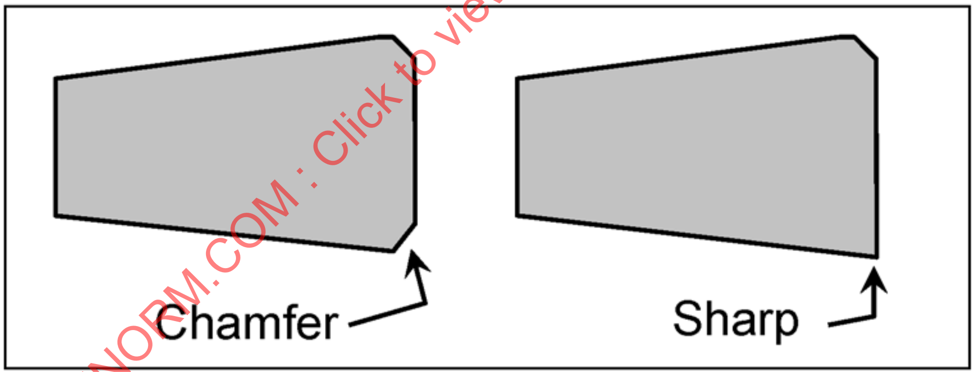


FIGURE 26 - SCHEMATICS OF BOTTOM SIDE OD CHAMFERS

Figure 27 shows different types of piston ring coatings. Typically, it is possible to get a sharper bottom outside diameter chamfer on piston rings with the semi-inlaid or inlaid coatings. The "inlaid" processing easily accommodates the sharp bottom corner because the bottom edge is the base iron material. If a coating is on the lower edge, a larger chamfer is typically required to aide in manufacturing and to prevent the coating from chipping.

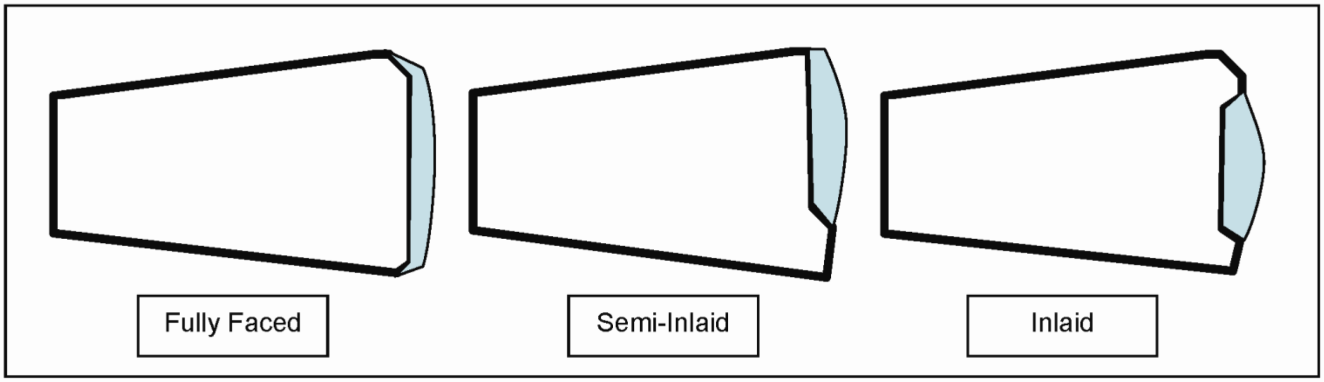


FIGURE 27 - PISTON RING COATING APPLICATION EXAMPLES

8.2.16 System Effects

The interaction of the piston 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 system.

8.3 Piston Ring Materials

8.3.1 Base Material (Medium Effect)

The piston ring base material properties will affect side wear. Excessive side wear can result in high blow-by and breakage.

8.3.2 Periphery Coating Material (Medium Effect)

The piston ring periphery material and its compatibility with the cylinder bore material will affect wear of the periphery and the cylinder bore. This could have a significant effect on how the piston rings operate and affect blow-by. A good wear couple needs to be chosen to prevent excessive wear and a corresponding increase in blow-by.

8.4 Oil Control Ring

8.4.1 General Oil Ring (Minor Effect)

The oil ring typically does not have a major effect on blow-by. However, there are characteristics that can affect blow-by.

8.4.1.1 End Gap Width (Minor Effect)

The end gap of the oil ring might affect blow-by. This effect might be more significant with three piece oil rings that have positive side sealing than two piece oil rings. This is because a piston ring with positive side sealing will better block gas flow around the piston ring sides. The flow of gases will be mainly controlled through the end gap..

8.4.1.2 Interactions with the Piston Ring Groove (Minor Effect)

The interface between the piston ring groove and the oil ring can affect how the blow-by gases flow around the piston ring. A wavy groove or wavy piston ring side will not seal gases effectively allowing oil to flow around the sides of the piston ring and increase blow-by. This effect is more pronounced with a three piece oil ring that has positive side sealing.

8.4.2 Two Piece Oil Ring

A two piece oil control ring is typically used by diesel engines and in some gasoline engines. The two pieces consist of the body and the spring expander. Friction and inertia will tend to drive the two piece oil control ring to the top side of the piston ring groove around top dead center firing. Gas pressures will force the oil ring downward. This results in a fluttering type of motion in which there is very little gas sealing. Therefore the effect of the two piece oil ring is very small on blow-by.

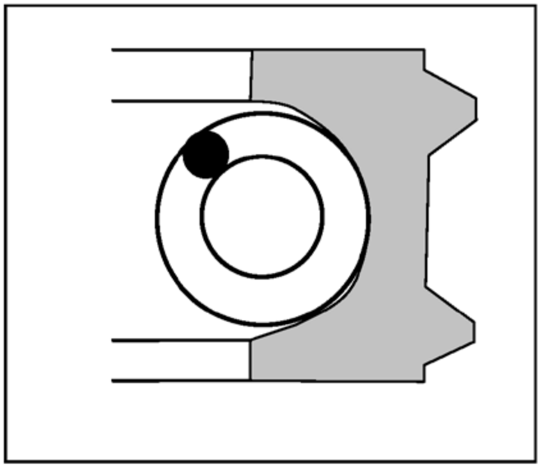


FIGURE 28 - TWO PIECE OIL RING

8.4.3 Three Piece Oil Ring

The three pieces consists of two rails and an expander spring. The expander spring has the effect of not only pushing the two rails radially against the cylinder wall but may also push axially against the piston ring groove depending on the lug design. This has the advantage of sealing both sides of the piston ring actively to the groove as well as the cylinder wall. When a three piece oil ring has active or positive side sealing, the oil ring has a larger effect on blow-by than the two piece oil ring. The amount of positive contact pressure between the sides of oil ring and the groove is dependent on the expander lug angle.

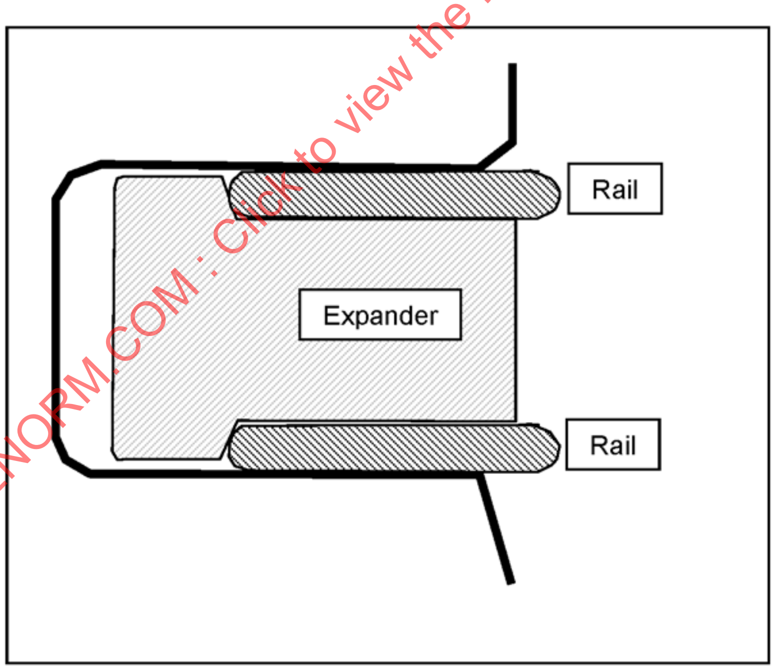


FIGURE 29 - THREE PIECE OIL RING

8.4.3.1 Rail and the Oil Drain Slot (Major Effect)

It is possible for the gap ends of the oil ring rail to get caught in the oil drain slot of the piston groove. This may result in high blow-by and should be avoided in the design.

8.4.3.2 Spacer Design - Lug Angle (Major Effect)

The three piece oil ring may be constructed in a way that allows the rails to exert axial force directly on the sides of the piston groove. The groove must be designed to be compatible with this design. The expander lug angle determines the amount of force that the rails apply to the sides of the oil groove. The force will affect how the oil ring seals the flow of gases around the sides of the rails and will thus affect blow-by.

8.4.3.3 Gap Alignment of the Rails (Minor Effect)

If the gaps of the two rails on a three piece oil ring are aligned, it will create a direct flow path for gases and result in high blow-by. Therefore when assembled the gaps should not be aligned with each other. Typically they are installed 180 deg apart (or greater than 30 degrees apart).

8.4.3.4 Engine Speed

The three piece oil ring may perform better than a two piece oil ring under high speed operation or high vacuum conditions. The high inertial forces might induce instabilities in the two piece design. Because of the positive side forces on the three piece oil ring, it will be more stable.

8.5 Piston Ring Alignment

8.5.1 Ring gap rotation and alignment functions to either block or facilitate flow or transport of fluids in the power cylinder.