



SURFACE VEHICLE INFORMATION REPORT

J2797™

FEB2022

Issued 2007-02
Revised 2022-02

Superseding J2797 AUG2014

Power Cylinder Blow-by: Blow-by Mechanisms

RATIONALE

This Five-Year Review and update include additional detail and clarifications on fundamental mechanisms of blow-by. Some of the updates are:

- Addition of Breathers that can affect blow-by. Removal of Oil Jets, Piston Pins, and Connecting Rods causing high blow-by
- Addition of Concentricity of the piston features that can cause blow-by
- Removed piston guidance and the associated figures as a cause of blow-by
- Removed Skirt Axial Profile and the associated figures as a cause of blow-by
- Added Microwelding as a factor that can cause high blow-by
- Updated the information regarding piston ring conformability
- Removed the effects of Oil Viscosity causing blow-by
- Removed Torque procedure and Improper O-rings affecting blow-by
- Added "Other Publications" in Section 2 with references to key technical publications on ring conformability

TABLE OF CONTENTS

1.	SCOPE.....	5
1.1	Purpose	5
2.	REFERENCES	5
2.1	Applicable Documents	5
2.1.1	SAE Publications	5
2.1.2	ISO Publications	6
2.2	Other Publications.....	6
3.	DEFINITIONS	6
4.	BASICS OF MECHANISMS OF BLOW-BY	6

SAE Executive Standards Committee Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2022 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
http://www.sae.org

SAE WEB ADDRESS:

Full document details: SAE J2797_202202

For more information on this standard, visit
https://www.sae.org/standards/content/J2797_202202/

Documents

Document Sharing Hub

5.	POWER CYLINDER COMPONENT - EFFECTS ON BLOW-BY	7
5.1	Piston and Piston Ring Pack	9
5.2	Piston	9
5.3	Top Piston Ring	9
5.4	Second Piston Ring.....	9
5.5	Oil Piston Ring	9
5.6	Cylinder Bore	9
6.	OTHER EFFECTS ON BLOW-BY	9
7.	PISTON EFFECTS ON BLOW-BY	10
7.1	Piston Ring Grooves	10
7.1.1	Groove Type (Medium Effect).....	10
7.1.2	Waviness and Flatness (Major Effect)	10
7.1.3	Surface Conditions (Major Effect).....	10
7.1.4	Tilt (Medium Effect).....	11
7.1.5	Concentricity (Minor Effect)	12
7.1.6	System Effects (Major Effect)	12
7.1.7	Piston Ring Groove Material (Minor Effect).....	12
7.2	Piston Lands	12
7.2.1	Diameters (Major Effect)	12
7.2.2	Piston Land Lengths (Medium Effect).....	12
7.2.3	Piston Land Profiles (Major Effect)	13
7.2.4	Piston Land Circumferential Profiles (Minor Effect).....	13
7.2.5	Piston Land Pressurization (Major Effect).....	14
7.2.6	Chamfers (Major Effect for the Top Groove Bottom Side, Medium Effect for Other Groove Chamfers)....	14
7.2.7	Accumulator Grooves (Medium Effect)	14
7.3	Oil Drain Features (Minor Effect).....	15
7.4	Piston Skirt	16
7.4.1	Piston Guidance or Piston Secondary Motion (Minor Effect)	16
7.5	Piston Cooling (Minor Effect).....	16
7.5.1	Piston Cooling (Minor Effect).....	16
7.6	Piston Temperatures (Minor Effect).....	16
7.6.1	Piston Thermal Distribution	17
7.6.2	Carbon Build Up.....	17
7.6.3	Microwelding	17
7.6.4	Thermal Expansion	17
8.	PISTON RING EFFECTS ON BLOW-BY.....	17
8.1	General Piston Rings	17
8.1.1	Conformability (Major Effect)	17
8.1.2	Surface Conditions (Major Effect).....	18
8.2	Piston Compression Rings	18
8.2.1	Twist (Major Effect).....	18
8.2.2	Closed Gap (Major Effect).....	19
8.2.3	Gap Ratios (Major Effect).....	19
8.2.4	Top Ring End Gap Chamfer or Rounding (Major Effect)	19
8.2.5	Piston Ring Axial Width (Major Effect)	20
8.2.6	Ring Mass (Major Effect).....	20
8.2.7	Waviness (Chatter) (Major Effect).....	20
8.2.8	Straightness (Medium Effect)	21
8.2.9	Roughness (Medium Effect)	21
8.2.10	Periphery Profile	21
8.2.11	Material (Medium Effect)	23
8.2.12	Piston Ring Side Configuration (Medium Effect)	23
8.2.13	Piston Ring Circumferential Shape (Minor Effect)	23
8.2.14	Tension (Minor Effect).....	24
8.2.15	OD Chamfers (Minor Effect).....	25
8.2.16	System Effects	25
8.3	Piston Ring Materials	26

8.3.1	Base Material (Medium Effect)	26
8.3.2	Periphery Coating Material (Medium Effect)	26
8.4	Oil Control Ring.....	26
8.4.1	General Oil Ring (Minor Effect).....	26
8.4.2	Two Piece Oil Ring.....	26
8.4.3	Three Piece Oil Ring.....	27
8.5	Piston Ring Alignment.....	28
9.	CYLINDER BORE EFFECT ON BLOW-BY	28
9.1	Bore Distortion (Major Effect)	28
9.2	Surface Condition (Medium Effect).....	29
9.3	Cylinder Bore Surface Finish (Minor Effect).....	29
9.4	Honing Angle (Minor Effect)	30
9.5	Material (Minor Effect).....	30
10.	SYSTEM EFFECTS ON BLOW-BY	30
10.1	Piston Ring Seating (Major Effect).....	30
10.2	Inter-Ring Gas Pressure and Piston Ring Dynamics (Major Effect)	31
10.3	Piston Ring/Groove Side Clearance (Medium Effect).....	31
10.4	Piston Ring/Groove Back Clearance (Medium Effect).....	32
10.4.1	Oil Volume Behind the Rings.....	32
10.4.2	Interference.....	32
10.4.3	Energizing the Piston Ring	32
10.5	Interactions with Oil Consumption	32
11.	ENGINE OPERATION	32
11.1	Engine Speed	32
11.2	Engine Load.....	32
11.3	Engine Maintenance	32
12.	QUALITY ISSUES	32
12.1	Potential Cylinder Bore Quality Issues.....	32
12.2	Potential Piston Quality Issues	33
12.3	Potential Piston Ring Quality Issues	33
12.4	Potential Assembly Issues.....	33
12.4.1	Incorrect Piston Ring in the Piston Groove	33
12.4.2	Missing Piston Rings.....	33
12.4.3	Broken Piston Rings.....	33
12.4.4	Chipped Piston Ring Periphery Coatings	33
12.4.5	Lack of Proper Lubrication During Installation.....	33
12.4.6	Excessive Core Sands from the Block or Head Casting.....	33
13.	OTHER CAUSES.....	34
13.1	Scuffing	34
13.2	Piston Ring Sticking	34
14.	HIGH MILEAGE EFFECTS	34
14.1	Critical Wear Couples	34
14.1.1	Carbon Causing Piston Ring Groove Sticking.....	34
15.	NOTES	34
15.1	Revision Indicator	34
Figure 1	Flow of oil and gases past a piston ring	7
Figure 2	Power cylinder	8
Figure 3	Piston ring pack - orifice/volume model	8
Figure 4	Types of rings and grooves	10
Figure 5	Piston groove waviness.....	10
Figure 6	Groove uptilt	10
Figure 7	Piston land diameters.....	12

Figure 8	Piston land profiles.....	13
Figure 9	Piston land and skirt profile example	13
Figure 10	Effect of a large piston land edge break.....	14
Figure 11	Piston land accumulator grooves.....	15
Figure 12	Piston oil drain slots	15
Figure 13	Piston oil drain trans slots	16
Figure 14	Gallery cooled piston.....	16
Figure 15	Piston ring twist terminology	19
Figure 16	End gap chamfer.....	20
Figure 17	Wavy piston ring example	20
Figure 18	Piston ring straightness example	21
Figure 19	Effect of periphery profile on net force acting on the piston ring	22
Figure 20	Second ring periphery profiles	23
Figure 21	Piston Ring Side Configurations	23
Figure 22	Example of calculated piston ring pressure pattern.....	24
Figure 23	Illustration of piston ring tension measurements	25
Figure 24	Schematics of bottom side OD chamfers.....	25
Figure 25	Piston ring coating application examples	26
Figure 26	Two piece oil ring	27
Figure 27	Three piece oil ring.....	27
Figure 28	Example of ring end gaps not aligned.....	28
Figure 29	Example of ring end gaps aligned.....	28
Figure 30	Examples of the effects of bore distortion	29
Figure 31	Different order bore distortions	29
Figure 32	Seating forces on the piston ring when $P_1 > P_2$ (P_1 = pressure above the piston ring, P_2 = pressure below the piston ring)	30
Figure 33	Examples of inter-ring gas pressure and piston ring motion	31

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
- Breather systems (PCV, CCV, breather tubes)

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 +1 724-776-4970 (outside USA), 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

2.2 Other Publications

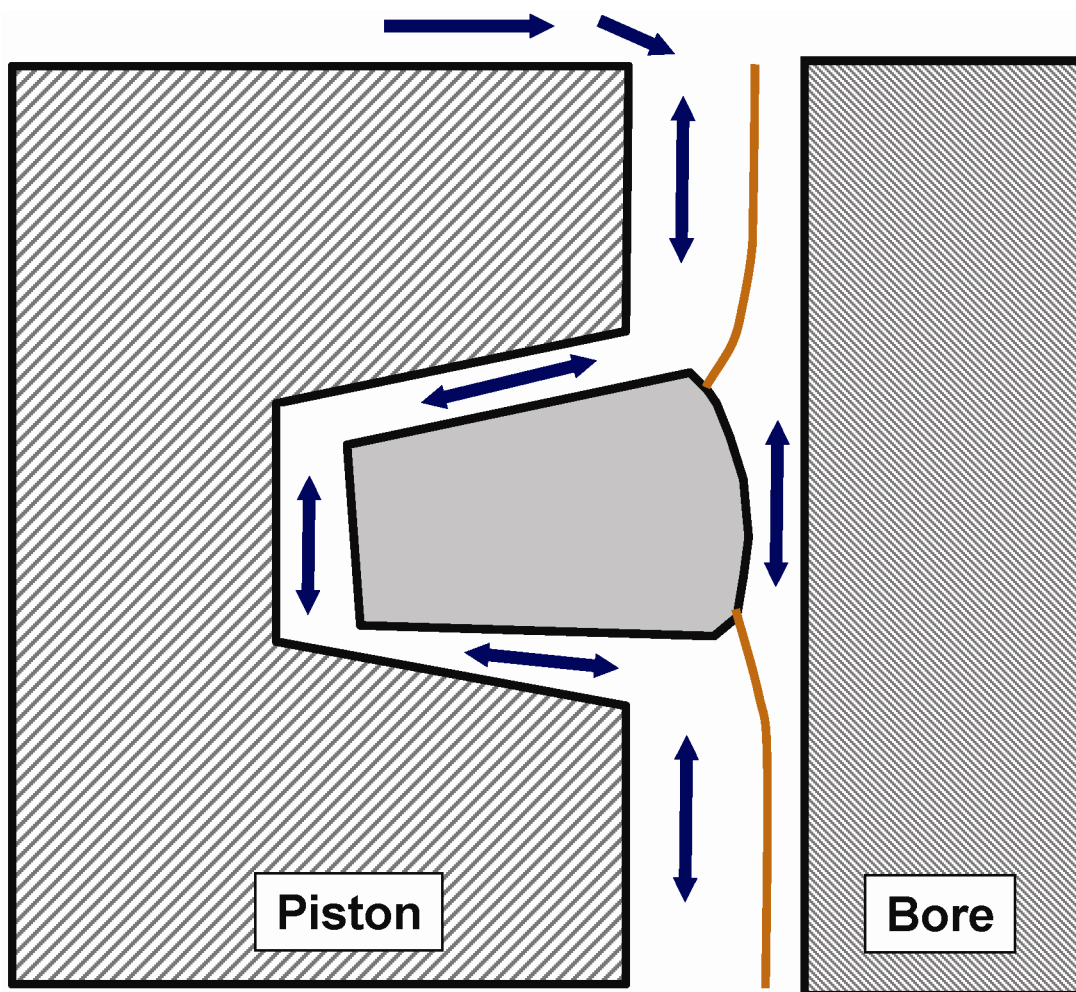
1. Englisch, C., Kolbenringe (Piston rings, Vol. 1, Theory, Production and Design), Springer-Verlag, Viena, 1958.
2. Dunaevsky, V. et al. "Analysis of Elastic Distortions of a Piston Ring in the Reciprocating Air Brake Compressor Due to the Installation Stresses," SAE Paper 1999-01-3770.
3. Dunaevsky, V., and Rudzit, J. "Clarification of a Semi-Empirical Approach in Piston Ring-Cylinder Bore Conformability Prediction," Journal of Tribology, April 2007, pp. 430-435.
4. Dunaevsky, V., Ariga, S., and Takiguchi, M. "A Study on Oil film Thickness for Reduction of Oil Consumption in a Reciprocating Air brake compressor," ImechE Conference Transactions 2001-7, London, pp. 423-431.

3. DEFINITIONS

Refer to SAE J2612 for the piston nomenclature.

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 blow-by.



(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
- Oil

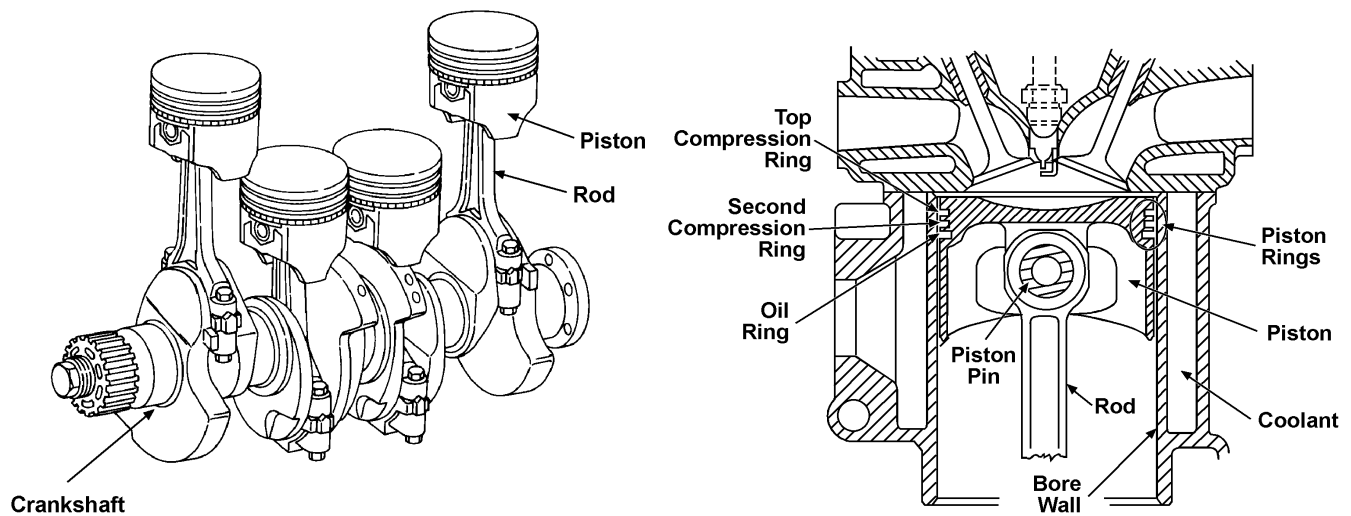


Figure 2 - Power cylinder

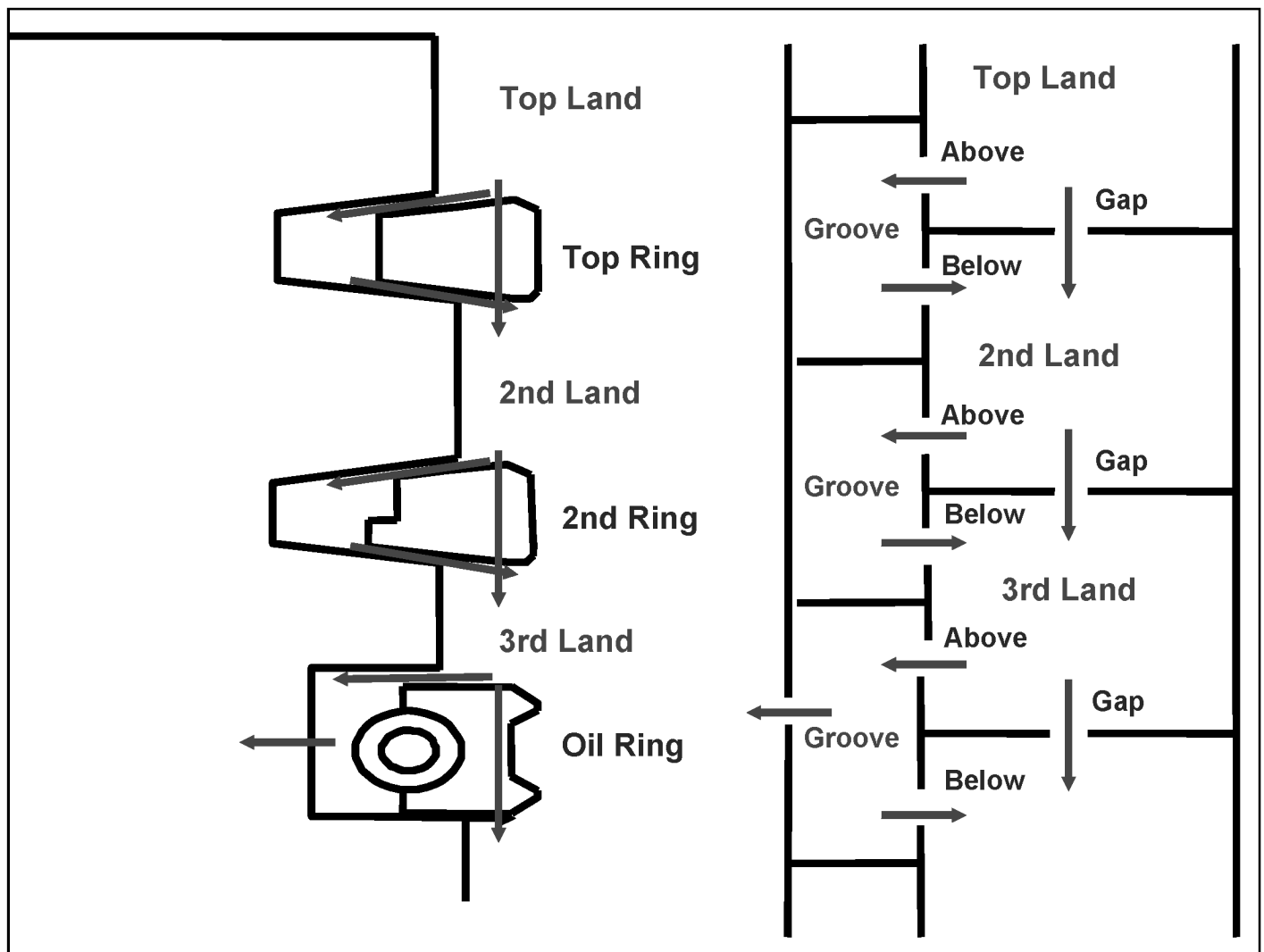


Figure 3 - Piston ring pack - orifice/volume model

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 and the cylinder bore, must provide a seal to control 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 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. Combustion gasses passing this piston 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 Piston Ring

The primary function of the second piston ring is to scrape the excess oil off the bore surface that passes by the oil piston ring. However, the second piston ring also 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 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 piston ring to affect 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 may need to be isolated in order to optimize or determine the blow-by contribution by the power cylinder system.

- Turbocharger
- Supercharger
- Breather systems (PCV, CCV, breather tubes)
- 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 piston ring grooves are better for oil and blow-by control. However, in some cases, keystone piston ring grooves are needed to prevent ring sticking, especially in diesel engines. If piston rings stick, they will lose their sealing capability.

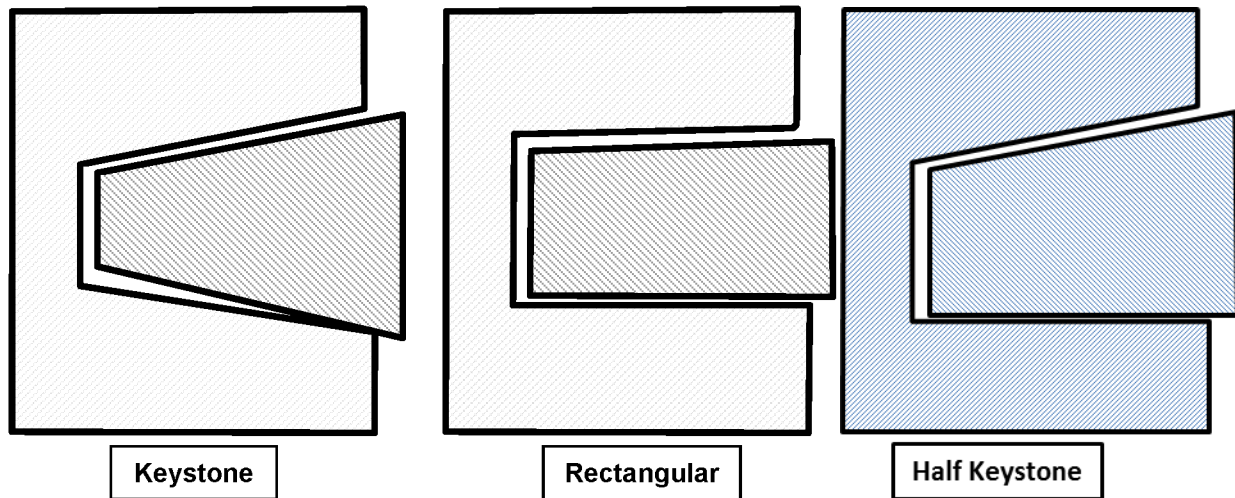


Figure 4 - Types of rings and grooves

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 gases to pass by the piston ring. The circumferential length and the height of a wavy portion determine whether there is a leak path.

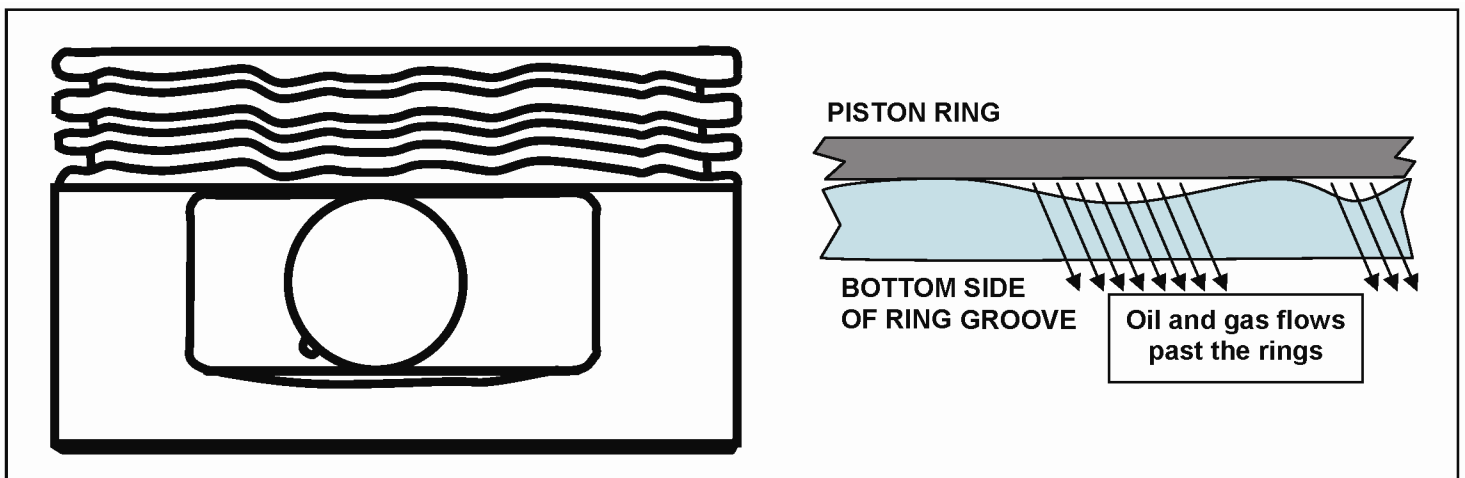


Figure 5 - Piston groove waviness

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 (Medium Effect)

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

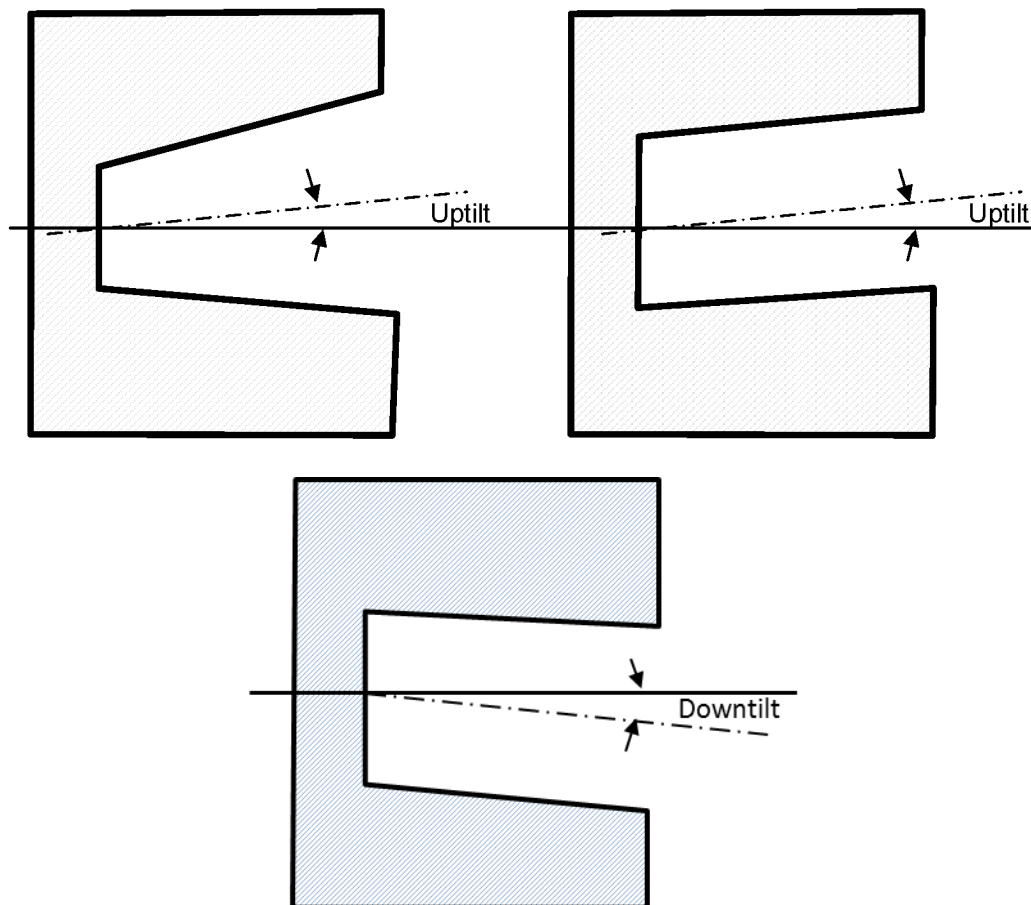


Figure 6 - Groove uptilt

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.

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.