



# SURFACE VEHICLE TECHNICAL INFORMATION REPORT

J3070™

AUG2020

Issued

2020-08

## Power Cylinder Scuffing: 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 occur. This document gives basic background information that will help give engineers working with power cylinders the knowledge that they need to help them be more effective.

### TABLE OF CONTENTS

|       |                                                                            |   |
|-------|----------------------------------------------------------------------------|---|
| 1.    | SCOPE.....                                                                 | 3 |
| 1.1   | Purpose.....                                                               | 3 |
| 2.    | REFERENCES.....                                                            | 3 |
| 2.1   | Related Publications .....                                                 | 3 |
| 3.    | DEFINITION.....                                                            | 3 |
| 4.    | TYPICAL POWER CYLINDER SCUFF POINTS.....                                   | 3 |
| 4.1   | Scuffing Between the Piston and the Cylinder Bore .....                    | 4 |
| 4.2   | Scuffing Between the Piston and Piston Pin.....                            | 4 |
| 4.3   | Scuffing Between the Piston and Piston Ring (Microwelding) .....           | 5 |
| 4.4   | Scuffing Between the Piston Ring and Cylinder Bore.....                    | 5 |
| 4.5   | Scuffing Between the Piston Pin and Connecting Rod Bore .....              | 5 |
| 5.    | CAUSES AND REMEDIES FOR SCUFFING BETWEEN THE PISTON AND CYLINDER BORE..... | 5 |
| 5.1   | Excessive Local Contact Pressure .....                                     | 5 |
| 5.1.1 | Improper Piston to Bore Fit .....                                          | 5 |
| 5.1.2 | Improper Piston Profile.....                                               | 6 |
| 5.1.3 | Bore Geometry Issues .....                                                 | 7 |
| 5.2   | Excessive Thermal Loading.....                                             | 7 |
| 5.2.1 | Overheat Condition .....                                                   | 7 |
| 5.2.2 | Abnormal Combustion (Knock, Detonation, Preignition) .....                 | 7 |
| 5.2.3 | Excessive Blow-By.....                                                     | 8 |
| 5.3   | Inadequate Lubrication.....                                                | 8 |
| 5.3.1 | Lubricant Contamination .....                                              | 8 |
| 5.3.2 | Lubricant Starvation .....                                                 | 8 |

SAE Technical Standards Board 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 © 2020 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 J3070\_202008

For more information on this standard, visit  
[https://www.sae.org/standards/content/J3070\\_202008](https://www.sae.org/standards/content/J3070_202008)

Documents

Document Sharing Hub

|          |                                                                                          |    |
|----------|------------------------------------------------------------------------------------------|----|
| 6.       | CAUSES AND REMEDIES FOR SCUFFING BETWEEN THE PISTON AND PIN .....                        | 9  |
| 6.1      | Excessive Temperature .....                                                              | 9  |
| 6.2      | Excessive Unit Loading .....                                                             | 9  |
| 6.2.1    | Pin Deflections .....                                                                    | 9  |
| 6.2.2    | Piston Pin and Pin Bore Form and Finish .....                                            | 9  |
| 6.2.3    | Pin and Pin Bore Materials and Surface Coatings .....                                    | 9  |
| 6.3      | Inadequate Lubrication .....                                                             | 10 |
| 6.3.1    | Piston to Piston Pin Fit .....                                                           | 10 |
| 6.3.2    | Lubrication Access Features .....                                                        | 10 |
| 7.       | CAUSES AND REMEDIES FOR SCUFFING BETWEEN THE PISTON AND RING<br>(MICROWELDING) .....     | 10 |
| 7.1      | Excessive Unit Loading .....                                                             | 10 |
| 7.2      | Excessive Thermal Loading .....                                                          | 10 |
| 7.3      | Insufficient Lubrication Between the Piston Ring and Piston Ring Groove .....            | 11 |
| 7.4      | Inadequate Hardness of the Piston .....                                                  | 11 |
| 8.       | CAUSES AND REMEDIES FOR SCUFFING BETWEEN THE PISTON RING AND<br>CYLINDER BORE .....      | 11 |
| 8.1      | Excessive Unit Loading .....                                                             | 11 |
| 8.1.1    | Ring Face Form and Finish .....                                                          | 11 |
| 8.1.2    | Insufficient Back Clearance Between the Piston Ring and Ring Groove .....                | 11 |
| 8.1.3    | Ring Tip Loading .....                                                                   | 12 |
| 8.1.4    | Sharp Edges or Asperities on Ring .....                                                  | 12 |
| 8.1.5    | Excessive Ring Tension .....                                                             | 12 |
| 8.1.6    | Improper Cylinder Bore Form or Surface Finish .....                                      | 12 |
| 8.2      | Excessive Thermal Loading .....                                                          | 12 |
| 8.3      | Inadequate Lubrication at the Piston Ring to Cylinder Bore Interface .....               | 12 |
| 8.4      | Material Incompatibility Between the Ring and Cylinder Bore .....                        | 12 |
| 9.       | CAUSES AND REMEDIES FOR SCUFFING BETWEEN THE PISTON PIN AND<br>CONNECTING ROD BORE ..... | 13 |
| 10.      | NOTES .....                                                                              | 13 |
| 10.1     | Revision Indicator .....                                                                 | 13 |
| Figure 1 | Power cylinder .....                                                                     | 4  |

## 1. SCOPE

This document describes the various scuffing failure modes of the power cylinder system in an internal combustion engine. The causes and preventative measures for each failure mode are discussed. It should be noted that many remedies for scuff can lead to NVH (noise vibration and harshness) issues. However, NVH is not considered in this document.

### 1.1 Purpose

The purpose of this document is to familiarize the reader with the basic scuffing mechanisms, along with the general design and development procedures, required to prevent this failure mode.

## 2. REFERENCES

### 2.1 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

Pistons and Engine Testing, by Mahle GmbH, 1st edition, 2012.

From Practice to Practice, by Kolbenschmidt AG.

Cylinder Systems - The Basics, Federal-Mogul.

## 3. DEFINITION

Scuffing in power cylinder components is an extreme case of adhesive wear that occurs between two components that are moving relative to one another. It occurs when the local unit loading between the two surfaces reaches a level that causes the asperities of each surface to break through the lubricant film and make direct contact with one another. The relative motion combined with the direct contact can create enough heat to locally melt one or both of the materials. The melted material is displaced across the surfaces and bonds itself back to the parent material and/or to the material of the other component. Cases of very high unit loading can create scuffing conditions with very little relative motion. The displaced material is destructive to the function of the power cylinder system. Extreme cases of power cylinder scuffing result in catastrophic engine failure.

## 4. TYPICAL POWER CYLINDER SCUFF POINTS

The design of the following power cylinder components can affect the scuffing tendencies of the power cylinder system. These effects will be described in subsequent sections.

Components:

- Piston
- Rings
  - Top compression ring
  - Second compression ring
  - Oil control ring
- Cylinder bore
- Oils

- Oil jets
  - Under-crown spraying
  - Gallery cooling sprays
  - Cylinder wall jet
- Piston pin
- Connecting rod

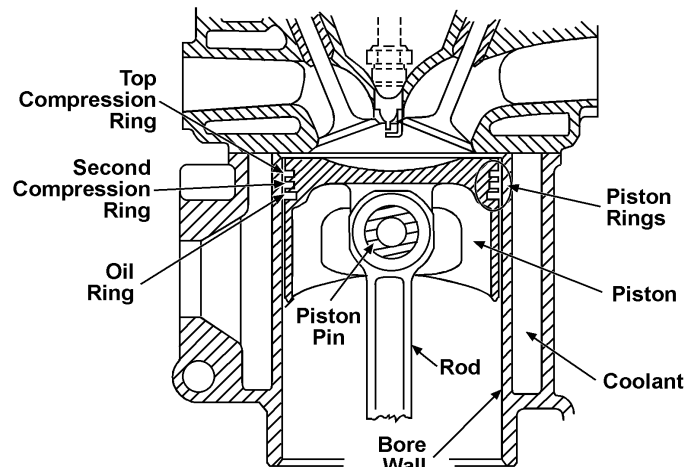


**Figure 1 - Power cylinder**

#### 4.1 Scuffing Between the Piston and the Cylinder Bore

This is a common scuffing failure mode in the power cylinder system. The material properties of aluminum pistons at elevated temperature are significantly lower than other components in the system. Large temperature gradients in the piston result in large thermal distortions. Furthermore, complex mechanical distortion patterns also exist on the piston due to the inherent stiffness variation between the crown and skirt axially, and between the pin boss and skirt circumferentially. These thermal and mechanical distortions can result in high unit pressures at the bearing interface of the skirt if the piston is not designed correctly. High temperatures and unit pressures combined with the high velocity relative to the cylinder bore creates conditions where scuffing can easily occur. For the case of aluminum pistons, large amounts of aluminum can be displaced leaving obvious evidence on the piston and cylinder bore. Steel pistons can also have high unit loading which causes local metal transfer if the skirt shape is not designed correctly by the same process as described for the aluminum piston, but at much higher loads and unit loading due to the properties of the steel compared to aluminum.

#### 4.2 Scuffing Between the Piston and Piston Pin

The unit loading between the piston and piston pin is typically higher than the unit loading between the piston and the cylinder bore. The relative velocities are lower which can reduce the amount of heat build up due to asperity interactions, but it also reduces the tendencies for a hydrodynamic lubrication condition between the piston and piston pin. Piston material is typically transferred to the piston pin when this failure mode occurs. This failure mode should not be confused with the failure mode of "piston pin bore pound out," which is the result of plastic deformation of the pin bore. That failure mode deforms the pin bore geometry without a scuffing mechanism.