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2019-05

Plain bearings — Appearance and characterization of damage to metallic hydrodynamic bearings —

Part 2: Cavitation erosion and its countermeasures

Paliers lisses — Aspect et caractérisation de l'endommagement des paliers métalliques à couche lubrifiante fluide —

Partie 2: Érosion de cavitation et sa contre-mesure

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 123, *Plain bearings*, Subcommittee SC 2, *Materials and lubricants, their properties, characteristics, test methods and testing conditions*.

This second edition cancels and replaces the first edition (ISO 7146-2:2008), of which it constitutes a minor revision. The changes compared to the previous edition are as follows:

— Adjustment to the ISO Directives, including the replacement of "may" with "can" throughout.

A list of all parts in the ISO 7146 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In practice, damage to a bearing can often be the result of several mechanisms operating simultaneously. The damage can result from improper assembly or maintenance or from faulty manufacture of the bearing, its housing or the counterface against which it operates. In some instances, damage can be caused by a design compromise made in the interests of economy or from unforeseen operating conditions. It is the complex combination of design, manufacture, assembly, operation, maintenance and possible reconditioning which often causes difficulty in establishing the primary cause of damage.

In the event of extensive damage or destruction of the bearing, the evidence is likely to be lost, in which case it is impossible to identify how the damage came about.

In all cases, knowledge of the actual operating conditions of the assembly and the maintenance history is of the utmost importance.

The classification of bearing damage established in this document is based primarily upon the features visible on the running surfaces and elsewhere, and consideration of each aspect is needed for reliable determination of the cause of bearing damage.

Since more than one process can cause similar effects on the running surface, a description of appearance alone is occasionally inadequate in determining the cause of damage. In such cases, the operating conditions need to be considered.

Cavitation erosion dealt with in ISO 7146-1 is treated in this document in more detail.

Plain bearings — Appearance and characterization of damage to metallic hydrodynamic bearings —

Part 2: Cavitation erosion and its countermeasures

1 Scope

This document defines, describes and classifies the characteristics of damage occurring in service in hydrodynamically lubricated metallic plain bearings due to cavitation erosion, together with possible countermeasures. It assists in understanding the various characteristic forms of damage which can occur.

Consideration is restricted to damage which has a well-defined appearance and which can be attributed to particular causes with a high degree of certainty. Various appearances are illustrated with photographs and diagrams.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4378-1, *Plain bearings — Terms, definitions, classification and symbols — Part 1: Design, bearing materials and their properties*

ISO 4378-2, *Plain bearings — Terms, definitions, classification and symbols — Part 2: Friction and wear*

ISO 4378-3, *Plain bearings — Terms, definitions, classification and symbols — Part 3: Lubrication*

ISO 7146-1, *Plain bearings — Appearance and characterization of damage to metallic hydrodynamic bearings — Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4378-1, ISO 4378-2, ISO 4378-3, and ISO 7146-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Cavitation erosion

4.1 Mechanism of cavitation erosion

Cavitation erosion is a form of damage to the surface of a solid body in liquid caused by implosion (violent inward collapse) of cavities or vapour bubbles. When the static pressure in the liquid is decreased under the vapour pressure of the liquid at a given temperature, evaporation occurs and bubbles of vapour are generated in the liquid. This phenomenon is called “cavitation”. When these cavities encounter higher pressure, because they have flowed to a place of higher pressure or the pressure at the place of cavitation has increased in the meantime, they condense instantaneously and implode, causing a very high and local pressure and high temperature in the liquid. It can lead, after repeated implosion, to "cavitation erosion" of the surface of the solid body near the place of implosion.

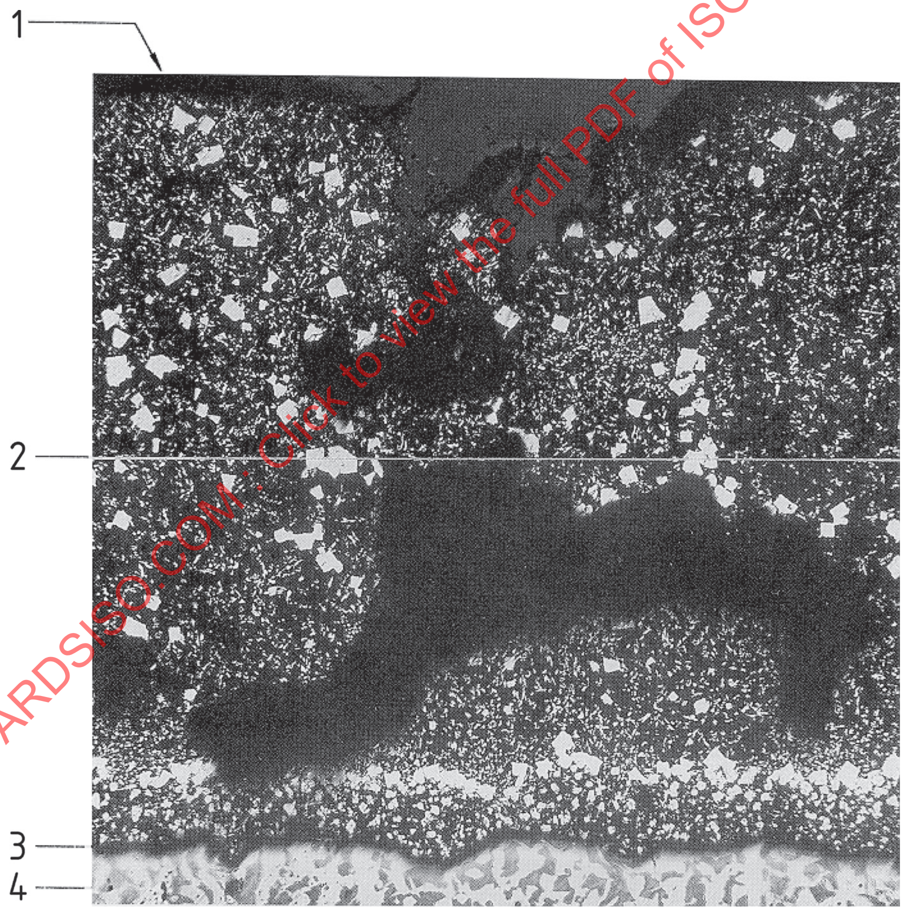
Because of the high intensity of cavity implosion, a chemical reaction called "cavitation corrosion" can take place. The damage can also occur together with "fluid erosion" and "cavitation erosion". A phenomenon known as the "micro-Diesel effect", where the imploding cavities release electrical charge, is also detected in plain bearing oil.

When a bearing surface is eroded by cavitation, the colour of the surface changes slightly due to roughening. Then small pores form, and cracks initiate on the surface, especially at grain boundaries. These cracks with sharp edges are spread first on the surface and then deepen according to the properties of the underlying material (see Figure 1). The cracks are joined together leading to break-out and wash-away of small particles of bearing materials.

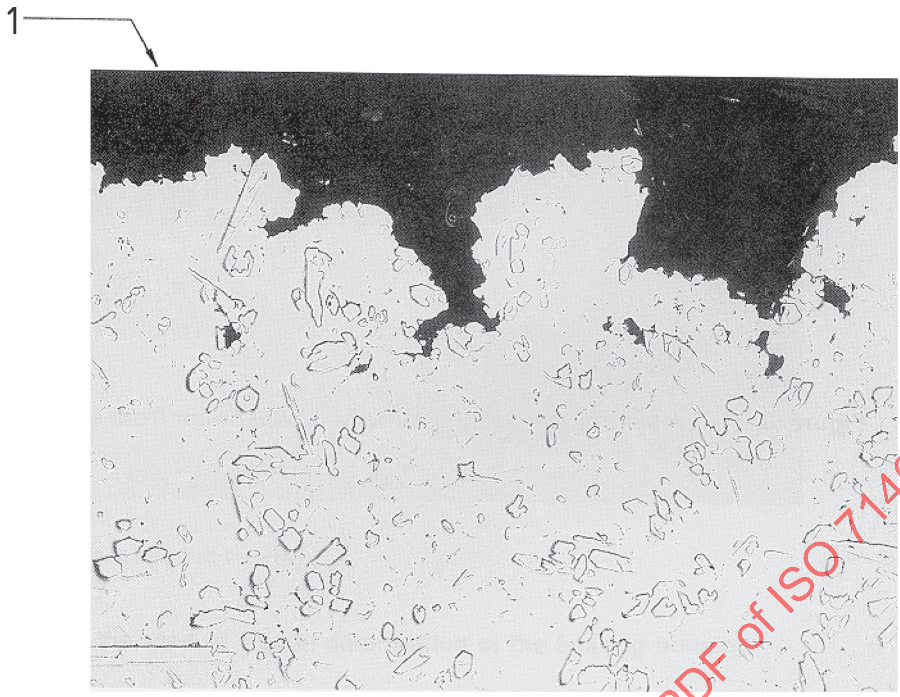
When the damage is caused solely by collapsing cavities, the attacked areas show a rough texture. Metallurgical section often shows signs of local work-hardening and fatigue cracking due to hammer blows caused by cavity collapse. But if particles are trapped in the damage pockets, the surface can be eroded and exhibits a smooth and polished appearance. The place of cavitation erosion is usually limited locally and spreads seldom to a broader region. The cavitation erosion usually appears in the unloaded areas of the bearing.

The occurrence of cavitation erosion depends on many factors as follows: journal speed, specific bearing load, dynamic load pattern (especially time rate of load variation), motion of journal center, bearing vibration, bearing clearance, size and geometry of bearing clearance space, edge form and location of oil hole, groove and pocket, existence and position of the drilling in journal, bearing material, especially its hardness, elastic modulus, toughness, fatigue strength and corrosion resistance, oil supply pressure, oil constituent and its vapor pressure, oil viscosity, oil temperature, air and water content and contamination of oil, etc.

a) View under magnification



b) Cross-section under magnification



c) Cross-section under higher magnification

Key

1 sliding surface

2 bearing metal (tin-based)

3 bonding area

4 steel backing

Figure 1 — Sliding surface with cavitation erosion

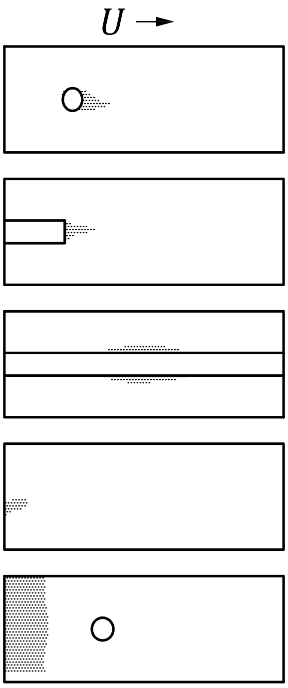
4.2 Classification of cavitation erosion

Though cavitation erosion occurs in plain bearings of various machines, that in bearings of internal combustion engines has been studied most intensively and has attracted increasing attention as engine performance has increased. For engine bearings, cavitation erosion has been classified into types 1 to 4 by the mechanism of cavity creation. However, this classification may also be applied to other kinds of machines, provided that the characteristic flow conditions are similar. Examples of characteristic appearances and mechanisms of four types of cavitation erosion in journal bearings are given in Figures 2 and 3. Besides these four types, there are some kinds of cavitation erosion which are not always easy to identify. These are classified as type 5, miscellaneous. (See Table 1.)

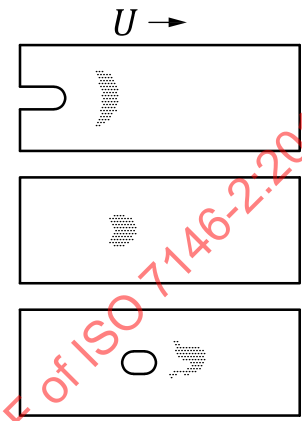
Table 1 — Cavitation erosion classification

Type number	Cavitation erosion classification
1	Flow
2	Impact
3	Suction
4	Discharge
5	Miscellaneous

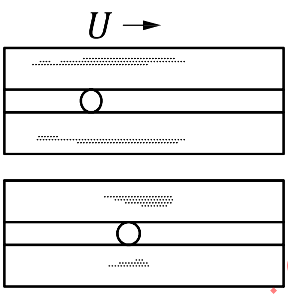
Types 1 and 2 take place under both static and dynamic bearing loads, whereas types 3 and 4 only under dynamic bearing load.



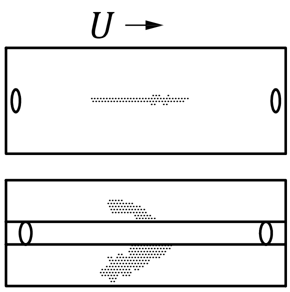
a) Cavitation erosion type 1: flow



b) Cavitation erosion type 2: impact



c) Cavitation erosion type 3: suction

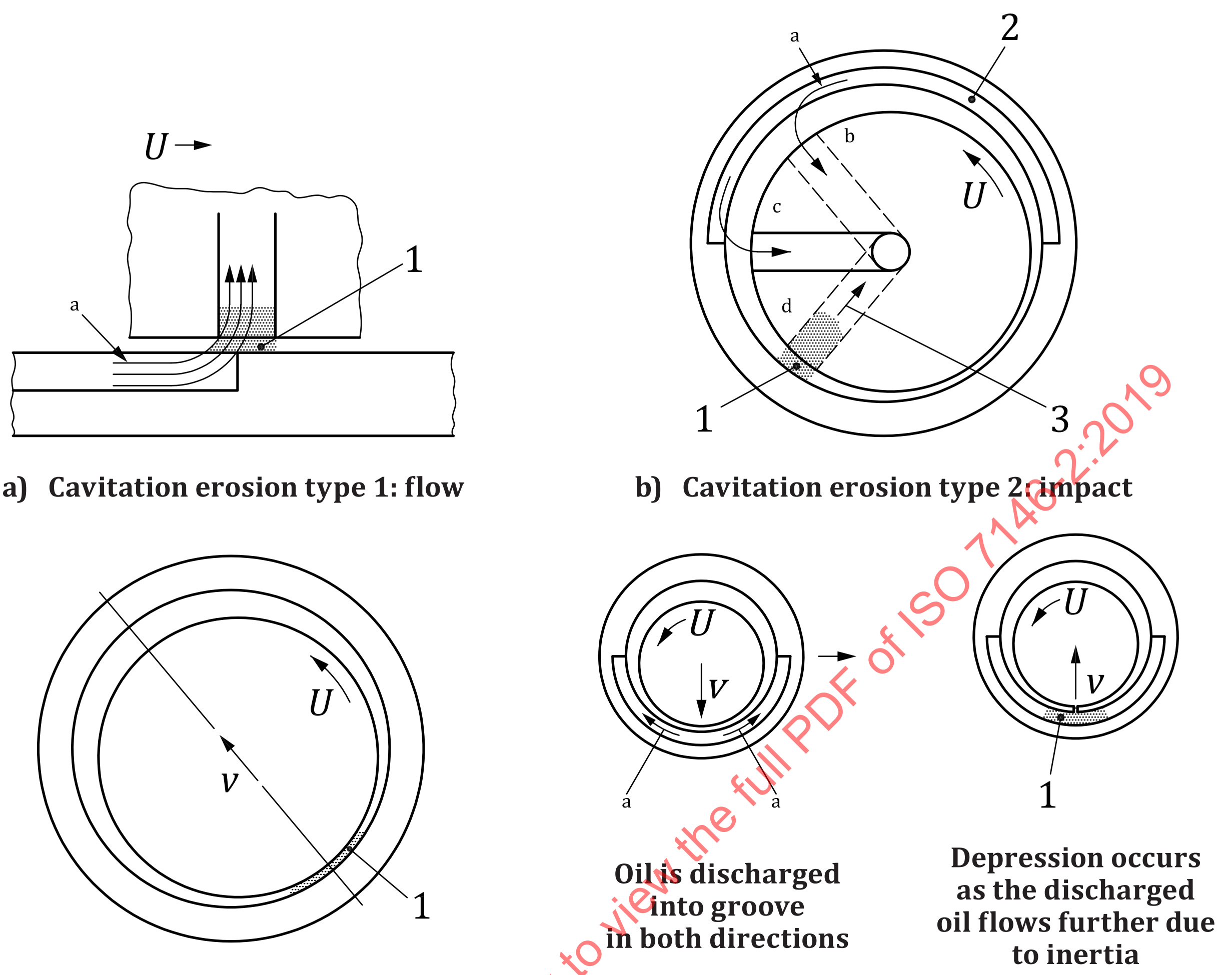


d) Cavitation erosion type 4: discharge

Key

U direction of journal rotation

Figure 2 — Examples of the characteristic appearance of four types of cavitation erosion in journal bearings



a) Cavitation erosion type 1: flow

b) Cavitation erosion type 2: impact

c) Cavitation erosion type 3: suction

d) Cavitation erosion type 4:discharge

Key

1 cavities in oil
2 partial oil groove
3 oil column
U direction of journal rotation
v velocity of journal center

a Oil flow.
b Continuous oil flow.
c Oil flow abruptly stopped.
d Oil inflow stopped, but oil column flows further by inertia, causing depression.

Figure 3 — Mechanisms of four types of cavitation erosion in journal bearings

4.3 General countermeasures against cavitation erosion

4.3.1 As general countermeasures against cavitation erosion, some of the following steps can be recommended, depending on the type or mechanism of cavitation erosion that has taken place.

4.3.2 Modify the oil flow in bearing and passage by:

a) making the oil flow as continuously and smoothly as possible, with minimal interruption;

b) avoiding sharp edges and discontinuous surfaces and providing a larger chamfer or radius at the edge of oil holes, grooves and pockets;

c) avoiding or reducing projection and relief on the bearing surface.

4.3.3 Increase the oil supply pressure.

4.3.4 Reduce the bearing clearance.

4.3.5 Select appropriate bearing material with increased:

a) resistance — tin is more resistant than lead, tin-based alloys are more resistant than lead-based alloys, and aluminium alloy (with less tin content) is more resistant than lead bronze;

b) hardness, toughness and fatigue strength;

c) homogeneity, freedom from slag and soft material, etc.

4.3.6 Make the bearing surface smooth and free of pores and crevices.

4.3.7 Maintain the oil free from water, dust and dirt, which act as nuclei for cavitation.

4.3.8 Minimize oil temperature and/or maximize oil viscosity, which measures are usually favourable to minimizing erosion.

4.3.9 Inclusion of air bubbles in oil reduces cavitation erosion, but this countermeasure is not recommended, as it promotes oil degradation and viscosity reduction.

4.3.10 If steps 4.3.2 to 4.3.9 do not help, relax the operating conditions, by:

a) reducing the journal speed;

b) reducing the specific bearing load;

c) changing the dynamic load pattern;

d) reducing the vibration of bearing housing.

5 Five types of cavitation erosion

5.1 General

For four types of cavitation erosion, typical damage appearance, possible causes, possible countermeasures and typical examples are given in the following (see Figures 2 and 3). General countermeasures are specified in 4.3. This clause gives some possible additional concrete countermeasures. In addition, some examples for miscellaneous cavitation erosion are given.

5.2 Flow cavitation erosion

5.2.1 Typical damage appearance

The bearing surface material has been removed or eroded locally. The depth of damage is often limited to the alloy layer or the overlay. In extreme cases, however, the damage can penetrate deeply into the bearing material. Flow cavitation erosion has been encountered, among other places:

e) at the edge of oil holes (see Figure 4);

f) at the downstream end of partial oil grooves in big-end bearings (see Figure 5);

g) on the side faces and adjacent bearing surface of circumferential oil grooves (see Figure 6);

h) adjacent to the joint face relief of a big-end bearing and a main bearing (see Figures 7 and 8);

i) in deep scores and indentation in bearing surfaces.

5.2.2 Possible causes

When the oil flows over discontinuous surfaces as shown in Figure 3 a) at high speed, it cannot follow the discontinuities smoothly and breaks away from the bearing surface, producing high flow velocity and turbulence and consequently local pressure fluctuation. Therefore, high depression and cavitation occur and erosion follows upon implosion. Flow cavitation erosion is different from fluid erosion, as the latter takes place without cavitation.

5.2.3 Possible countermeasures

Make chamfers smoother, provide a radius on the edges of partial circumferential oil groove ends or reduce joint face relief and the depth of scores on sliding surfaces.

5.2.4 Typical examples (see Figures 4 to 8)

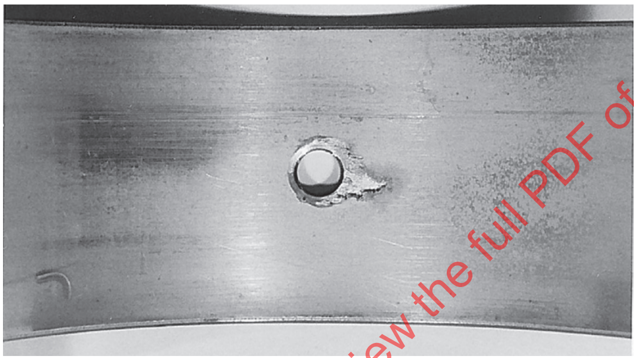


Figure 4 — Flow cavitation erosion at the oil hole of a rod half big-end bearing in a petrol engine (material: steel/Al-Sn)

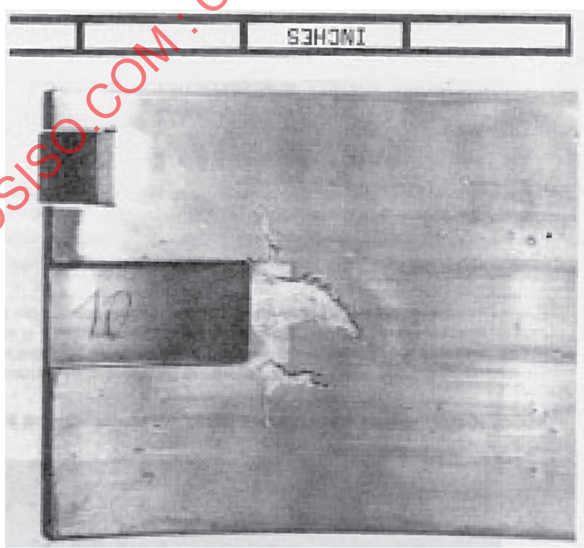


Figure 5 — Flow cavitation erosion at the downstream end of a partial groove in a big-end bearing

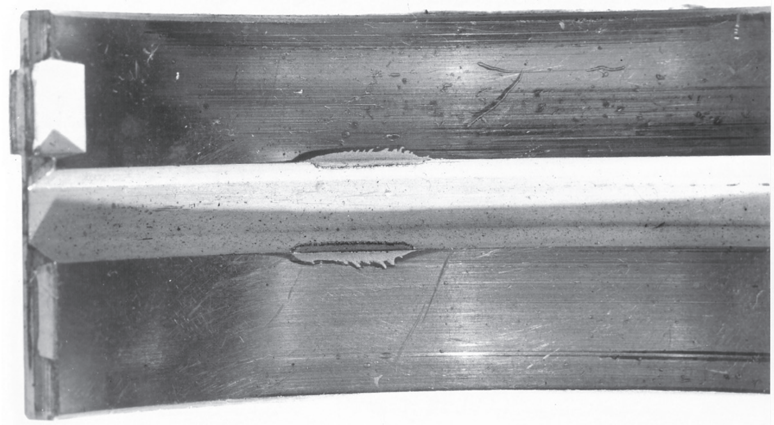
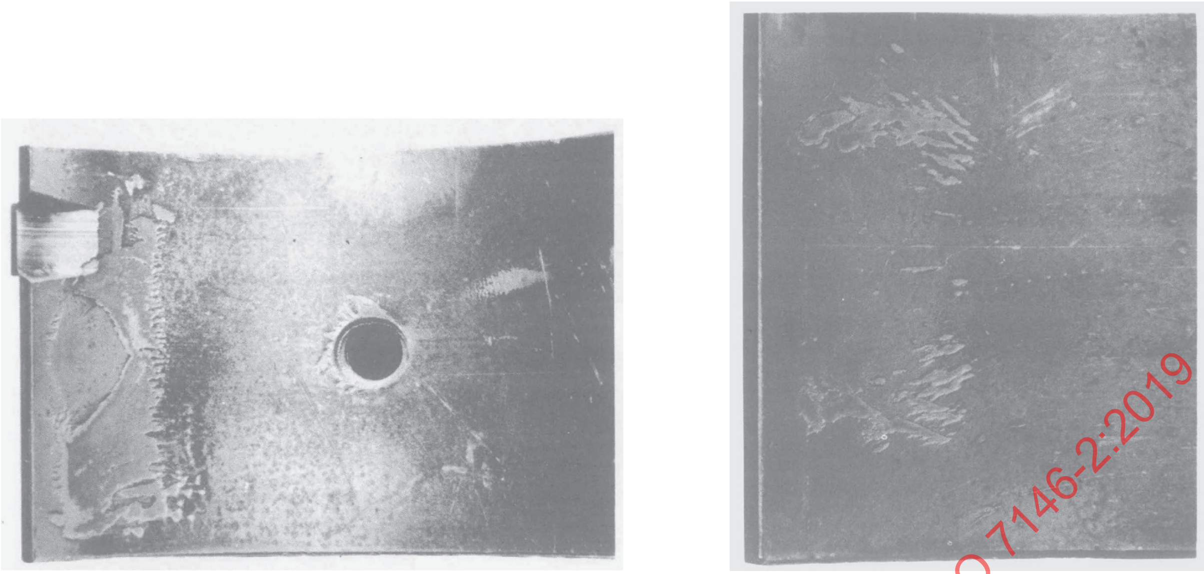


Figure 6 — Flow cavitation erosion on both groove sides of the lower half of a center main bearing in a turbo charged 6-cylinder diesel engine

Figure 7 — Flow cavitation erosion at the joint face relief in a big-end bearing



a) b)

NOTE Only the lining material is damaged.

Figure 8 — Flow cavitation erosion adjacent to the joint face relief of a main bearing and a big-end bearing of an automotive diesel engine

5.3 Impact cavitation erosion

5.3.1 Typical damage appearance

The erosion usually takes the form of a kidney, ring or half-moon. Figure 9 shows a typical example of the impact cavitation erosion behind and at some distance from the downstream end of a partial-circumferential oil groove in a lower half main bearing, where the journal is provided with drillings for supplying oil to a big-end bearing in a high-speed engine. Figure 10 depicts the damage at two circumferentially different spots, as the engine has run at two different constant speeds. Similar erosion has also been experienced near the end of an oil bleed slot in the rod half of a big-end bearing (see Figure 11).

5.3.2 Possible damage causes

In cases where a journal bearing feeds oil via a partial-circumferential oil groove to an oil drilling in a rotating journal, the continuous oil flow [see Figure 3 b), footnote a] is stopped instantaneously when the opening of the oil drilling passes the groove end [see Figure 3 b), footnote b]. However, the oil column in the oil drilling flows still further due to its inertia [see Figure 3 b), footnote c] and depression and cavitation take place in the drilling, thus causing erosion by implosion downstream of the oil groove end.

5.3.3 Possible countermeasures

Smooth the sharp cut-off edges of oil groove end and holes.

5.3.4 Typical examples (see Figures 9 to 11)

Figure 9 — Impact cavitation erosion at the end of 210° groove in a main bearing

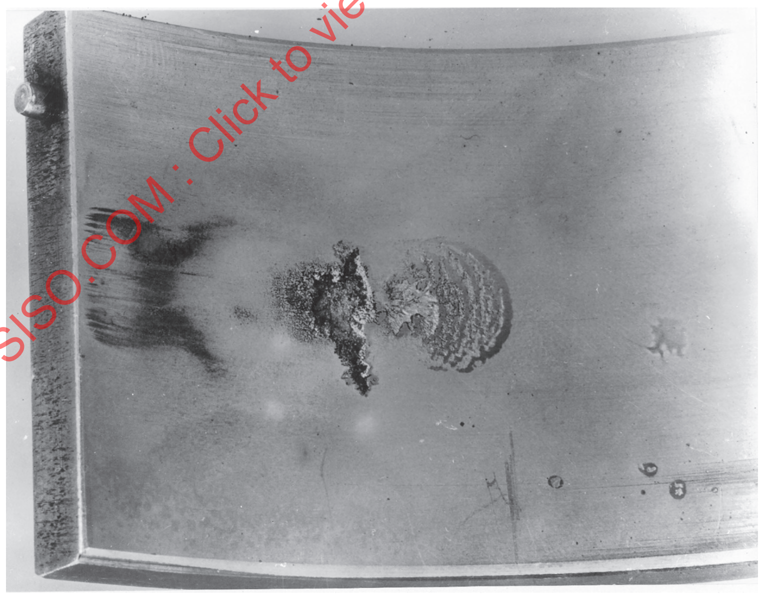


Figure 10 — Impact cavitation erosion behind the end of a 180° main bearing groove

Figure 11 — Impact cavitation erosion near the end of an oil bleed slot in the rod half of a big-end bearing

5.4 Suction cavitation erosion

5.4.1 Typical damage appearance

This erosion takes place only in dynamically loaded bearings. It has been experienced on the upper halves of main bearings and near the circumferential centre lines of the bearing lands. The damage took a long lancet-like form in a mild case (see Figure 12), and other forms (see Figures 13 and 14) in severe cases.

5.4.2 Possible causes

When the journal, in a dynamically loaded journal bearing, moves rapidly away from the bearing surface [see Figure 3 c)], suction or depression occurs behind the journal surface due to the negative squeeze effect, leading to evaporation of oil and then cavitation erosion by implosion.

5.4.3 Possible countermeasures

Stiffening the bearing cap (lower half housing), increasing the oil supply pressure and reducing the bearing mean diametral clearance can reduce the damage. Otherwise, change the dynamic load pattern, in particular, reduce the time rate of dynamic load variation.

5.4.4 Typical examples (see Figures 12 to 14)

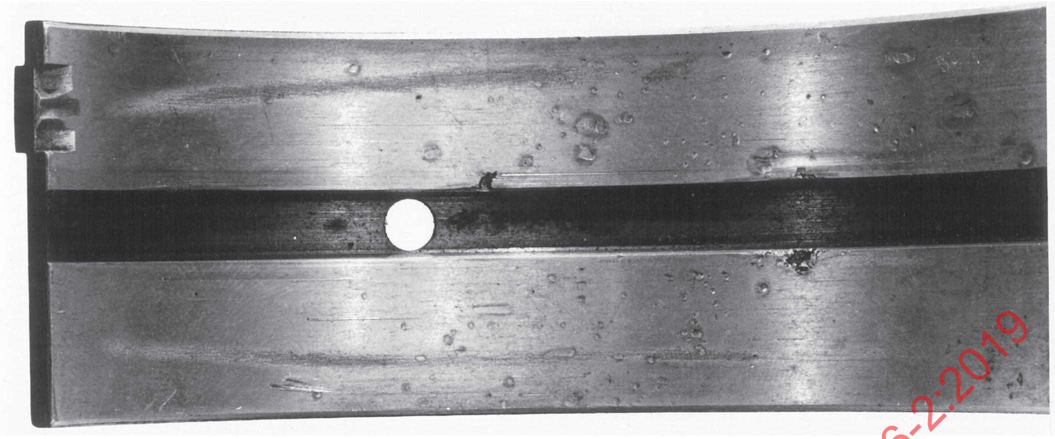


Figure 12 — Suction cavitation erosion in the upper half main bearing of a diesel engine

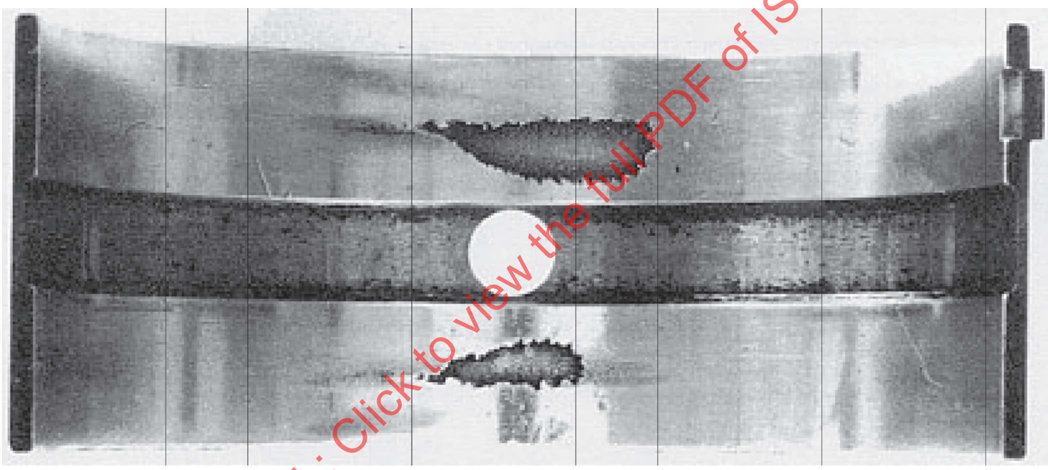
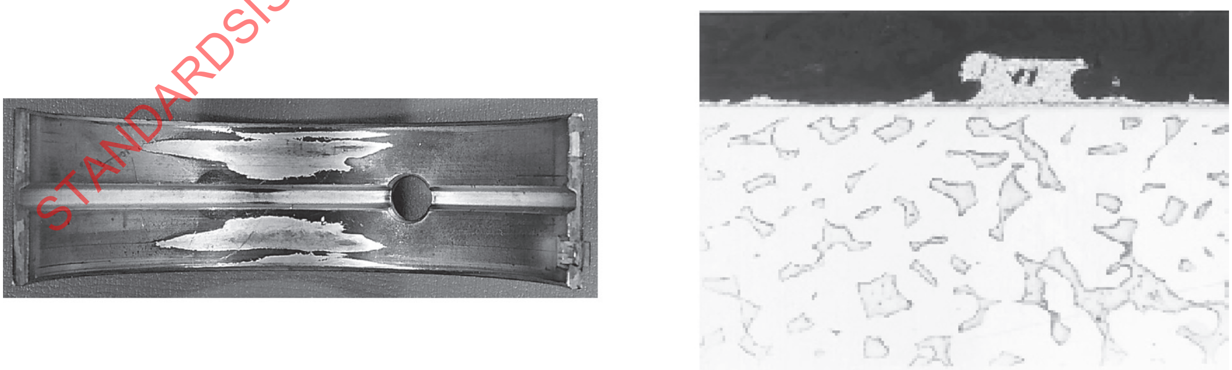


Figure 13 — Suction cavitation erosion in the relatively unloaded upper half of a main bearing in a high-speed diesel engine



NOTE The overlay was attacked on both lands of the upper half of a main bearing in a diesel engine.

Figure 14 — Suction cavitation erosion (material: steel/lead bronze/electroplated overlay)

5.5 Discharge cavitation erosion

5.5.1 Typical damage appearance

This erosion occurs only in dynamically loaded bearings with a circumferential oil groove. Mild erosion appears in the lower half main bearing groove of a petrol engine, in the form of a long spear (see Figure 15). Severe erosion appears on both bearing lands in the lower half main bearing of a diesel engine, originating from the edges of the groove and progressing in the form of a V against the journal rotation direction (see Figure 16).

5.5.2 Possible causes

When the journal, in a dynamically loaded journal bearing with a circumferential oil groove, rapidly approaches the bearing surface, the oil is squeezed out (discharged) from both sides of the bearing into the circumferential oil groove, where it rushes circumferentially in both directions [see left side of Figure 3 d)]. Both flows, due to their inertia, do not cease at the moment at which the journal motion direction reverses and no further oil is discharged into the groove. This leads to depression and cavitation erosion upon implosion [see right side of Figure 3 d)].

5.5.3 Possible countermeasures

In order to decrease the oil discharge velocity and so the depression, increase the area of the flow escape paths from the eroded bearing region. For this purpose, increase the cross-sectional area of the bearing groove, or provide a suitable escape hole in the shaft or bearing at the critical point.

5.5.4 Typical examples (see **Figures 15** to **16**)

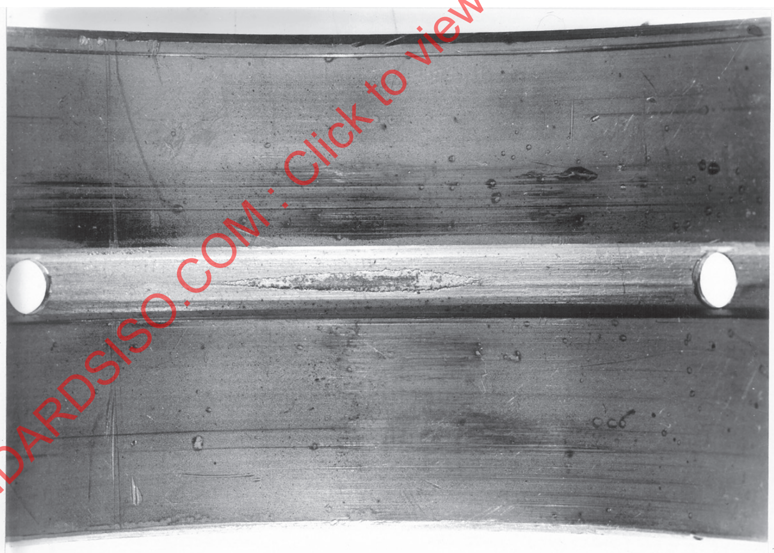


Figure 15 — Discharge cavitation erosion in a groove of the lower half main bearing of a petrol engine

