PLAIN BEARING FAILURES

BY

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Almost everything on earth that turns is supported either by balls or rollers or by a journal and plain bearing, frequently of the replaceable precision sleeve type widely used in gasoline and Diesel engines. The lubrication of plain bearings is by far the largest single application of lubricants, and is most commonly accomplished with a fluid lubricant like an oil.

Journal bearings may be as refined as those in aircraft and high speed Diesel engines, as delicate as those of a fine watch, as simple as on a child's toy wagon or as primitive as on an ox cart. In all cases these bearings turn more smoothly and with greater durability when lubricated, but their very multitude evokes the greatest number of inquiries or complaints arising from bearing malfunction or failure.

Although one cannot expect infinite bearing life, properly lubricated sleeve bearings often outlast other parts of the mechanism. Certain applications such as well-designed pedestal bearings in steam turbines with proper lubrication run for many years without change or adjustment. When bearings do experience premature failure, it is to the operator's benefit to be able to determine the reason for the malfunction so as to take proper safeguards against a recurrence.

Visual inspection of a damaged bearing frequently can reveal what happened; other instances may involve complex laboratory techniques to arrive at the probable cause of failure. Sometimes the damage has progressed so far that examination of the bearing itself is useless. When such is the situation in an enclosed system, such as a gearbox or engine crankcase, the nature of deposits in the bottom of the case or adhering to other components may shed light on the failure pattern. Physical characteristics of the bearing metal and other mineral constituents in the deposit sometimes reveal evidence of abrasion, seizure with the journal, overheating, melting, fatigue or corrosion.

This article has been compiled with the thought of describing and illustrating the more common causes of journal bearing failures in such a manner that a certain amount of diagnostic work can be done in place and before repair or replacement is undertaken. On-site diagnoses can thus speed the remedy without waiting for the laboratory to 'determine cause of failure'. Some causes of bearing damage like misalignment, erosion, defective bond or particle embedment can be recognized from viewing the bearing surface, perhaps with the aid of a simple hand magnifier; this makes for ready field handling. However, the confirmation of suspected defects like corrosion or porosity, and the identification of embedded material may need the support of microscopic examinations or complex laboratory techniques.

EXAMINATION PREPARATION

Examination of bearing surfaces frequently can be facilitated with some sort of hand magnifier, jeweller's loupe or low-power microscope: a magnification of five to ten diameters will often suffice. Higher magnifications—50 diameters or more—usually are not necessary for surface examinations and frequently are quite impractical due to the roughness of the unprepared surfaces. The

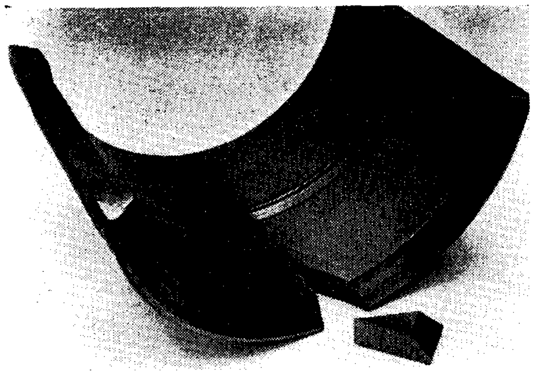

FIG. 1—A PRECISION TYPE PLAIN BEARING OR SLEEVE ENGINE BEARING WITH CROSS-SECTIONAL SAMPLE REMOVED IN PREPARATION FOR ROUGH GRINDING, MOUNTING, POLISHING, ETCHING AND MICROSCOPIC EXAMINATION

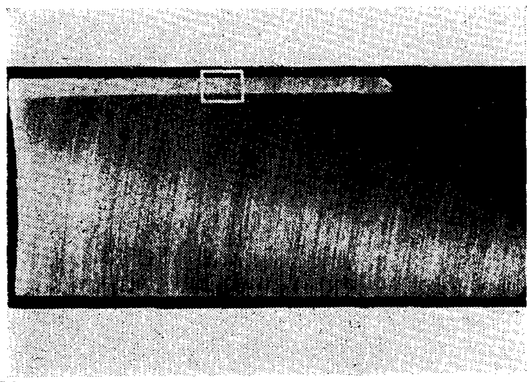

FIG. 2—SAMPLE SAWED FROM FIG. 1 AND ROUGH GROUND. NOTE 0·047 IN. LAYER OF BEARING ALLOY AT *TOP BONDED TO* A STEEL BACKING 0·5 IN. THICK (× 2½)

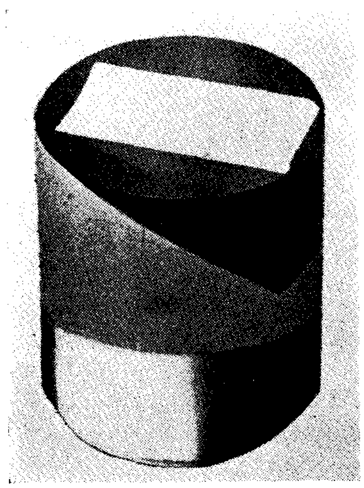

FIG. 3—SPECIMEN MOUNTED IN PLASTIC, POLISHED AND READY FOR FINAL ETCHING (APPROX. FULL SIZE)

magnifications listed under the photographs of various bearing surfaces indicates the detail that can be seen with relatively inexpensive equipment. Surface scratching, embedded particles, fatigue cracks, bond failures and wiped zones are among those forms of damage readily observed with relatively low magnification.

Microscopic examination of bearings at higher powers—usually of cross-sections—becomes necessary when observations must be made of the micro-structure, that is, of the crystal arrangements, grain structure, deformations, intergranular cracks, depth of corrosion penetration, phase changes, etc. A great volume of work can be done in the 100 to 500 diameters magnification range; however, at times, magnifications as high as 1500X may be necessary which requires a high-grade metallurgical microscope. Such work demands skilled laboratory sample preparation. To do this the bearing shell must be cut. rendering it unfit for any further service.

For example, to prepare a cross-section of a heavy-duty Diesel connecting rod bearing for microscopic examination, the desired portion is cut out as indicated in FIG. 1 with a saw or cutting wheel. Selection of the proper area is of paramount importance; defects are seldom evenly disbuted over a bearing and, when a particular kind is in question—for instance, shallow fatigue cracks—several sections from different locations may have to be examined to find views suitable for diagnosis.

FIG. 2 shows a specimen cross-section which has been lightly ground to reveal the bearing alloy layer 0·047 in. thick on a steel backing 0·5 in. thick. The specimen was then trimmed and moulded or cast into a round plastic mount. FIG. 3 shows a mounting which happens to be in lucite, however black or colored bakelites also make suitable mounts. The plastic mount provides the means of holding irregular specimens for polishing while a number inscribed on the base of the mount facilitates filing and retrieval.

After mounting, the specimen is polished with progressively finer abrasives

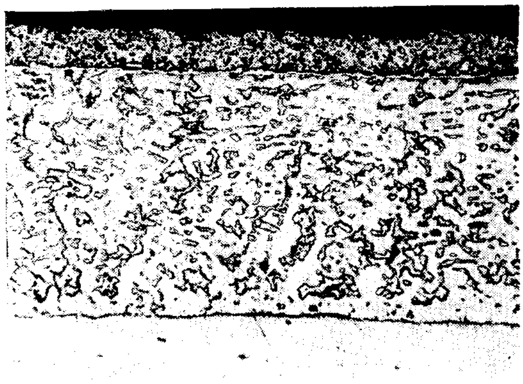

FIG. 4—PHOTOMICROGRAPH OF CROSS-SECTION OF BEARING SHOWN IN FIGS. 1, 2 AND 3. FROM TOP TO BOTTOM: (i) THE GREY-COLOURED LEAD-TIN BEARING SURFACE LAYER OR FLASHING, ABOUT 0·001IN. THICK; (ii) THE NARROW WHITE-COLOURED NICKEL 'DAM'; (iii) THE WHITE-COLOURED COPPER MATRIX WITH ITS INTERSTICES FILLED WITH GREY-COLOURED LEAD; (iv) A SMALL PORTION OF THE STEEL BACKING (× 200)

FIG. 5—PATCHY REMOVAL OF LEAD FLASHING ON A SILVER BEARING BY OIL-BORNE ABRASIVE. ALSO NOTE SCRATCHING OF BOTH LEAD AND SILVER BY HARD PARTICLES (x 4)

until a scratch-free mirror finish is obtained. This surface is then chemically etched by reagents specifically compounded to selectively attack one phase or grain type differently from the others and, in so doing, to create an optical differentiation between grains or microconstituents. FIG. 4 is a photomicrograph of a portion of the etched specimen ready for microscopic examination. The area shown represents the rectangle in FIG. 2, which includes the lead-tin bearing surface (10 per cent tin) approximately 0·001 in. thick, several thousandths of an inch of copper-lead substructure and a portion of the steel shell. Note the narrow, irregular white line between the copper-lead and lead-tin: this is electro-deposited nickel which serves as a diffusion barrier. It prevents the migration of tin from the surface layer into the underlying copper and thereby maintains the corrosion resistance of the surface layer. A structure such as this is frequently used in heavy duty Diesel bearings.

FAILURE TYPES

Following are descriptions and illustrations of sixteen types of failures which may occur in plain bearings. It will be noted that the lubricant can be justly blamed for very few of these, or that any lubricant could have prevented them. On the other hand, several types of failure indicate incorrect installation, improper operation, or contamination of the lubricant which must be corrected before satisfactory bearing life can be obtained.

Scratching

Hard solid particles entrained in the lubricant will, if they escape filtration, eventually be delivered to a bearing clearance space. Very fine particles which are smaller than the minimum bearing clearance of only a few ten-thousandths of an inch can circulate without causing serious bearing damage. The shaft may become lapped or slowly worn to a non-cylindrical shape while the bearing may develop a dull spot at the location of minimum clearance. A thin lead alloy overlay can become worn through with minor scratches as shown in FIG. 5. When the specimen is a copper-lead bearing with the conventional lead overlay, wear of only one thousandth of an inch can expose a narrow area of the bronze-coloured copper-lead which, alone, does not signify that the bearing had been worn beyond tolerances. Because of the colour difference between the overlay and the copper-lead, however, wear can appear more severe than it really is. Automotive bearings with copper-lead exposed by gentl

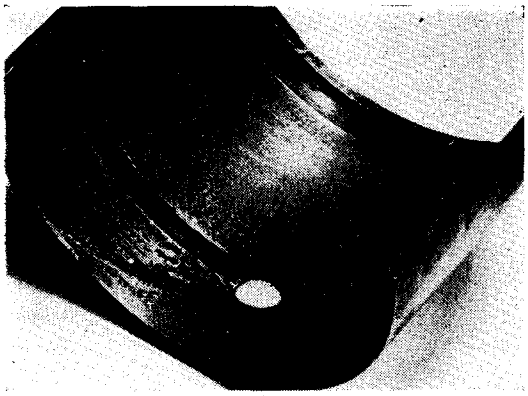

Fig. 6—Surface erosion by oil-borne particulate matter flowing from bearing's oil supply hole

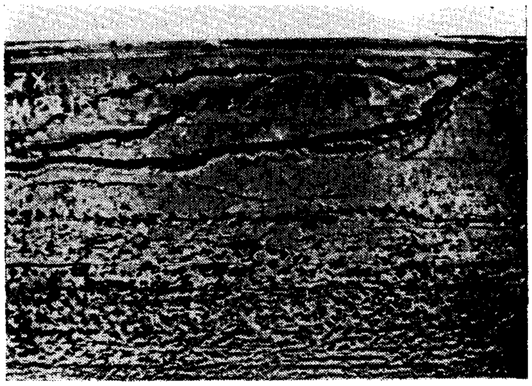

Fig. 7—Grooving or tracks made by relatively large hard particles migrating slowly through the bearing clearance

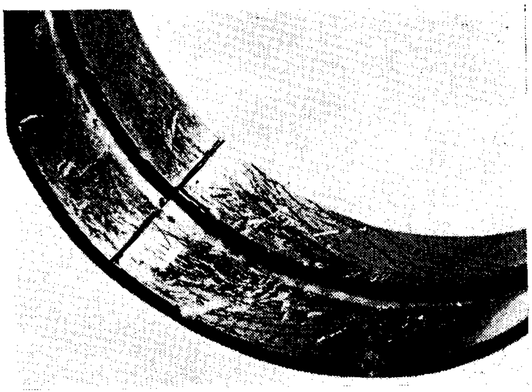

Fig. 8—Ploughing or surface scoring of babbit bearing caused by oil-borne hard particles flowing outward diagonally from central oil supply groove

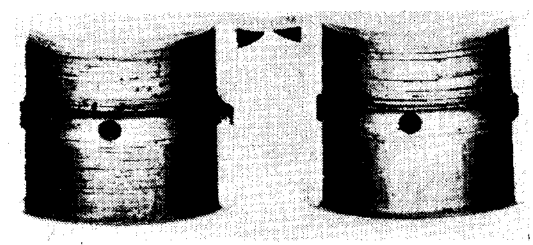

Fig. 9—Shallow embedment and grooving of hard metallic particles in lead flashing of silver bearing

wear frequently can continue in service for an indefinite period provided that corrosion does not occur on the exposed areas. The degree and location of wear can often be evaluated with a micrometer calliper by measuring variations in bearing shell thickness.

Erosion

A high velocity oil flow with very fine hard particulate matter can locally wash out a gully in the bearing surface as illustrated in Fig. 6; this is sometimes called 'erosion'.

Grooving

Larger particles—in the range of a few thousandths of an inch or more—can get into the bearing clearance but not freely enough to squeeze through.

For example, large particles may migrate through the clearance space as conditions of load and speed permit; such action can be recognized on the bearing surface by a path of indentations of similar shape wandering more or less in the direction of journal motion. Several such tracks are shown on the bearing surface in Fig. 7.

Plowing

Large hard particles can be dragged along by shaft motion and oil flow, plowing grooves in the softer bearing alloy. Fig. 8 shows a babbitt bearing in which the lubricant delivered hard particles to a central oil groove; as the oil spread outward across the bearing surface, the particles moved with it, cutting diagonal, branched paths in both halves of the babbitt.

Shallow Embedments

Figs. 9 and 10 show a lead-flashed silver bearing in which hard metallic particles plowed grooves for short distances and then became embedded in the thin lead overlay: the causative particles can be found at the ends of the score paths. The harder silver base, having poor 'embedability', prevented these particles from being depressed any further. Embedments such as these are especially

FIG. 10—ENLARGEMENT OF A PORTION OF FIG. 9 SHOWING THE CAUSATIVE PARTICLES AT THE RIGHT END OF THEIR GROOVES AND PROJECTING ABOVE THE BEARING SURFACE

FIG. 11—A HARDENED STEEL JOURNAL SCRATCHED BY ABRASIVE PARTICLES

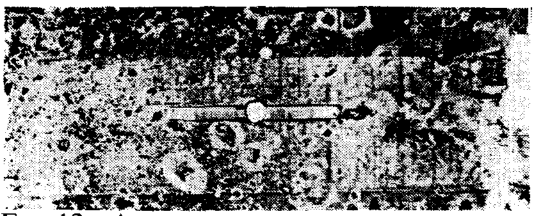

FIG. 12—A SEMI-CIRCULAR BEARING SHELL WHICH HAS BEEN 'OPTICALLY UNWRAPPED' TO SHOW INDENTATIONS MADE IN ITS BABBIT BY CARBONACEOUS AGGLOMERATES IN ENGINE SLUDGE

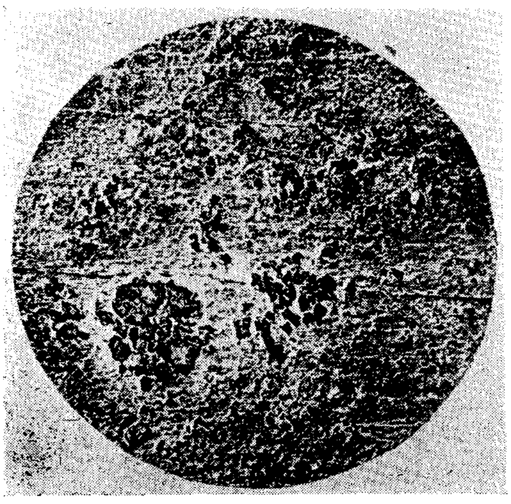

FIG. 13—THE SURFACE OF ANOTHER BEARING WHICH HAS BEEN INDENTED BY CLUMPS OF SLUDGE PARTICLES (x 40)

bad as they project slightly above the surface and are in perfect position to heavily score the shaft. FIG. 11 shows a hardened steel journal scratched by abrasive particles.

On the other hand, soft-bearing metals can be damaged by relatively *soft* particulate matter; for example, carbonaceous agglomerates can indent a bearing surface as illustrated in FIG. 12. These markings show how compressed lumps of common sludge produced shallow cavities with raised edges. Cavities appear as circular dark spots and the raised edges are bright and shiny from direct contact with the journal. Sometimes the surface is only indented as in FIG. 13.

Plowing produced by moving chips and particles raises the bearing metal on either side of the path; the elevation results from displacement of bearing alloy from the centre of the groove. High spots or raised regions on a bearing surface often have light shiny faces from direct contact with the shaft. Shiny rubbing spots are evident at the ends of two paths in FIG. 10—two white crescents, one surrounding a cavity caused by a metallic chip and the other surrounding a particle in place. Abrasion such as this causes hot spots which can destroy fluid lubrication and possibly result in bearing seizure.

Deep Embedments

Hard particulate matter can become completely embedded in the bearing alloy and, in effect, be taken out of circulation. This requires a comparatively soft-bearing metal such as lead or babbitt. FIG. 14 shows a cross-section through a babbitt-impregnated, sintered bearing with many hard metallic chips embedded in the babbitt. When thus buried in the alloy their tendency to damage the shaft is less than if they protrude as in FIG. 10.

Insert-Housing Contamination

Hard foreign matter also causes trouble if it becomes trapped behind a shell. i.e., between the steel backing of the bearing insert and its housing. Grit is particularly troublesome when

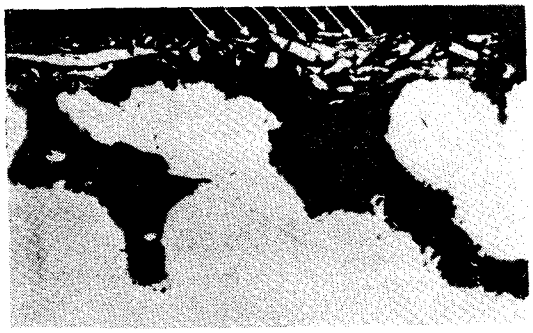

FIG. 14—PHOTOMICROGRAPH OF CROSS-SECTION OF A BABBIT-IMPREGNATED SINTERED BEARING WHICH HAS EMBEDDED AND LARGELY NEUTRALIZED THE HARD STEEL CHIPS INDICATED BY THE ARROWS (X 100)

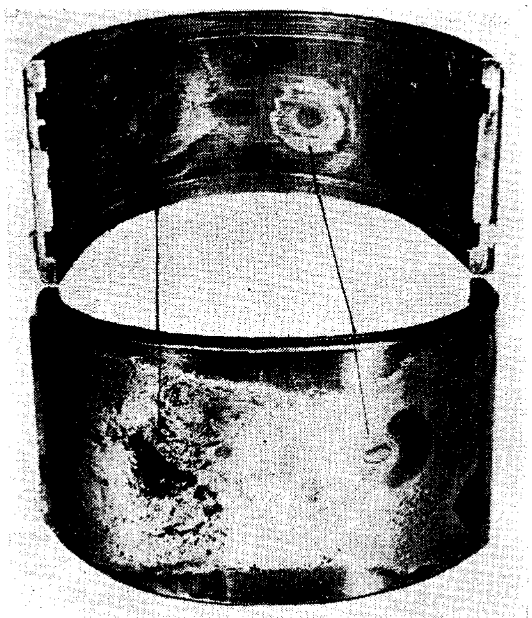

FIG. 15—THE BEARING SURFACE (TOP) AND CORRESPONDING BACKING SURFACE (BOTTOM) OF A RAILWAY DIESEL CONNECTING ROD BEARING SHOWING DISTORTION, EXCESSIVE WEAR AND INCIPIENT FAILURES ON THE BEARING SURFACE CAUSED BY TWO HARD FOREIGN PARTICLES BETWEEN THE BEARING BACKING AND ITS CONNECTING ROD

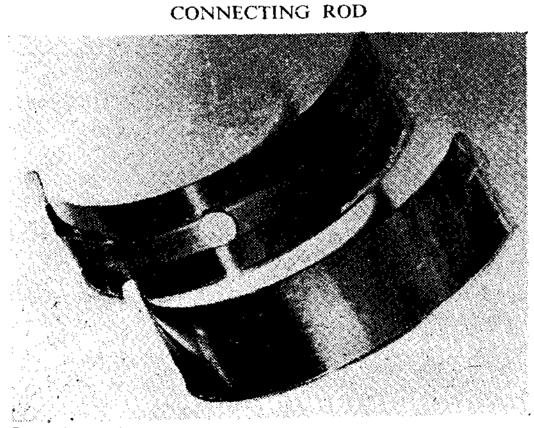

FIG. 16—A MATED SET OF MAIN BEARING INSERTS, ONLY THE UPPER LIGHTLY-LOADED HALF BEING PROVIDED WITH A CENTRAL OIL GROOVE

overhaul of automotive engines is carried out in dirty surroundings. A metallic chip or grain on the back of the bearing shell or on its housing can easily escape notice during installation; however, even normal bearing loads are sufficiently great to deform the steel shell around that particle, dent the back, and create a high spot on the bearing face. The high spot will run excessively hot in wearing down and may lead to seizure or fatigue breakouts. Dents or nicks on either the back of the bearing insert or its housing will cause similar failures. The lower part of FIG. 15 shows the back of a Diesel connecting rod bearing shell which was installed on two hard particles; even though the steel back was a quarter of an inch thick. it was deformed and created matching wear spots on the bearing face as shown in the upper part of the figure. Relatively thin steel backings common to automotive service are even more sensitive to this type of damage. Therefore, when inspecting any damaged bearing shell, one should always look for marks on the steel back to determine if dirty seating is associated with disfigurations on the bearing surface.

Journal Ridging

Abrasive shaft wear occurring at a slow rate can be offset by corresponding bearing wear so that no gross misfit occurs, even though the journal may wear to a barrel or hourglass profile. For example, a shaft riding on a bearing shell having a central oil groove can become worn on the load-bearing areas so that the shaft develops a 'non-wear' ridge or band corresponding to the oil groove. If the groove is contained in only one half-shell of a full bearing as in FIG. 16, a ridge can still form on the shaft; however, the non-grooved half-shell will wear at the same time along a band matching the ridge, so that an even distribution of load continues. Such a bearing shell will show a narrow circumferential

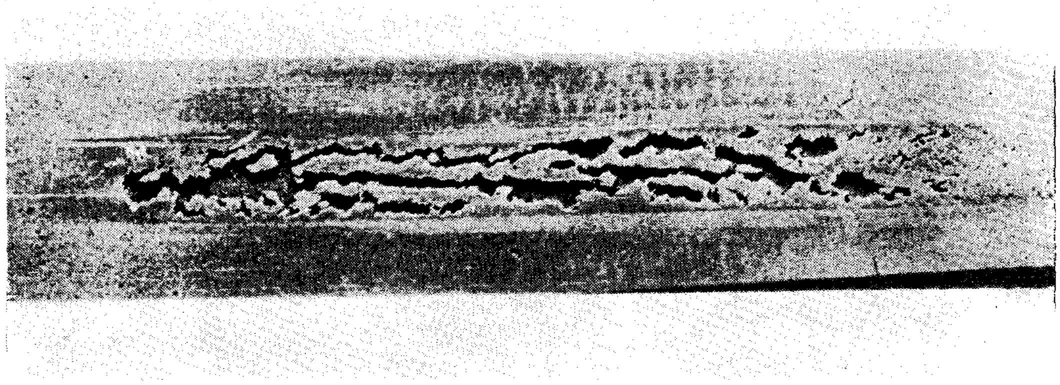

FIG. 17—FATIGUE BREAKOUT IN LOWER LOADED HALF OF A REPLACEMENT BEARING LIKE FIG. 16 CAUSED BY FAILURE TO REMOVE RAISED RIDGE WORN ON JOURNAL BY THE OIL GROOVE IN THE UPPER HALF

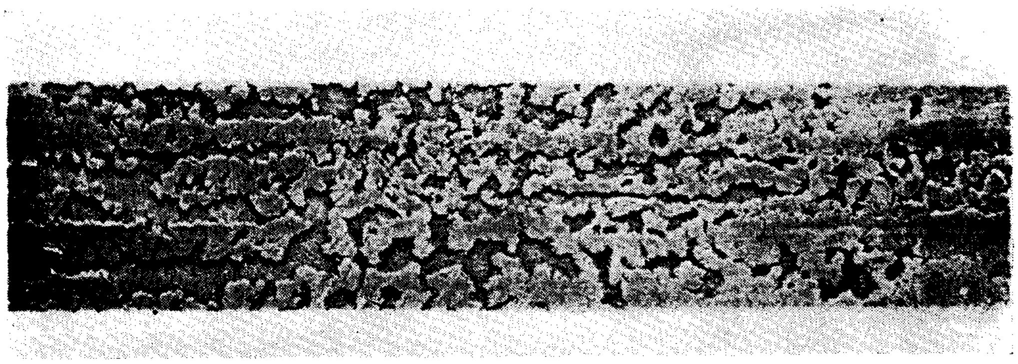

FIG. 18—IN CONTINUATION OF FIG. 17, THE REDUCTION IN AREA OF THE LOWER BEARING BY FATIGUE BREAKOUT RAISES UNIT LOADING ON THE REMAINING AREA AND ACCELERATES FATIGUE FAILURE OVER THE ENTIRE BEARING SURFACE

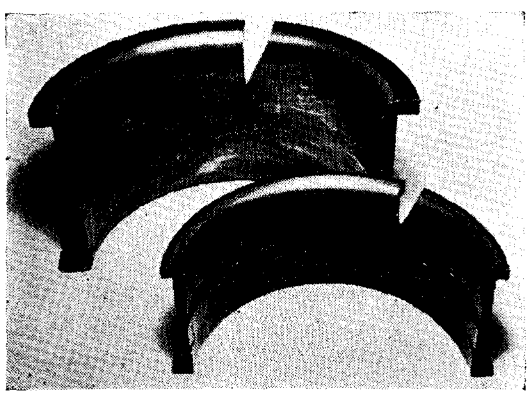

FIG. 19—CRESCENT-SHAPED WEAR SPOTS CAUSED BY MISALIGNMENT

groove along the centre and, although worn, can be quite serviceable.

However, if the worn bearing shells should now be replaced *without refinishing the journal*, a high stress area will be set up where the non-grooved bearing makes contact with the journal ridge, and rapid failure can be expected. FIG. 17 shows such a bearing shell where a band of fatigue breakouts defines the overload zone. In FIG. 18 this kind of fatigue breakout is even more pronounced.

A journal surface worn to any other non-cylindrical shape would also produce abnormal local stresses corresponding to the areas of highest load. In such instances it is essential to regrind the shaft before installing a new bearing set.

Misalignment

Misalignment between a journal and its bearing is readily apparent from a distorted wear pattern on the bearing surfaces. In sleeve bearing lubrication, misalignment generally can be regarded as any instance where the axes of the journal and bearing are not parallel. Normal wear produces a more-or-less rectangular visible band of contact across the bearing face; whereas misalignment forms a wear zone—depending on clearance ratio, degree of skew between the bearing and journal, etc.—which may be roughly trapezoidal, triangular or half-moon in shape as in FIGS. 19 and 20.