DEPARTMENT OF THE ARMY
UNITED STATES ARMY AVIATION TEST BOARD
Fort Rucker, Alabama 36360

STEBG-TD 28 DEC 1966

SUBJECT: Letter Report, "Product-Improvement Test of Component TBO Extension, UH-1( ) Helicopter," RDT&E Project No. USATECOM Project No. 4-5-0101-03

TO: See Distribution

1. References.

a. Letter, AMCPM-IRFO-T-023, Iroquois Field Office, US Army Materiel Command, 10 December 1964, subject: "UH-1A, UH-1B, and UH-1D Aircraft: Revised Replacement and Retirement Schedule."

b. Letter, STEBG-TP-A, President, US Army Aviation Test Board, 26 January 1965, subject: "Minutes of UH-1B/D TBO Program and Test Coordination Meeting."

c. Letter, AMCPM-IR-T, Headquarters, US Army Materiel Command, 2 April 1965, subject: "Trip Report Summarizing UH-1 TBO Meeting of 25-26 March 1965."

d. Message, ASCV-ZP3132, Commanding General, US Army Support Command Vietnam, 17 April 1965, subject: "Return of Certain Component Parts from UH-1B Helicopters."

e. Letter, SMOSM-EEL-UH-1-19, Headquarters, US Army Aviation Materiel Command, 27 April 1965, subject: "Product Improvement Test, UH-1B Helicopter."

f. Letter, AMSTE-BG, Headquarters, US Army Test and Evaluation Command, 1 June 1965, subject: "Test Directive, USATECOM Project No. 4-5-0101-( ), Product Improvement Test, UH-1B Items."

g. Report of Test, USATECOM Project No. 4-3-0100-08, "Logistical Evaluation of the UH-1B Helicopter at High Gross Takeoff Weight," US Army Aviation Test Board, 28 June 1965.

h. Letter, AMSTE-BG, Headquarters, US Army Test and Evaluation Command, 16 August 1965, subject: "Logistical Evaluations and Extension of Times Between Overhaul, UH-1 Components."

i. Letter, AMSTE-BG, Headquarters, US Army Test and Evaluation Command, 24 August 1965, subject: "Planning Guidance for Logistical Evaluation."

j. Letter, STEBG-TP-A, US Army Aviation Test Board, 9 September 1965, subject: "Iroquois Test Coordination Meeting."

k. Message, AMC 10576, Commanding General, US Army Materiel Command, 9 September 1965.

l. Letter, Bell Helicopter Company, 17 September 1965, subject: "Fatigue Life, UH-1B Main Rotor Retention Strap."

m. Letter, SMOSM-EAA, Headquarters, US Army Aviation Materiel Command, 27 September 1965, subject: "Fatigue Life, UH-1B Main Rotor Retention Strap."

n. Letter, AMSTE-BG, Headquarters, US Army Test and Evaluation Command, 1 October 1965, subject: "Test Directive, USATECOM Project No. 4-5-0101-03, Product Improvement Test (Component TBO Extension) UH-1B Helicopter."

o. Letter, AMSTE-BG, Headquarters, US Army Test and Evaluation Command, 7 October 1965, subject: "Safety Release for Operation of UH-1B Main Rotor Retention Strap."

p. Plan of Test, USATECOM Project No. 4-5-0101-( ), "UH-1B Items, Product Improvement Test," US Army Aviation Test Board, 8 October 1965.

q. Letter, STEBG-TD, US Army Aviation Test Board, 25 April 1966, subject: "First Partial Report, USATECOM Project No. 4-5-0101-03, Product Improvement Test of the UH-1B Helicopter (Investigation of Difficulties, Main Rotor Hub)."

r. Final Report of Test, USATECOM Project No. 4-3-0150-15, "Logistical Evaluation (Phase F) of UH-1D Helicopter at High Gross Weight," US Army Aviation Test Board, 31 August 1966.

2. Background.

a. The majority of UH-1( ) dynamic components are replaced for overhaul or retirement at 1100-hour intervals. The UH-1( ) flying-hour program in the Republic of Vietnam (RVN) is 70 hours per month. Extension of the time between overhaul (TBO) of major dynamic components of the UH-1B and UH-1D Helicopters is highly desirable to improve the world-wide UH-1( ) supply posture and the availability rate of aircraft affected, and to provide substantial monetary savings. TBO extensions should be based only on experience gained from overhauls and from operation of sufficient number of test components beyond the authorized TBO.

b. At the request of the Iroquois Project Manager, a meeting was held on 19 January 1965, at the US Army Aviation Test Board (USAAVNTBD) to establish a TBO extension program. It was decided that high-operating-time components acquired from the field and from tests at the USAAVNTBD would be operated beyond the authorized field TBO. To insure safety, the components would be inspected thoroughly prior to extended operation. A TBO Committee would be established to review test results and make recommendations to the Iroquois Project Manager.

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c. A UH-1( ) TBO Committee Meeting was held at the airframe manufacturer's plant on 25 and 26 March 1965 to examine the dynamic components removed at the completion of the logistical evaluation of the UH-1B Helicopter (serial number 63-8659) at high takeoff gross weight, USATECOM Project No. 4-3-0100-08 (reference g). It was decided at the meeting that the only UH-1( ) components suitable for a TBO extension program were:

(1) Main-rotor hub assembly, P/N 204-011-101-9.

(2) Intermediate (42-degree) gearbox, P/N 204-040-003-23.

(3) Tail-rotor (90-degree) gearbox, P/N 204-040-012-7.

All other components required either improvement or major redesign prior to entering a TBO extension program. Six samples of each test component would be operated 200 hours beyond the authorized 1100-hour TBO. The type inspection required for each component was not satisfactorily resolved at the meeting. It was decided that the USAAVNTBD project engineer would inspect high-operating-time components and overhaul records at the US Army Aeronautical Depot Maintenance Center (USAADMAC) to determine the type of inspection required prior to testing. It was agreed that UH-1B Helicopter, S/N 63-8659, would be the test vehicle and that this test would be one of several conducted under USATECOM Project No. 4-5-0101-( ), "UH-1B Items Product Improvement Test."

d. The primary limiting factor to extension of the TBO of the main-rotor hub assembly was the 1100-hour retirement schedule of the main-rotor retention straps. Prior to the initiation of testing, sufficient justification was provided by the manufacturer to permit extended service-life testing of the main-rotor hub assembly. Safety releases for extended service-life testing were issued by the US Army Aviation Materiel Command (USAAVCOM) and US Army Test and Evaluation Command (USATECOM).

3. Description of Materiel.

a. Main-Rotor Hub Assembly, P/N 204-011-101-9. The main-rotor hub is splined to the top of the mast on an underslung mounting trunnion. Two pillow blocks provide a flapping axis for the main rotor. The main-rotor blade grips rotate on the yoke spindle, providing changes in pitch to the blades. The main-rotor blades are retained by straps. Counterweights counteract the aerodynamic forces which tend to change blade pitch. An adjustable drag brace connects the trailing edge of each blade to the hub, providing a means of aligning the blades.

b. Intermediate (42-Degree) Gearbox, P/N 204-040-003-23. The intermediate gearbox, installed on the top of the tail boom at station 392.4 at the base of the vertical fin, provides a 42-degree change in direction of the tail-rotor drive shaft with no speed reduction. The assembly consists of a case with gear quills at each end. The case is fitted with an oil filler cap, a vent breather, an oil level sight gauge, and a drain plug equipped with a magnetic insert. The input and output quills incorporate flexible couplings for attachment of the input and output drive shaft sections.

c. Tail-Rotor (90-Degree) Gearbox, P/N 204-040-012-7. The tail-rotor gearbox, installed on the top of the tail boom vertical fin at station 453.25, provides a 90-degree change in direction and a 2.6-to-1 speed reduction of the tail-rotor drive. The tail-rotor assembly is installed at the end of the tail-rotor gearbox output shaft, and consists of mating input and output gear quill assemblies set into the gear case. The case incorporates a vented oil filler cap, an oil level sight gauge, and a drain plug equipped with a magnetic insert. The input quill incorporates a flexible coupling for attachment of the drive shaft.

4. Test Objective. To determine the feasibility of extending the authorized TBO and retirement schedule of selected UH-1( ) dynamic components.

5. Method.

a. General. Six high-operating-time samples of each test component were selected to operate to a total of 1300 flight hours each. The components were inspected by USAAVNTBD personnel prior to initial installation and at approximately 1200 and 1300 total operating hours, as follows:

(1) Intermediate and Tail-Rotor Gearboxes. The gearboxes were disassembled and the gears visually inspected for unusual wear patterns or pickout. The input and output quills or shafts were rotated to check for bearing roughness. Other inspections as determined necessary during the test were conducted.

(2) Main-Rotor Hub Assembly. The assembly was disassembled. The strap retention pins, P/N 204-011-176-1, were magnafluxed. The strap was inspected for cracks. Other inspections as determined necessary during the test were conducted.

b. Operational Checks. The magnetic plugs installed in each gearbox were connected to a chip detector warning light mounted on the instrument panel. During the first 10 hours of operation beyond 1100 and 1200 hours, oil samples were collected from the test gearboxes and analyzed after each flight. At the same time, the magnetic plugs were visually inspected. After the first 10 hours of operation after 1100 and 1200 hours, oil samples were collected and analyzed and the magnetic plugs were visually inspected at the completion of each day's flight period.

c. Analytical Inspections. Analytical inspections of components were performed by USAADMAC personnel and the project engineer.

d. Abnormal Operation. If the chip detector light illuminated or if oil analysis revealed abnormal metal content, the test gearbox was removed and inspected to determine the cause. If hub assembly operation was abnormal, the test hub assembly was removed, with approval of the project officer and project engineer, and inspected to ascertain the cause.

e. Changes to Scheduled Maintenance. Recommended changes in inspection frequency, type, and procedure required as the result of testing were reported.

6. Summary of Results.

a. Main-Rotor Hub Assembly, P/N 204-011-101-9.

(1) All six main-rotor hub assemblies received from depot were unserviceable because of trunnion bearing deterioration and this test was discontinued. A partial report covering this portion of the test was submitted on 25 April 1966 (reference q).

(2) The most probable cause of the trunnion bearing deterioration is inadequate lubrication; a contributing factor, however, may be a deficiency in the load capability of the inner race of the trunnion bearing.

(3) Investigation of main-rotor hub assemblies returned to USAADMAC revealed that seal deterioration was a major cause of their not achieving the present 1100-hour TBO.

b. Intermediate (42-Degree) Gearbox, P/N 204-040-003-23.

(1) The intermediate gearboxes were all found to be serviceable after completion of testing. (See inclosure 1.)

(2) Gearboxes tested and time acquired were:

Gearbox	Serial Number	Hours
No. 1	B13-1431	1301.9
No. 2	B13-1411	1310.4

Gearbox	Serial Number	Hours
No. 3	B13-1127	1301.5
No. 4	B13-1371	1309.9
No. 5	B13-1277	1307.4
No. 6	B13-2931	1310.9

(3) Data obtained from USAADMAC showed that seal deterioration was the primary reason for 42-degree gearboxes being returned from the field for premature overhaul. During this test, no problems were experienced with the seals; however, this may have been due to the frequent seal replacement required by inspections and was not necessarily indicative of seal life.

c. Tail-Rotor (90-Degree) Gearbox, P/N 204-040-012-7.

(1) The tail-rotor gearboxes were found to be unserviceable after various operating hours beyond the normal 1100-hour TBO due to pitting on the convex side of the output gear teeth. (See inclosure 1.)

(2) Gearboxes tested and time acquired were:

Gearbox	Serial Number	Hours
No. 1	B13-1194	1173.0
No. 2	B13-1285	1300.8
No. 3	B13-1499	1301.3
No. 4	B13-1233	1310.3
No. 5	B13-1068	1241.9
No. 6	B13-1209	1245.9
No. 7	B13-1276	1107.0
No. 8	B13-1394	1274.3

(3) No problems were experienced with seal deterioration in the 90-degree gearboxes during this test; however, this may have

been due to the frequent seal replacement required by inspection and was not necessarily indicative of seal life. Data obtained from USAADMAC showed that 61 percent of the gearboxes returned from the field for overhaul was due to seal deterioration.

7. Conclusions.

a. Main-Rotor Hub Assembly, P/N 204-011-101-9.

(1) An increase in TBO of the main-rotor hub assembly beyond 1100 hours is not feasible.

(2) Improvement of the main-rotor seals is required. (Improved grip seals are presently being tested under USATECOM Project No. 4-5-0151-10.)

(3) Lubrication of the trunnion bearings should be improved.

(4) The possibility of a materiel or design deficiency in the trunnion bearings should be investigated.

b. Intermediate (42-Degree) Gearbox, P/N 204-040-003-23.

(1) A 1300-hour TBO is feasible for the 42-degree gearbox.

(2) The gearbox appears suitable for further TBO advancement.

(3) Seal deterioration represents a major cause of gearboxes not achieving the present 1100-hour TBO.

c. Tail-Rotor (90-Degree) Gearbox, P/N 204-040-012-7.

(1) A 1300-hour TBO is not feasible for the 90-degree gearbox.

(2) Seal deterioration represents a major cause of gearboxes not achieving the present 1100-hour TBO.

8. Recommendations.

a. Main-Rotor Hub Assembly, P/N 204-011-101-9. It is recommended that:

(1) The TBO for the main-rotor hub assembly remain at 1100 hours.

(2) Efforts to improve the main-rotor hub seals be continued.

(3) The manufacturer investigate the possibility of a materiel or design deficiency in the trunnion bearings.

(4) The following technical manual changes be made to improve the lubrication of the trunnion bearings:

(a) Add to TM 55-1520-211-20PMP and TM 55-1520-210-20PMP as a requirement for each second periodic: "Flush trunnion bearings."

(b) Add to TM 55-1520-211-20 and to TM 55-1520-210-20:

"Flush trunnion bearings as follows:

(1) Remove reservoir.

(2) Pump oil (MIL-7808) into inlet hole of bearing cups until clean oil emerges from the other oil hole; move the main rotor blades so that trunnion rotates in bearing housing while oil is being pumped into inlet hole."

b. Intermediate (42-Degree) Gearbox, P/N 204-040-003-23. It is recommended that:

(1) The TBO of the 42-degree gearbox be extended from 1100 to 1300 hours.

(2) Further testing of the 42-degree gearbox be conducted to determine the feasibility of extending the TBO from 1300 to 1500 hours, provided the gearbox is not "retirement-life" limited to less than 1500 hours.

(3) Product-improvement efforts be initiated on the seals.

c. Tail-Rotor (90-Degree) Gearbox, P/N 204-040-012-7. It is recommended that:

(1) The TBO of the 90-degree gearbox remain at 1100 hours.

(2) An 1100-hour accelerated bench test be conducted on two gearboxes in which pitting is present. This testing will be to determine the effect of the presence of pitting on a gearbox when operated over another full TBO cycle. The results will serve as a basis for a decision to retire the gears or to initiate product improvement.

(3) The output gears either be retired at overhaul or be refurbished to blend out the wear-pattern overlap area until such time that results of additional testing are available.

(4) Product-improvement efforts be initiated on the seals.

Raymond E. Johnson

RAYMOND E. JOHNSON
Colonel, Artillery
President

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ENGINEERING ANALYSIS

The detailed results and engineering analysis are based on information obtained from testing at the USAAVNTBD and on data obtained from USAADMAC.

1. Main-Rotor Hub, FSN 1560-991-8904, P/N 204-011-101-9.

a. S/N A2-1340. This hub operated 1100.0 hours on a UH-1B Helicopter at the USAAVNTBD. It was inspected at the manufacturer's facility. Inspection of the grip, yoke, and trunnion bearings revealed no discrepancies. Inspection of the tension/torsion straps revealed no cracks. Magnetic-particle inspection revealed the retention pins to be serviceable. The hub was serviceable for testing. After accumulating 1200.8 hours, the hub was inspected at the USAAVNTBD. Visual inspection of the grip, yoke, and trunnion bearings revealed them to be serviceable. Visual inspection of the tension/torsion straps and magnetic-particle inspection of the retention pins revealed no cracks. The hub was reinstalled for testing and accumulated 1300.7 hours prior to the next inspection. That inspection revealed the hub to be serviceable for further testing. The trunnion bearing races had, however, begun to show signs of surface fatigue. The hub was reinstalled and accumulated 1388.3 hours before the test was terminated. Inspection at 1388.3 hours revealed the hub to be still serviceable for testing.

b. S/N A2-695. This hub had operated 1100.6 hours in RVN prior to receipt. Inspection revealed that the hub was unserviceable for testing because of damaged trunnion bearings. One of the bearings had three rollers missing and one had five missing. At disassembly, several of the cracked rollers came loose from their pockets (figure 1). The trunnion bearing inner race was badly galled (figure 2). The bearing cage was not pressed out for inspection of the outer race.

c. S/N A2-1051. This hub had operated 1148.3 hours in RVN. Inspection revealed the hub to be unserviceable because of trunnion bearing race deterioration. The inner race on one trunnion spindle had a galled mark 0.875 inch longitudinally by 0.250 inch circumferentially (figure 3). No deterioration was evident in the roller bearings.

d. S/N G-135. This hub had operated 1081.0 hours in RVN. Inspection revealed the hub to be unserviceable because of trunnion bearing deterioration. One bearing had two rollers with approximately

0.25 inch cracked off. Both trunnion spindles were badly scored and galled.

e. S/N A2-705. This hub had operated 1098.1 hours in RVN. The hub was unserviceable for testing because of trunnion bearing deterioration. Inspection revealed that one of the trunnion spindles was badly scored and galled, and the mating roller bearing had one roller missing from the cage and two rollers with approximately 0.250 inch missing (figure 4).

f. S/N H1-252. This hub had operated 1099.0 hours in RVN. Inspection revealed the hub to be unserviceable because the trunnion spindles were badly galled and scored. None of the roller bearings were missing or appeared to be cracked.

g. S/N H1-311. This hub had operated 993.0 hours in RVN. Inspection revealed the hub to be unserviceable because of cracked strap retention pins. The pins were the old type, P/N 204-011-168-1. One of the pins had cracked completely (figures 5 and 6), while two of the remaining three had circumferential cracks (figure 7).

h. S/N A2-361. This hub had operated 866.0 hours in RVN. Inspection revealed this hub to be unserviceable because of trunnion bearing deterioration. Both trunnion spindles were badly galled and scored (figures 8 and 9), and several roller bearings were broken in both bearing housings (figure 10).

i. S/N A2-858. In addition to the above-mentioned hubs that were tested or received for testing in the TBO extension program, another hub, S/N A2-858, was inspected as typical of a low-operating-time hub. This hub had previously operated 324.4 hours at Fort Benning, Georgia, on a UH-1B and had been turned in to Atlanta General Depot as serviceable. The operating time at the USAAVNTBD was 207.9 hours for a total operating time of 532.3 hours. Inspection revealed that one trunnion spindle was galled (figure 11). The gall mark was located in the center of the maximum wear area on the inner race of the spindle (figure 12).

j. Discussion. Two factors might have contributed to deterioration of the hub trunnion bearings. One factor may be that the trunnion bearings are overloaded, leading to a failure of the inner race bearing surface. This would be supported by the early deterioration in hub, S/N A2-858, in the center of the maximum load area. Another factor might be inadequate lubrication. The following four factors would support the theory that the deterioration of the bearings is associated with a lubrication problem:

(1) Hub, S/N A2-1340, operated a total of 1388.3 hours at the USAAVNTBD with the helicopter lifting off each hour at maximum gross weight (8,600 pounds) and flying profiles to simulate RVN missions. After the 1388.3 hours, the trunnion bearings were serviceable.

(2) Four of the reservoirs on the RVN hubs showed evidence of leakage.

(3) The reservoirs on the hubs from RVN contained evidence of contamination.

(4) The transparent plastic of which the reservoir is made was discolored on all hubs, making it quite difficult or even impossible for organizational maintenance personnel to inspect the lubrication level adequately.

k. USAADMAC Data. Data were collected from USAADMAC on 177 main-rotor hubs, P/N 204-011-101-9, which had been returned for overhaul. This included all -9 hubs received in CY 1965. Assuming the removals for unknown reasons to follow the same general distribution as the other removals prior to TBO, and discounting the externally caused failures, approximately 22 percent of the components achieved the 1100-hour TBO. Seventy-two percent of the main-rotor hubs returned to USAADMAC for inherent problems (i.e., problems not caused by external factors such as crash or battle damage, etc.) prior to TBO was due to seal deterioration; thus, seal deterioration was a primary cause of the low percentage achieving the 1100-hour TBO. Approximately 22 percent of the hubs returned for inherent problems prior to TBO was due to trunnion bearing deterioration. The mean time to trunnion bearing failure was 569.0 hours with the failures ranging between 107.0 and 995.5 hours.

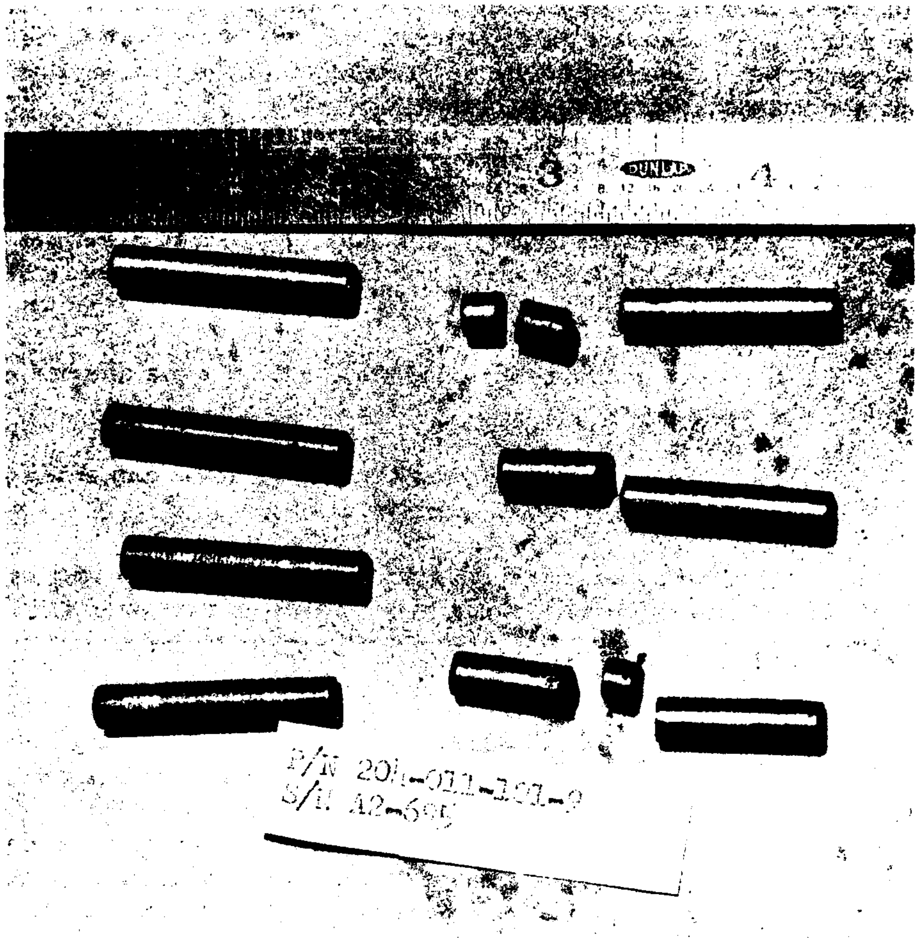


Figure 1. Dislodged and broken roller bearings (main-rotor hub, S/N A2-695, 1100.6 operating hours).

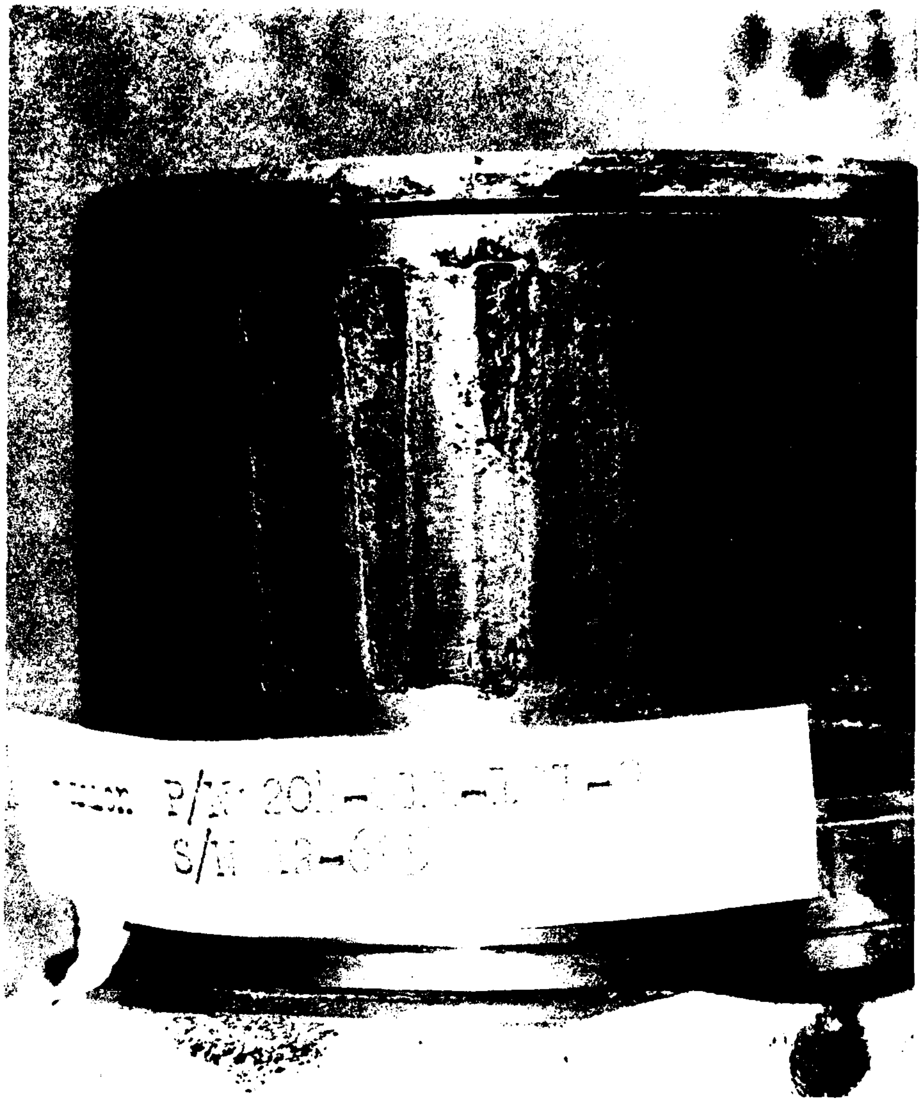


Figure 2. Galling of trunnion bearing inner race. (Main-rotor hub, S/N A2-695, 1100.6 operating hours.)

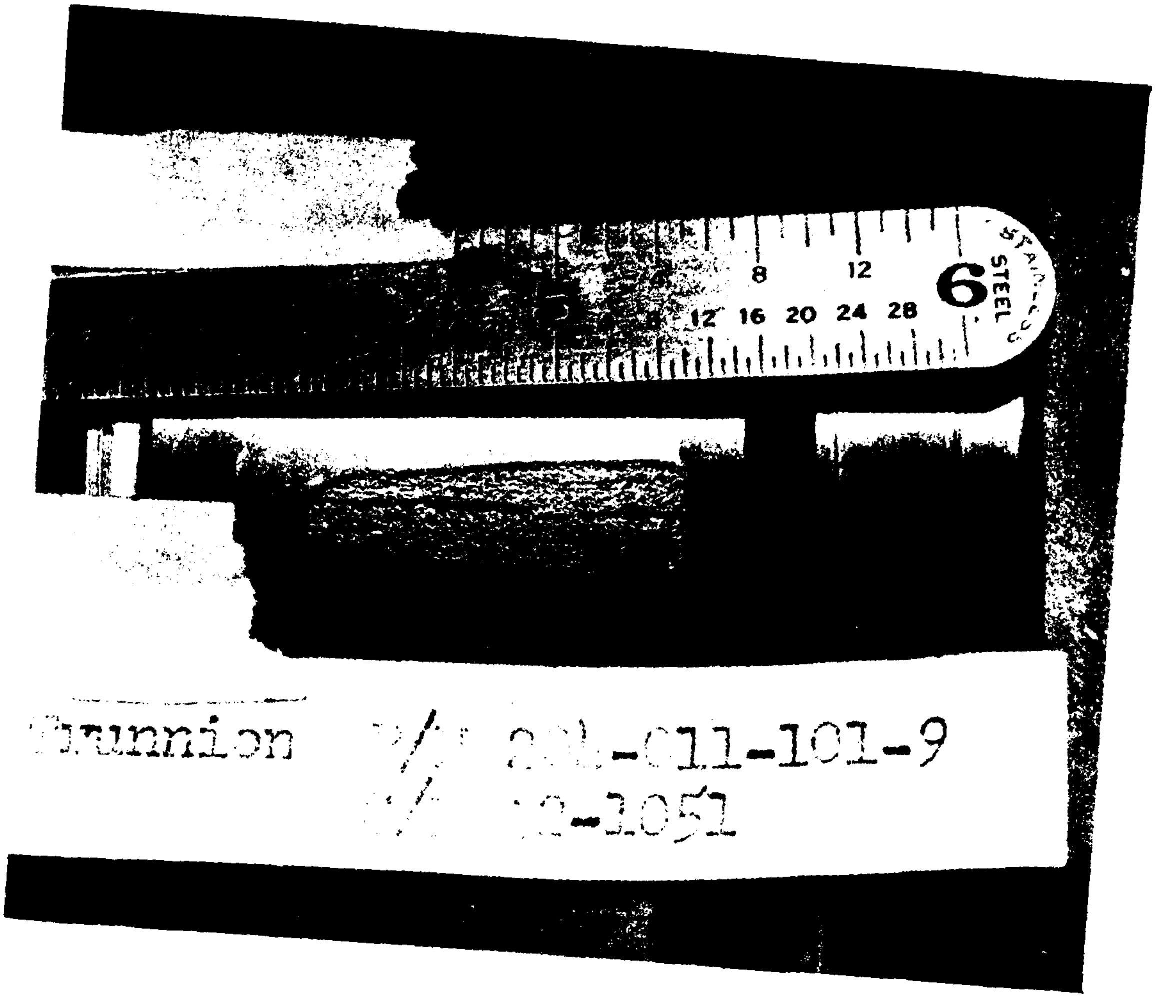


Figure 3. Galling of trunnion bearing inner race. (Main-rotor hub, S/N A2-1051, 1148.3 operating hours.)

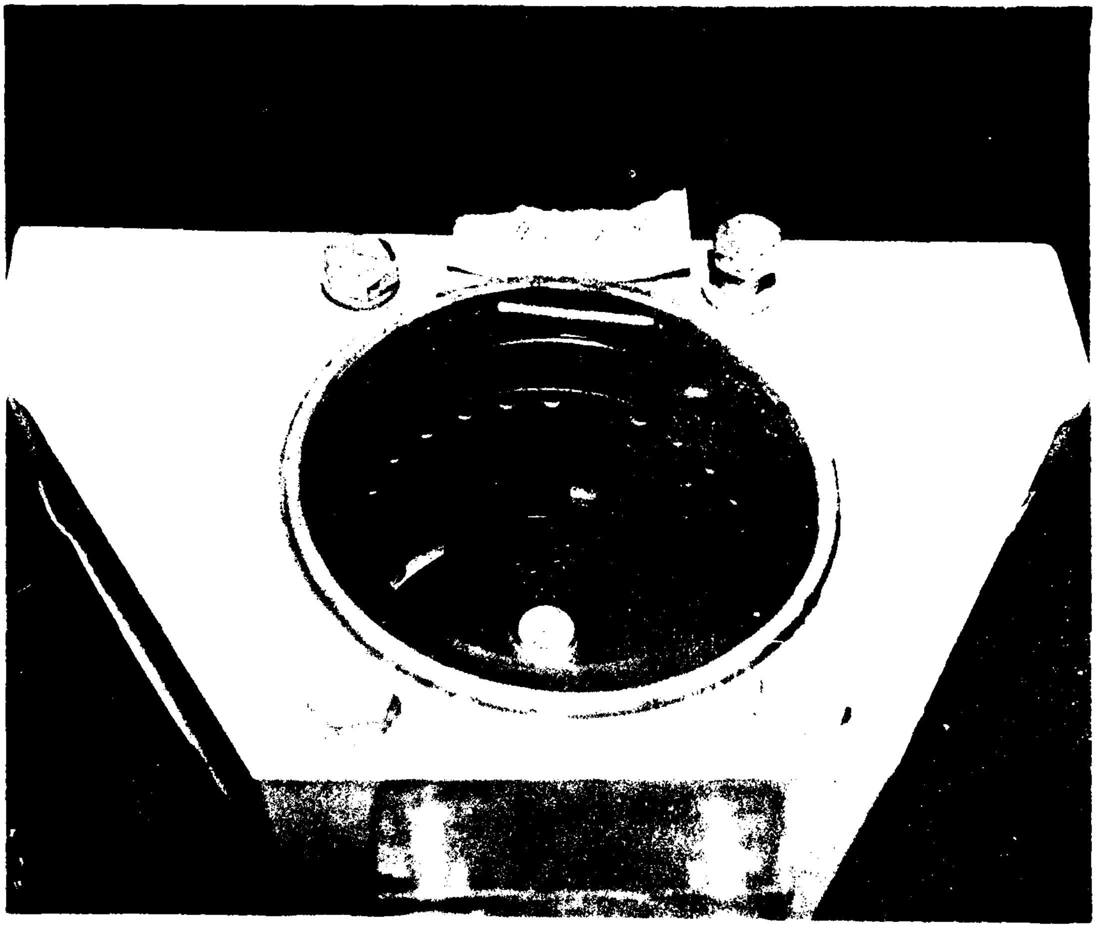


Figure 4. Damaged trunnion bearing rollers. (Main-rotor hub, S/N A2-705, 1098.1 operating hours.)

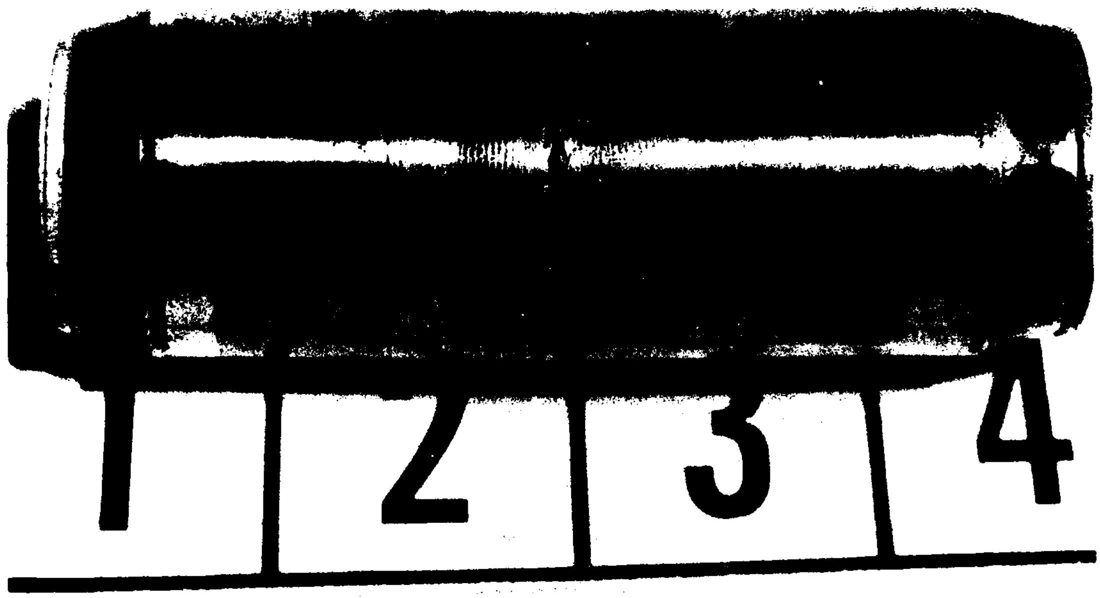


Figure 5. Cracked strap retention pin. (Main-rotor hub, S/N H1-311, 993.0 operating hours.)

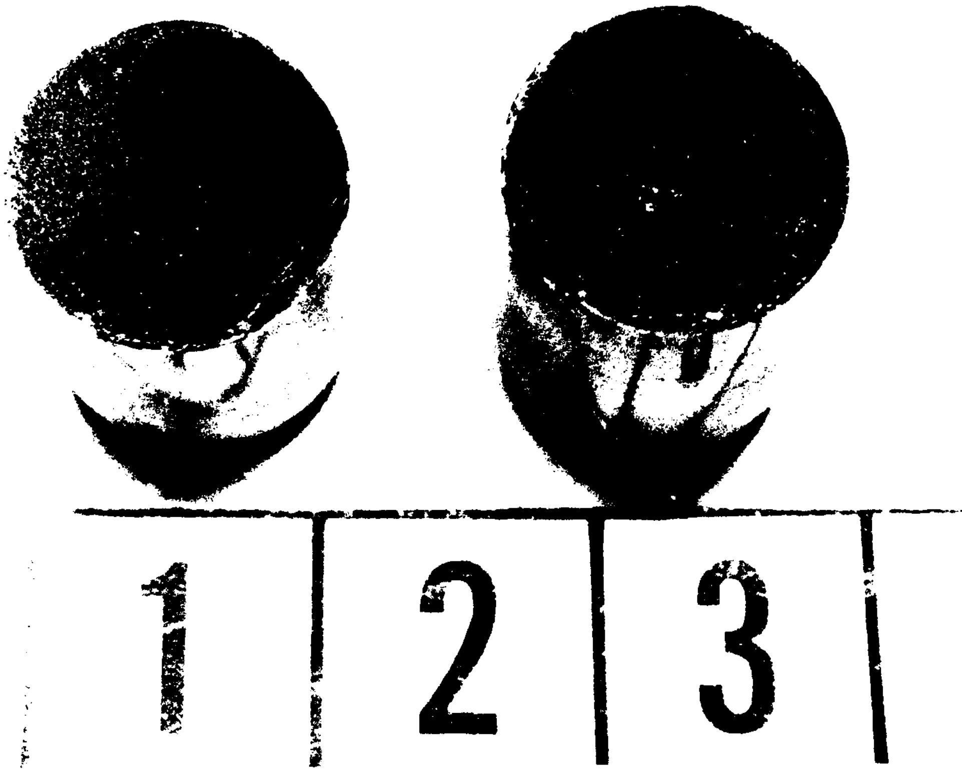


Figure 6. Cross section of cracked retention pin. (Main-rotor hub, S/N H1-311, 993.0 operating hours.)

Figure 7. Circumferential cracks in strap retention pin. (Main-rotor hub, S/N H1-311, 993.0 operating hours.)

Figure 8. Galled trunnion bearing inner race. (Main-rotor hub, S/N A2-361, 866.0 operating hours.)

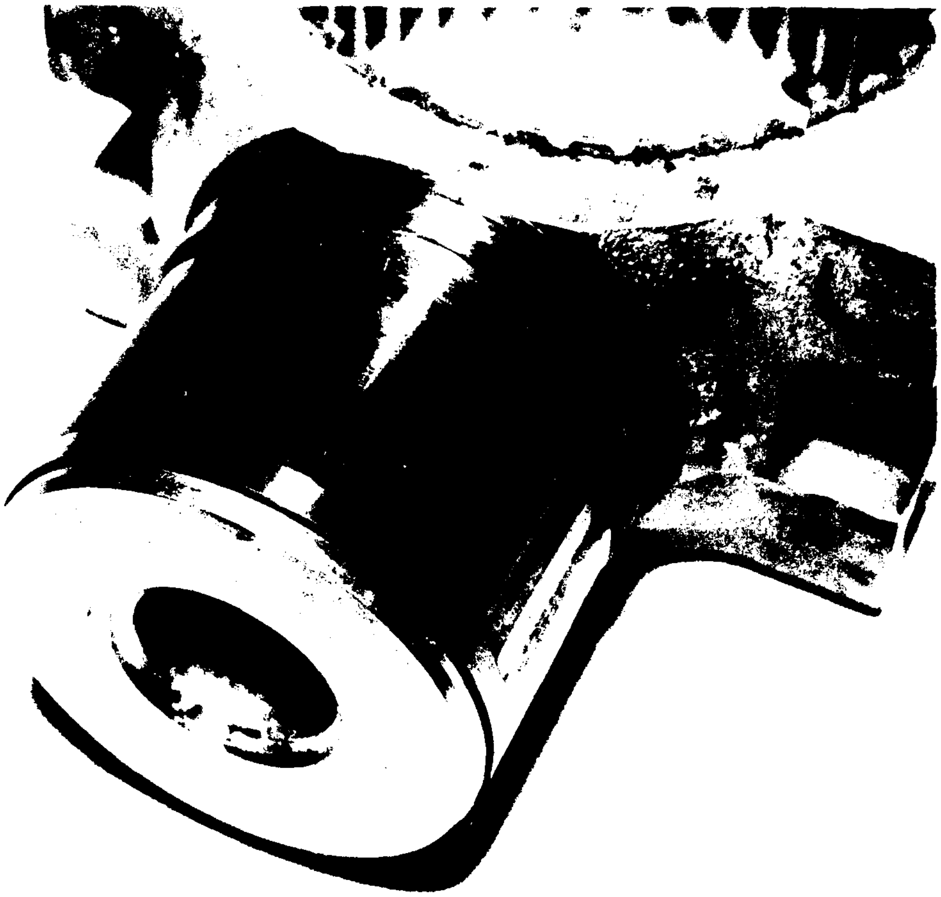


Figure 9. Galled trunnion bearing inner race. (Main-rotor hub, S/N A2-361, 866.0 operating hours.)

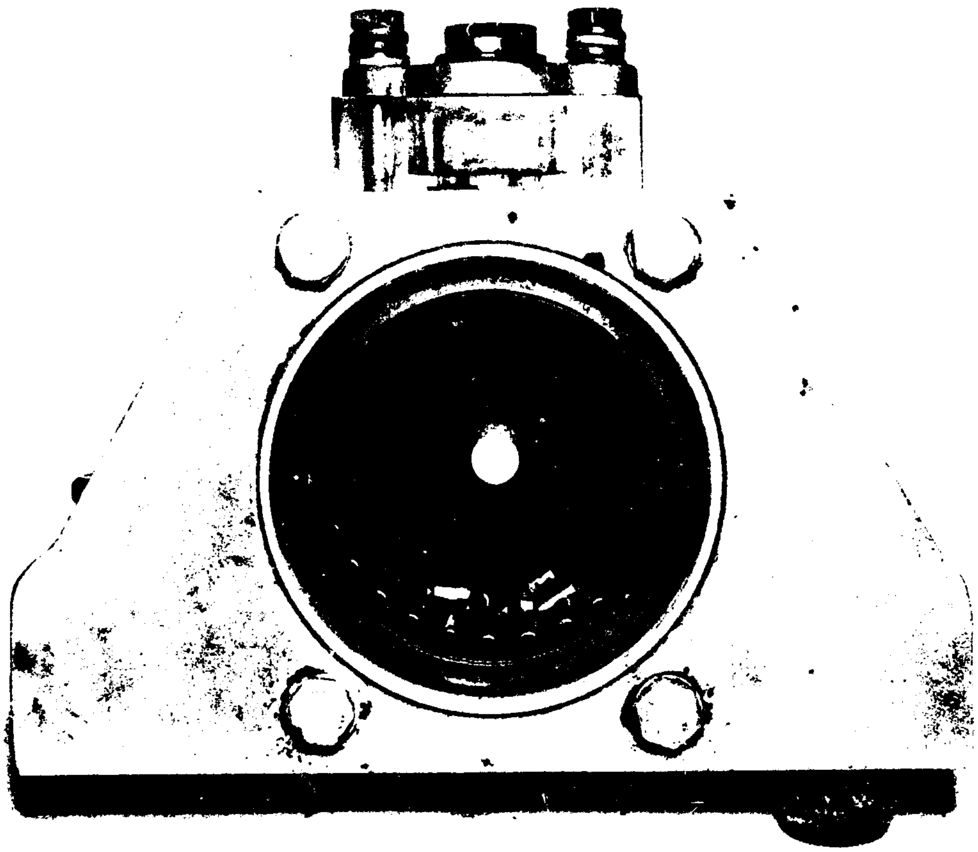


Figure 10. Broken roller bearings. (Main-rotor hub, S/N A2-361, 866.0 operating hours.)

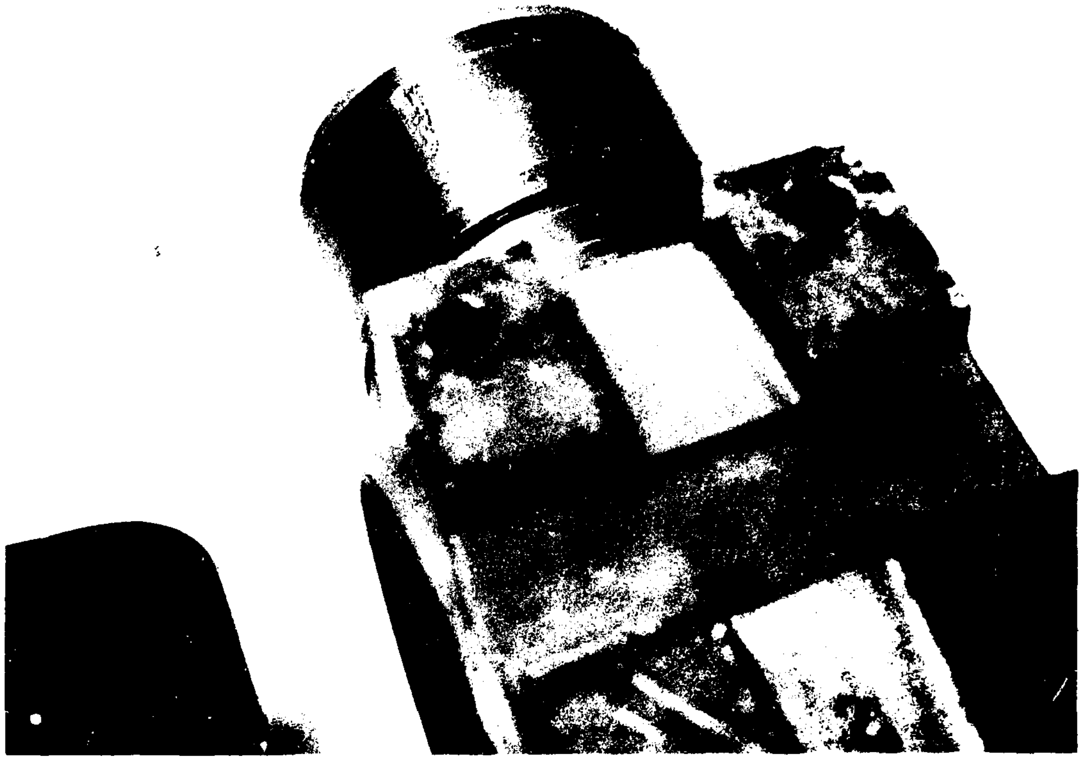
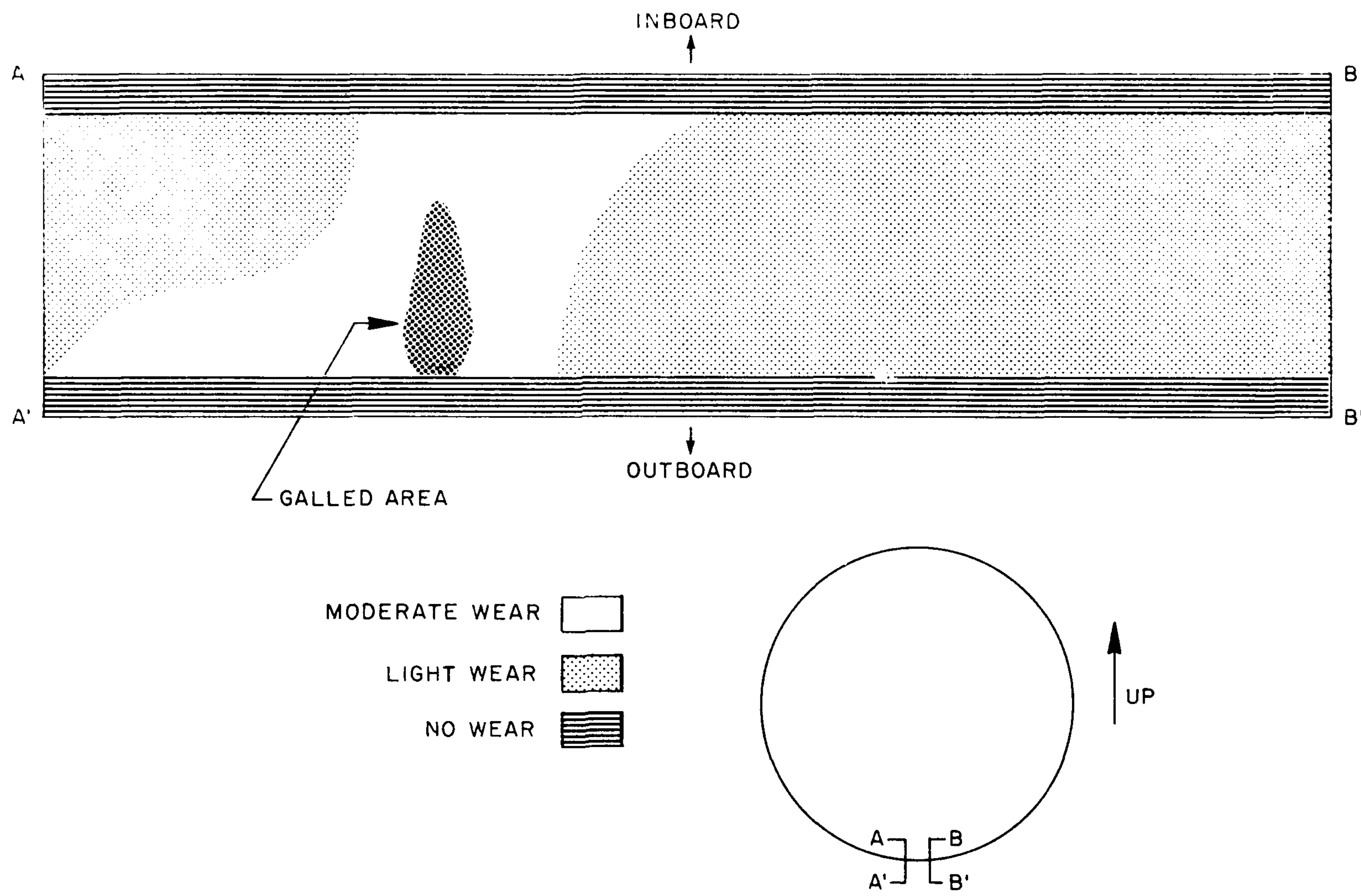


Figure 11. Galled trunnion bearing inner race. (Main-rotor hub, S/N A2-858, 532.3 operating hours.)



AREA OF GALLING ON MAIN ROTOR HUB S/N A2-858

Figure 12.

2. Intermediate (42-Degree) Gearbox, FSN 1560-776-1626, P/N 204-040-003-23.

a. S/N B13-1431. This gearbox had operated 1100.0 hours in RVN. The gearbox was inspected and photographed (figures 13, 14, 15, and 16). Gear wear and backlash patterns are shown in figure 17. The bearings were somewhat rough; however, the gearbox was considered serviceable for testing and was installed on the test aircraft. After accumulating 1199.9 hours, the gearbox was again inspected. No change in the wear or backlash pattern had occurred, and the bearings now rotated smoothly. The gearbox was reinstalled on the test aircraft. After accumulating 1301.9 hours, the gearbox was again inspected. No appreciable change in the wear or backlash pattern had occurred since the initial inspection. The bearings turned smoothly. The gearbox was still serviceable after 1301.9 operating hours.

b. S/N B13-1411. This gearbox had operated 1099.0 hours in RVN. The gearbox was inspected and photographed (figures 18, 19, 20, and 21). Gear wear and backlash patterns are shown in figure 22. The bearings turned smoothly. A slight indentation was present on the top of one of the input gear teeth at the concave edge; however, the gearbox was considered serviceable for testing and was installed on the test aircraft. After accumulating 1200.9 hours, the gearbox was again inspected. No appreciable change in the wear or backlash pattern had occurred. The indentation observed at 1099.0 hours had not changed. Two more of the input gear teeth developed indentations on the top concave edge. On one of the gear teeth of the output gear, a small bump or protrusion had developed on the outboard concave side. The protrusion was detectable by touch and was approximately 0.062 inch in diameter. All bearings turned smoothly. The gearbox was serviceable for continued testing and was reinstalled. After accumulating 1310.4 hours, the gearbox was again removed for inspection. The wear and backlash patterns had not changed. The indentations were still present on the input gear teeth, but had not changed in any way since the previous inspection. The protrusion discovered on one of the output gear teeth at the 1200-hour inspection appeared to have worn smooth, although it could still be seen. The bearings turned smoothly. The gearbox was still serviceable after 1310.4 hours.

c. S/N B13-1127. This gearbox had operated 1089.0 hours in RVN. Both the input and the output bearings rotated smoothly. Figures 23, 24, 25, and 26 show the gears prior to testing. Figure 27 shows sketches of the wear and backlash patterns of both gears prior to beginning of test. One input gear tooth was slightly chipped on the concave edge near the outboard end of the tooth. The gearbox, however, was considered serviceable for testing. After accumulating 1186.3 hours, the gearbox was again inspected. The wear and backlash patterns on the output gear and the backlash pattern on the input gear had not changed since the 1089-hour inspection; however, additional areas of light wear had appeared on the concave (load) side of the input gear (figure 28). The chip on the concave edge of one of the input gear teeth was still present, but had not progressed since the previous inspection. In addition, four other input gear teeth had developed slight chips on the outboard convex edge. The input and output quills rotated smoothly and the gearbox was considered serviceable for further testing. After accumulating 1301.5 hours, the gearbox was again inspected. The input and output quill bearings operated smoothly. The wear and backlash patterns on the output gear and the backlash pattern on the input gear had not changed. The uneven wear pattern observed on the concave (load) side of the input gear teeth at 1186.3 hours had smoothed out so that the wear pattern was more uniform (figure 29). The small depression on the concave outboard edge of the input gear was still present, but had not progressed. The depressions on the convex outboard edges were still present on two of the input gear teeth; however, the depressions that had existed on two other gear teeth at 1186.3 hours appeared to have worn smooth. The gearbox was still serviceable at 1310.5 hours.

d. S/N B13-1371. This gearbox had operated 1081.0 hours in RVN. Figures 30, 31, 32, and 33 show the gears as received. The bearings of both quills rotated smoothly. The wear and backlash patterns that were present on the teeth at 1081.0 hours are displayed in figure 34. One input gear tooth had a pit on the top near the convex edge approximately 0.062 inch in diameter. The gearbox was considered serviceable for testing and accumulated 1181.4 hours prior to the next inspection. At the 1181.4-hour inspection, the bearings in both quills turned smoothly. No change in wear or backlash patterns on the output gear teeth had occurred since the 1081-hour inspection; however, some change had occurred to the input gear teeth (figure 35). The pit that was present on the top of one of the input gear teeth at the 1081-hour inspection was no longer present. The gearbox was considered serviceable for further testing. After accumulating 1309.9 hours, the gearbox was again inspected. No change in wear or backlash patterns had occurred, and no discrepancies were observed. Both quills were somewhat tighter in rotation than before; however, no roughness was present and the gearbox was considered serviceable.

e. S/N B13-1277. This gearbox had operated 1071.0 hours in RVN. Figures 36, 37, 38, and 39 show the gear teeth prior to test. Both the input and output quills turned smoothly. The wear and backlash patterns on both the input and output gear teeth are shown in figure 40. One output gear tooth had a small hole in the top. Four other teeth were pitted on the top, and another tooth had a depression on the top convex edge approximately 0.031 inch from the outboard end. The gearbox, however, was considered serviceable for testing. After accumulating 1211.4 hours, the gearbox was again inspected. The wear pattern on the concave (load) side of the input gear had not changed since the 1071-hour inspection; however, the backlash pattern on the convex side had enlarged substantially (figure 41). The wear and backlash patterns on the output gear teeth had not changed. The hole in the top of one of the teeth and the pitting on the top of the other four teeth were still present but had not changed. The depression on the top convex edge of one tooth (observed at the 1071-hour inspection) had worn smooth and appeared to be a scuff mark. The output quill bearings rotated smoothly; however, the input quill bearings had a rough spot when rotated. Oil analysis had shown a slight rise in iron prior to the 1211.4-hour inspection; however, neither the level nor the rate of increase of iron was considered significant. The gearbox was reassembled and flushed with fresh oil. Flushing the gearbox eliminated the roughness. The flushed oil was filtered, and the sediment was microscopically examined. No metal particles were observed. The gearbox was considered serviceable for further testing and was reinstalled. After accumulating 1307.4 hours, the gearbox was again inspected. No change in the wear or backlash patterns had occurred since the 1211.4-hour inspection. A straight diagonal line was present on the convex (load) side of several of the output gear teeth. Dye-penetrant inspection revealed no crack. The line was probably produced during reassembly of the gearbox after the 1211.4-hour inspection, possibly by forcing the gears together prior to meshing. The output quill bearings turned smoothly; however, a slight roughness was detectable in the input quill. The roughness was not of such a degree as to affect the serviceability of the gearbox; therefore, the component was considered serviceable after accumulating 1307.4 hours.

f. S/N B13-2931. This gearbox was previously operated 1101.9 hours on UH-1B/540, S/N 64-14104, during the Phase F testing at the USAAVNTBD. The gearbox was inspected prior to test and the gear teeth were photographed (figures 42 and 43). The wear and backlash patterns present at 1101.9 hours are shown in figure 44. The bearings were somewhat tight in rotation; however, no roughness was found. The gearbox was considered serviceable for testing. After accumulating 1203. 0 hours, the gearbox was again inspected. The bearings in both quills rotated smoothly, and the tightness observed at the 1101. 9-hour inspection was not present. The only change in wear and backlash patterns was in the wear pattern on the input gear teeth. The new pattern is shown in figure 45. The gearbox was considered serviceable for further testing and after accumulating 1310. 9 hours was again inspected. No change in wear or backlash patterns had occurred since the 1203-hour inspection, and the bearings in both quills still rotated smoothly. The gearbox was considered serviceable after accumulating 1310. 9 hours.

g. USAADMAC Data. Data were collected from USAADMAC on 221 42-degree gearboxes, P/N 204-040-003-23, in support of the logistical evaluation (Phase F) of the UH-1D Helicopter at high gross weight, USATECOM Project No. 4-3-0150-15. The analysis of that data was reported in the final report of the above-mentioned project; however, due to its relevance to this project, the information is repeated:

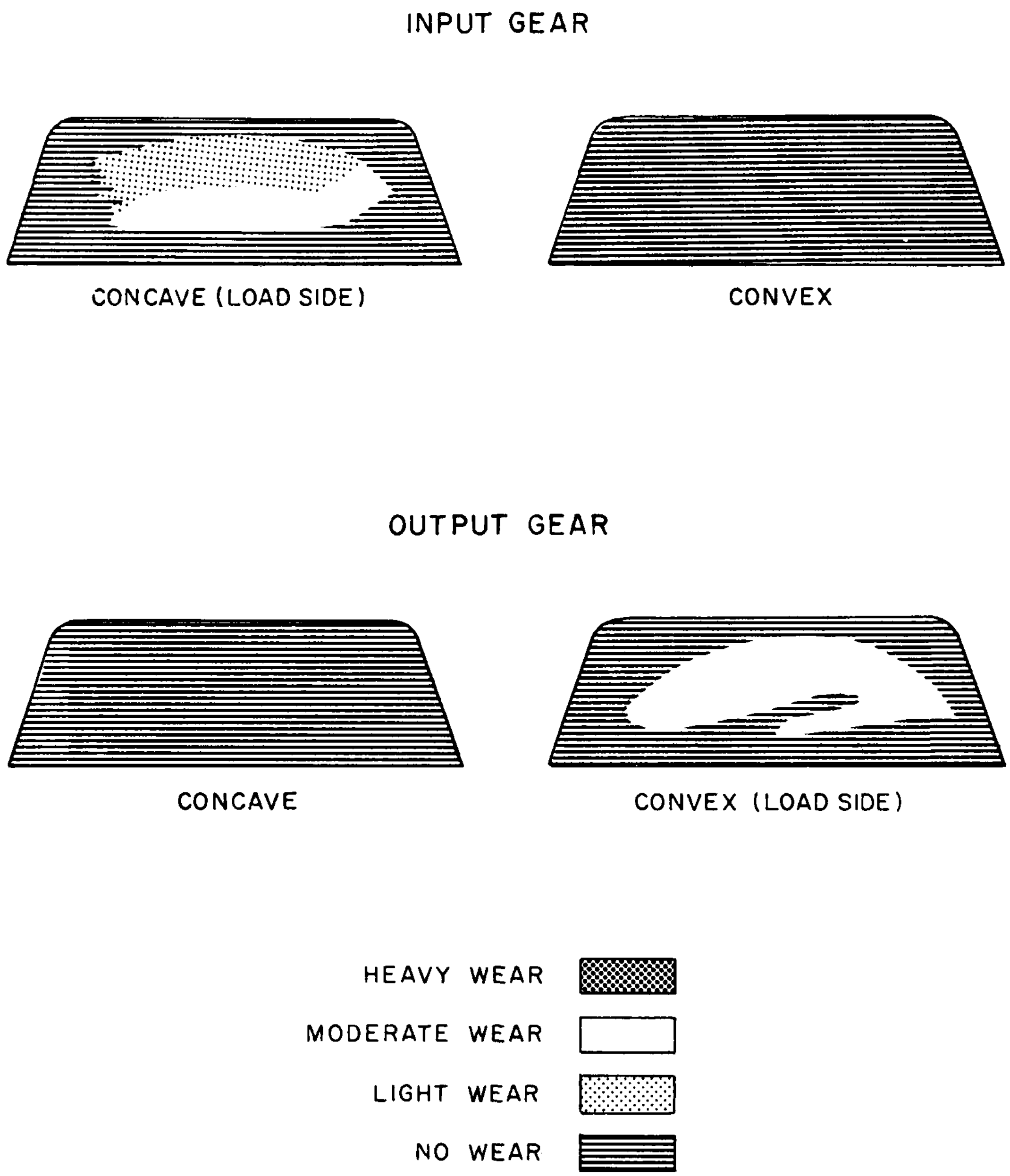
The mean time to removal for all causes was 748 hours. Assuming the removals for unknown reasons to follow the same general distribution as the other removals prior to TBO, and discounting the externally caused failures, approximately 56 percent of the components achieved the 1100-hour TBO. Seventy-five percent of the gearboxes returned to USAADMAC for inherent gearbox problems (inherent problems defined as problems not caused by external factors such as crash or battle damage, etc.) prior to TBO was due to seal deterioration; thus, seal deterioration was the primary reason for a low percentage achieving the 1100-hour TBO. The seal failures ranged from 1. 0 hour to 859. 0 hours with a mean time to failure of 424. 0 hours. There are two seals in the gearbox. One seal, P/N 204-040-611-1, can be replaced at direct-support maintenance or above, while the technical manual (-35P) requires that the other, P/N 45-185H60 be replaced at depot maintenance.

Figure 13. Convex side of input gear teeth. (42-degree gearbox, S/N B13-1431, 1100.0 operating hours.)

Figure 14. Concave side of input gear teeth. (42-degree gearbox, S/N B13-1431, 1100.0 operating hours.)

Figure 15. Concave side of output gear teeth. (42-degree gearbox, S/N B13-1431, 1100.0 operating hours.)

Figure 16. Convex side of output gear teeth. (42-degree gearbox, S/N B13-1431, 1100.0 operating hours.)



42° GEAR BOX, S/N B13-1431, 1100.0 HOURS

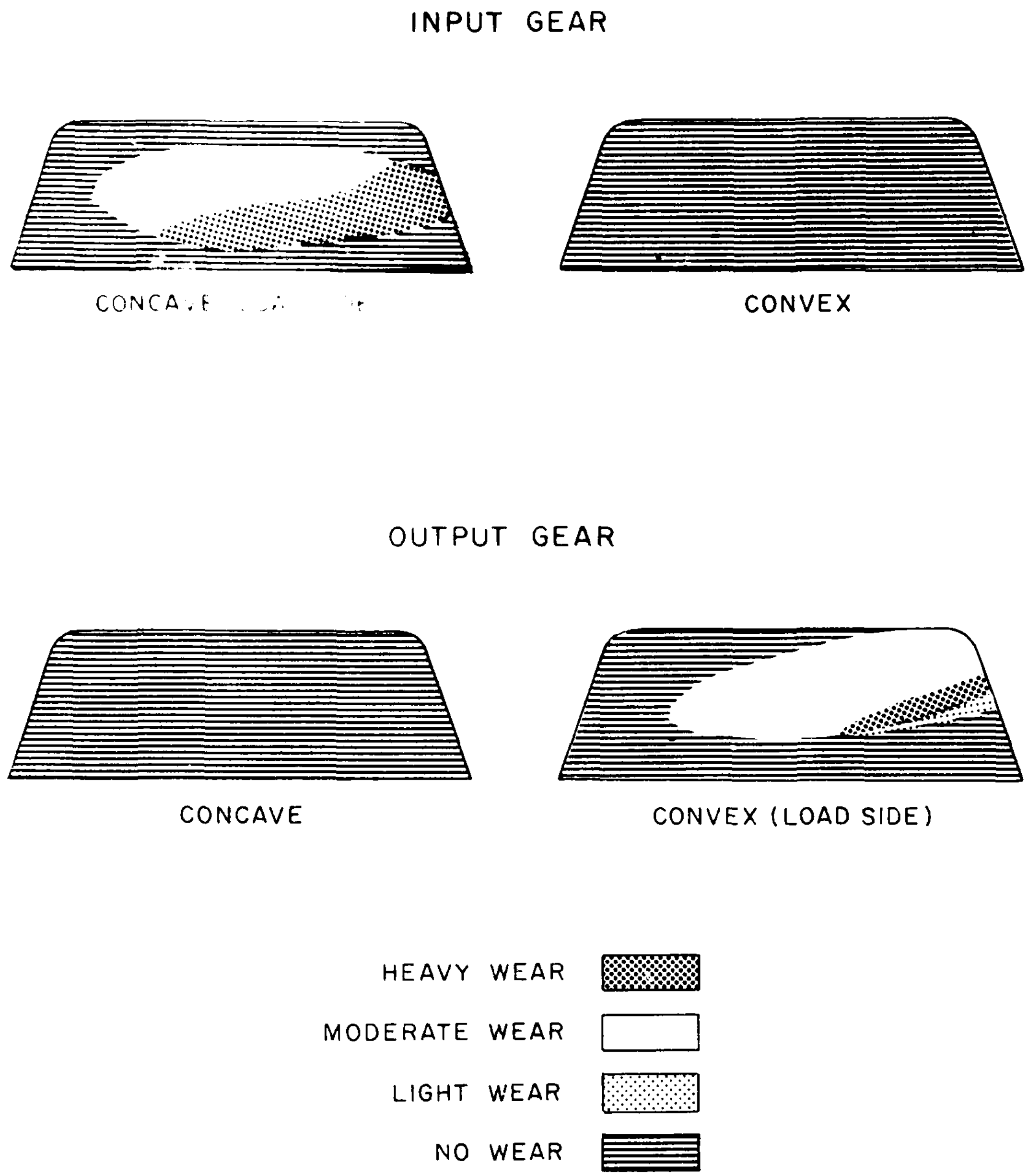
Figure 17.

Figure 18. Convex side of input gear teeth. (42-degree gearbox, S/N B13-1411, 1099.0 operating hours.)

Figure 14. Concave side of input gear teeth. (42 degree gearbox, S/N B13-1411, 1099.0 operating hours.)

Figure 20. Concave side of output gear teeth. (42-degree gearbox, S/N B13-1411, 1099.0 operating hours.)

Figure 21. Convex side of output gear teeth. (42-degree gearbox, S/N B13-1411, 1099.0 operating hours.)



42° GEAR BOX, S/N B13-1411, 1099.0 HOURS

Figure 22.

Figure 23. Convex side of input gear teeth. (42-degree gearbox, S/N B13-1127, 1089.0 operating hours.)

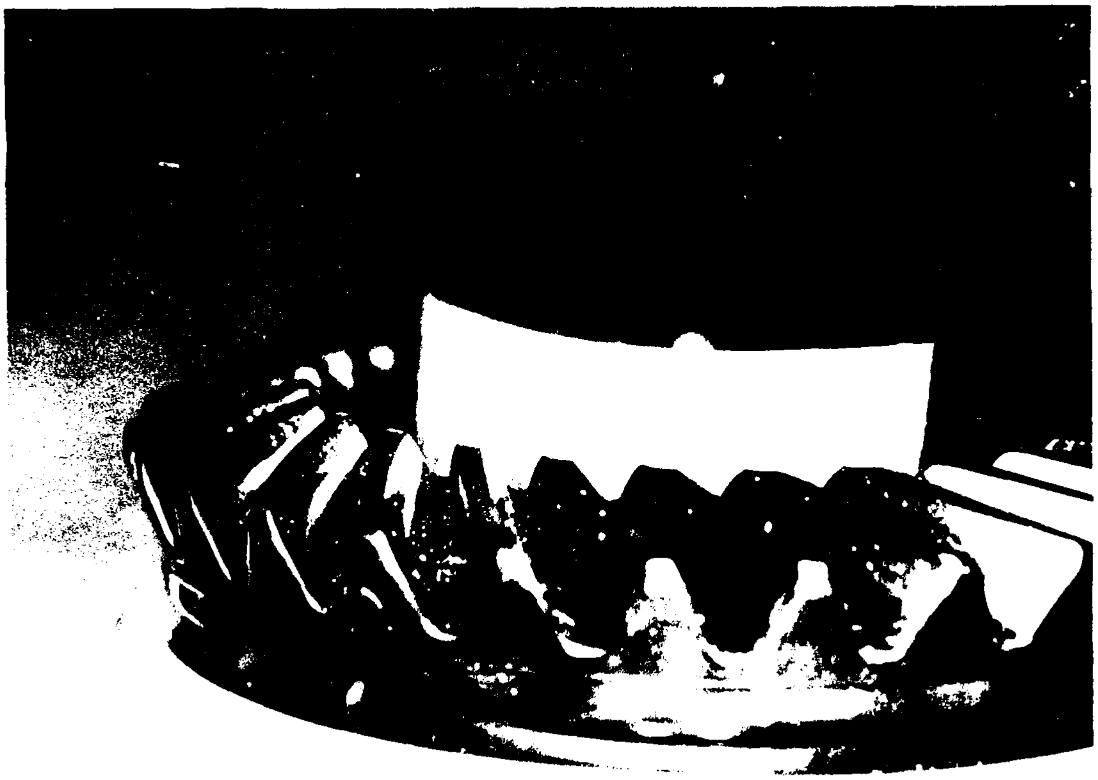


Figure 24. Concave side of input gear teeth. (42-degree gearbox, S/N B13-1127, 1089.0 operating hours.)

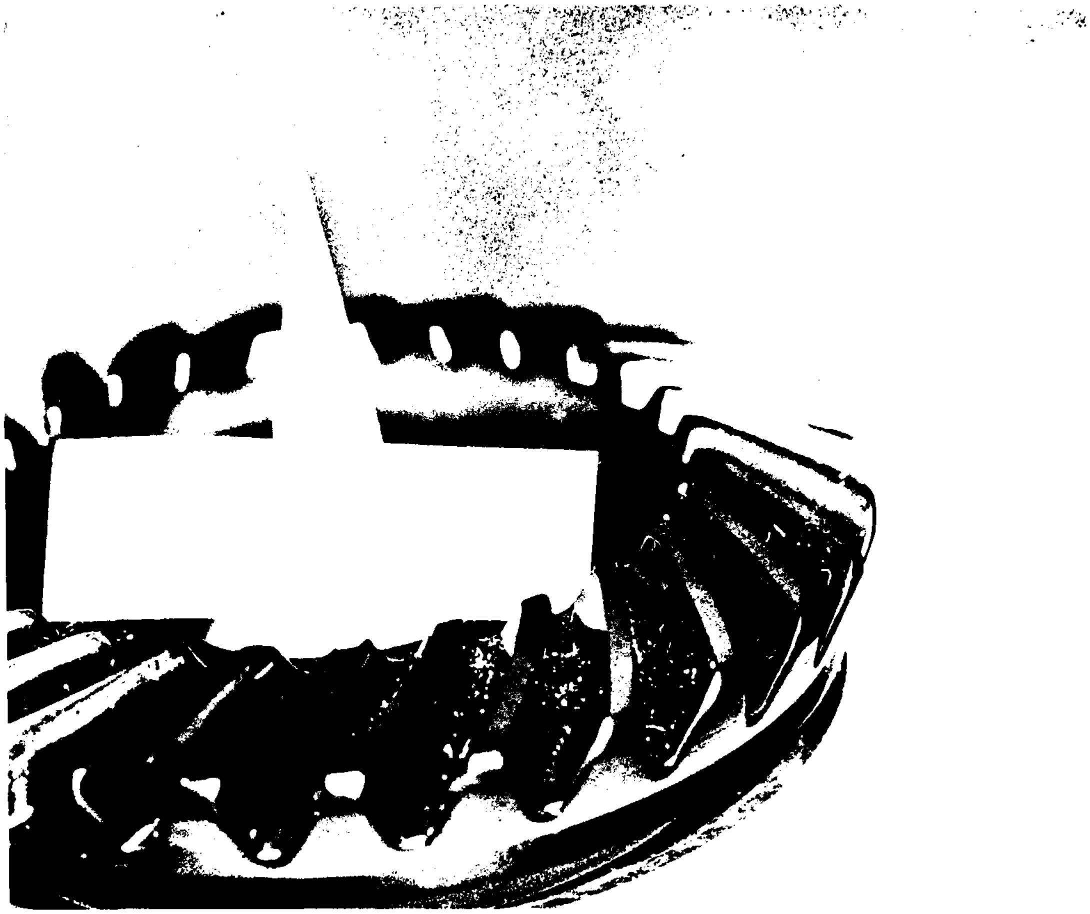


Figure 25. Concave side of output gear teeth. (42-degree gearbox, S/N B13-1127, 1089.0 operating hours.)

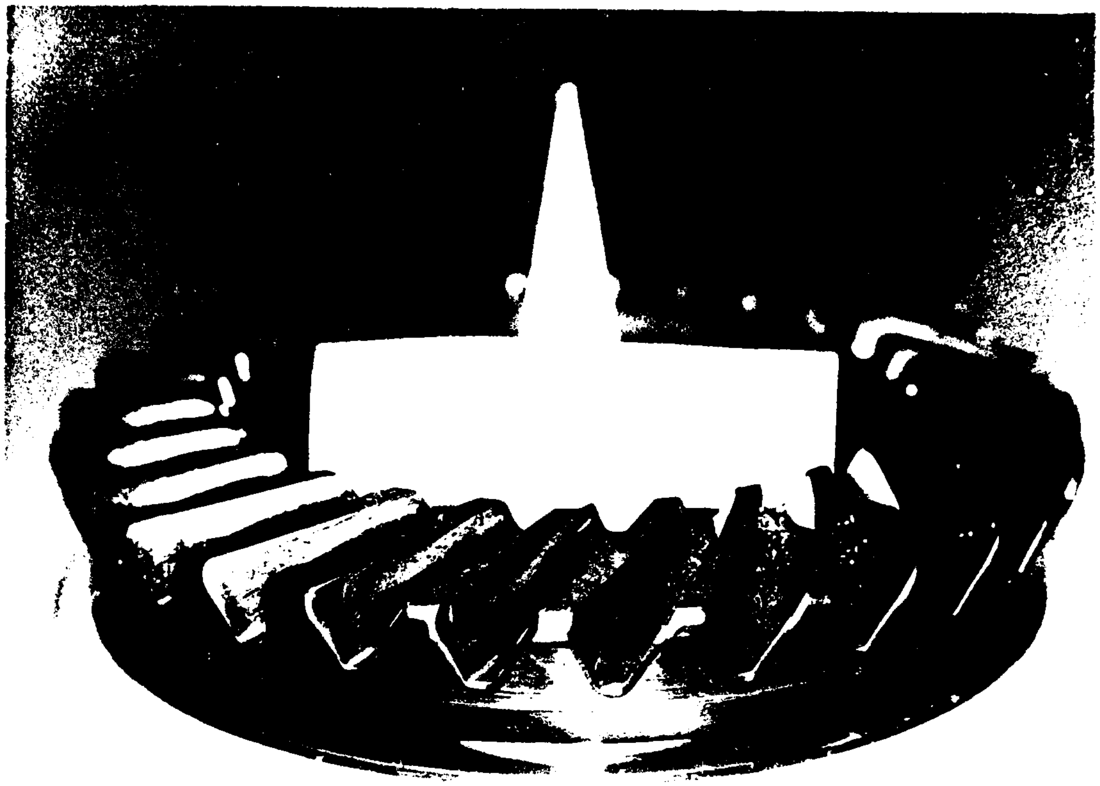
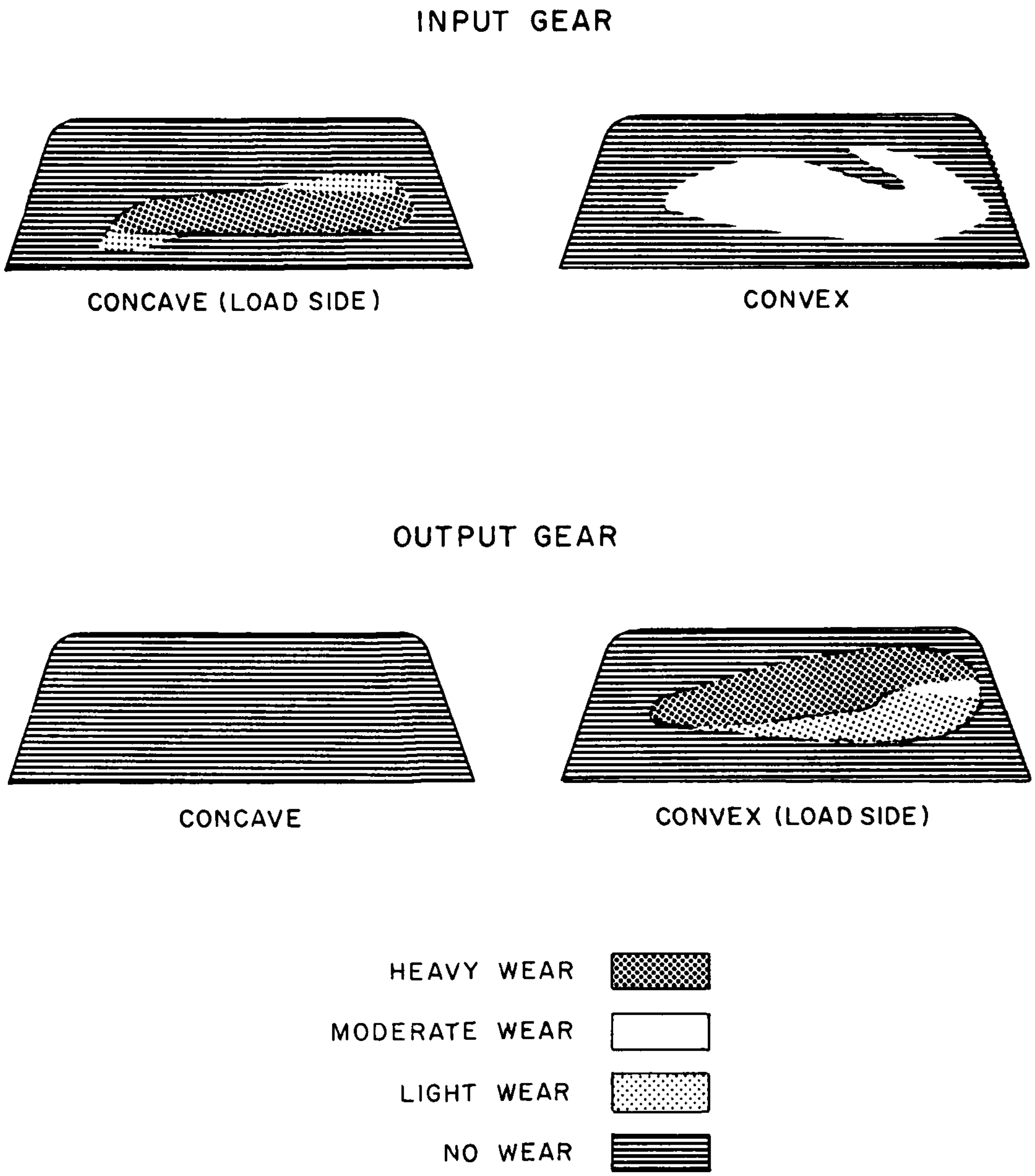


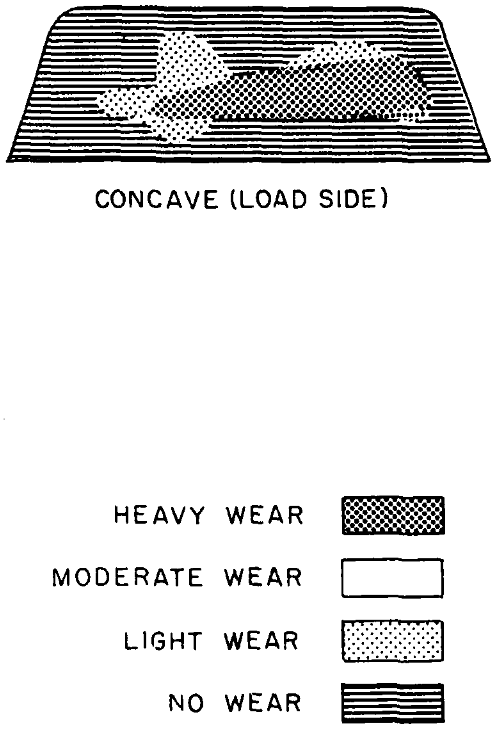
Figure 26. Convex side of output gear teeth. (42-degree gearbox, S/N B13-1127, 1089.0 operating hours.)



42° GEAR BOX, S/N B13-1127, 1089.0 HOURS

Figure 27.

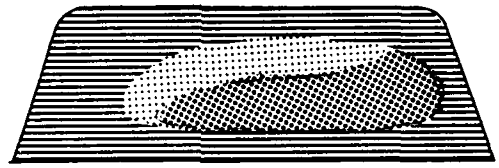
INPUT GEAR



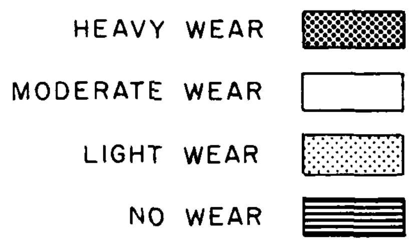
42° GEAR BOX, S/N B13-1127, 1186.3 HOURS

Figure 28.

INPUT GEAR



CONCAVE (LOAD SIDE)



42° GEAR BOX, S/N B13-1127, 1301.5 HOURS

Figure 29.

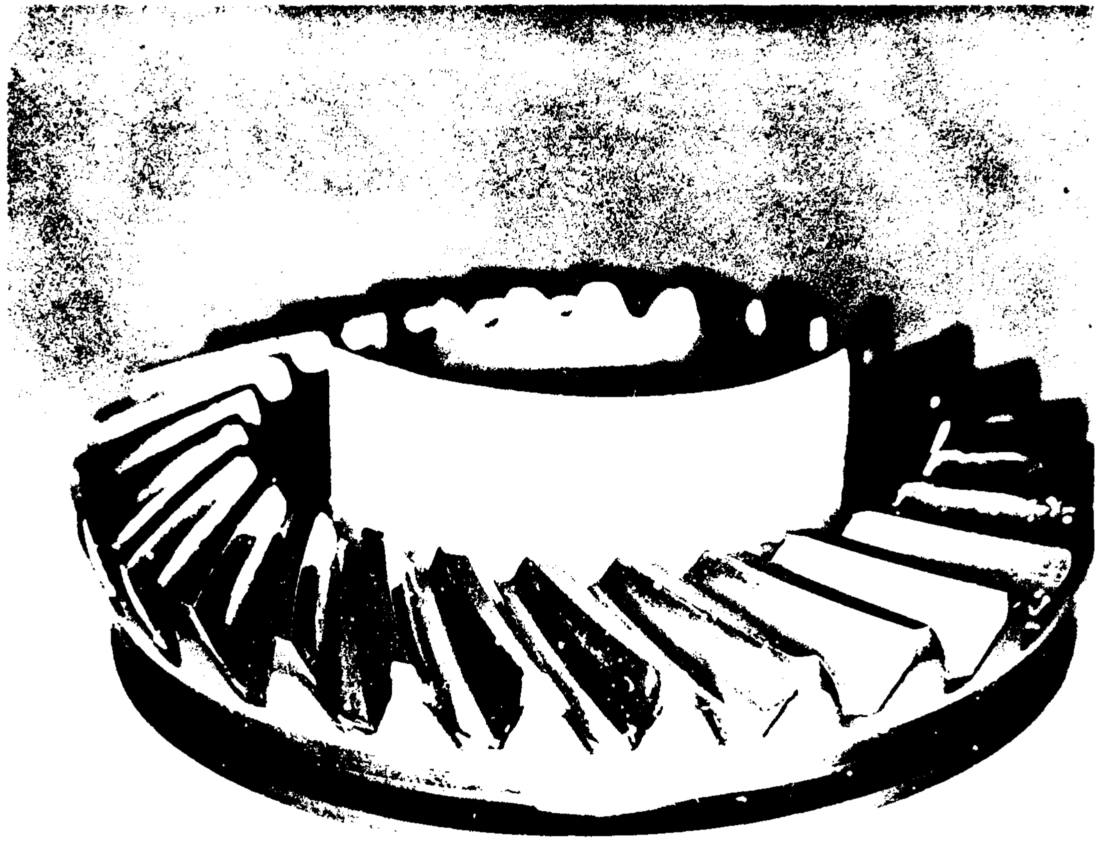


Figure 30. Convex side of input gear teeth. (42-degree gearbox, S/N B13-1371, 1081.0 operating hours.)

Figure 31. Concave side of input gear teeth. (42-degree gearbox, S/N B13-1371, 1081.0 operating hours.).

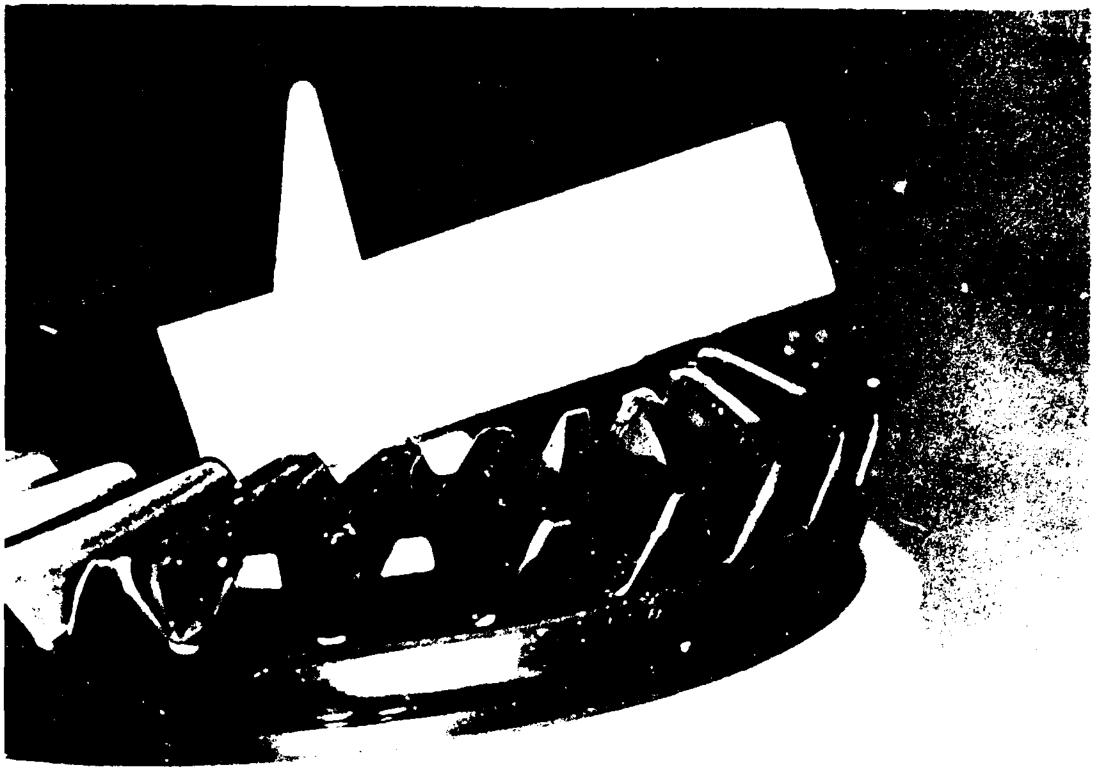


Figure 32. Concave side of output gear teeth. (42-degree gearbox, S/N B13-1371, 1081.0 operating hours.)

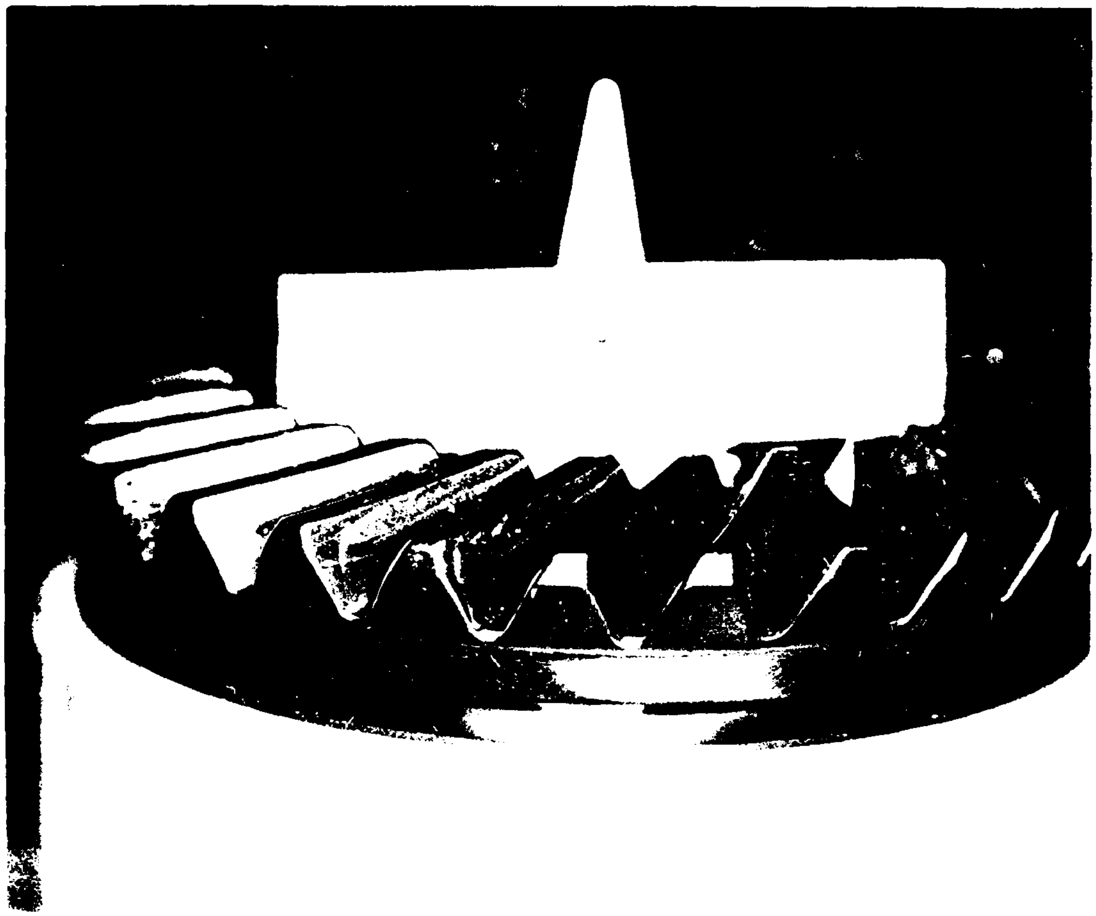
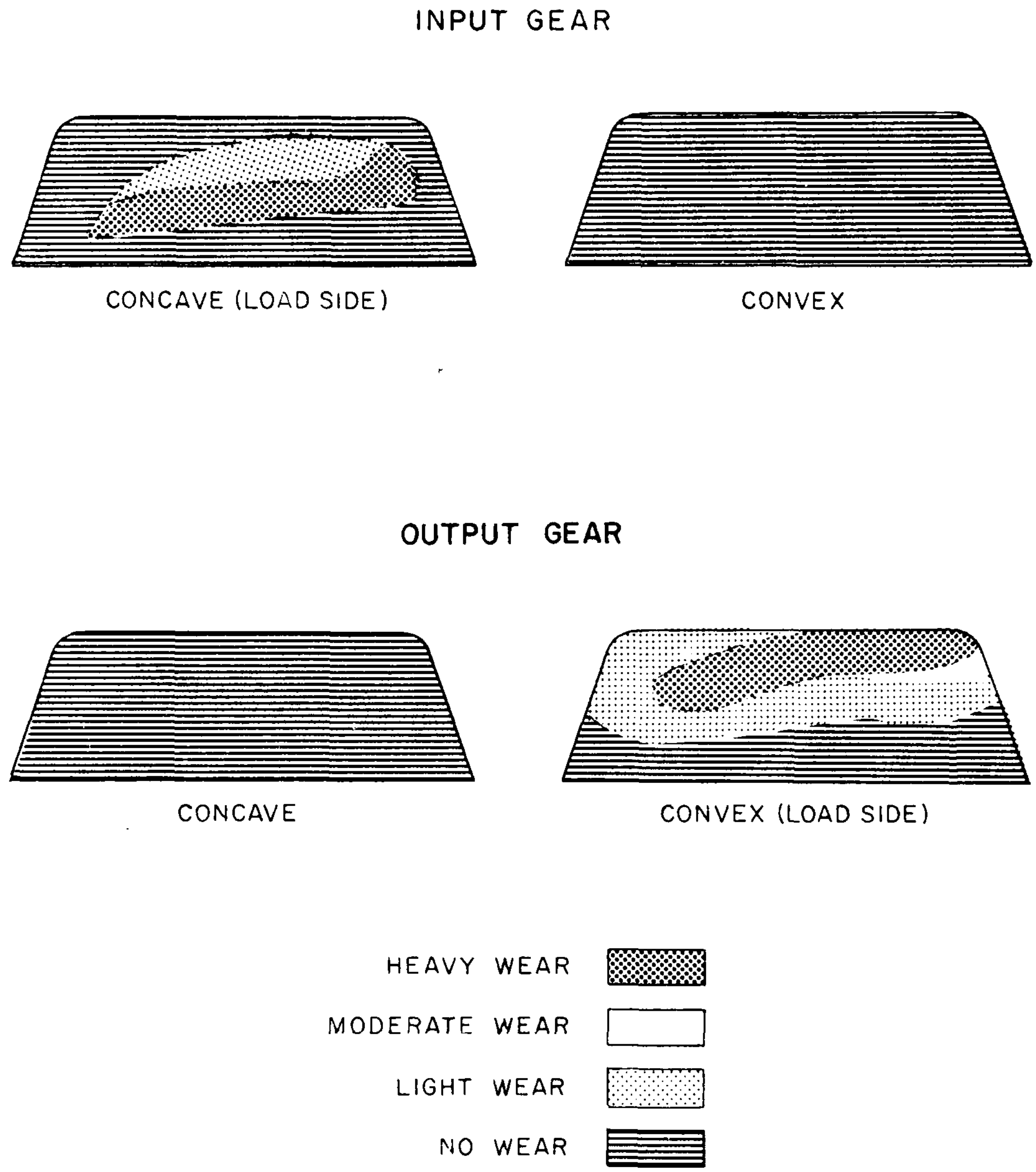


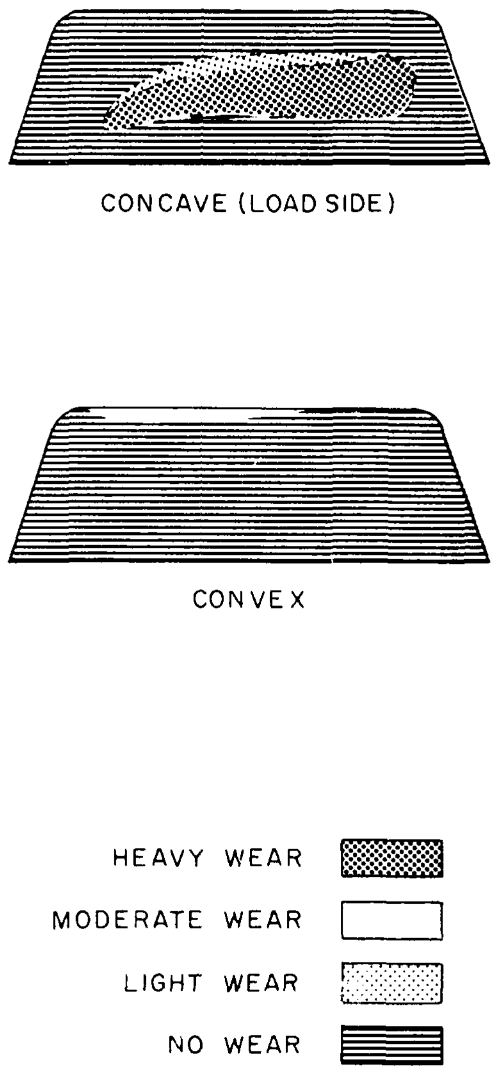
Figure 33. Convex side of output gear teeth (42-degree gearbox, S/N B13-1371, 1081.0 operating hours.)



42° GEAR BOX, S/N B13-1371, 1081.0 HOURS

Figure 34.

INPUT GEAR



42° GEAR BOX, S/N B13-1371, 1181.4 HOURS

Figure 35.

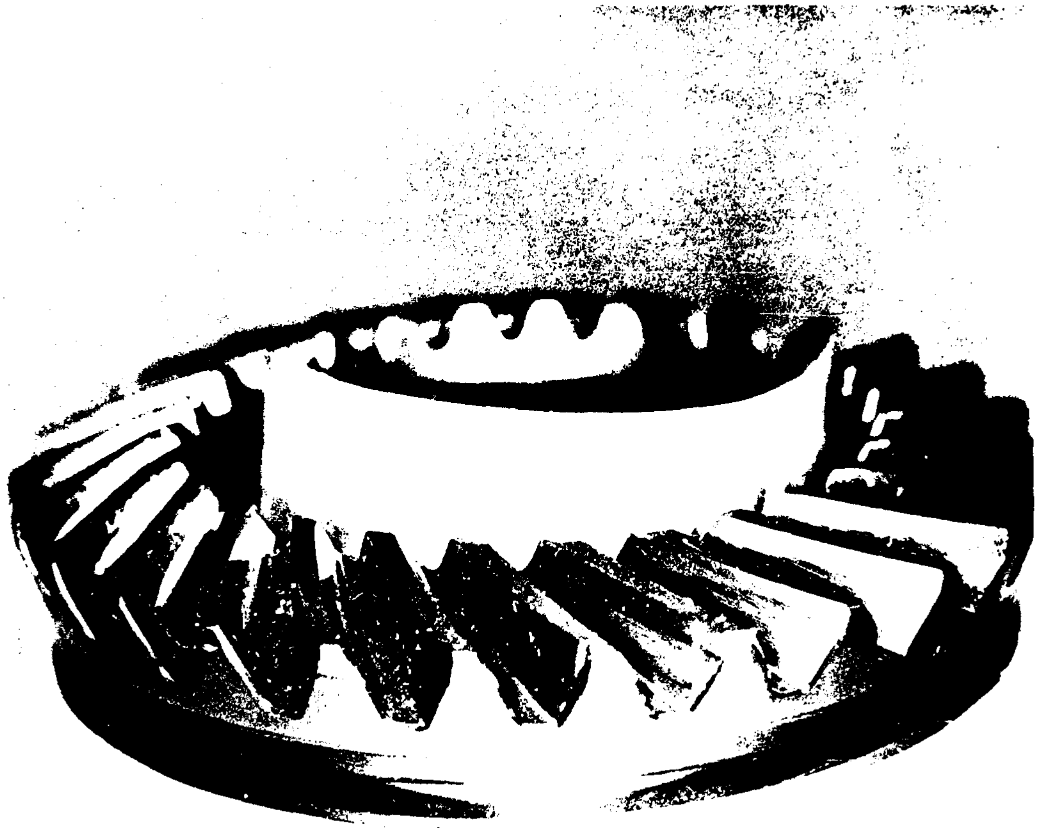


Figure 36. Convex side of input gear teeth. (42-degree gearbox, S/N B13-1277, 1071.0 operating hours.)

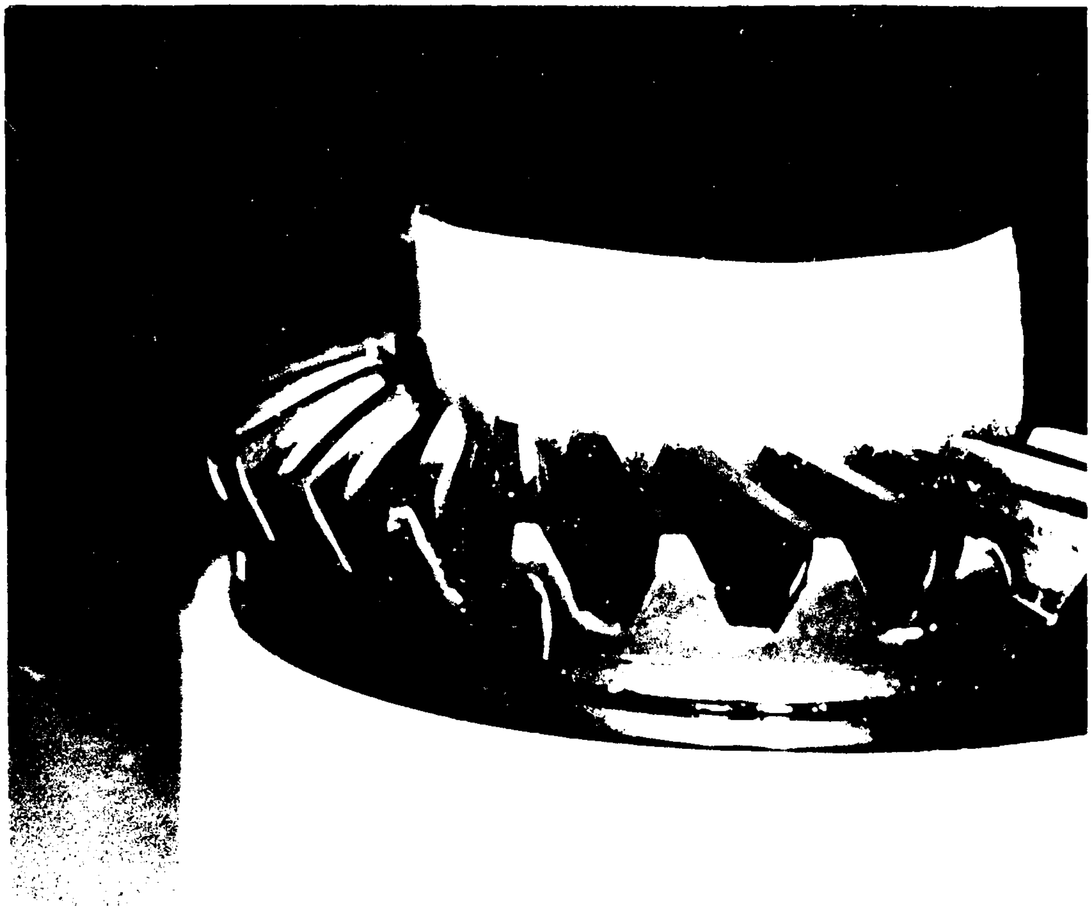


Figure 57. Concave side of input gear teeth. (42-degree gearbox, S/N B13-1277, 1071.[illegible] operating hours.)

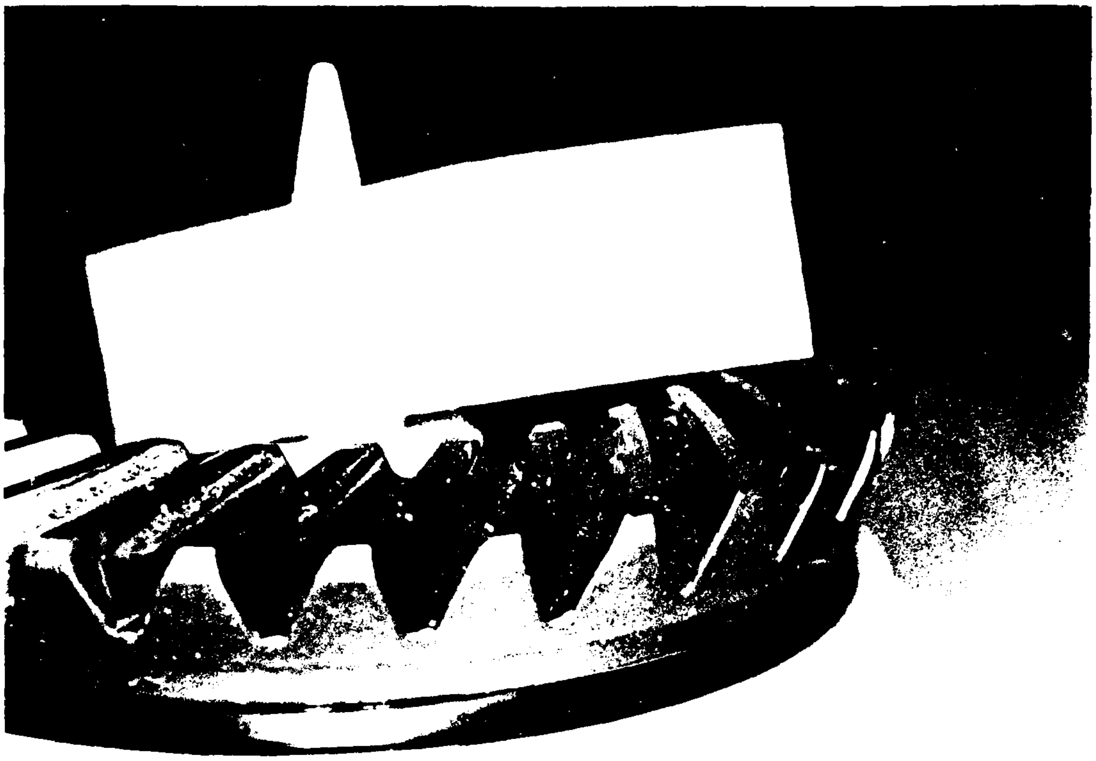


Figure 38. Concave side of output gear teeth. (42-degree gearbox, S/N B13-1277, 1071.0 operating hours.)

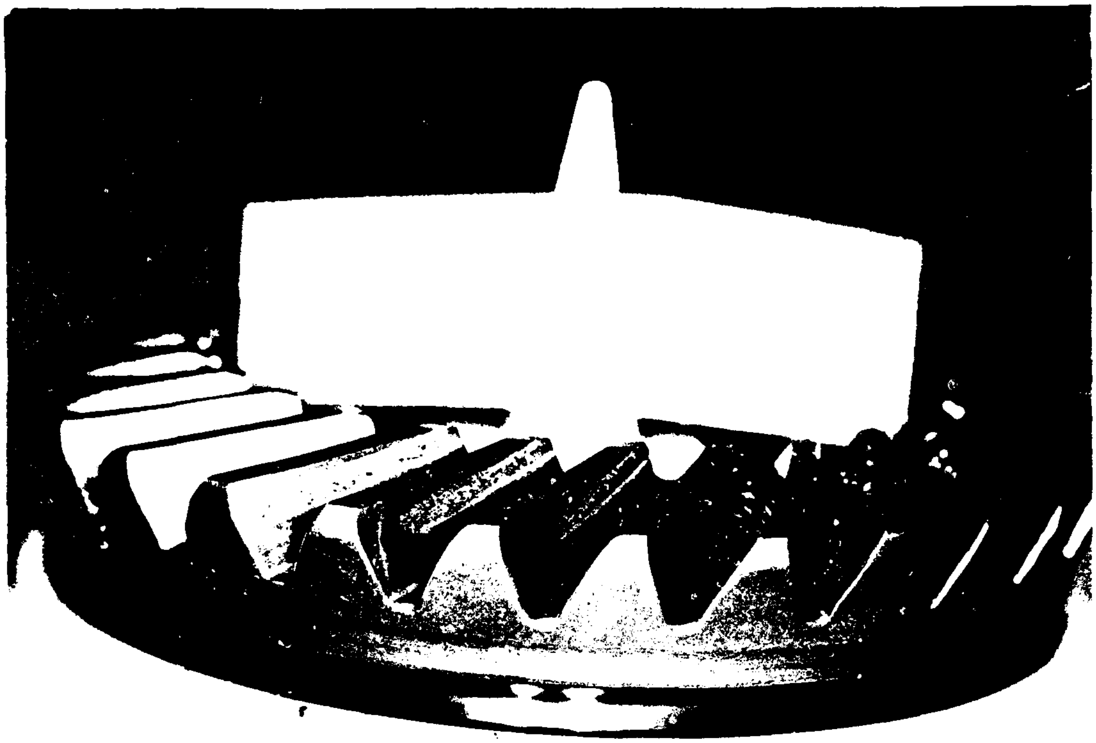
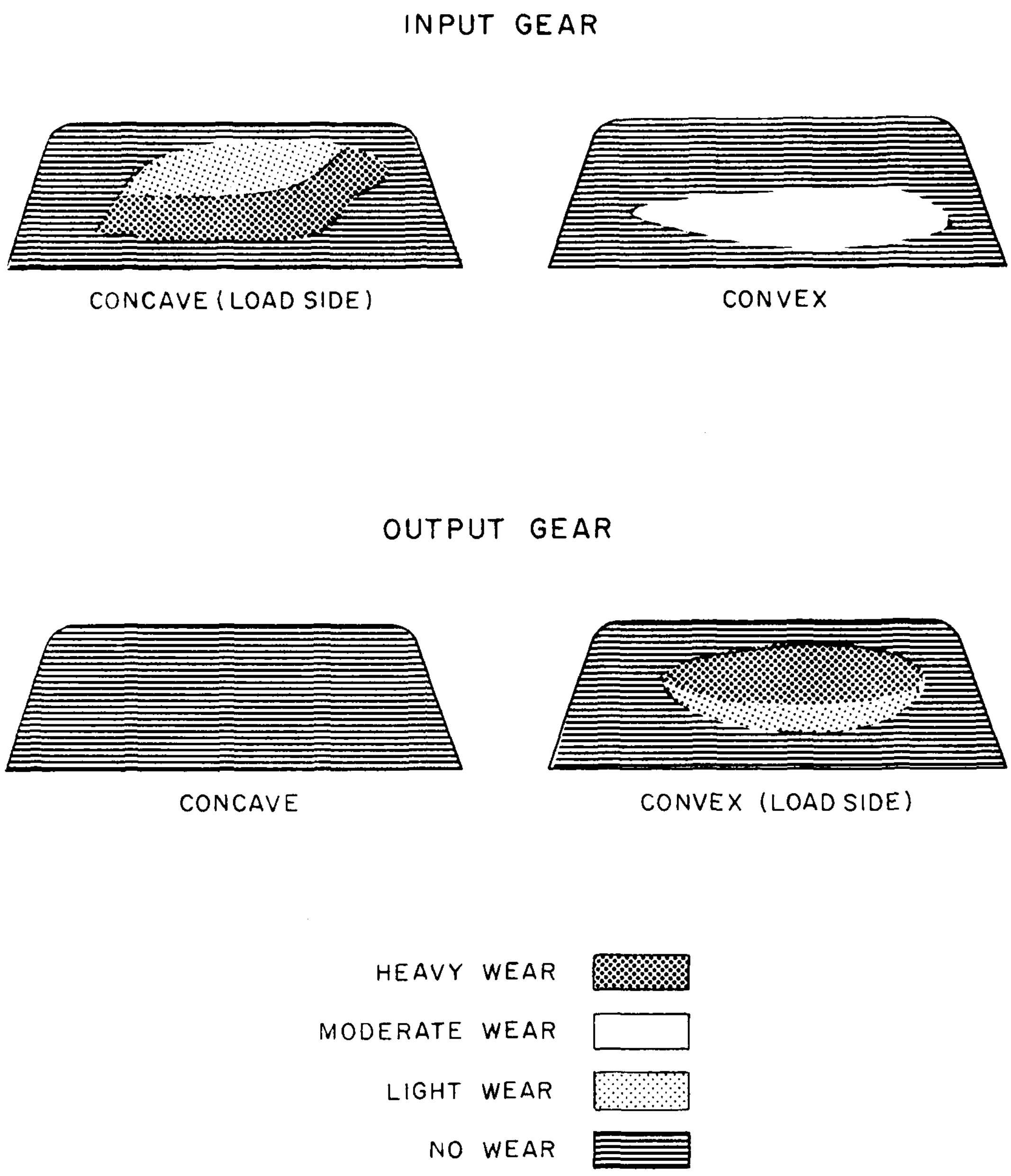


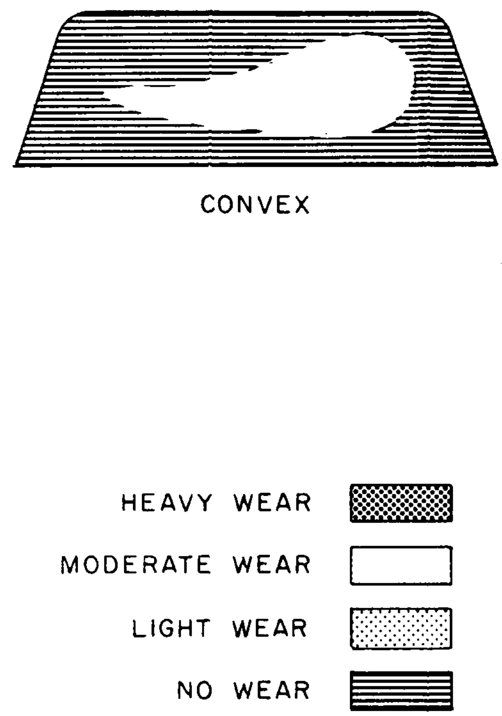
Figure 39. Convex side of output gear teeth. (42-degree gearbox, S/N B13-1277, 1071.0 operating hours.)



42° GEAR BOX, S/N B13-1277, 1071.0 HOURS

Figure 40.

INPUT GEAR

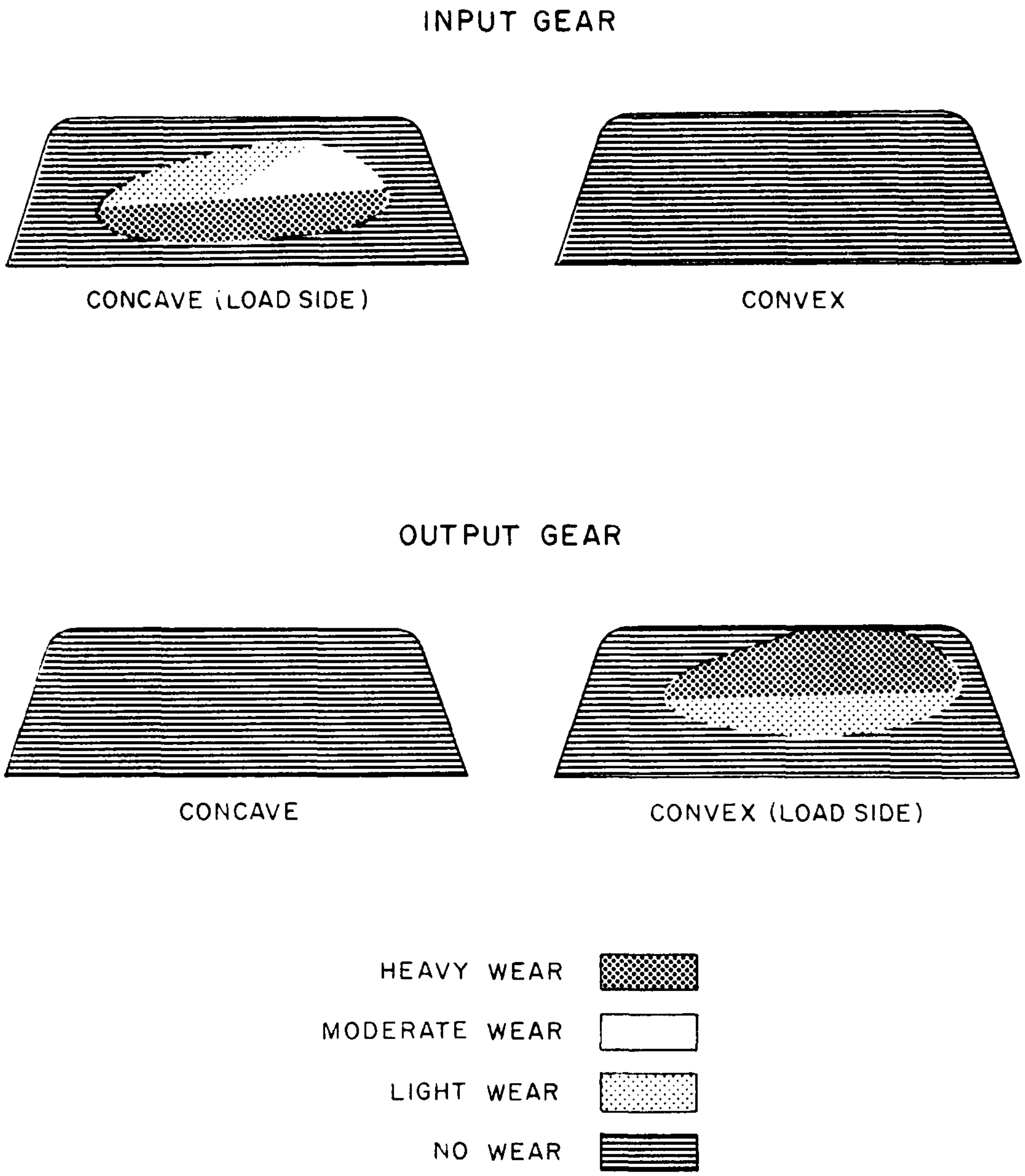


42° GEAR BOX, S/N B13-1277, 1211.4 HOURS

Figure 41.

Figure 42. Concave side of input gear teeth. (42-degree gearbox, S/N B13-2931, 1101.9 operating hours.)

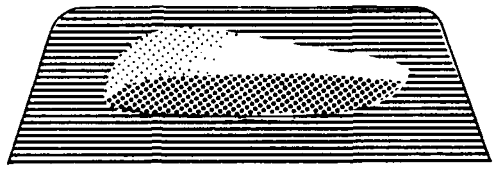
Figure 43. Convex side of output gear teeth. (42-degree gearbox, S/N B13-2931, 1101.9 operating hours.)



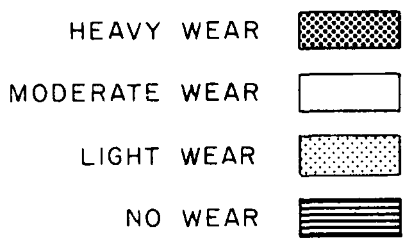
42° GEAR BOX, S/N B13-2931, 1101.9 HOURS

Figure 44.

INPUT GEAR



CONCAVE (LOAD SIDE)



42° GEAR BOX, S/N B13-2931, 1203.0 HOURS.

Figure 45.

3. 90-Degree Gearbox, FSN 1560-472-7305, P/N 204-040-012-7.

a. S/N B13-1194. This gearbox had operated 1144.0 hours in RVN. The gearbox was inspected and photographed (figures 46, 47, 48, and 49). Gear wear and backlash patterns are shown in figure 50. Both the input and output quills turned smoothly; therefore, the gearbox was considered suitable for testing. After accumulating 1171.3 hours, the chip detector light illuminated. Visual inspection of the magnetic plug confirmed the presence of metal particles. Disassembly inspection revealed that the wear pattern now extended off the top edge on the inboard end of the input gear teeth on the concave side (figure 51). The bearings in both quills rotated smoothly. The metal particles may have originated from the extended wear area on the concave side of the input gear or from loose material remaining after drilling of a magnetic plug safety wire hole. The gearbox was flushed with fresh oil and reinstalled for further testing. After one hour and forty-five minutes, at 1173.0 component hours, the chip detector light again illuminated; however, no chips were found on the plug. The gearbox was again disassembled and inspected. No change in the wear or backlash pattern on either gear was evident and the bearings in both quills rotated smoothly. In general, no deterioration was evident. Oil analysis had indicated a small increase in iron and copper between 1171.3 and 1173.0 hours. The gearbox was carried to USAADMAC for a test-cell run and complete disassembly inspection. Four and one-half hours of test-cell run were accomplished at the following speeds and torque loads:

Time (hr.)	Speed (r. p. m.)	Torque (ft.-lb.)
1.0	4170	63
1.5	4590	63
1.0	4170	25
1.0	4170	107

Analysis of oil samples during the test-cell operation revealed the following:

Test-Cell Operation Time (hr.)	Metal in Parts Per Million			
	Iron	Copper	Magnesium	Silicon
0.0	1	1	1	1
1.5	6	5	4	1

Test-Cell Operation Time (hr.)	Metal in Parts Per Million			
	Iron	Copper	Magnesium	Silicon
2.5	4	5	3	1
4.5	14	13	6	1

The disassembly inspection revealed no change in the wear pattern since 1171.3 hours. Microscopic inspection of the races of the output shaft bearings revealed several small pits approximately 0.030-inch in diameter. Pits of less than 0.050-inch diameter were present on the balls. No discrepancies were noted on the input quill bearings. Since the source of the metal contamination was never definitely determined, another gearbox was inserted into the program.

b. S/N B13-1285. This gearbox had operated 1096.0 hours in RVN. The gearbox was inspected and photographed (figures 52, 53, 54, and 55). The wear and backlash patterns that were observed at the 1096-hour inspection are shown in figure 56. The input quill bearings had some light roughness in rotation; however, the output quill bearings rotated smoothly. The gearbox was considered serviceable for testing. After accumulating 1168.7 hours, the gearbox was again inspected. Some change had occurred in the wear and backlash patterns on both gears (figure 57). The tops of the input gear teeth had developed some scratch-like marks, but these marks were not feel detectable. The input quill bearings still had light roughness in rotation; however, the output quill bearings rotated smoothly. The gearbox was considered serviceable for further testing and was reinstalled. After accumulating 1300.8 hours, the gearbox was again inspected. The wear pattern on the concave side of the input gear had not changed. A slight change, however, had occurred in the backlash pattern on the convex side of the input gear (figure 58). The wear or backlash pattern on the output gear had not changed since the 1168.7-hour inspection; however, a discrepancy had developed on the convex (load) side of the output gear. The discrepancy appeared to be a hairline crack in the center of the gear (figures 58 and 59); microscopic examination revealed it to be a [illegible] small interlocking pits. The pits appeared on approximately [illegible] percent of the output gear teeth. The lines of pitting varied from 0.125 to 0.187 inch in length. This gearbox, which was considered unserviceable after accumulating 1300.8 hours, and gearbox, S/N B13-1276, which is discussed in paragraph g, and which had a similar discrepancy, were taken to USAADMAC for laboratory analyses. Laboratory analyses (USAADMAC

Report No. 66-729) revealed that cracks were present along the gear teeth pitch line and that these cracks resulted from contact stress fatigue. The report stated that the fatigue cracks progressed from the surface at shallow angles into the case, while other cracks appeared to have formed subsurface parallel to the surface, before turning toward the surface. The volume of metal surrounded by the cracks flaked out, leaving pits. Smaller micro pits and depressions in the gear teeth surface appear to have resulted from metal particles becoming meshed between the gear teeth. Metallurgical examination of specimens removed from the two gears revealed that the effective gear tooth case depth (0.023 inch) and case hardness (R 15_N89) were slightly below the minimum specification requirements of 0.025 inch minimum case depth and R $15_N90.0$ minimum case hardness. The microstructures of the carburized case and core of the gear teeth were found to be satisfactory for the material (steel 4620) and processing to which it was subjected, and were exceptionally free from non-metallic inclusions. The core hardness (R_c37) of the gears met specification requirements of R_c33-41. The report concluded that the two distinct wear patterns on the load side of the gear teeth resulted in a slight ridge along the edge of the overlap, which may have resulted in high localized stresses and subsequent fatigue failure of the surface along the overlap edge. Figure 60 shows the sectioned gear teeth.

c. S/N B13-1499. This gearbox had operated 1095.0 hours in RVN. The gearbox was disassembled and photographed (figures 61 and 62). Inspection revealed no discrepancies. The input quill bearings exhibited a very light roughness. The output quill bearings rotated smoothly. The wear and backlash patterns that existed at 1095.0 hours are shown in figure 63. The gearbox was considered serviceable for test and accumulated 1197.4 hours prior to the next inspection. The wear and backlash pattern had changed on both gears (figure 64). The input quill still had a slight roughness; however, the output quill rotated smoothly, and the gearbox was considered serviceable for additional testing. After accumulating 1301.3 hours, the gearbox was again inspected. The wear and backlash patterns had not changed since the 1197.4-hour inspection; however, pitting had developed on the convex (load) side of the output gear along the line where the two wear patterns overlap. The pitting was similar in all respects to that observed on gearbox, S/N B13-1285. Minor pitting was also evident on the load side of both the input and output gears. The gearbox was considered unserviceable after accumulating 1301.3 hours.

d. S/N B13-1233. This gearbox had operated 1088.0 hours in RVN. The gearbox was inspected and photographed prior to testing (figures 65 and 66). Inspection revealed a small scratch-like mark on the top of the outboard convex end of one of the input gear teeth. The wear and backlash patterns that were present are shown in figure 67. The bearings in both quills rotated smoothly. The gearbox was serviceable for testing and accumulated 1183.0 hours prior to the next inspection. The wear and backlash patterns on the output gear teeth had changed since the last inspection (figure 68). The wear and backlash patterns had not changed on the input gear. Both quills' bearings rotated smoothly. The gearbox was serviceable for additional testing and accumulated 1310.3 hours prior to the next inspection. The wear and backlash patterns on the load side of both gears were basically unchanged. The only exception was that the backlash pattern on the input gear seemed to have extended itself longitudinally over a larger area of the tooth. Concentrated interlocking pitting, however, was noted at the pattern-overlap area on the convex side of the output gear. The interlocking pits appeared on 12 of the teeth and varied in length from 0.062 to 0.125 inch (figure 69). The pitting was the same as that observed on gearbox, S/N B13-1285. In addition to numerous very small pits on the load side of both gears, an area of pick-out appeared on four of the input gear teeth on the concave (load) side where an overlap of patterns appeared. One pit measured 0.125 inch in length and 0.031 inch in width (figure 70). The bearings on both quills rotated smoothly; however, the gearbox was considered unserviceable after accumulating 1310.3 hours.

e. S/N B13-1068. This gearbox had operated 1091.0 hours in RVN. The gearbox was disassembled and photographed (figures 71, 72, 73, and 74). No discrepancies were noted, and the bearings in both quills rotated smoothly. The wear and backlash patterns are shown in figure 75. The gearbox was considered serviceable and accumulated 1191.4 hours prior to the next inspection. No change in the wear or backlash patterns was evident on either gear, and the bearings in both quills rotated smoothly. No discrepancies of any kind were present on the gear teeth, and the gearbox was determined serviceable for further testing. During the next 50.5 hours, spectrographic oil analysis revealed the following:

Component Hours	Contaminant Present in Parts Per Million						
	Iron	Aluminum	Copper	Silver	Chromium	Magnesium	Silicon
1,194	65	20	50	--	--	11	4
1,195	36	13	38	--	--	9	1

	Contaminant Present in Parts Per Million						
Component Hours	Iron	Aluminum	Copper	Silver	Chromium	Magnesium	Silicon
1,196	65	23	60	--	--	12	6
1,197	48	15	44	--	--	9	4
1,198	65	19	56	--	--	11	5
1,199	58	18	56	--	--	9	8
1,200	60	20	54	--	2	11	8
1,201	58	18	54	--	2	10	6
1,214	56	12	49	--	--	7	4
1,224	65	18	65	--	1	10	8
1,234	540	13	29	--	10	12	10
1,241	600+	16	38	--	14	13	12
1,241	600+	17	39	--	16	13	13
1,241	600+	19	38	--	14	13	13

Rapid deterioration began sometime after 1224.0 component hours, and in less than 10 hours, iron contamination increased from a normal figure of 66 parts per million to 540 parts per million. The gearbox was disassembled at 1241.9 hours. Figures 76 and 77 show the deterioration on the load side of both the input and output gears. The unloaded sides of both gears showed no change in backlash pattern. The bearings in both quills rotated with some roughness, which was probably caused by metal particles from the gears. This gearbox was unserviceable after 1241.9 hours.

f. S/N B13-1209. This gearbox had operated 1080.0 hours in RVN. The gearbox was disassembled for inspection and photographed (figures 78 and 79). The wear and backlash patterns that were present are shown in figure 80. The bearings rotated smoothly, and the gearbox was considered serviceable for testing. After accumulating 1201.4 hours, the gearbox was again inspected. The wear and backlash patterns had not changed since the last inspection. The bearings on both quills turned freely, and no discrepancies were evident on the gears. The gearbox was considered serviceable for further testing. The gearbox accumulated 1245.9 hours by the next inspection. Disassembly revealed no change in the wear or backlash patterns; however, the same type of concentrated pitting had developed on the load or convex side of the output gear as had developed on gearbox, S/N B13-1285. The pitting was at the point of overlap of the two wear patterns (figure 81). A similar line of pits was present on the load (concave) side of the input gear where two patterns overlapped (figure 81). The bearings in both quills rotated smoothly. The gearbox was considered unserviceable after accumulating 1245.0 hours.

g. S/N B13-1276. This gearbox had operated 1107.0 hours in RVN. Inspection revealed the wear and backlash patterns shown in figure 82. A line of pits was present on the convex (load) side of the output gear at the point of overlap of the two wear patterns (figures 82 and 83). The pitting was the same as that encountered in gearbox, S/N B13-1285. The bearings in both quills rotated smoothly; however, the gearbox was considered unserviceable and was sent to USAADMAC for laboratory analysis (see paragraph b, above).

h. S/N B13-1394. This gearbox was received with a total accumulated time of 1067.0 hours. The wear and backlash patterns are shown in figure 84. A line of interlocking pits was detectable where the two wear patterns met on the convex side of the output gear (figure 84). These pits were in the same location as those discovered on gearbox, S/N B13-1285. The pitting, however, was much lighter and less developed than that on the other gearboxes. A very light line of pitting was also evident on several of the input gears on the concave side (figure 84). No rotational roughness was present in the output quill, but a slight roughness could be felt in the input quill during rotation. It was decided to install the gearbox for a 50-hour period to determine whether the pitting would progress to any degree. The additional testing was considered acceptable from a safety standpoint, since the pits were apparently at an earlier stage of development than those previously observed. After accumulating 1156.6 hours, the gearbox was again disassembled. The pits had not progressed. The wear and backlash patterns had not changed, and the quills rotated smoothly. The gearbox was reinstalled and accumulated 1206.8 hours prior to the next inspection. No change in the wear or backlash patterns had occurred. The pitting on the input gear had not progressed; in fact, it seemed to have smoothed itself out somewhat. The pitting on the output gear had lengthened and seemed somewhat deeper. Both quills rotated smoothly. The gearbox was reinstalled and accumulated 1265.8 hours prior to the next inspection. This inspection revealed no change in the wear or backlash patterns. The pitting had completely disappeared from the face of the input gear but was still present and unchanged on the output gear; the bearings rotated smoothly. The gearbox was reinstalled and accumulated 1268.0 hours prior to an excessive metal count in the oil, dictating removal. The oil sample revealed the following:

Component Hours	Contaminant Present in Parts Per Million						
	Iron	Aluminum	Copper	Silve.	Chromium	Magnesium	Silicon
1247	21	11	37	--	2	7	3
1254	23	12	44	--	2	4	3
1256	22	12	38	--	2	6	-
1264	38	18	32	1.2	3	7	4
1266	110	49	83	1.0	2	39	-

No change in the wear or backlash patterns was evident, and the bearing rotated smoothly. The pitting had not progressed on the output gear and was no longer visible on the input gear. The gearbox was flushed, re-installed, and operated for one hour on a ground run. The metal count in the oil was satisfactory, and the gearbox resumed flight testing. At 1274.3 hours, the gearbox was again removed for excessive metal contamination in the oil sample. The oil sample revealed the following:

Component Hours	Contaminant Present in Parts Per Million						
	Iron	Aluminum	Copper	Silver	Chromium	Magnesium	Silicon
1271.3	36	20	23	1.8	2	5	6
1273.3	90	44	50	---	-	9	5
1274.3	80	42	50	---	-	13	-

The gearbox was inspected; however, no change had occurred since 1268.0 component hours. It was decided to end the program and send the gearbox to USAADMAC for inspection. Inspection revealed that roller bearing, P/N 204-040-407-3, had some scuffing on the outer race. It appeared that the rollers had slid over the outer race (to some degree) rather than rolled. Some light pitting was also observed on the outer race. The remainder of the bearing was serviceable; however, the bearing would have been rejected at overhaul. The pitting appeared to be the early stages of surface fatigue. Roller bearing, P/N 204-040-406-1D, had experienced the most severe deterioration. The outer race of the bearing, approximately 0.062 inch from the edge of the roller path, had chips of material missing throughout the entire circumference. The pits varied from 0.031 to 0.062 inch in diameter. The chips appeared to have been caused by the presence of foreign material. Some scuffing marks were also present on the edge of the roller path and extended into the path. The bearing would have been rejected at overhaul. Metal particles, possibly from the output gear teeth, may have caused the pitting on the outer race of bearing, P/N 204-040-406-1D. The scuffing marks may have been caused during the numerous assemblies and disassemblies of this gearbox during the test. Either the severe pitting in bearing, P/N 204-040-406-1D, or the incipient pitting on the roller path on the outer race of bearing, P/N 204-040-407-3, would appear to have been the most probable cause of the rise in metal contamination in the oil. The additional deterioration of the output gear teeth may have also contributed to the metal contamination. This gearbox was unserviceable for further operation because of output gear tooth pitting (present since 1067.0 hours) and the damaged bearings, P/N's 204-040-406-1D and 204-040-407-3.

i. Discussion. None of the gearboxes had been previously overhauled. The concentration of interlocking pits developed on the convex side of the output gear on six of the eight gearboxes tested. In addition, some pitting developed on the concave side of the input gear on two of the six gearboxes. The operating times of the gearboxes when the pitting was discovered were 1300.8, 1301.3, 1310.3, 1245.9, 1107.0, and 1067.0 hours. In addition, one other gearbox suffered a complete gear tooth surface failure (galling) after 1241.9 hours. No pitting had been observed on the gear teeth prior to the surface failure. The eighth gearbox was dropped from the program after accumulating 1173.0 hours due to the presence of magnetic chips and metal contaminant in the oil. The source of the contaminant was never precisely determined. The gearbox that had light pitting present on the convex surface of the output gear at 1067.0 hours was operated 207.3 additional hours. During this time, the length and depth of the pitting increased slightly; however, no gear surface failure occurred. Although the pitting observed on six of the eight output gearboxes was not definitely shown to be the cause of the gear surface failure (galling) experienced on gearbox, S/N B13-1068, at 1241.9 hours, it would appear from observation and the laboratory analysis performed at USAADMAC that the two were related.

j. USAADMAC Data. Data were collected from USAADMAC on 237 90-degree gearboxes, P/N 204-040-012-7, in support of the logistical evaluation (Phase F) of the UH-1D Helicopter at high gross weight, USATECOM Project No. 4-3-0150-15. The analysis of that data was reported in the final report on the above-mentioned project; due to its relevance to this project, however, the information is repeated:

The mean time to removal for all causes was 627.0 hours. Assuming the removals for unknown reasons to follow the same general distribution as the other removals prior to TBO, and discounting the externally caused failures, approximately 36 percent of the components achieved the 1100-hour TBO. Sixty-one percent of the gearboxes returned to USAADMAC for inherent gearbox problems (i.e., problems not caused by external factors such as crash or battle damage, etc.) prior to TBO were due to seal deterioration; thus, seal deterioration was the primary cause of the low percentage which achieved the 1100-hour TBO. The seal failures ranged from a low of 25.0 hours to a high of 933.0 hours. Generally, the failure trend for seals is such that a significant number of failures occur during the first 250 hours. All seals in the 90-degree gearbox are replaced at depot maintenance, where the gearbox is overhauled, with the exception of the tail-rotor seal, P/N 204-040-611-1, which may be replaced at direct-support maintenance.

Figure 46. Convex side of input gear teeth. (90-degree gearbox, S/N B13-1194, 1144.0 operating hours.)

Figure 47. Concave side of input gear teeth. (90-degree gearbox, S/N B13-1194, 1144.0 operating hours.)

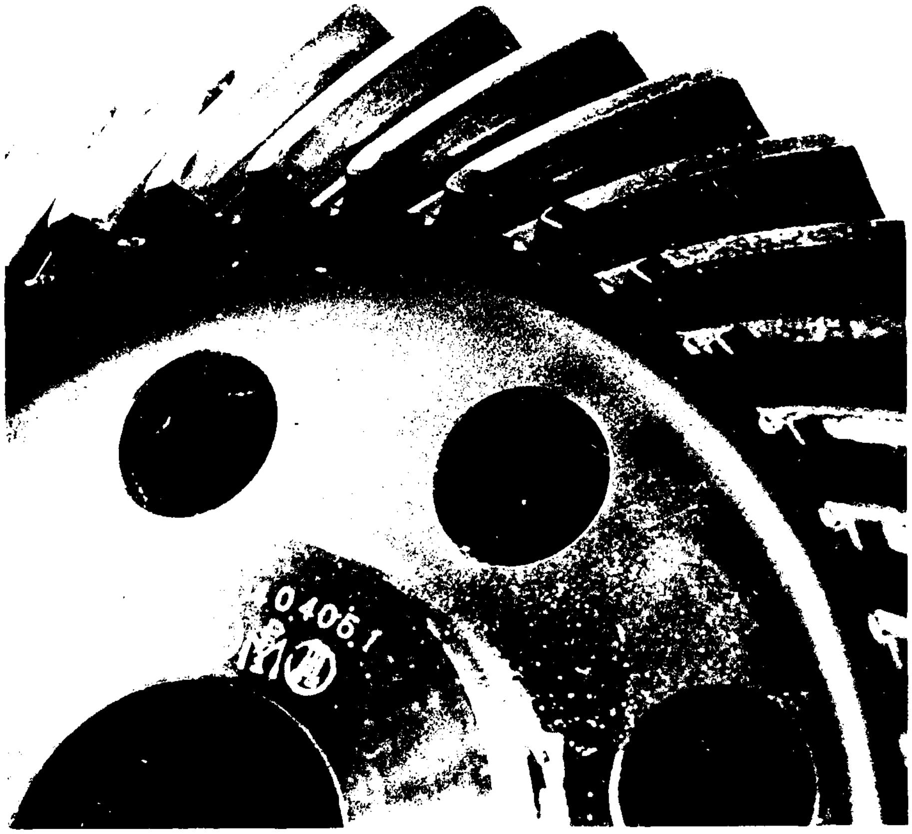
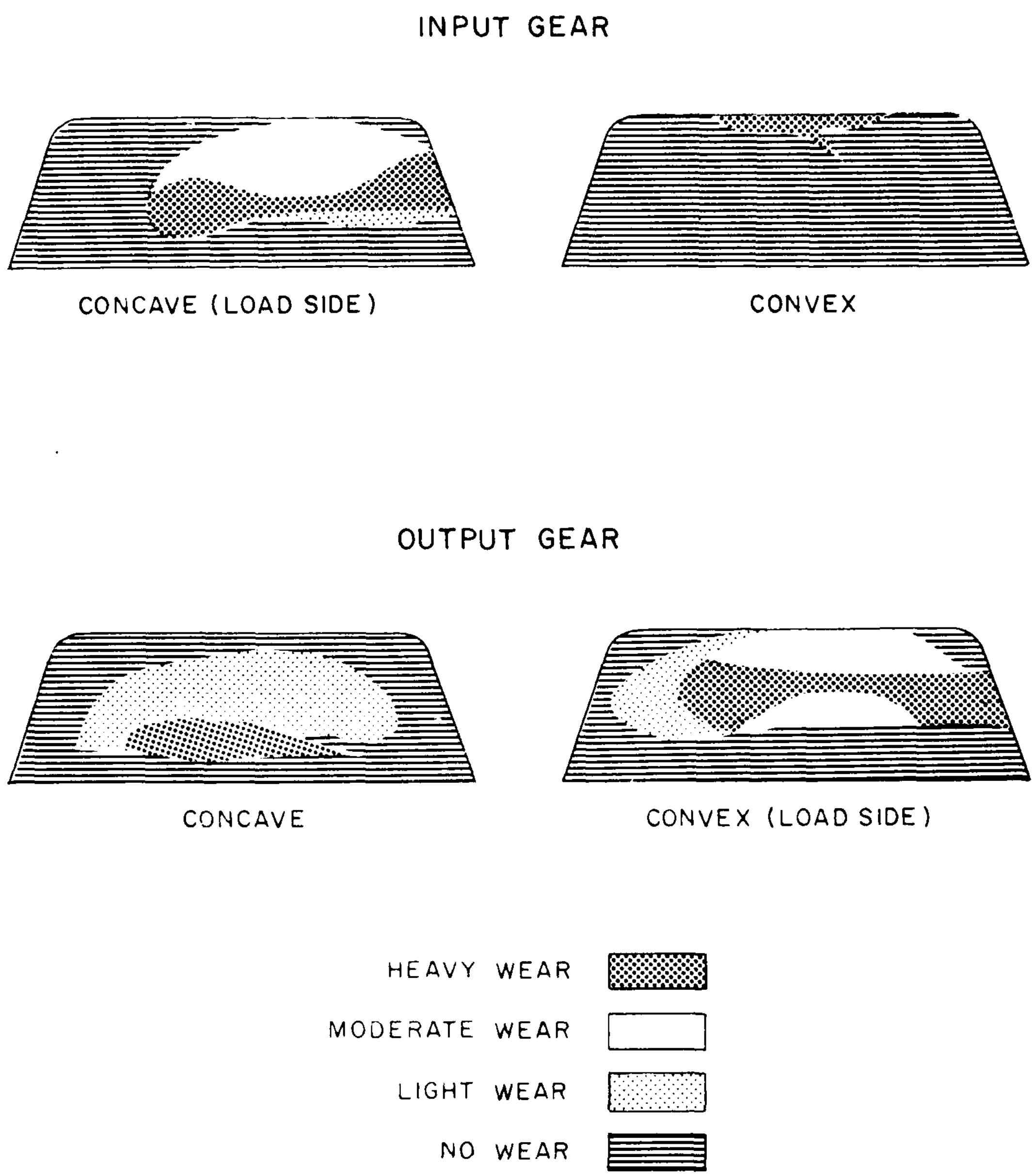


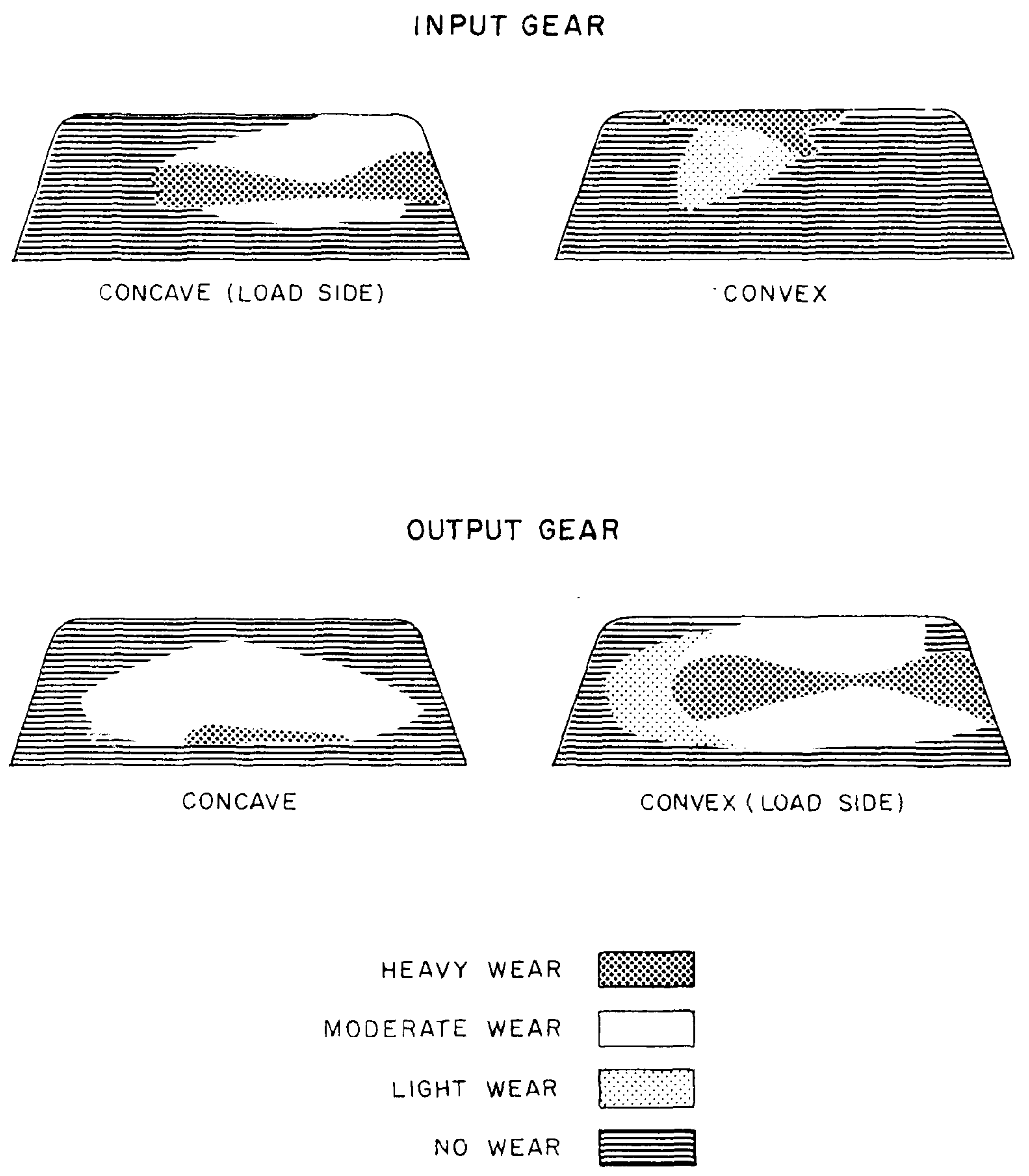
Figure 48. Concave side of output gear teeth. (90-degree gearbox, S/N B13-1194, 1144.0 operating hours.)

Figure 49. Convex side of output gear teeth. (90-degree gearbox, S/N B13-1194, 1144.6 operating hours.)



90° GEAR BOX, S/N B13-1194, 1144.0 HOURS.

Figure 50.



90° GEAR BOX, S/N B13-1194, 1171.25 HOURS

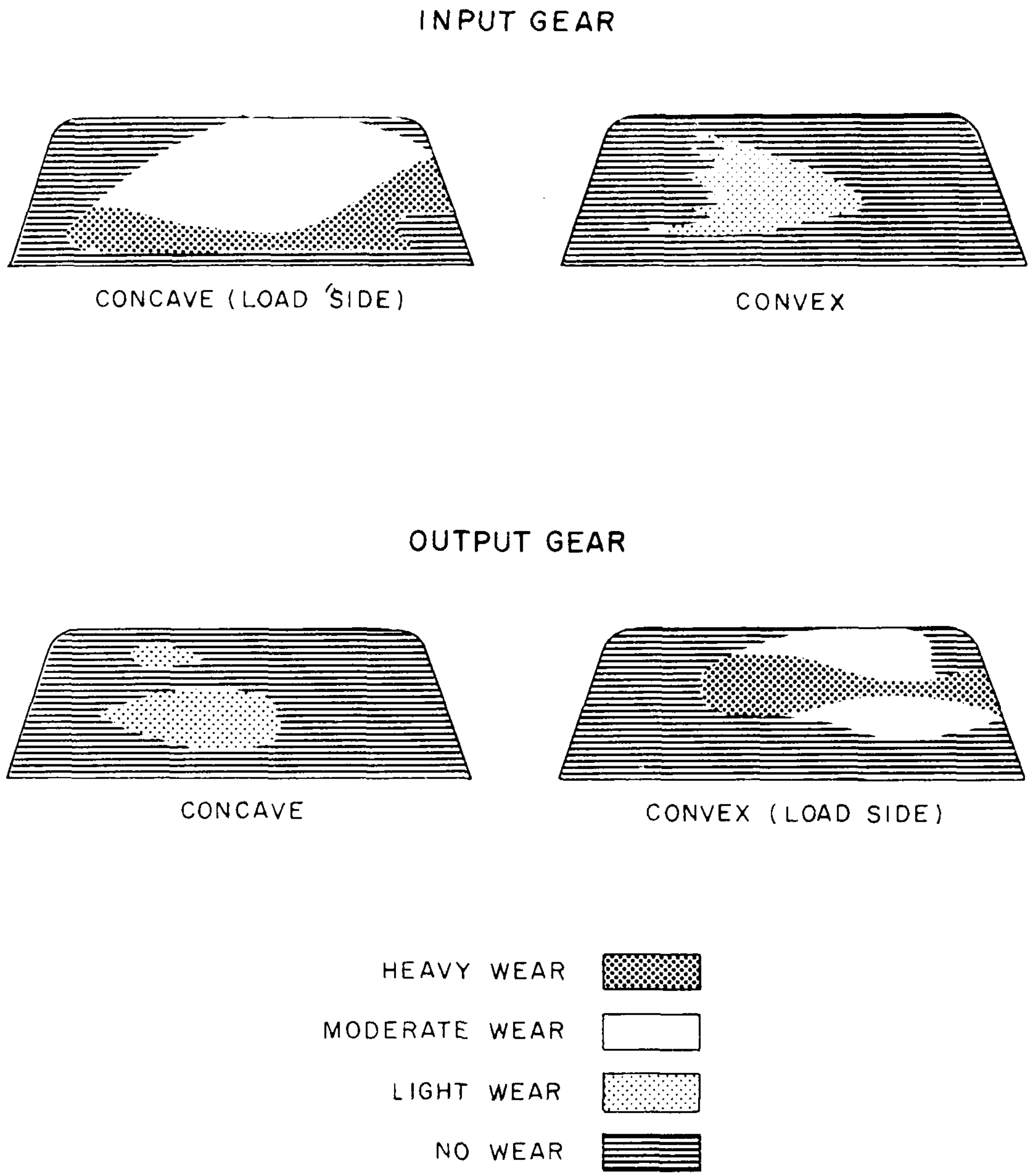
Figure 51.

Figure 52. Convex side of input gear teeth. (90-degree gearbox, S/N B13-1285, 1096.0 operating hours.)

Figure [illegible]. Concave side of input gear teeth. ([illegible]-degree gearbox, S/N [illegible], [illegible] operating hours.)

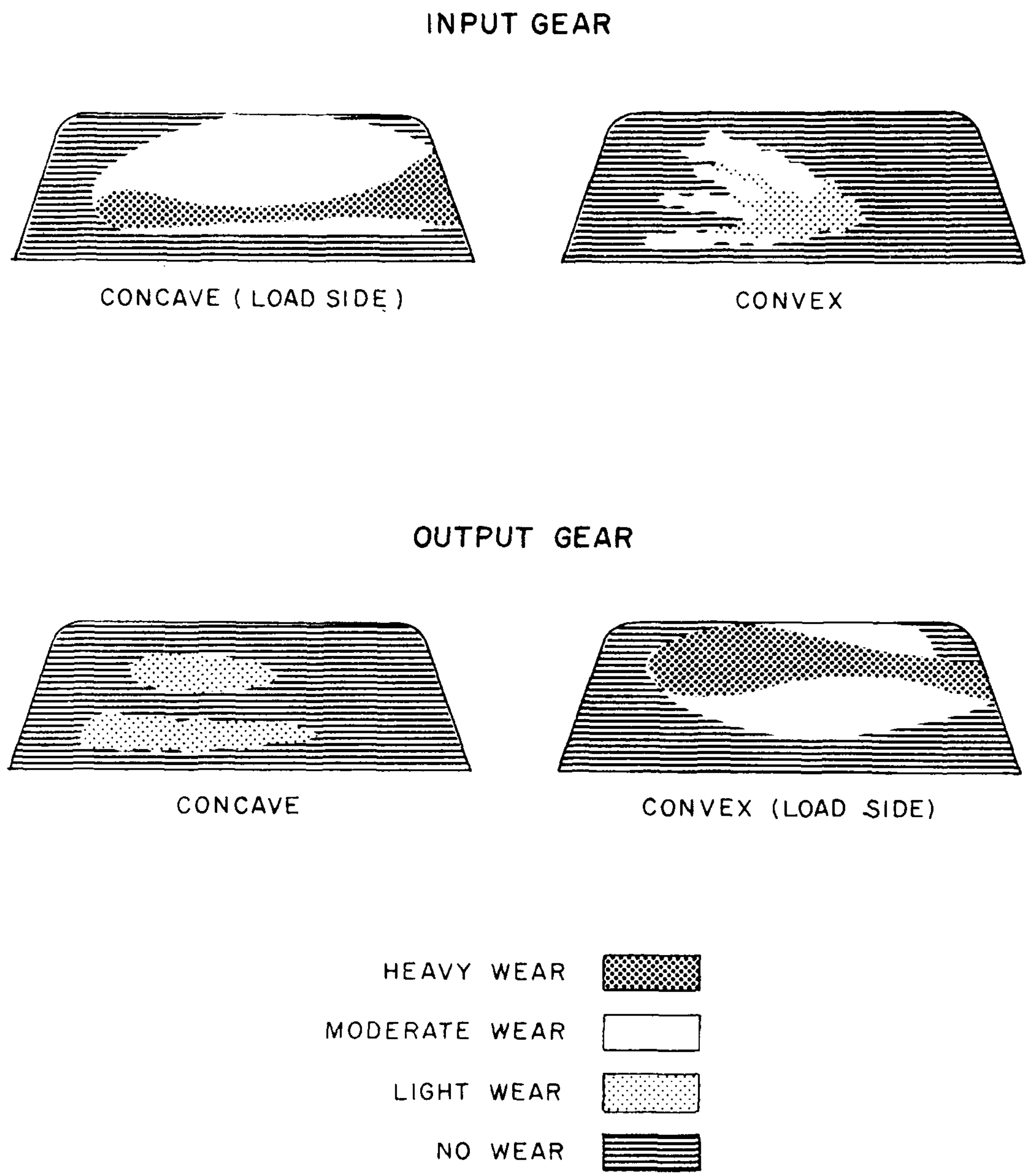
Figure 54. Concave side of output gear teeth. (90-degree gearbox, S/N B13-1285, 1096.0 operating hours.)

Figure 55. Convex side of output gear [illegible]
(90-degree gearbox, S/N B[illegible], [illegible]
operating hours.)



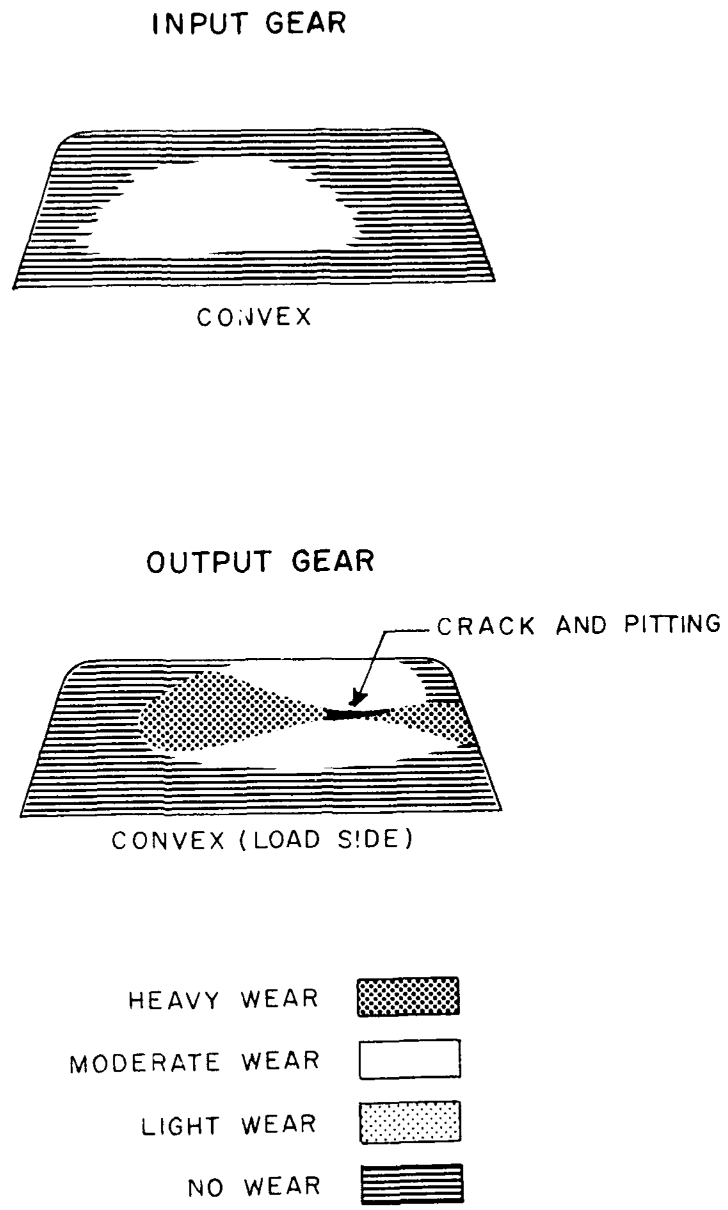
90° GEAR BOX, S/N B 13-1285, 1096.0 HOURS

Figure 56.



90° GEAR BOX, S/N B13-1285, 1168.7 HOURS

Figure 57.



90° GEAR BOX, S/N B13-1285, 1300.75 HOURS

Figure 58.

Figure 59. Crack or pit on convex side of output gear tooth (90-degree gearbox, S/N B13-1285, 1300.8 operating hours).

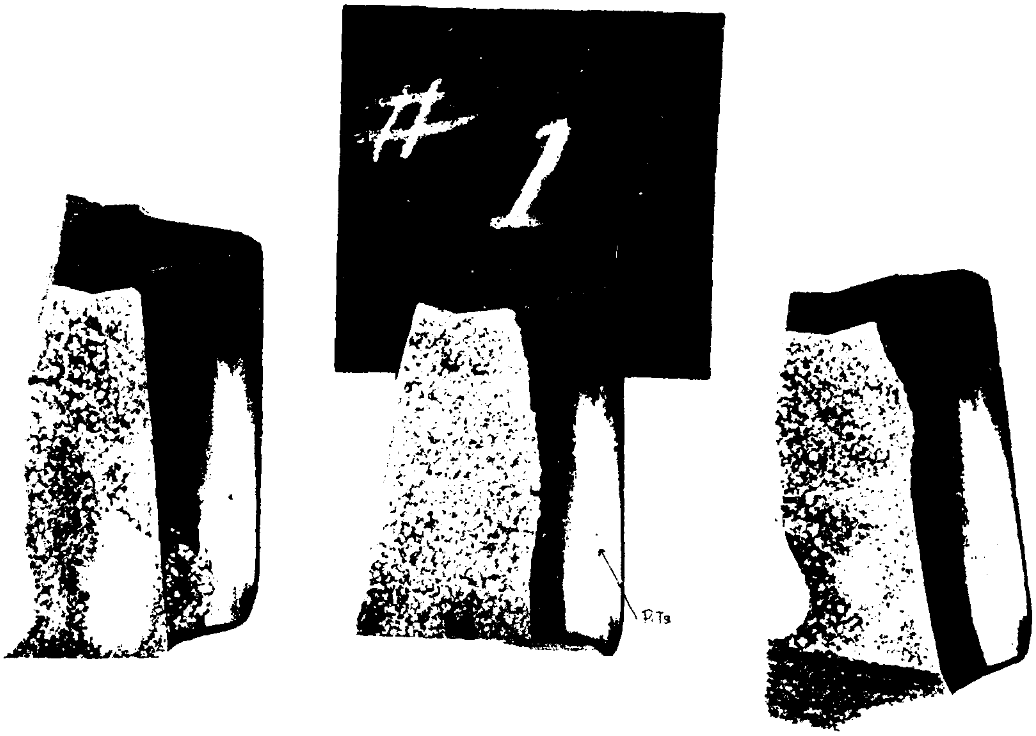
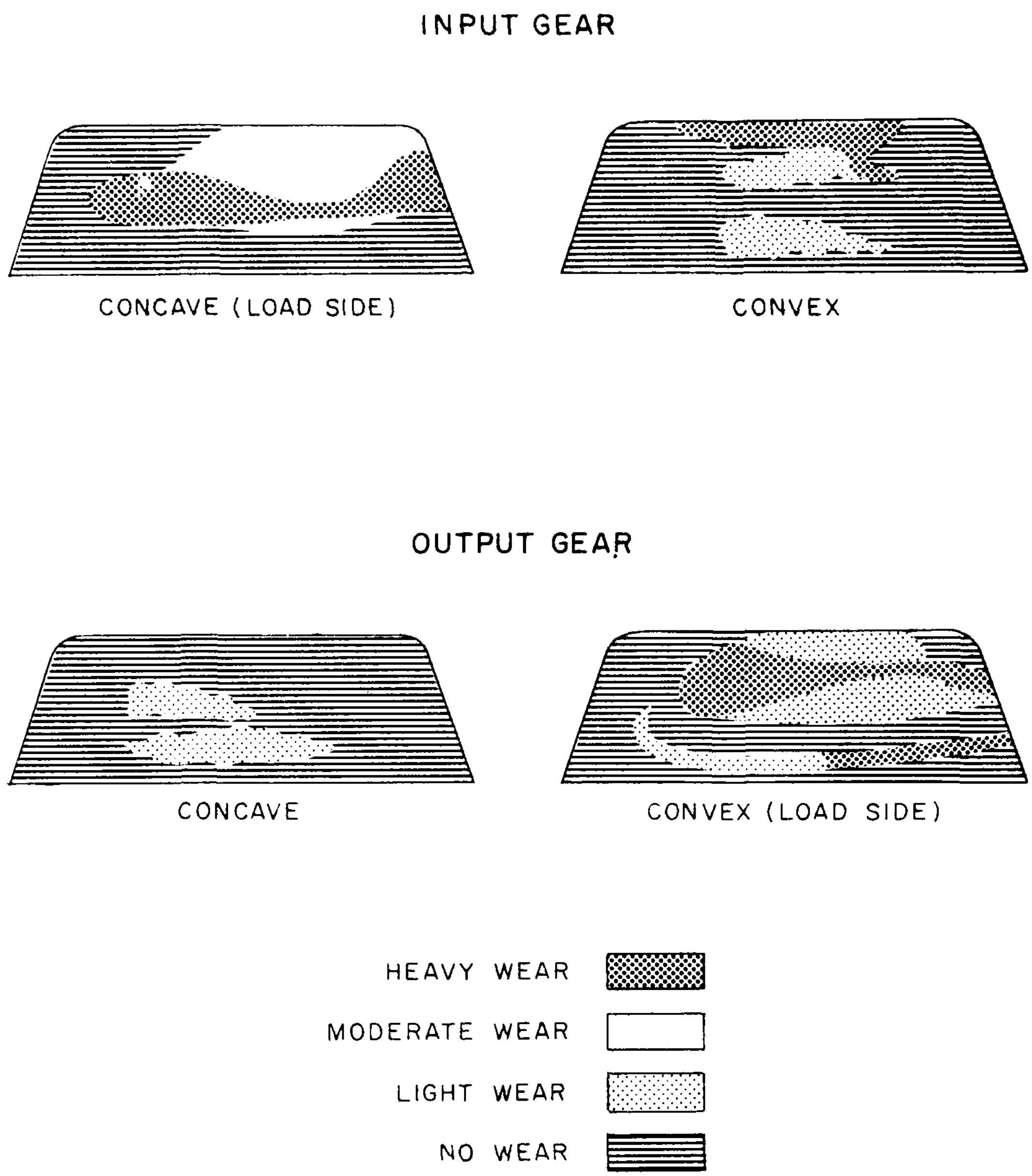


Figure 60. Sectioned output gear teeth showing crack or pits on convex side (90-degree gearbox, S/N B13-1285, 1300.8 operating hours).

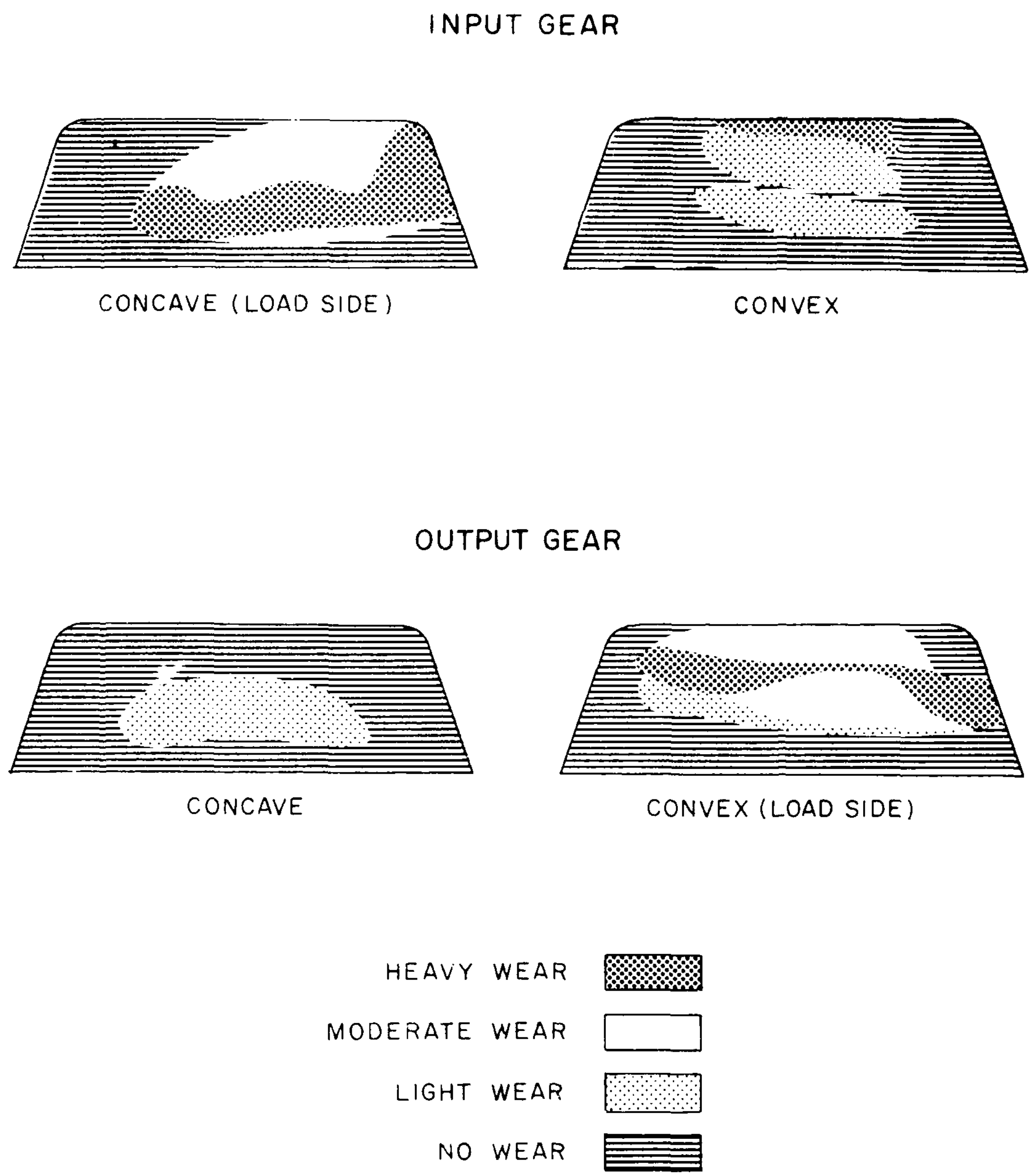
Figure 61. Convex and concave sides of input gear teeth (90-degree gearbox, S/N B13-1499, 1095.0 operating hours).

Figure 62. Convex and concave sides of output gear teeth (90-degree gearbox, S/N B13-1499, 1095.0 operating hours).



90° GEAR BOX, S/N B13-1499, 1095.0 HOURS

Figure 63.

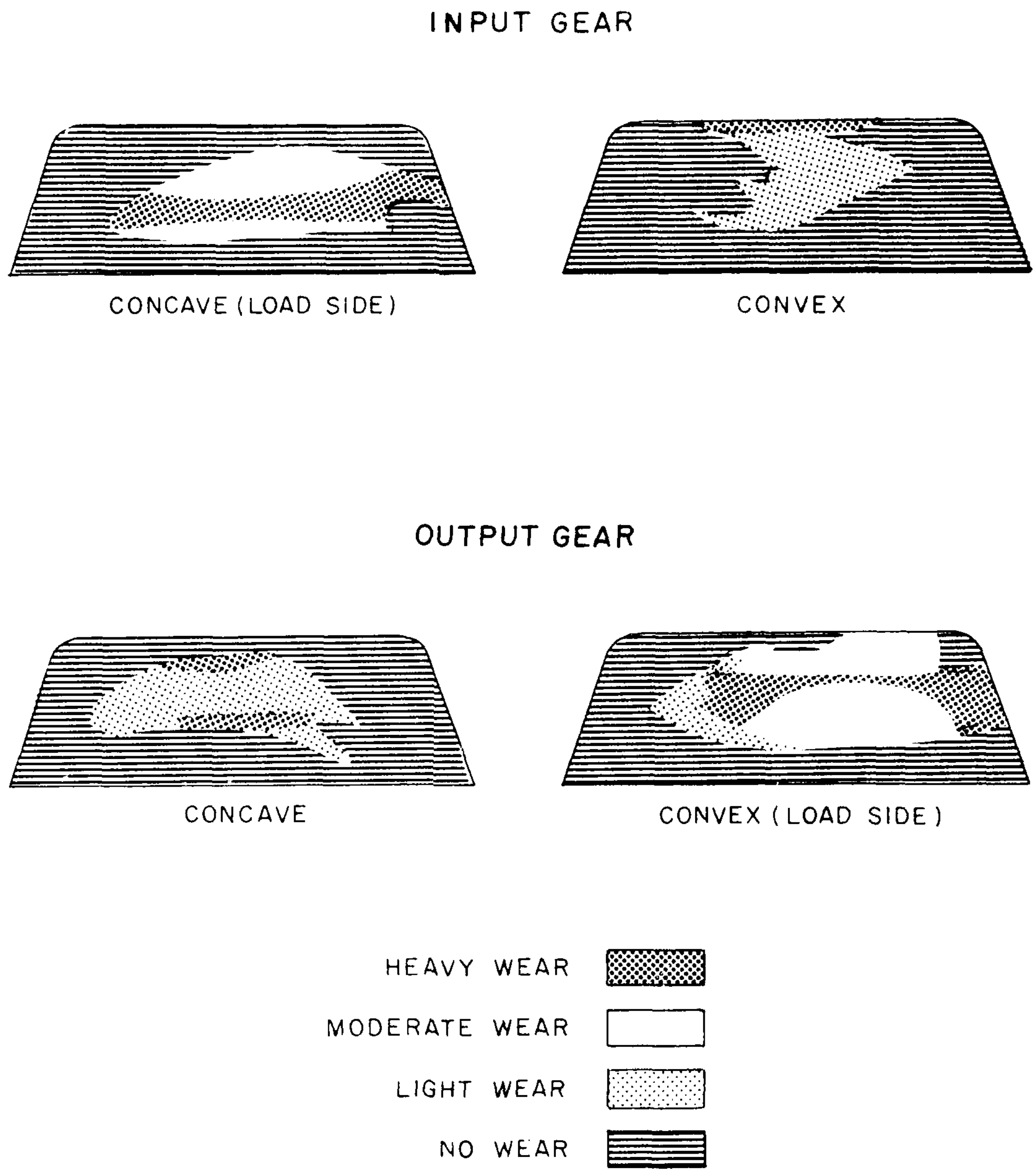


90° GEAR BOX, S/N B13-1499, 1197.4 HOURS

Figure 64.

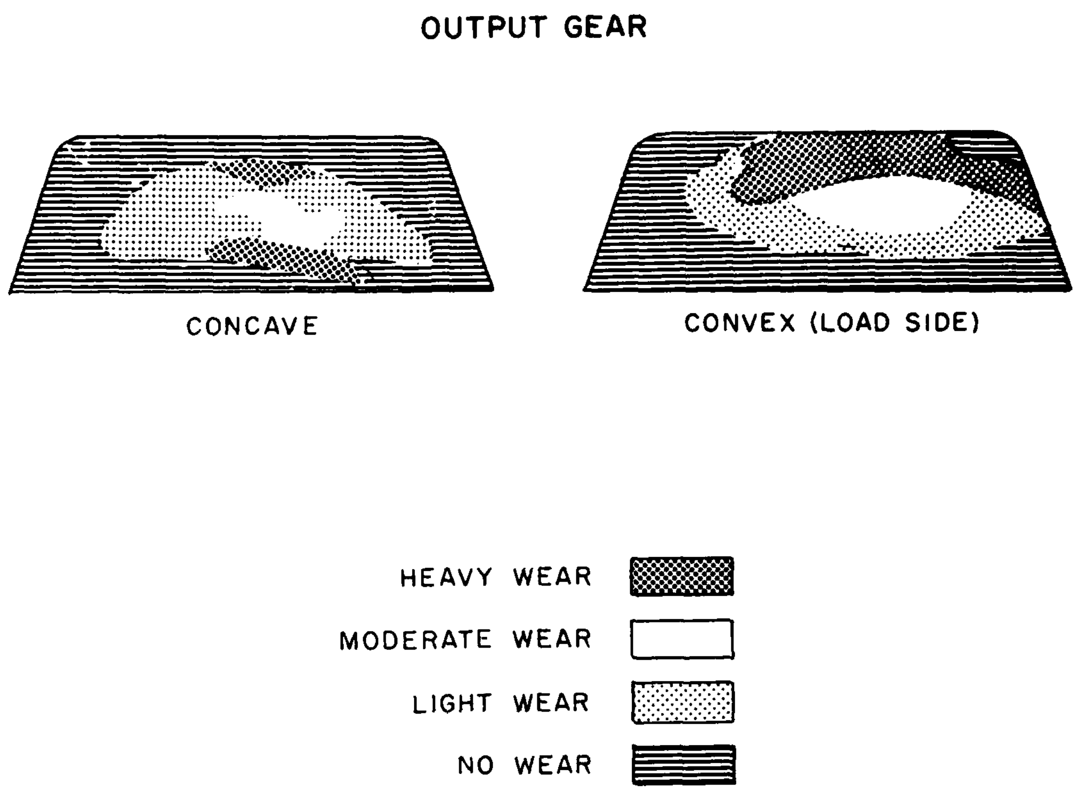
Figure 65. Convex and concave sides of input gear teeth (90-degree gearbox, S/N B13-1233, 1088.0 operating hours).

Figure 66. Convex and concave sides of output gear teeth (90-degree gearbox, SN B13-1233, 1088.0 operating hours).



90° GEAR BOX, S/N B13-1233, 1088.0 HOURS

Figure 67.



90° GEAR BOX, S/N B13-1233, 1183.0 HOURS

Figure 68.

Figure 69. Pitting on convex side of output gear tooth (90-degree gearbox, S/N B13-125[illegible], 1310.3 operating hours).

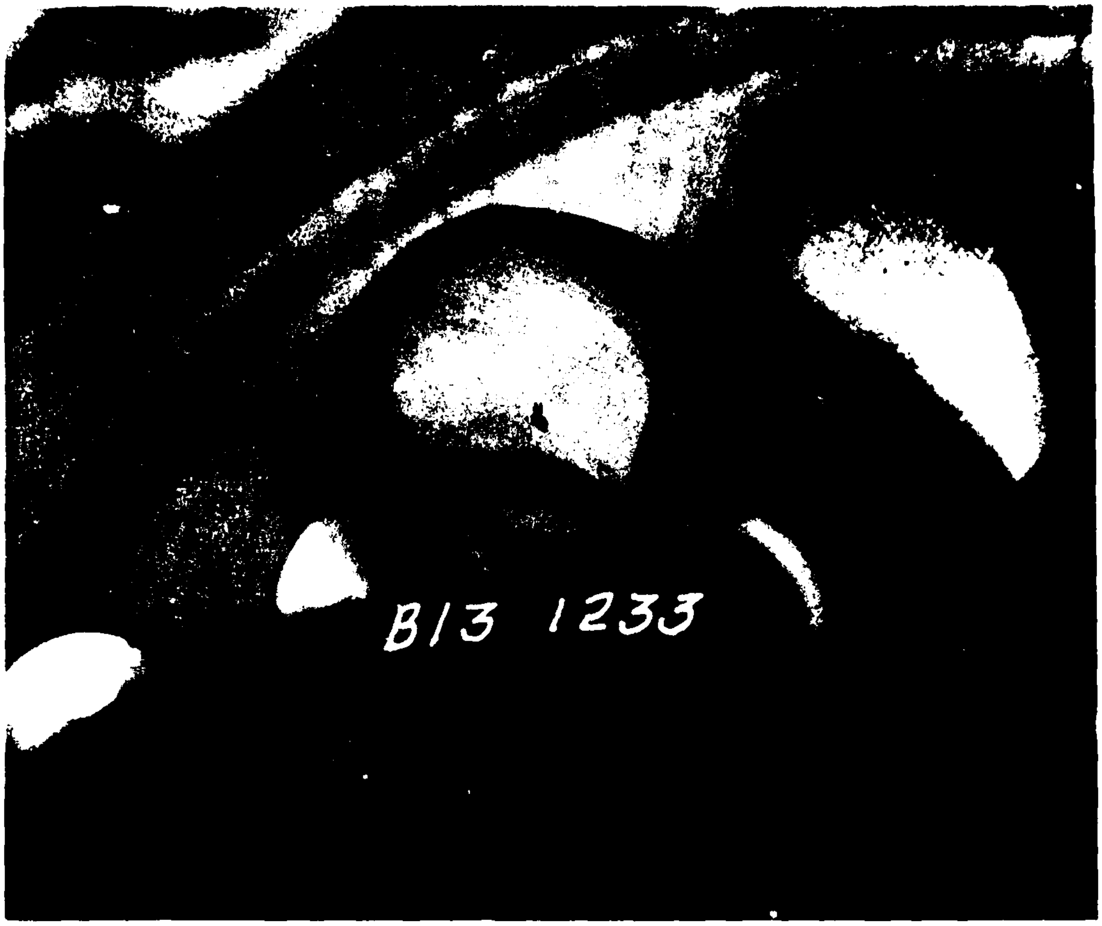


Figure 70. "Pick-out" on concave side of output gear tooth (90-degree gearbox, S/N B13-1233, 1310.3 operating hours).

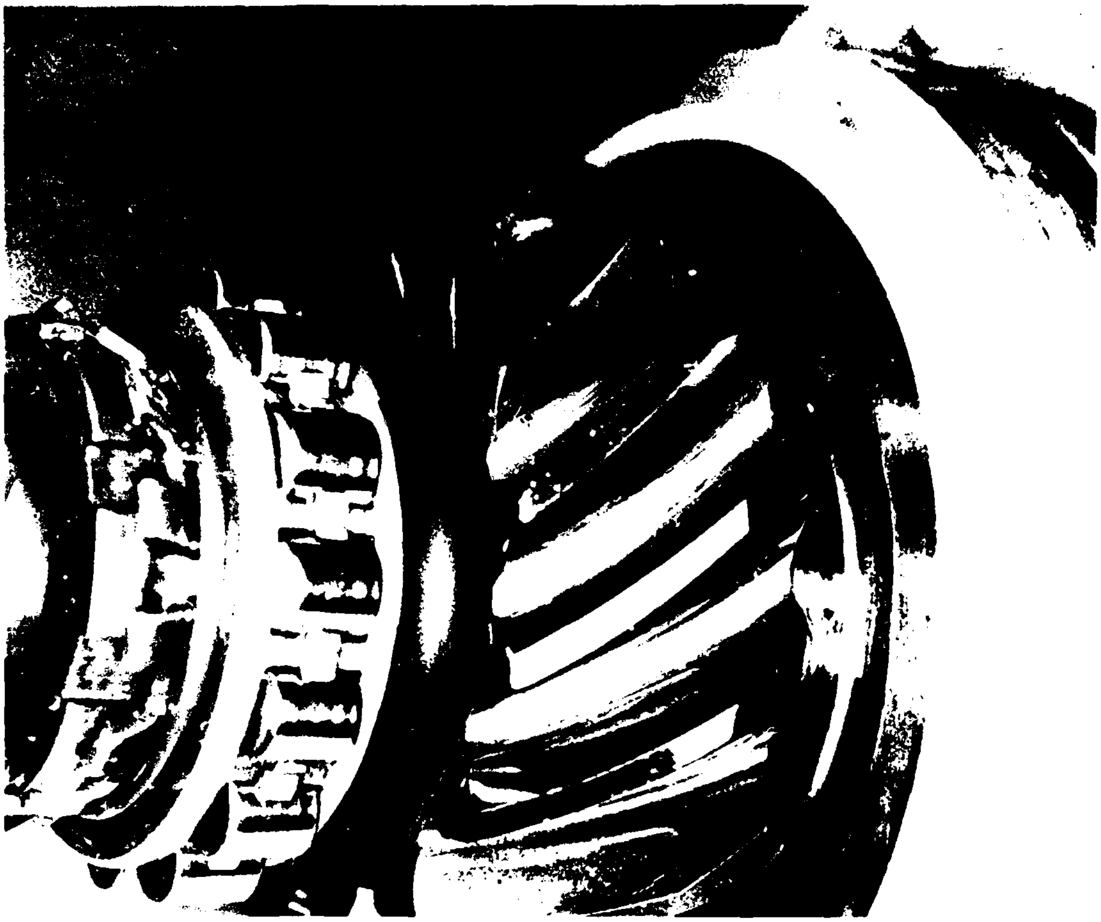


Figure 71. Convex side of input gear teeth (90-degree gearbox, S/N B13-1068, 1091.0 operating hours).

Figure 72. Concave side of input gear teeth (90-degree gearbox, S/N B13-1068, 1091.0 operating hours).

Figure 73. Concave side of output gear teeth (90-degree gearbox, S/N B13-1068, 1091.0 operating hours).

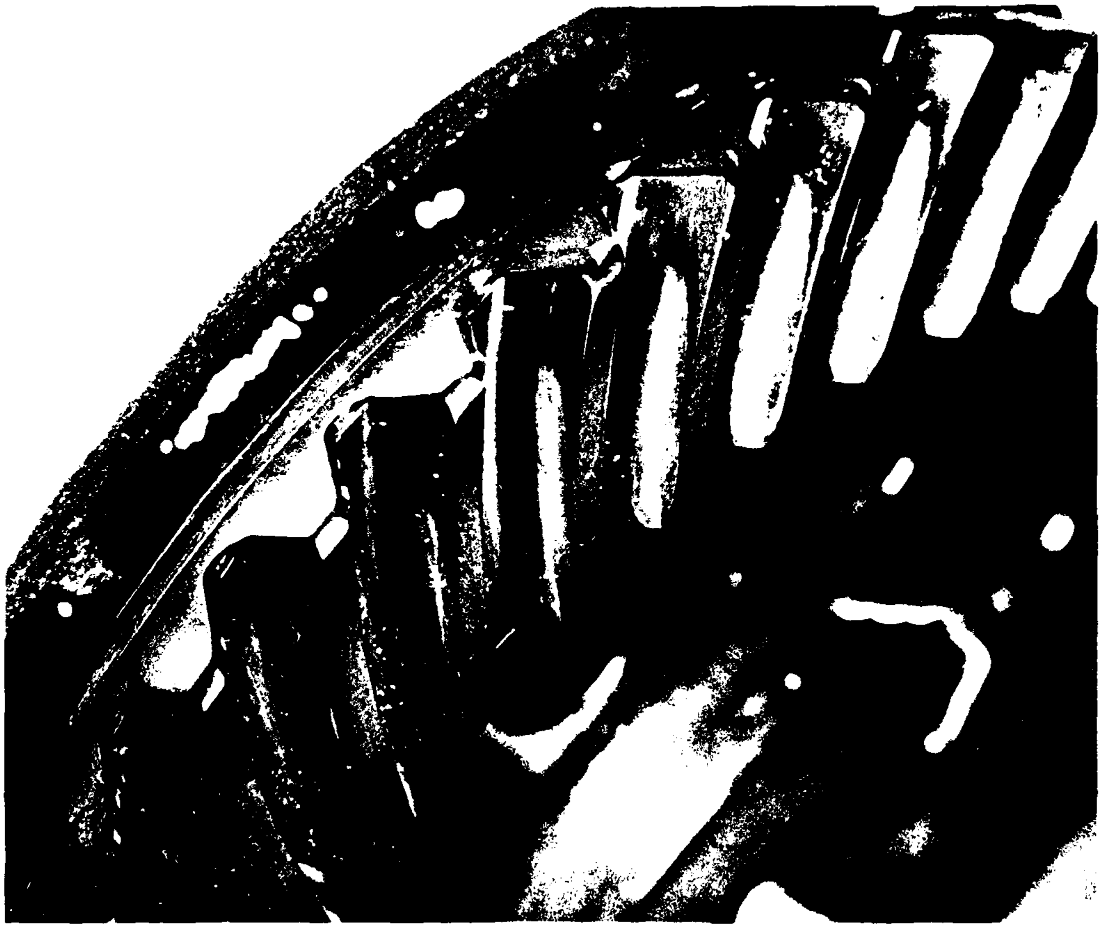
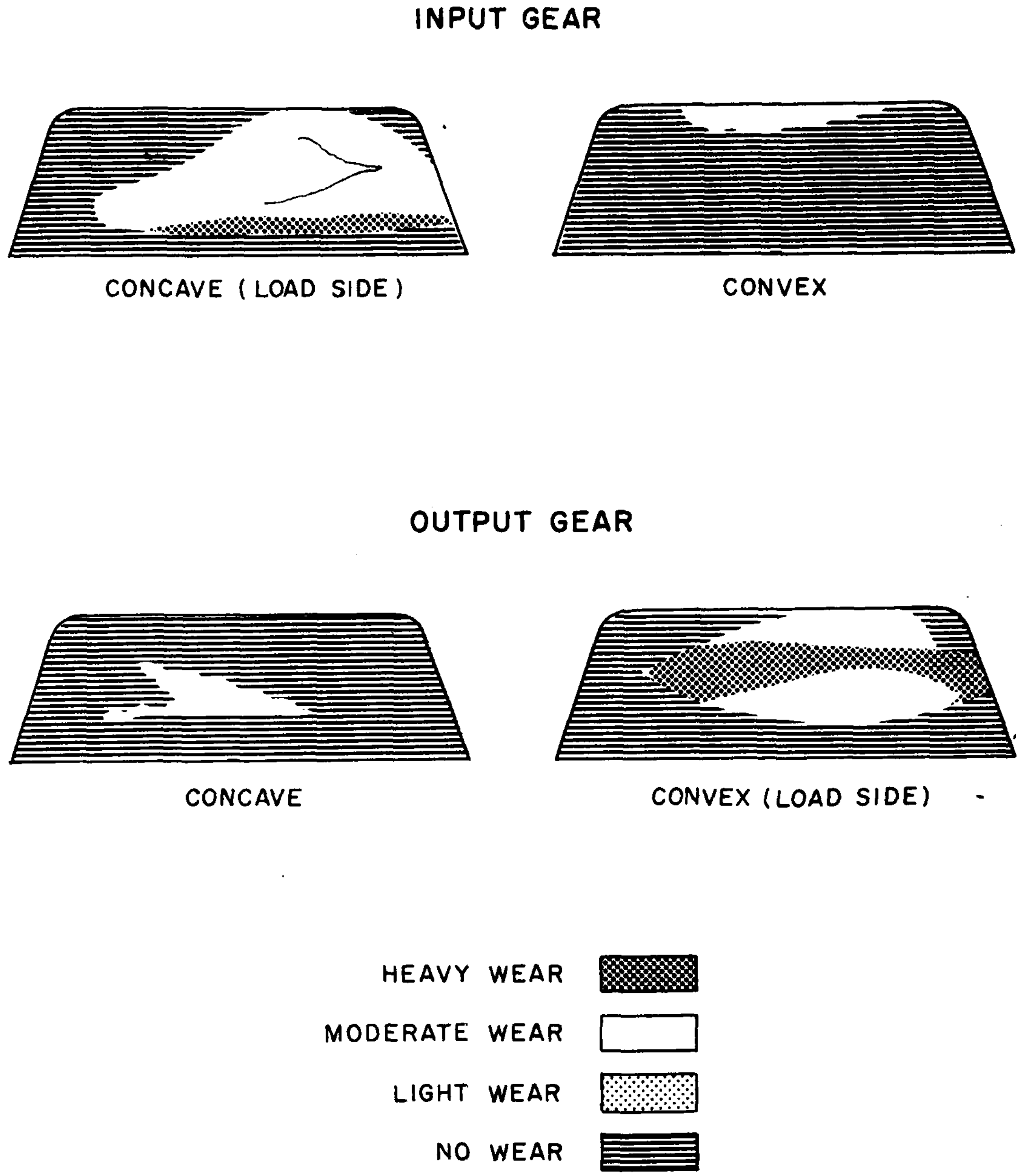


Figure 74. Convex side of output gear teeth (90-degree gearbox, S/N B13-1068, 1091.0 operating hours).



90° GEAR BOX, S/N B13-1068, 1091.0 HOURS

Figure 75.

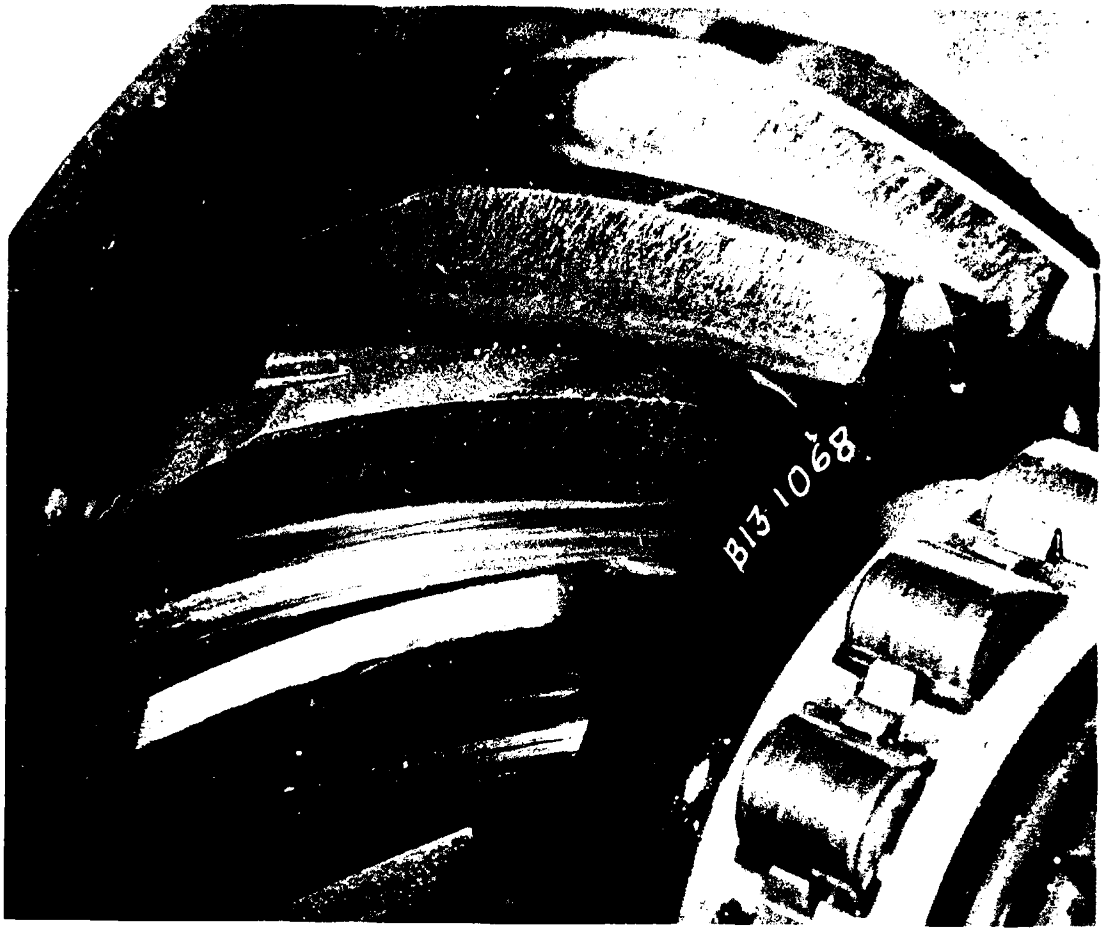


Figure 76. Concave side of input gear teeth (90-degree gearbox, S/N B13-1068, 1241.9 operating hours).

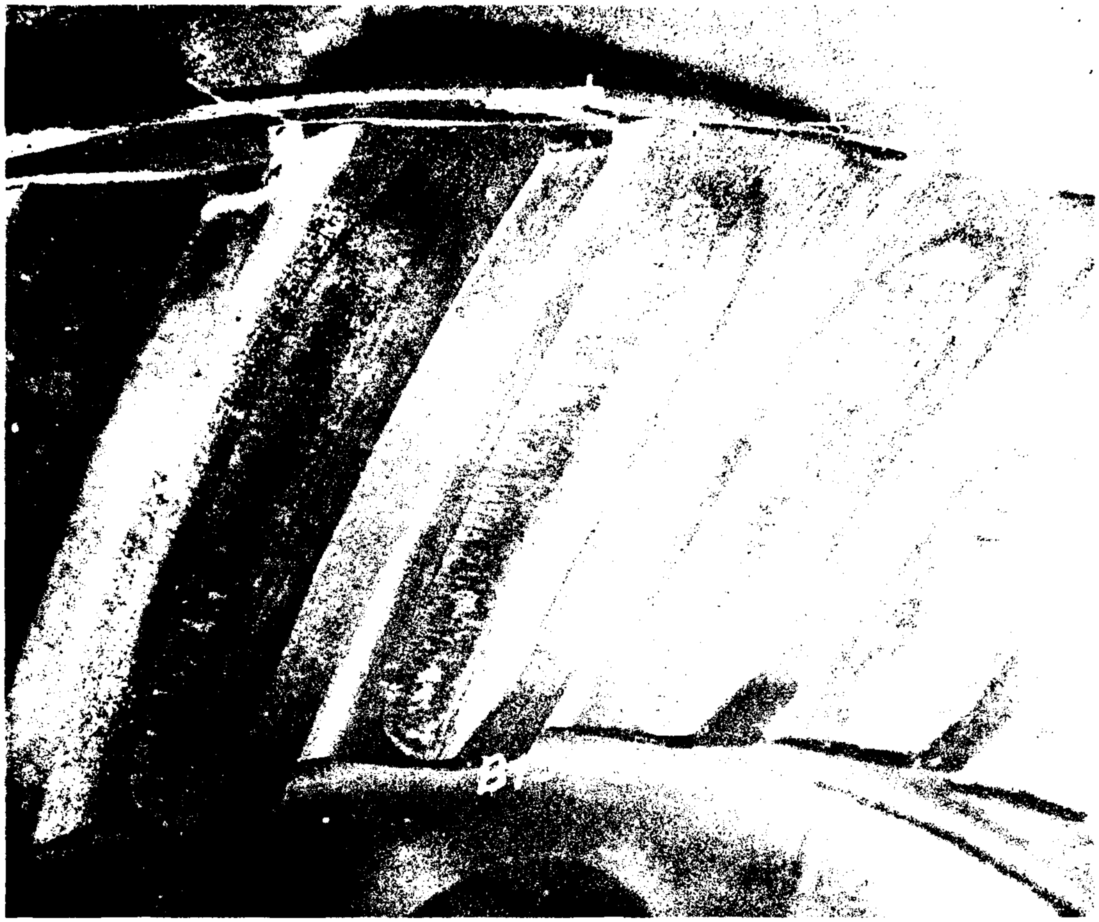


Figure 77. Convex side of output gear teeth (90-degree gearbox, S/N B13-1068, 1241.9 operating hours).

Figure 78. Convex and concave sides of input gear teeth (90-degree gearbox, S/N B13-1209, 1107.0 operating hours).

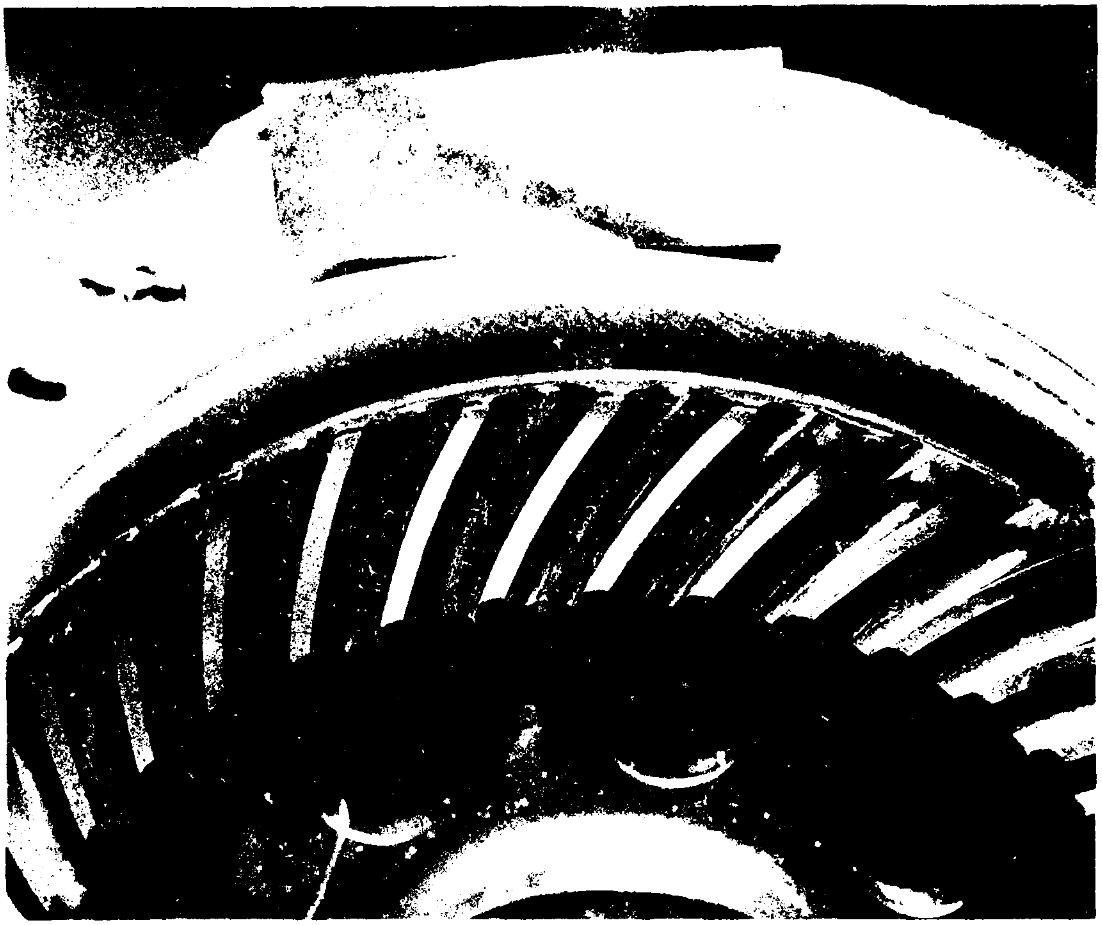
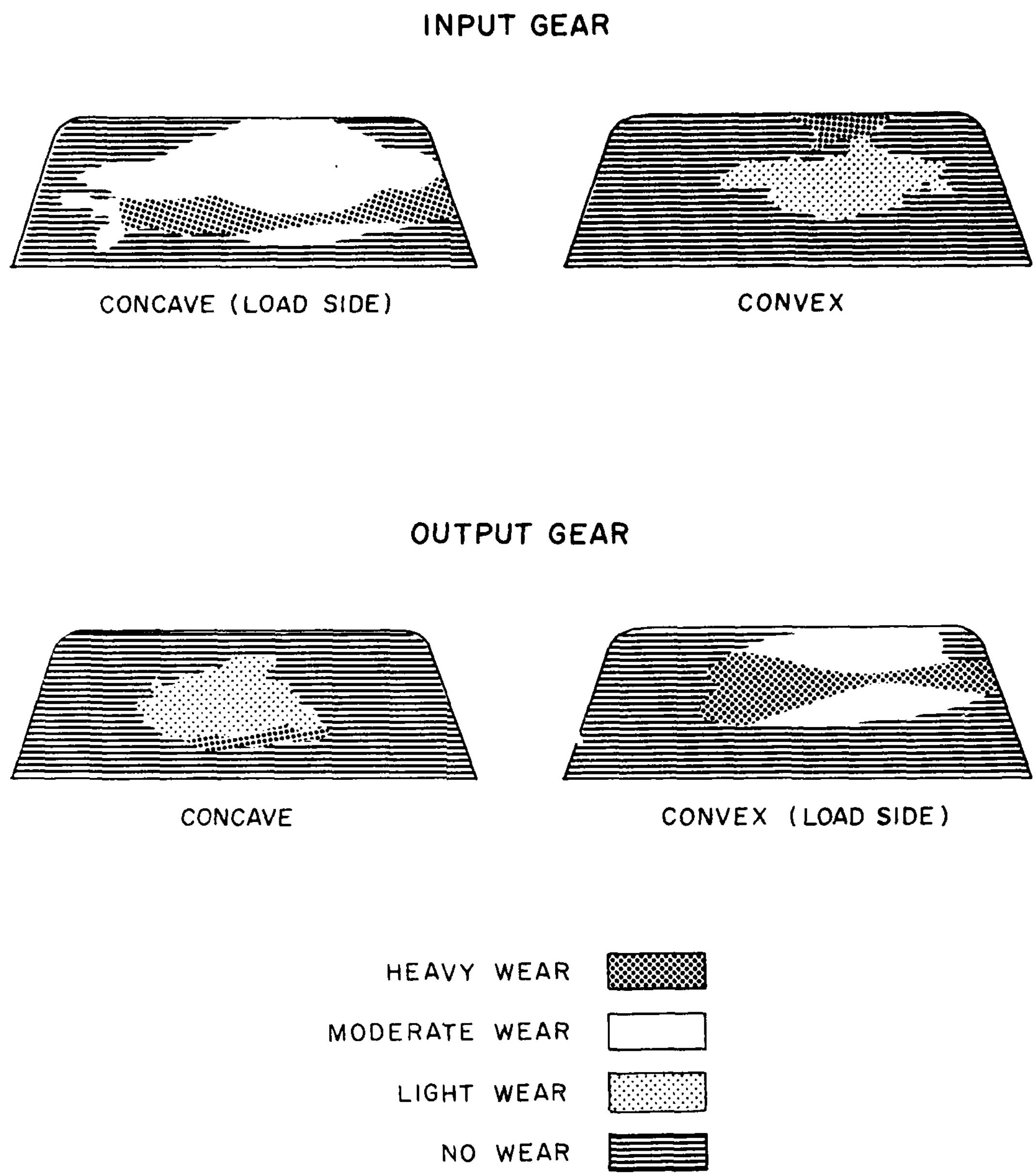
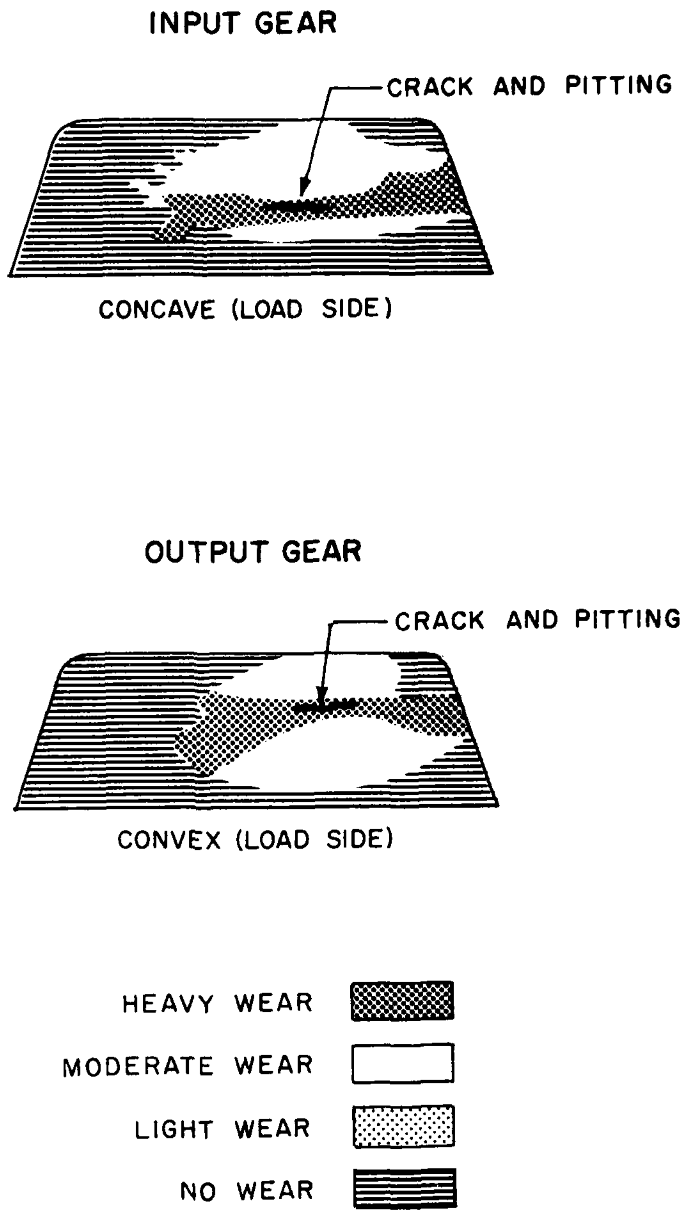


Figure 79. Convex and concave sides of output gear teeth (90-degree gearbox, S/N B13-1209, 1107.0 operating hours).



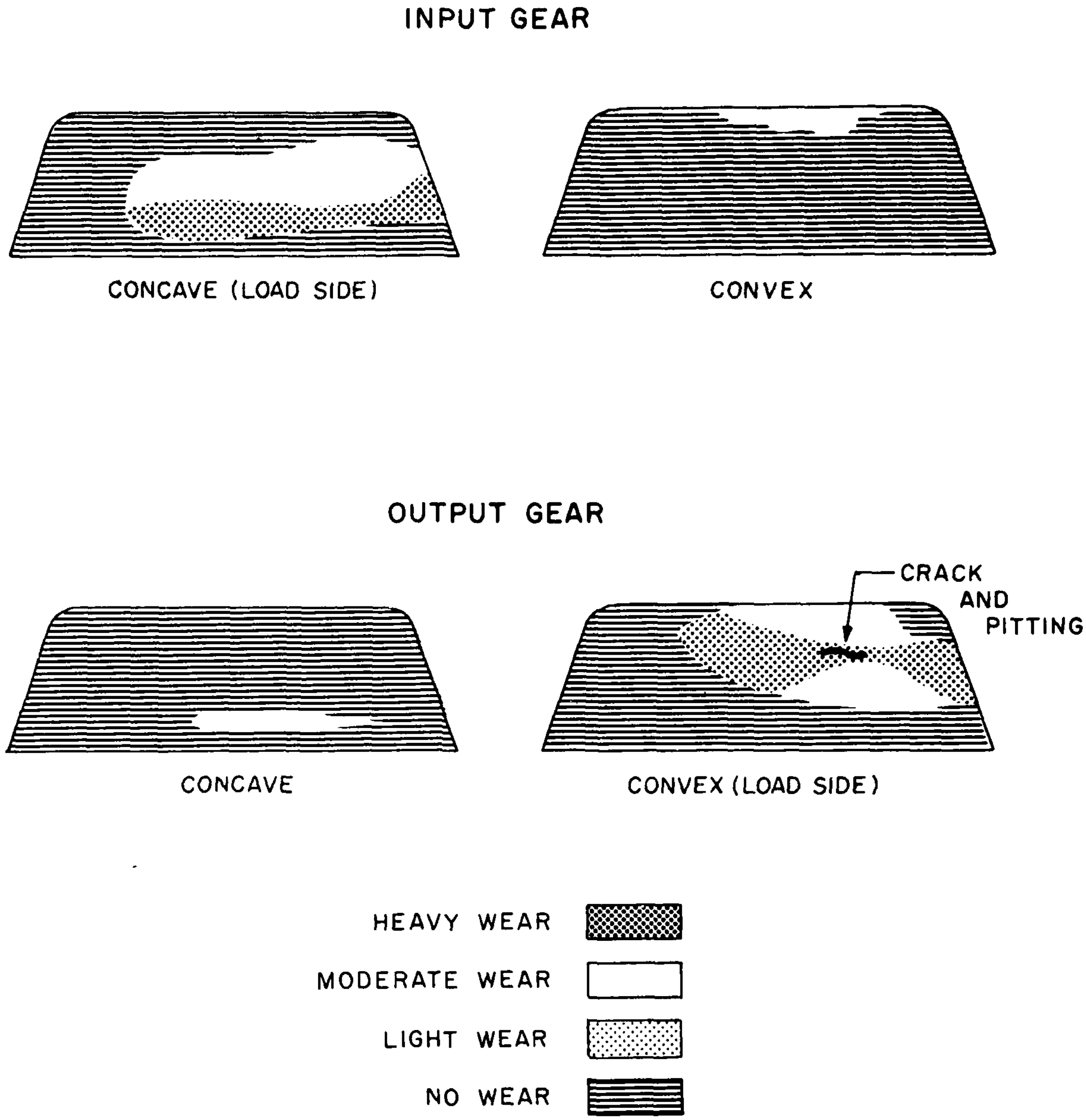
90° GEAR BOX, S/N B13-1209, 1080.0 HOURS

Figure 80.



90° GEAR BOX, S/N B13-1209, 1245.9 HOURS

Figure 81.



90° GEAR BOX, S/N B13-1276, 1107.0 HOURS

Figure 82.

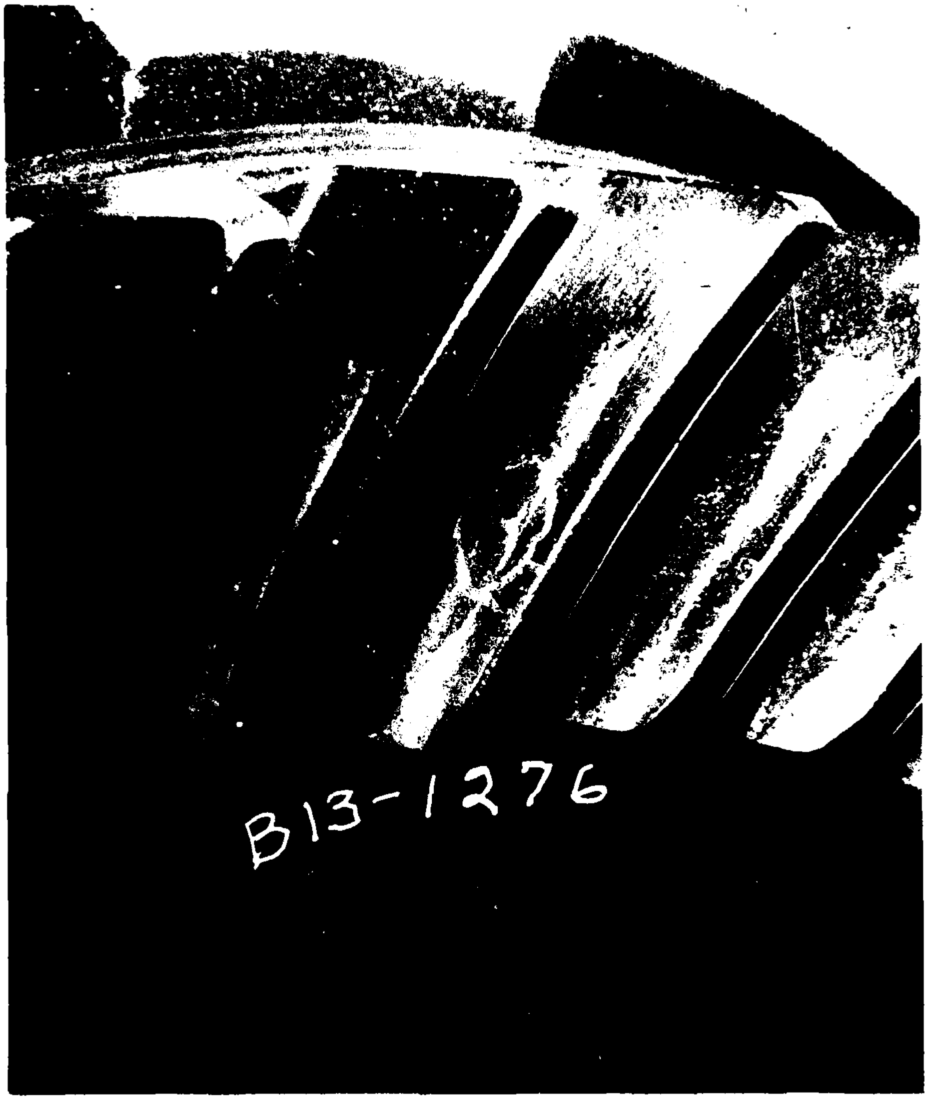


Figure 83. Pitting on convex side of output gear tooth (90-degree gearbox, S/N B13-1276, 1107.0 operating hours).