National Transportation Safety Board
Office of Research and Engineering
Washington, DC 20594

DCA22MA193

MATERIALS LABORATORY

Factual Report 23-020 Actuator - Exemplar

April 27, 2023

(This page intentionally left blank)

A. ACCIDENT INFORMATION

Location: Freeland, Washington
Date: September 4, 2022
Vehicle: de Havilland Aircraft DHC-3 Otter, N725TH
Investigator: Adam Huray

B. COMPONENTS EXAMINED

Exemplar horizontal stabilizer trim actuator assembly, with installed top eye bolt assembly (also referred to in the maintenance manual as the "top eye end and bearing assembly") and lock ring, from an airplane that was not involved in the accident.[1]

C. EXAMINATION PARTICIPANTS

Specialist	Frank Zakar NTSB Washington, DC
Specialist	Adam Huray NTSB Washington, DC

D. DETAILS OF THE EXAMINATION

1.0 As-received

Figure 1 shows a photograph of an exemplar horizontal stabilizer trim actuator assembly, P/N C3CF290, that was removed from an airplane that was not involved in the accident.[2] The submitted actuator assembly included the top eye bolt assembly and lock ring (see figure 2). The actuator assembly showed no evidence of mechanical damage.

1.1 Barrel

Examination of the barrel revealed no indication of a part number. The top end of the barrel at the outer surface contained a circumferential groove that accommodated a circular wire lock ring. A lock ring was attached to the groove and the tang portion of the lock ring was inserted into a drilled hole within the groove (see figure 3). For reference purpose, figure 4 shows an example of a lock ring where the tang portion was not engaged with a hole in the clamp nut (the tang portion is sitting at the root of the thread for the nut clamp). Also, for reference

[1] Exemplar parts were from airplane N703TH; NTSB investigation ANC22LA035.
[2] The horizontal stabilizer trim actuator is also referred to as the trim jack assembly.

purposes, figure 5 shows an example of a lock ring where the tang portion was resting in the circumferential groove of the barrel.[3]

The lock ring was disassembled from the barrel and the top eye bolt assembly was unscrewed from the barrel. The top eye bolt assembly was pulled out of the barrel portion. The exposed bearing assemblies and attachment nut at the bottom of the bearing assembly were covered with a liberal amount of green opaque grease. Figures 6 and 7 show photographs of the barrel after removal of the grease. The inner surface of the barrel in the area below the inner threads contained two bands that corresponded to the position of the two ball bearing assemblies. The inner threads and areas corresponding to the location of the two ball bearing assemblies were cleaned with a cotton rag soaked with acetone. Stereo microscope examination of the upper barrel end revealed the inner threads were intact and contained no evidence of sheared threads (stripped threads). The two areas corresponding to the location of the duplex ball bearing assemblies exhibited light scouring marks that were oriented in the circumferential direction (see figure 8).

Examination of the barrel after removal of the lock ring revealed the outer groove contained two drilled holes (see figure 6). The drilled holes were located nearly diametrically opposite each other. The diameter of the hole (for the lock ring) was specified as 0.098 inch. The shank portion of the 0.098 inch nominal diameter drill bit was inserted into each hole. The drill bit easily fit into each hole.

1.2 Lock Ring

The lock ring was specified as AN996-28, 1-3/4 inch inner diameter ring; length of the tang portion was specified as 0.3125 inch; and the nominal diameter of the wire was specified as 0.08 inch.[4] The properties of this lock ring are governed by specification QQ-W-470 "Carbon Steel Spring Wire", which specified a tensile strength between 282 kilo-pounds per square inch (KSI) and 312 KSI and coated with cadmium or zinc.

The dimensions of the lock ring mostly were measured with a caliper. The diameter of the lock ring measured approximately 0.08 inch (within the specified range 0.07 inch and 0.09 inch). The length of the tang portion, between arrows "C" in figure 2, measured approximately 0.321 inch (within the specified range of 0.297 inch and 0.328 inch). The inner diameter of the ring, in the general area of the tang, measured approximately 1.79 inch (outside of the specified range 1.73 inches and 1.77 inches), and when rotated 90 degrees rotation away from the tang portion measured approximately 1.77 inches (within the specified range 1.73 inches and 1.77

[3] The photographs in figures 4 and 5 were taken after the exemplar actuator was disassembled at the NTSB Materials Laboratory and re-assembled.
[4] According to AN996 (Lock Ring), the tolerance for decimal dimension is +/- 0.010 inch and for fraction dimension is +/- 1/64 inch.

inches). AN996-28 provides a dimension for the inner curvature at the base of the tang (where the tang intersects the overall curvature of the lock ring). This is the specified inner radius dimension. The specified range for the inner radius was between 0.0782 inch and 0.109 inch. The inner radius at the base of the tang measured (with a Keyence VHX digital microscope) approximately 0.04 inches, which was less than the range for the specified inner radius. Bench binocular examination of the lock ring revealed the tang portion contained a beveled end. The AN996-28 specification does not call out a requirement for how to terminate the tang end.

1.3 Top Eye Bolt Assembly

Figures 9 and 10 show photographs of the top eye bolt assembly after removal from the barrel. The top eye bolt assembly contained an eye bolt portion, a grease (Zerk) fitting at the top of the eye bolt portion, clamp nut, moisture seal (not called for in the manual), duplex bearing assemblies, castellated nut, washer, and cotter pin. Duplex bearing assemblies are two matched bearing assemblies that are placed next to each other. The outer race of the two bearing assemblies could be rotated by hand, relative to the eye bolt.

1.4 Clamp Nut

The clamp nut showed no evidence of a part number. The external threads of the clamp nut were cleaned with a rag that was soaked with acetone. Stereo microscope examination of the clamp nut revealed the external threads were intact and showed no evidence of sheared threads (stripped threads). The clamp nut in the area of the external threads contained a total of three drilled holes. For the purpose of this report, the rotational position of the drilled holes were measured when looking down at the center of the eye bolt and rotating clockwise relative to the square key slot (where the slot was arbitrarily assigned the zero degrees position). The drilled holes in the clamp nut were located at approximately the 180, 210, and 350 degrees position relative to the slot (see figure 10).

The hole at approximately the 180 degrees position was a through-hole (hole was drilled through the wall of the clamp nut); see figure 11. The drilled hole at approximately the 210 degrees position extended partially into the wall of the clamp nut (see figure 12). It was not a through-hole. The bottom of the hole exhibited a cone contour consistent with the contour at the tip of a drill bit. The bottom of the drilled hole extended slightly below the root portion of the threads. The drilled hole at approximately the 350 degrees position was obstructed by deformation in the wall that constricted (reduced) the diameter of the hole; see figure 13. The deformation was in the form of a round flat bottom land that extended partially down into the hole and on one side of the hole. The center of the round flat bottom land was offset from the center of the hole. The flat bottom land in the hole extended slightly below the root portion of the threads. The contour of the flat land exhibited a round shape that appeared similar to the contour of a metal surface that was struck with a round flat bottom tool punch.

The nominal diameter of the circular wire lock ring is specified as 0.08 inch and the hole in the clamp nut is specified as 0.098 inch nominal diameter. The shank end of a 0.0755 inch diameter drill bit was inserted into the drilled holes within the clamp nut to determine whether the drill bit could be fully inserted into each respective hole. The drill bit simulated the diameter of the lock ring. The drill bit penetrated the hole at approximately the 180 degrees position. The drill bit hit the bottom of the partially drilled hole at approximately the 210 degrees position. The drill bit did not penetrate the hole at approximately the 350 degrees position (struck the flat bottom of the damaged hole).

The clamp nut was specified as 4130 steel alloy. The material grade of the thread portion was identified with an Olympus Vanta X-ray fluorescence (XRF) portable alloy analyzer as grade 4130 steel alloy.

1.5 Eye Bolt

The part number of the eye bolt was not found at the flat face (location where the part number is expected to be stamp marked). Examination of the flat faces of the eye bolt revealed mechanical scrape marks related to assembly of the eye bolt and relative movement between the eye bolt and structure of the airplane during service that obliterated the part number.

The eye bolt portion of the actuator was specified as 4130 steel alloy. The material grade of the eye bolt was identified by an Olympus Vanta X-ray fluorescence (XRF) portable alloy analyzer as grade 4130 steel alloy.

1.6 Ball Bearings

The de Havilland illustrated parts catalog for the "Fuselage – Controls Installation – Elevator Trim", revision 18 Dec 2019 indicated part number "7202W-DB" "Bearing-Duplex (FAF)" bearings are to be installed on the eye bolt. A "duplex" bearing is comprised of two single-row bearings that are manufactured specially for use as a unit.[5] "FAF" indicates the bearing was made to the FAFNIR Bearing Company specification. "7202W" is the part number. The DB designation after the part number indicates the bearings are supplied in a set of two and for use in a back-to-back configuration. Appendix 1 shows illustrations of two common duplex bearing configurations.

The engineering drawing "C3 CF 290" for the "Assembly of the Tailplane Actuator" specifies to install "7202W-DB" duplex bearings and indicated that "it is

[5] Timken Engineering Manual, 11-22 Order No. 10424, © 2022 The Timken Company, p95.

important that the thrust faces of the bearings are mounted together".[6] On the same engineering drawing, a cross section of the duplex bearings are shown assembled in a back-to-back configuration. The engineering drawing bill of material further states that the bearings are to be assembled in a face-to-face configuration.[7]

The eye bolt assembly was disassembled to expose the ball bearing assemblies. The cotter pin at the threaded end of the eye bolt was intact and secured to the castellated nut. The cotter pin and the nut were disassembled from the threaded end of the eye bolt. The two bearing assemblies were placed/secured between the jaws of a bench vice (jaws covered with rubber inserts) and the bottom end of the eye bolt was tapped with a hammer. The shank portion of the eye bolt slipped out of the two bearing assemblies. The shank portion of the eye bolt did not show evidence of mechanical damage. One side of each bearing assembly on the outer race portion was marked with the characters "FAFNIR® 7202W DU" SF136 USA THRUST X 05G LOT# 0007663724". The marked side of the bearings were facing each other. "7202W DU" is not per the aircraft type design. The "DU" suffix indicates flush ground on both faces for universal mounting - bearing can be oriented in any configuration such as DB or DF (face-to-face configuration).

All portions of the two disassembled bearing assemblies (including the balls and cage) were covered with green opaque grease. As indicated earlier, the outer race of each bearing assembly could easily be rotated by hand relative to the eye bolt. The two bearing assemblies were immersed in a glass beaker filled with trichloroethylene and ultrasonically cleaned for one hour, which removed the grease and exposed the cage and bearing elements. Each bearing assembly was identified as an angular contact ball bearing assembly. Stereo microscope examination of the bearing assembly revealed the ball portions exhibited a smooth surface with no evidence of corrosion. The bearings rotated freely without binding. The bearing assemblies were examined and found to be in a back-to-back configuration and as indicated earlier, with the thrust (marked) faces of the bearing mounted together.

1.7 Moisture Seal Assembly

A moisture seal assembly was installed between the inner face of the clamp nut and the larger diameter portion of the eye bolt shank (see figure 14 through 17). The moisture seal assembly was comprised of a metal ring, with a circumferential groove on the inner and outer diameter portion, and elastomer seals that were installed at inner and outer diameter groove portions of the ring. A moisture seal assembly is not

[6] The de Havilland maintenance manual (section 2.27.4, revision 15, dated September 1959) also indicated the bearings must be re-assembled in a manner to "ensure that the thrust faces of the bearings are mounted together".
[7] This statement is in conflict with the rest of the drawing which specified to mount the bearings in a back-to-back (thrust faces together) configuration.

shown or listed on the de Havilland illustrated parts catalog, aircraft maintenance manual, or actuator assembly drawing.

2.0 Measurements

2.1 Clamp Nut Threads

The engineering drawing for the clamp nut part number C3-CF-277 specified 1.5 inch-12NF3 threads. The major and minor diameters[8] of the threads were measured with an optical comparator, OPG Optical Gaging Products Inc., model Opticom Qualifier 14B. The major and minor diameters were measured in one area of the clamp nut and it is not an average of measurements from multiple locations of the clamp nut. The major and minor diameters of the external thread on the clamp nut measured approximately 1.498 inches and approximately 1.384 inches, respectively. The minor diameter on the internal threads of the barrel portion of the actuator measured approximately 1.389 inches. A screw thread pitch gauge set was utilized to measure the pitch and size of the threads. The inner threads on the barrel and outer threads on the clamp nut matched the threads that corresponded to 12 NF size threads (12 threads per inch). The distance between the root of the thread and the inner surface of the clamp nut measured approximately 0.069 inch.[9]

2.2 Extension of the Jackscrew

The actuator was received with the jackscrew in the fully retracted position. The lower eye bolt assembly was actuated (rotated) by hand to determine the full travel distance of the jackscrew portion. The travel distance was measured with a caliper, distance between the bottom end of barrel and approximate center of the bolt hole, indicated by distance “D” in figure 1. Measurements were made for an actuator in the retracted and fully extended position. The measured distance “D” in figure 1 for the retracted and fully extended positions measured 1.6 inches and 3.7 inches, respectively.

2.3 Lock Ring Tang Protrusion Beyond the Barrel Inner Thread

A lock ring was attached to (inserted into) the circumferential outer groove portion of the barrel, and the length of the tang portion that extended (protruded) beyond the inner threads of the barrel was measured with the Keyence VHX digital microscope. The length of the tang portion that extended beyond the crown portion of the inner threads measured approximately 0.027 inch, see figures 18 and 19.

---

[8] Major diameter is the largest diameter of the threads of the screw or nut, whereas the minor diameter is the smallest diameter of the threads of the screw or nut.
[9] Measured with a point-to-point micrometer.

At the base of the tang (where the tang is bent into the circumferential portion of the lock ring), a gap existed between the inner diameter of the lock ring and the outer face of the groove. To close this gap, the diametrically opposite ends of the lock ring, in the area of the tang, was compressed with a c-clamp so that all portions of the lock ring made full contact with the groove portion of the barrel. Having been compressed, the tang portion of the lock ring extended (protruded) further beyond the inner thread of the barrel, compared to when the lock ring was not compressed, see the right image in figure 19. The distance between the crown portion of the barrel inner thread and the tip of the tang portion measured approximately 0.064 inch (slightly more than double the length compared to that of a free sitting non-compressed lock ring).

Submitted by:

Frank Zakar
Senior Metallurgist

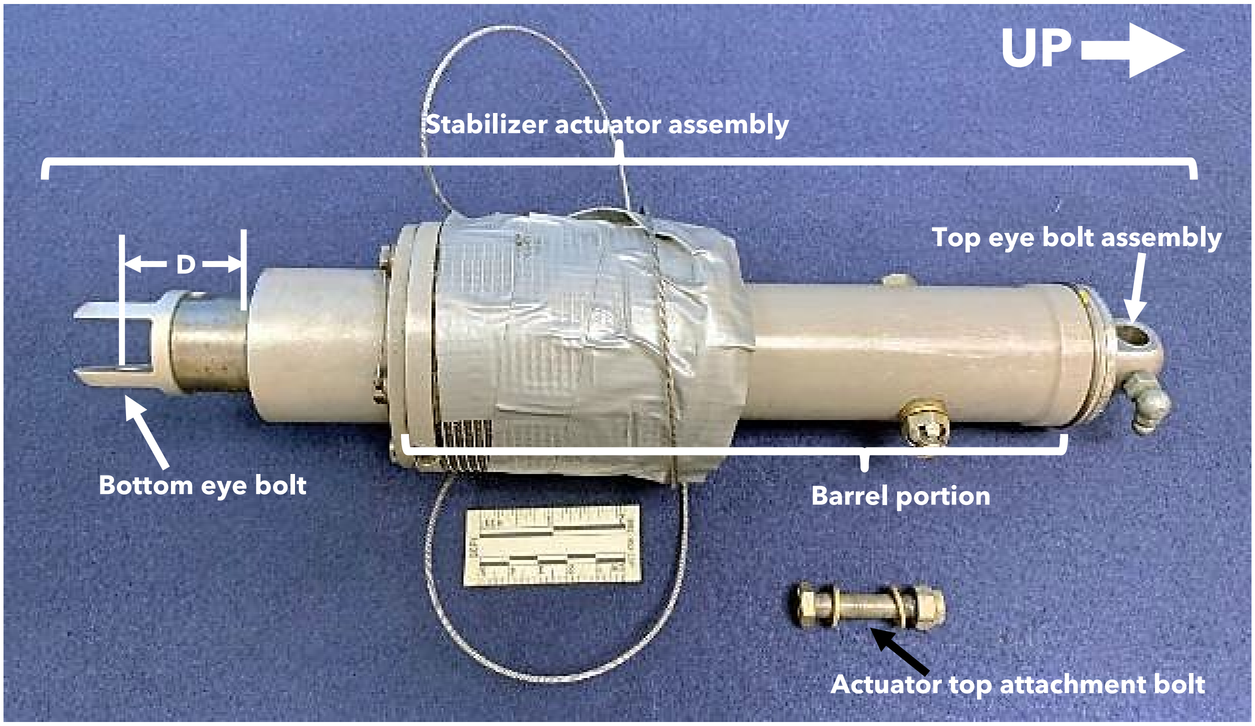


Figure 1. Exemplar horizontal stabilizer trim actuator assembly.

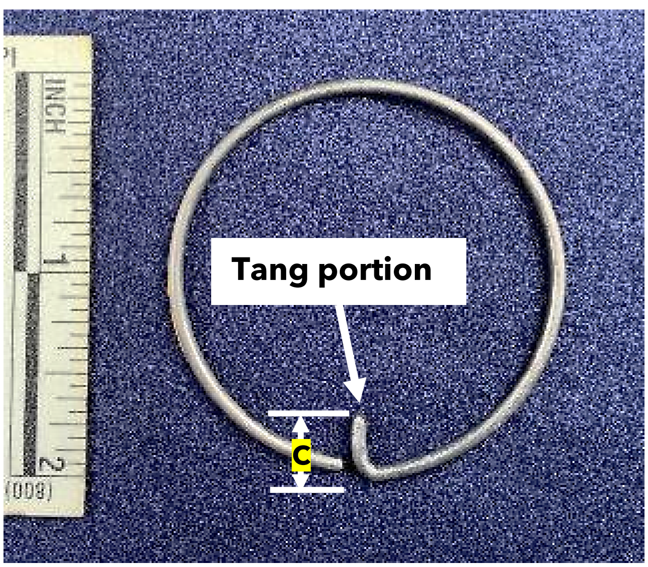


Figure 2. Lock ring that was disassembled from the exemplar actuator. The portion that is curved radially inward is referred to as the tang portion (between arrows "C").

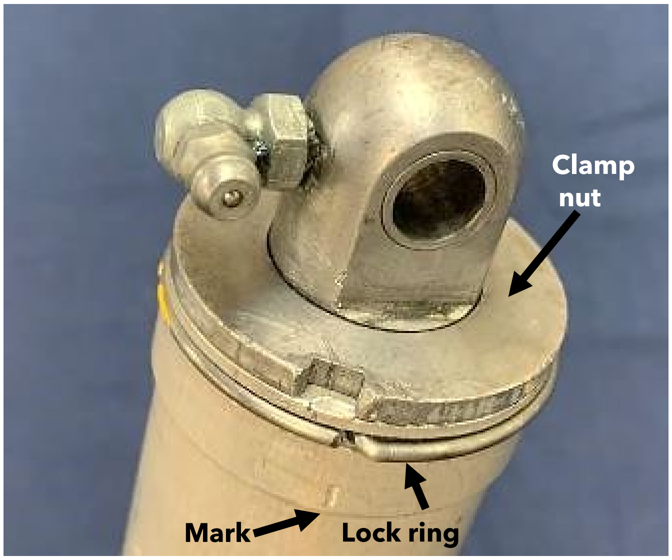


Figure 3. Oblique view of the top eye bolt assembly in the as-received condition showing a lock ring that is in the fully engaged position. Area indicated by "mark" was vibro-peen marked by the NTSB Materials Laboratory to mark the as-received position of the lock ring. Lock ring is bent to the right relative to the tang portion when looking into exterior hole of the barrel.

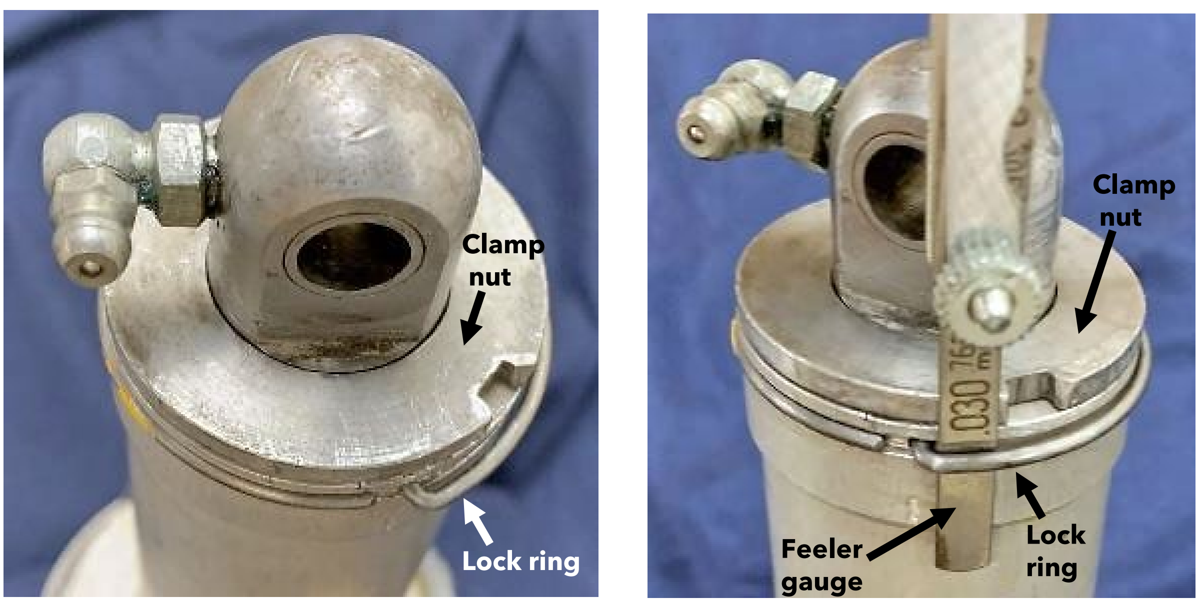


Figure 4. Oblique view of the top eye bolt assembly showing a lock ring that is partially engaged (inserted in the hole of the actuator barrel groove but not inserted in the hole of the clamp nut) [left side of page]; and with a feeler gauge between the lock ring and barrel showing a gap of 0.030 inches (right side of page).

Figure 5. Oblique view of the top end of the barrel showing the tang portion of the lock ring intentionally positioned in the groove portion outside of the hole. The purpose of this demonstration was to show the large gap between the lock ring and barrel.

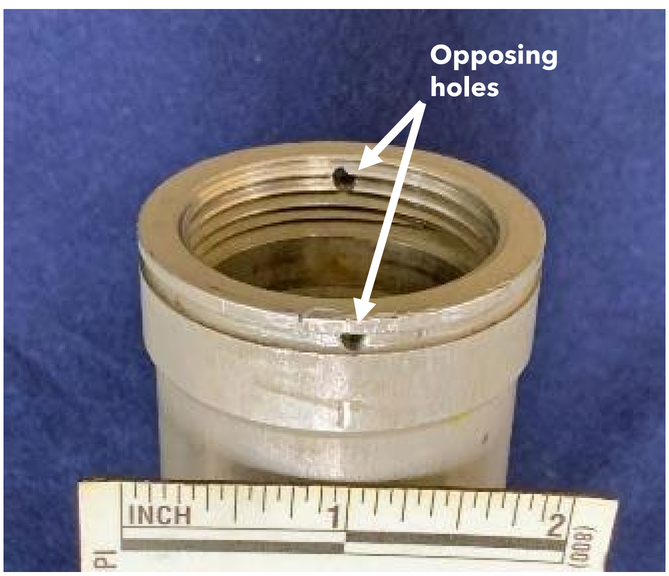


Figure 6. Oblique view of the top end of the barrel showing two drilled holes that were located approximately diametrically opposite each other and in the groove.

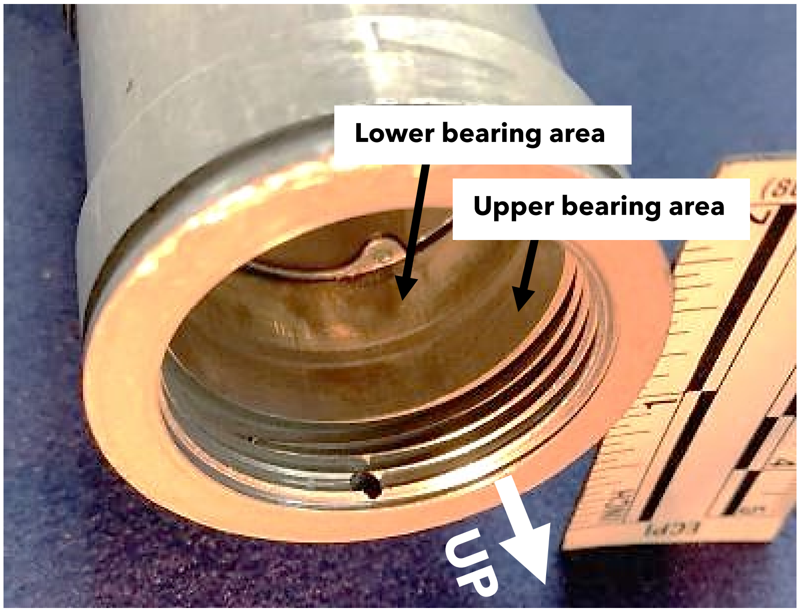


Figure 7. Inner threads at the upper end of the barrel portion, after cleaning.

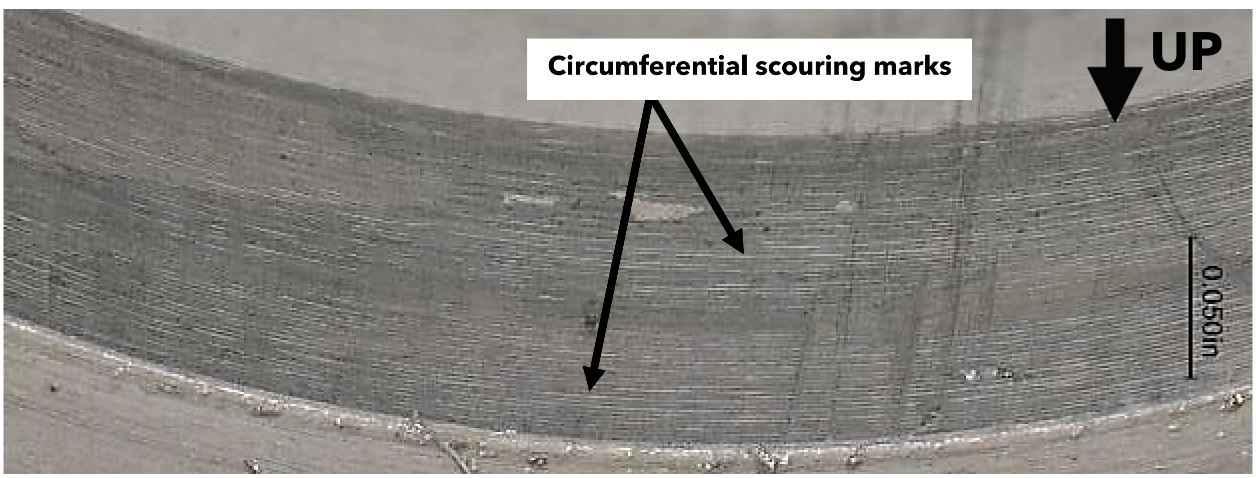


Figure 8. Inner surface of barrel showing circumferentially oriented scouring marks in the area that corresponded to the upper bearing assembly (after cleaning).

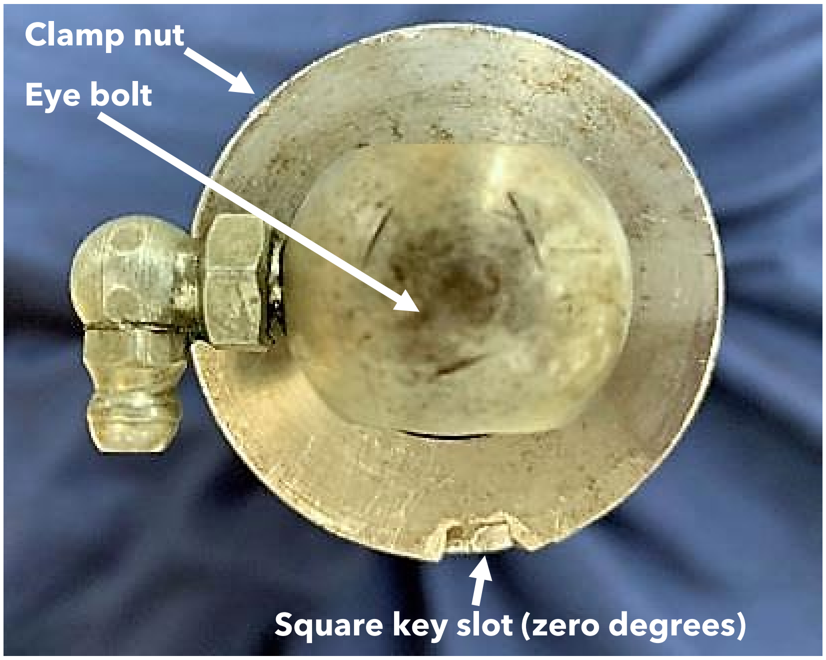


Figure 9. Top view of the eye bolt and clamp nut. For the purpose of this report, the position of the drilled holes in the clamp nut outer threads were measured when looking down at the center of the eye bolt and when rotating clockwise relative to the square key slot, where the slot is the arbitrary zero position.

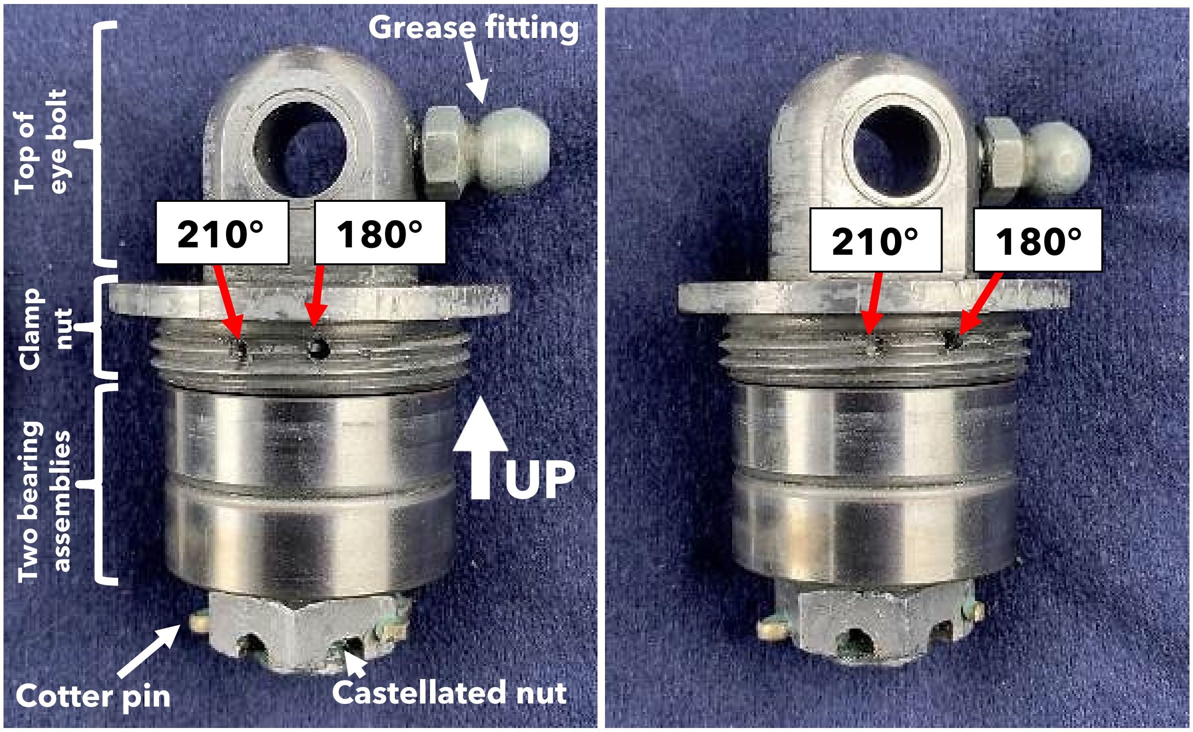


Figure 10. Side view of the eye bolt, after cleaning, showing drilled holes in the outer threads of the clamp nut, at approximately the 180, 210 and 350 degrees positions, relative to the square key slot; when looking down at the eye bolt and rotating clockwise. The square key slot is the zero degrees position.

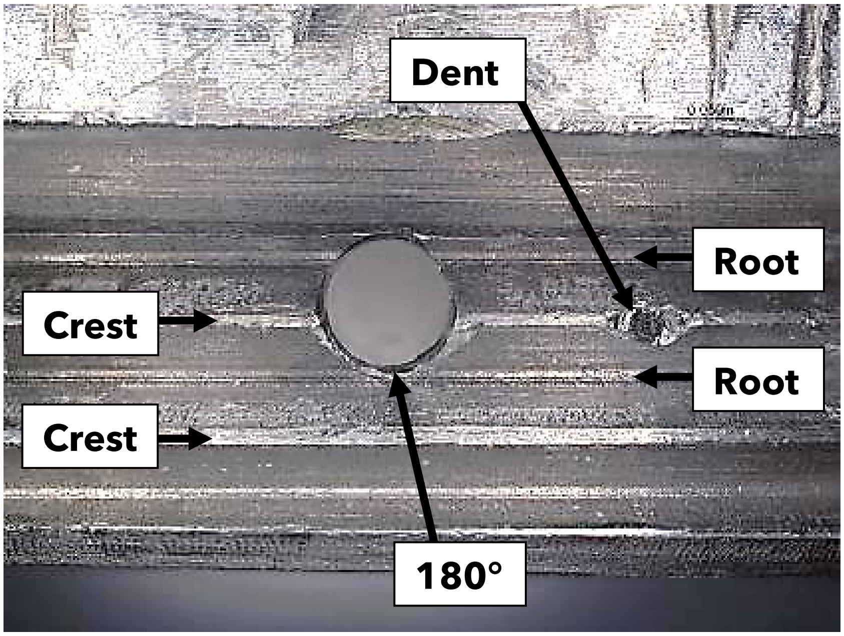


Figure 11. Outer threads of the clamp nut showing a drilled through-hole at approximately the 180 degrees position; after ultrasonically cleaning the clamp nut with acetone. The clamp nut is in the full disassembled condition (notice that the moisture seal is not behind the hole).

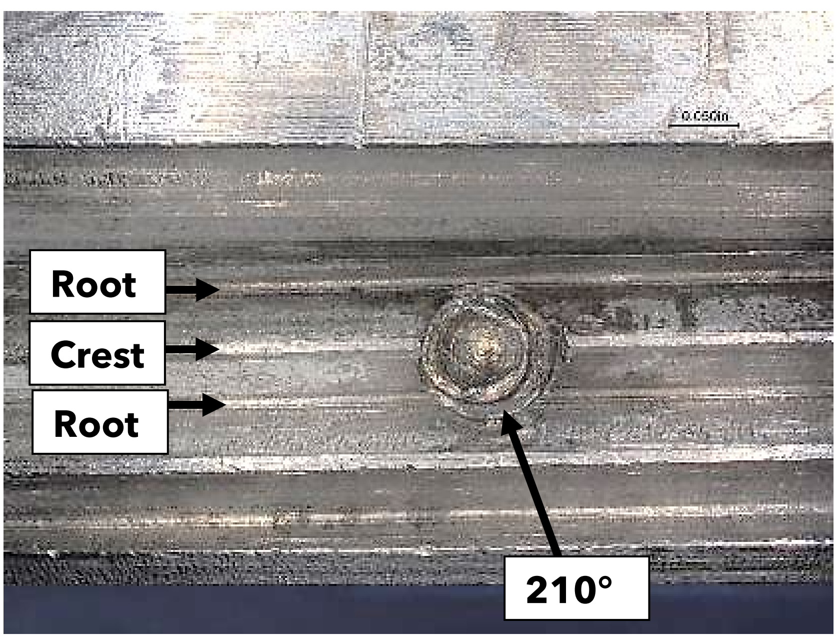


Figure 12. Outer threads of the clamp nut showing a partially drilled hole that did not penetrate the wall of the clamp nut at approximately the 210 degrees position; after ultrasonically cleaning with acetone. This is not a through-hole. The clamp nut is in the full disassembled condition.

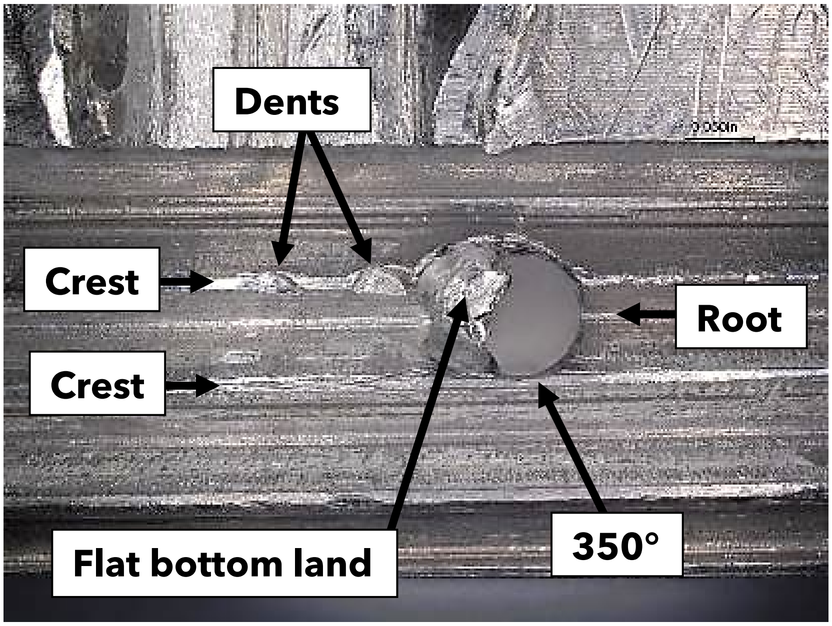


Figure 13. Outer threads of the clamp nut showing a partially obstructed through-hole at approximately the 350 degrees position; after ultrasonically cleaning the clamp nut with acetone. The clamp nut is in the full disassembled condition.

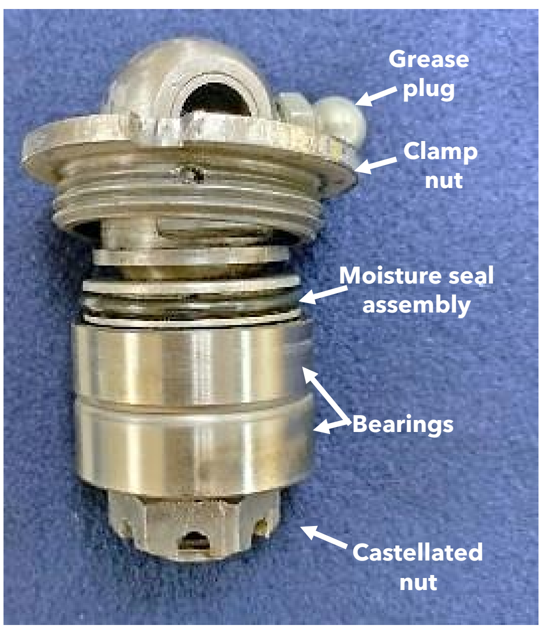


Figure 14. Partially disassembled eye bolt assembly where the clamp nut was pulled up to expose the moisture seal assembly (ring with elastomer seals).

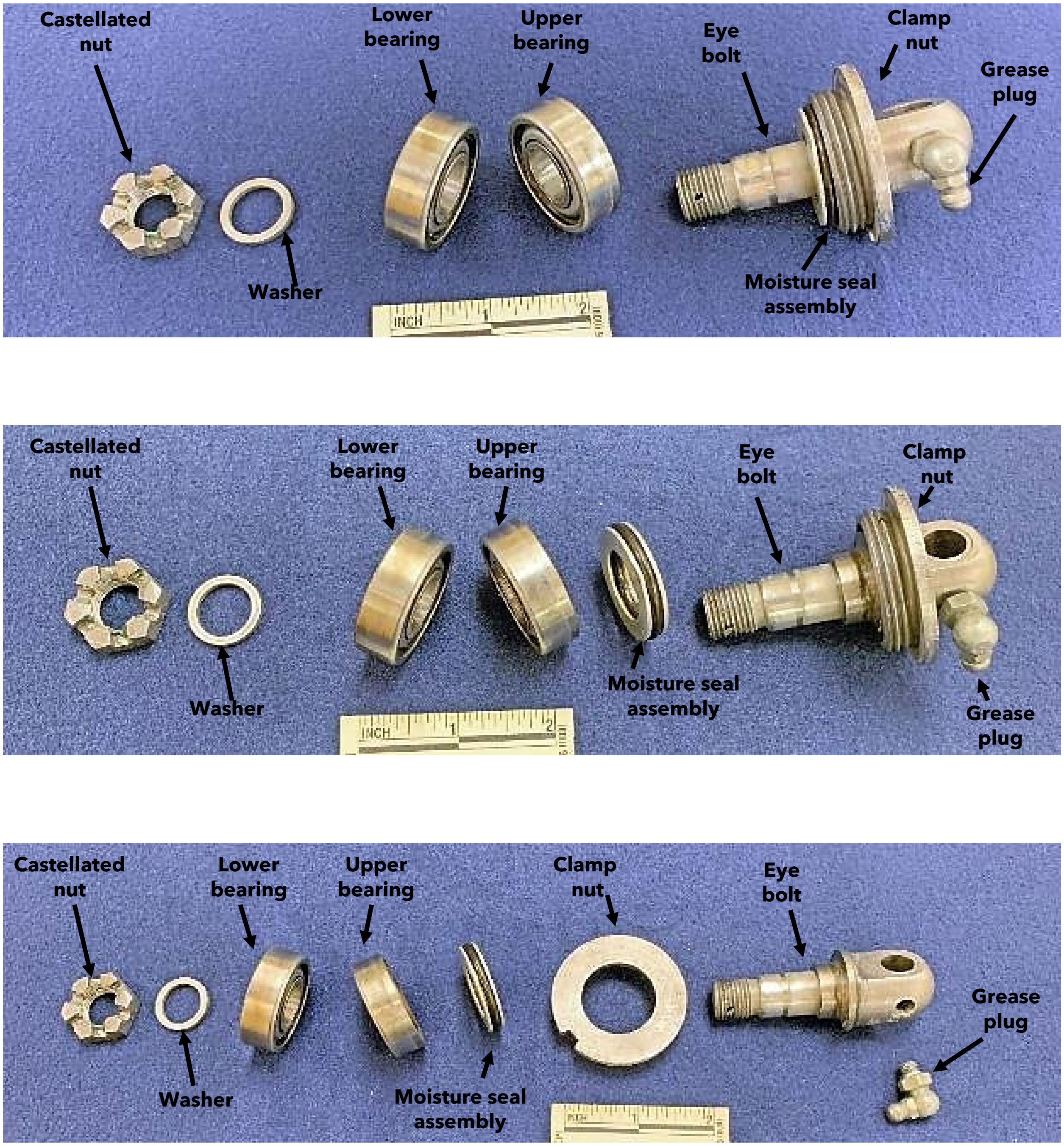


Figure 15. Eye bolt assembly in various stages of disassembly showing the castellated nut; washer; lower and upper bearing assemblies; moisture seal assembly; clamp nut; eye bolt; and grease fitting (left to right).

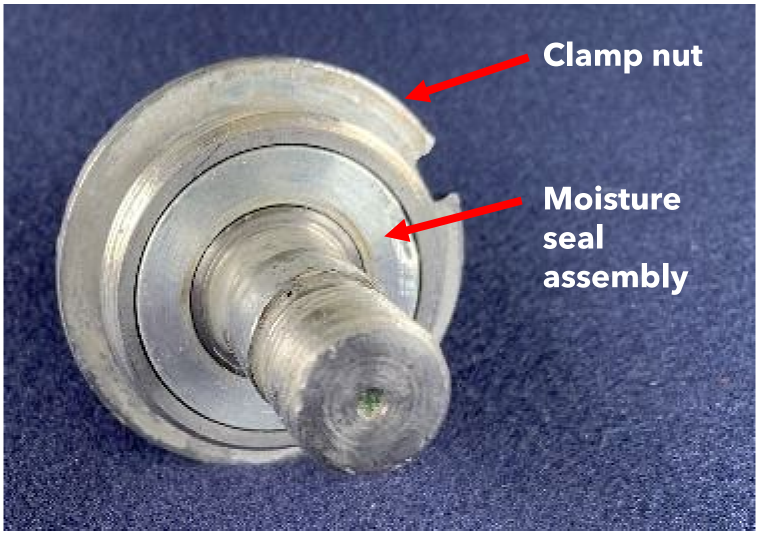


Figure 16. Bottom view of the clamp nut showing the moisture seal in the installed condition.

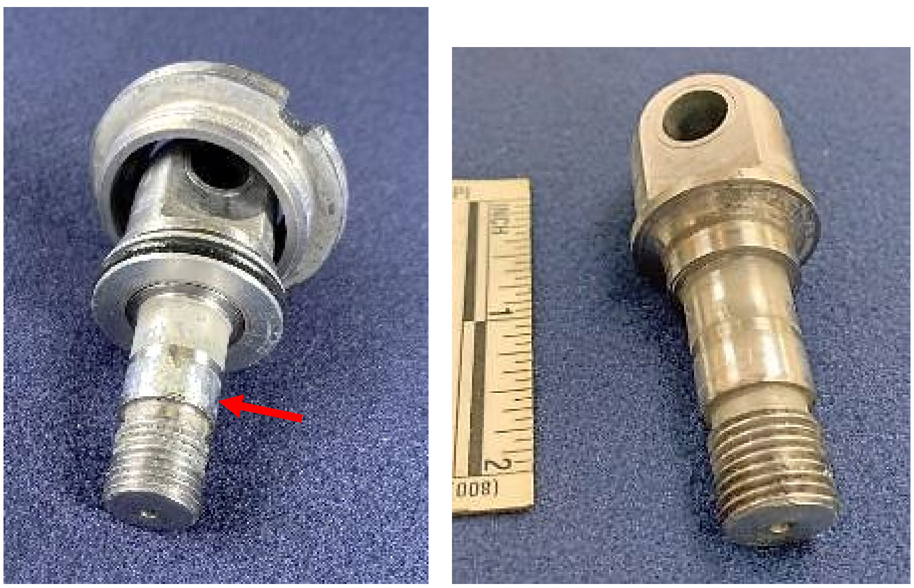


Figure 17. Left photograph shows a partially disassembled eye bolt with moisture seal. Right photograph shows an exposed eye bolt. During reassembly exercises at the NTSB Materials Laboratory, the shank in the area that corresponded to the lower bearing, indicated by an arrow, was ground with a file (to facilitate reassembly).

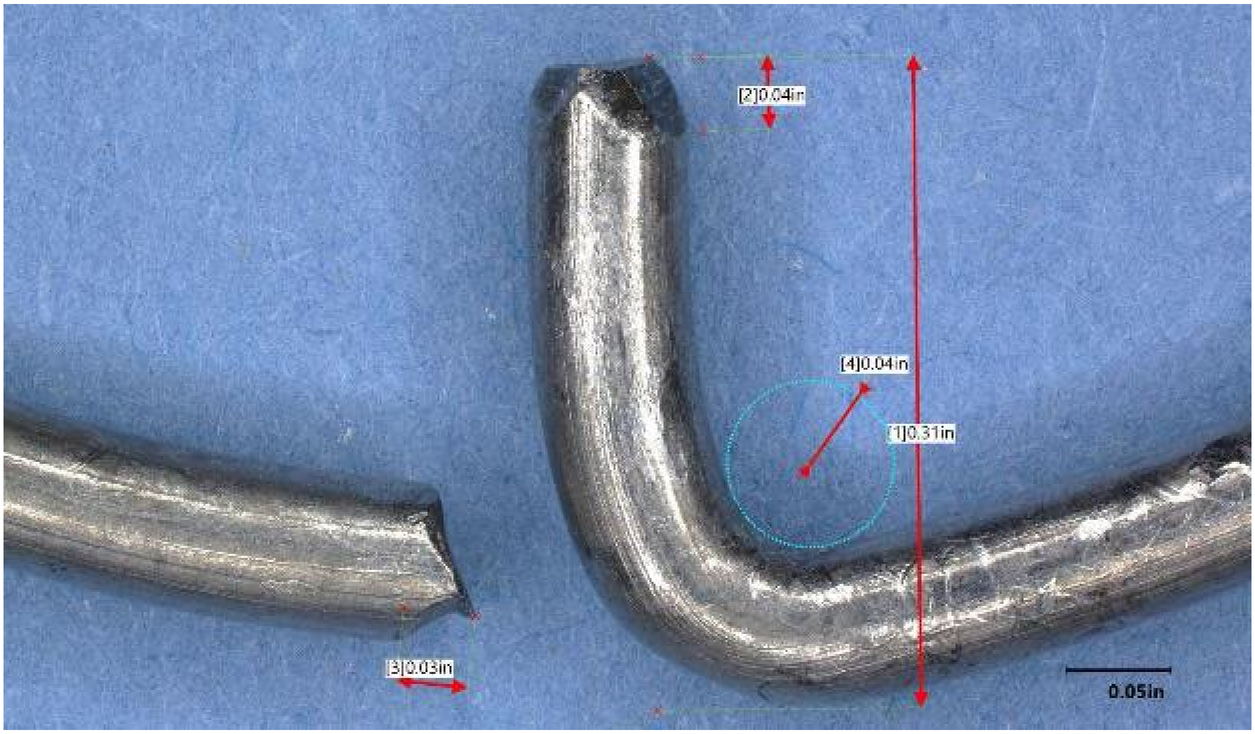


Figure 18. Side view of the lock ring in the area of the tang portion. The inner radius at the base of the tang measured approximately 0.04 inch.

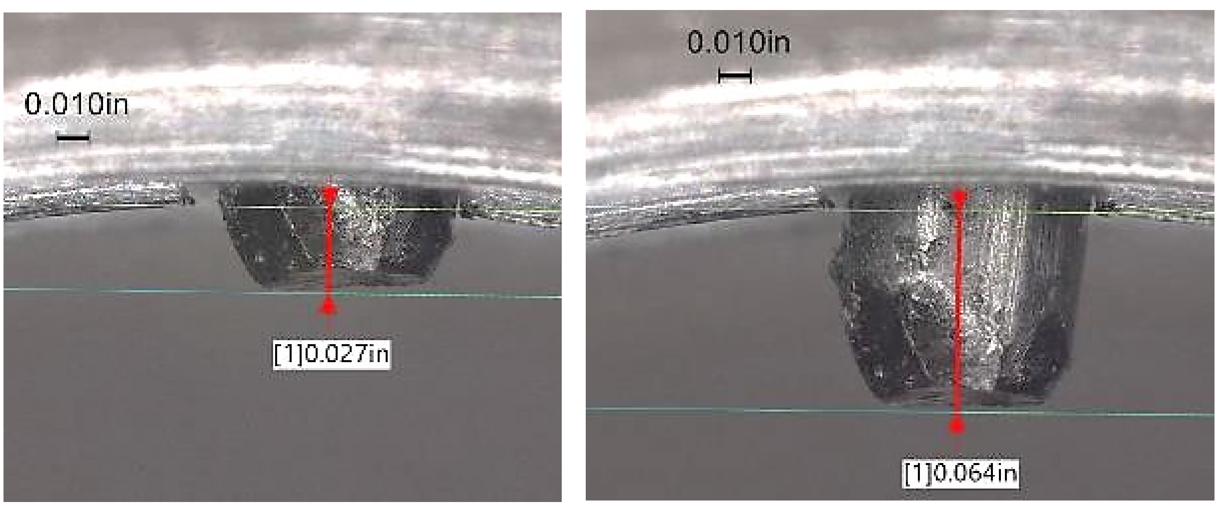
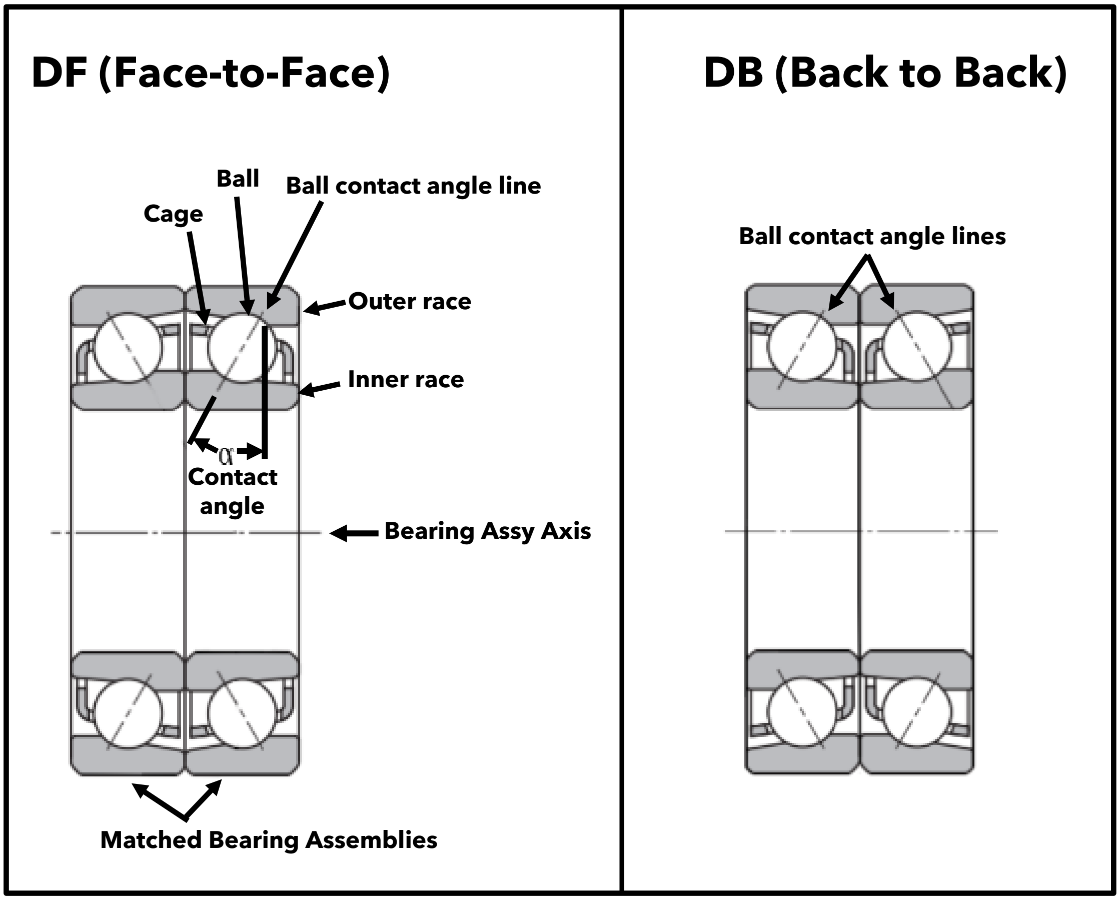


Figure 19. Side view of the barrel inner thread showing the tip end of the tang portion of a lock ring that extended approximately 0.027 inch out of the hole (left side of page) and when the lock ring was pressed inward into the groove portion of the barrel showing the tip end of the tang portion that extended approximately 0.064 inch out of the hole. Measurements were made between the crest of the inner thread and the tip end of the tang portion of the lock ring.

APPENDIX 1

Examples of Different

Duplex Bearing Configurations



Appendix 1. In the face-to face duplex bearing configuration (also known as "DF" configuration), the two halves are placed next to each other so that the contact angles of the ball portions converge inwardly to the bearing axis inside of the bearing envelope. In a back-to-back duplex bearing configuration (also known as "DB configuration") the two halves of the bearing assemblies are placed next to each other so that contact angle lines of the ball portions diverge inwardly to the bearing axis inside the bearing envelope." The contact angle is the angle between a plane perpendicular to the ball bearing axis and a line joining the two points where the ball contacts the inner and outer raceways. The unlabeled diagram shown on this page was obtained from an NTN Bearing Corp of America catalog and labels were later added to identify various parts of the bearing. (Examples of bearing configurations can be found in references such as "Timken Angular Contact Ball Bearing Catalog, 06-22 Order No. 11193; and Timken Engineering Manual, 11-22 Order No. 10424, © 2022 The Timken Company, p95).