NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

February 22, 2013

MATERIALS LABORATORY FACTUAL REPORT Report No. 13-008

A. ACCIDENT

Place	:	Gulf of Mexico
Date	:	April 17, 2012
Vehicle	:	Sikorsky S-76B, N56RD
NTSB No.	:	CEN12FA250
Investigator	:	James Silliman, AS-CEN(CHI)

B. COMPONENTS EXAMINED

Kearfott Stepper Motor

C. DETAILS OF THE EXAMINATION

A group examination on a variety of components from a Kearfott gear head redundant stepper motor (P/N CU09609324) was conducted at the Materials Laboratory at NTSB Washington, DC headquarters on January 15, 2013 (see Figure 1). The following party representatives attended:

- Al Crain – Reliability Engineer, Kearfott Corporation
- Rick Wise – Program Manager, Kearfott Corporation
- John Guttermuth – Manager, Hamilton Sundstrand

The stepper motor was the #2 motor on the helicopter (starboard engine). Testing at the Kearfott Corporation in Black Mountain, NC before disassembly revealed that the #2 stepper motor did not actuate the lever attached to the output gearshaft when the motor was energized. The #2 stepper motor commutator had been severely corroded and exhibited rust over all the exposed steel components (see Figure 2). The assembly had been submerged in seawater at the time of the accident. The #1 stepper motor that was recovered did step when energized.

1. Output spur gearshaft

The investigation focused primarily on the output spur gearshaft (P/N C310072980) and began with a visual examination of the part, illustrated in Figure 3. The gearshaft exhibited an overall dark, dull luster typical of surface treatments—according to the drawing, the part is to be case hardened by nitriding. The top of the output gearshaft depicted in Figure 3b was affixed to a lever by riveting the lever to the gearshaft via a cross-drilled hole in the gearshaft. The end of the output gearshaft exhibited severe mechanical damage, incurred during removal of the riveted lever during disassembly prior to receipt at the NTSB. During examination at Kearfott, the gearshaft could not be removed without sectioning the affixed lever that was riveted into a cavity at the end of the gearshaft.

Figures 4, 5, and 6 highlight the end of the gearshaft. Portions of material from the end had been damaged when removing the lever during disassembly of the stepper motor at Kearfott. The remnant of the rivet is shown in Figure 5. The output gearshaft exhibited a slight bend (runout) 90° from the rivet that was measured as a 0.0048” deflection at Kearfott (see Figure 4). Of note was the cracking apparent on the gearshaft end, shown in Figure 6. The main portions of the crack penetrated along the gearshaft long direction into the cylindrical cavity occupied by the rivet remnant.

The gear teeth of the output gearshaft were examined to determine if there was any mechanical damage. Several of the faces of the gear teeth exhibited raised masses consistent with foreign material (see Figure 7). The crests and valleys of the gear teeth did not exhibit any indications of mechanical damage, and the case hardened surface layer did not appear compromised (see Figure 8). No extraneous material was found between the gear teeth.

The output gearshaft was examined in a scanning electron microscope. Figure 9 illustrates the face of the gearshaft, showing at least five cracks nearly parallel to each other. The character of these cracks was not consistent with progressive cracking, which typically exhibits branched rather than parallel cracks. In addition, organic material was embedded inside the cracks on the gearshaft face.

A portion of the output gearshaft above the rivet was backcut in order to reveal the crack faces. Part of the fracture surface is illustrated in Figure 10. Approximately 90% of the fracture surface exhibited dimple rupture fracture features, indicative of tensile overstress in ductile materials (see Figure 11). The pattern of the fracture features was elongated towards the long direction of the output gearshaft, consistent with the grain direction of the part. The fracture surface area closest to the gearshaft exterior exhibited a faceted morphology indicative of cleavage fracture (see Figure 12). This morphology is consistent with fracture in case hardened steel, where the hardness is enhanced but ductility is reduced.

The chemical composition of the output gearshaft was inspected using energy dispersive X-ray spectroscopy (EDS). The composition was consistent with a 400-series stainless steel. According to the drawing, the material specification was AISI type 416 stainless steel that was quenched and tempered, followed by surface nitriding. The dissimilar material found on the gear faces, as illustrated in Figure 13, was inspected by EDS and found to be consistent with an austenitic stainless steel. This was consistent with the chemical composition of the rivet. According to the manufacturer, the rivet material is an austenitic stainless steel.

Some non-conductive material was observed on the fracture surface of the gearshaft by EDS analysis. This material was predominately carbon and oxygen, with significant quantities of nitrogen, silicon, sulfur, and calcium. These elements are commonly found in epoxy-based materials. The bond material used in the riveting process is Hysol® EA-901 (Henkel Corporation, Westlake, OH), an epoxy bonding compound.

The core hardness and nitride case depth were inspected per ASTM E384. The average core hardness is 32 HRC (322 HK_{500}), which is within the prescribed drawing requirement. The average nitride case depth is 0.016 in, which is within with the drawing requirements and consistent with the depth of the cleavage portion of the examined fracture surface.

2. Output Front Bearing

The output front bearing the surrounds the output gearshaft is shown in Figure 14 as received. The bearing was able to freely spin about the inner race when force was placed on the outer race. No indications of external corrosion or mechanical damage were observed.

The bearing was disassembled by removing the cage/retainer. All of the roller balls exhibited a polished, shiny surface. No indications of distortion, missing material, or other damage were found on the balls. Likewise, the inner race showed no signs of corrosion or mechanical damage. The contact surface of the inner race appeared relatively smooth with no indications of spalling or brinelling.

The outer race exhibited some isolated areas of material spalling, as shown in Figure 15. These areas were less than 0.01 in and did not appear to have a depth that would interfere with immediate bearing operation. There were several shallow circular impressions on one side of the contact surface of the outer race consistent with brinelling of the bearing balls. This pattern in the outer race typically occurs with axial loading on the bearing.

3. Output Lever

The remnants of the output lever are illustrated in Figures 16 and 17. The lever had been sectioned at Kearfott in order to remove it from the output gearshaft. Of most concern were the circular impressions on the inner bore surface of the lever, labeled in Figure 16. These were consistent with the adjacent component in contact with the lever. Another small deformation mark was found on the edge of the lever toward the bore surface.

Erik Mueller
Materials Research Engineer

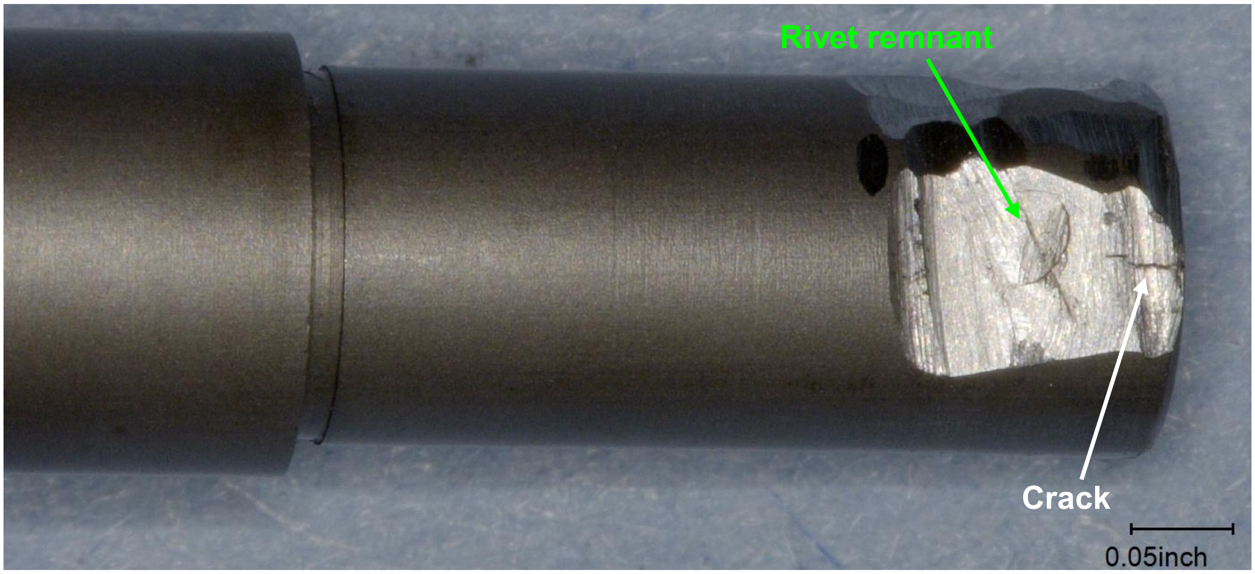

Figure 5 – The output gearshaft, rotated 90° from Figure 4, showing one of the cracks and the rivet remnant in the gearshaft cavity.

Rivet
remnant

Figure 6 – The end of the output gearshaft, showing the cracking parallel to the position of the rivet.

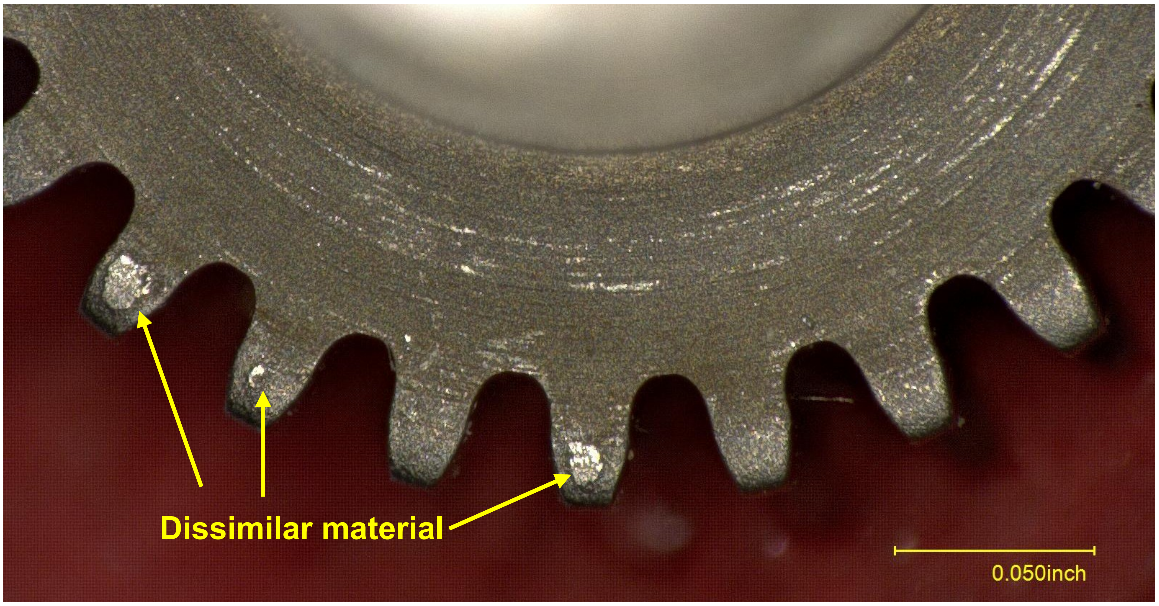

Figure 7 – The gear teeth of the output gearshaft, as viewed from above. Some areas of foreign material were found on the teeth faces.

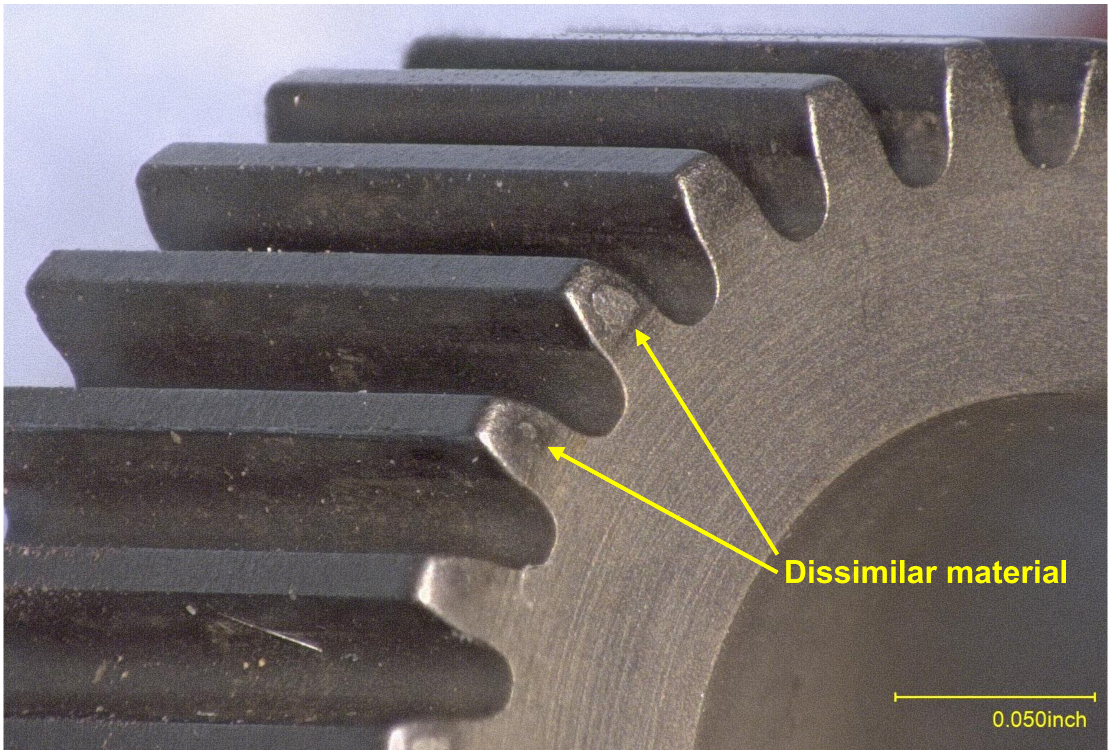

Figure 8 – The output gearshaft gear teeth, from a 45° angle.

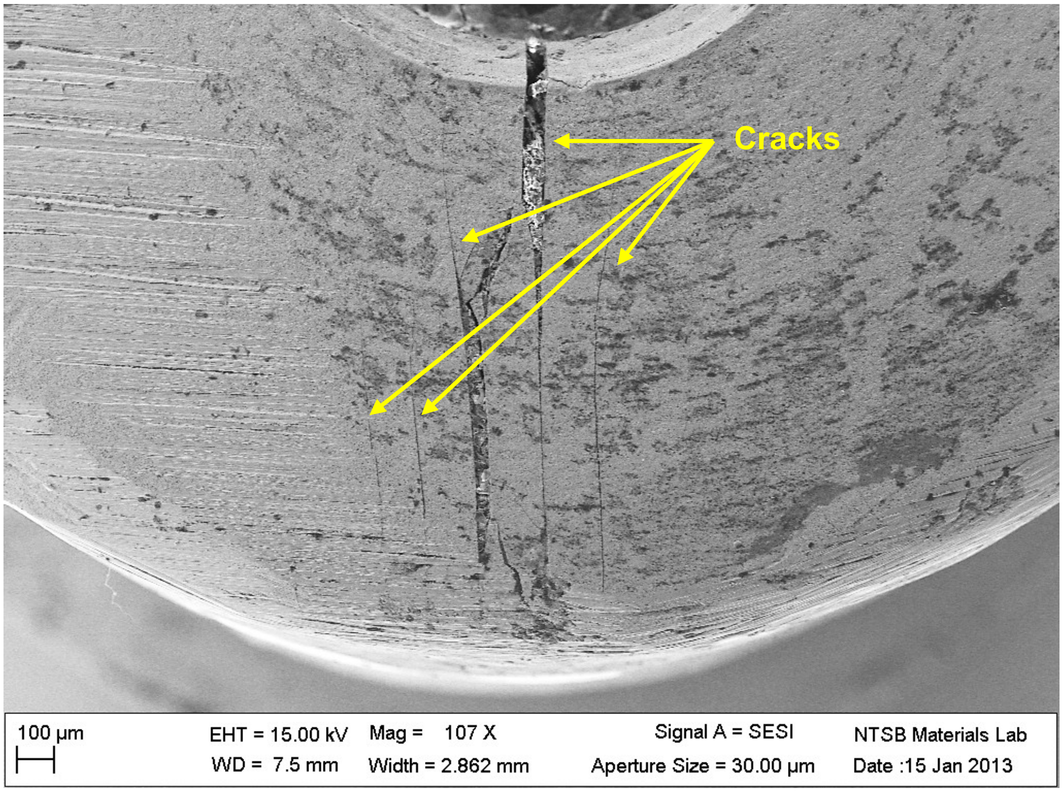

Figure 9 – Secondary electron (SE) micrograph of cracks on the face of the output gearshaft.

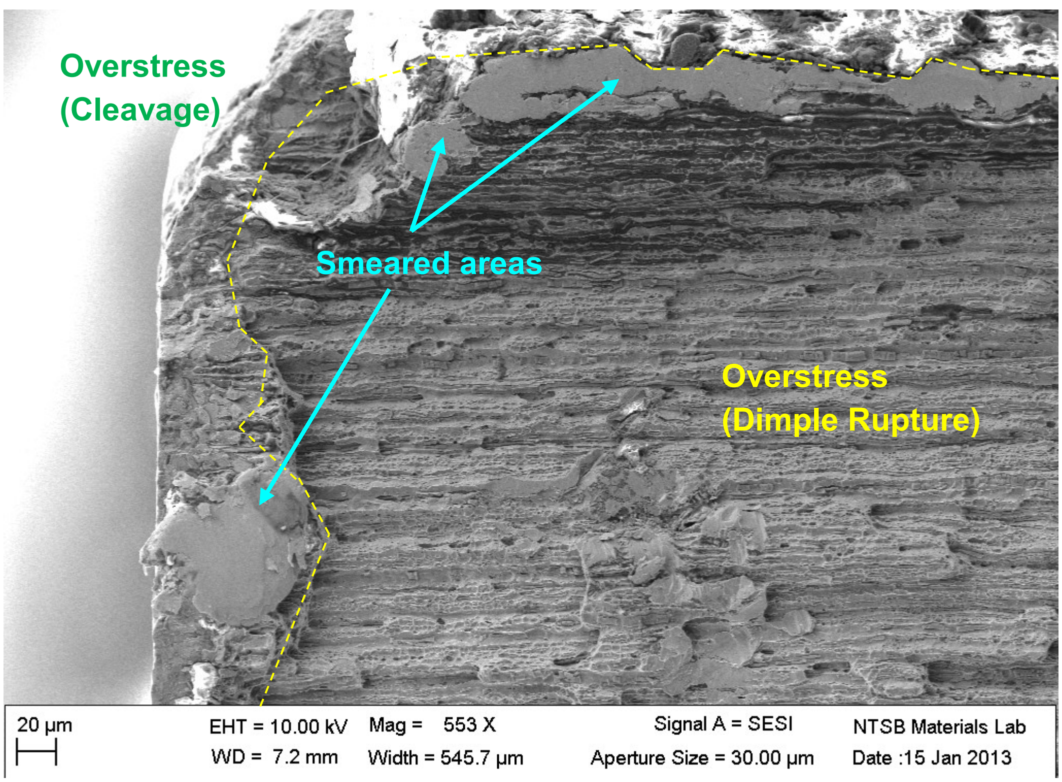

Figure 10 – SE micrograph of the output gearshaft fracture surface after opening. The case hardened layer could be distinguished from the rest of the gearshaft fracture.

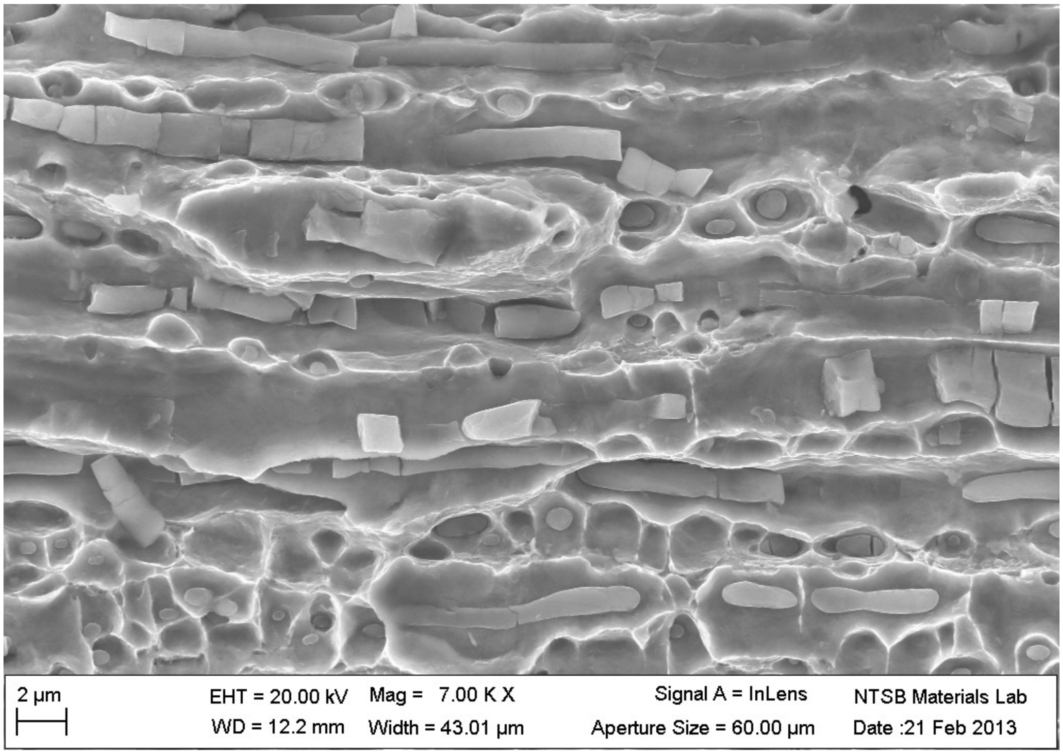

Figure 11 – SE micrograph showing dimple rupture, indicative of overstress, on the output gearshaft fracture surface.

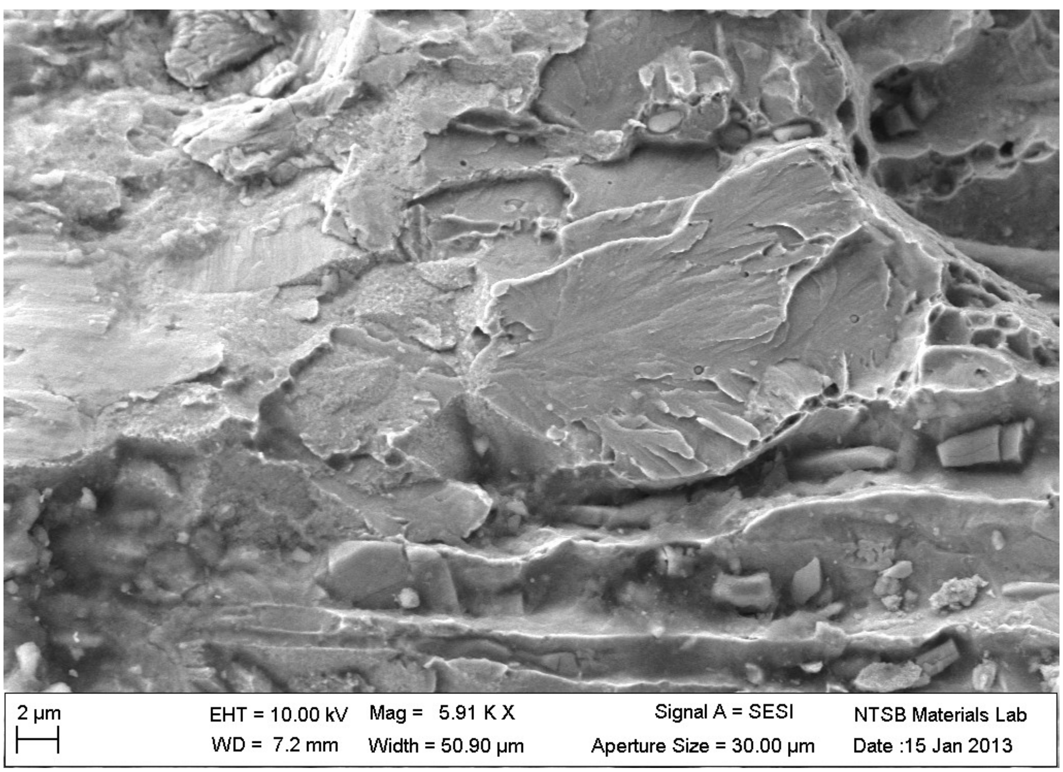

Figure 12 – SE micrograph of cleavage facets on the nitrided area of the output gearshaft fracture surface.

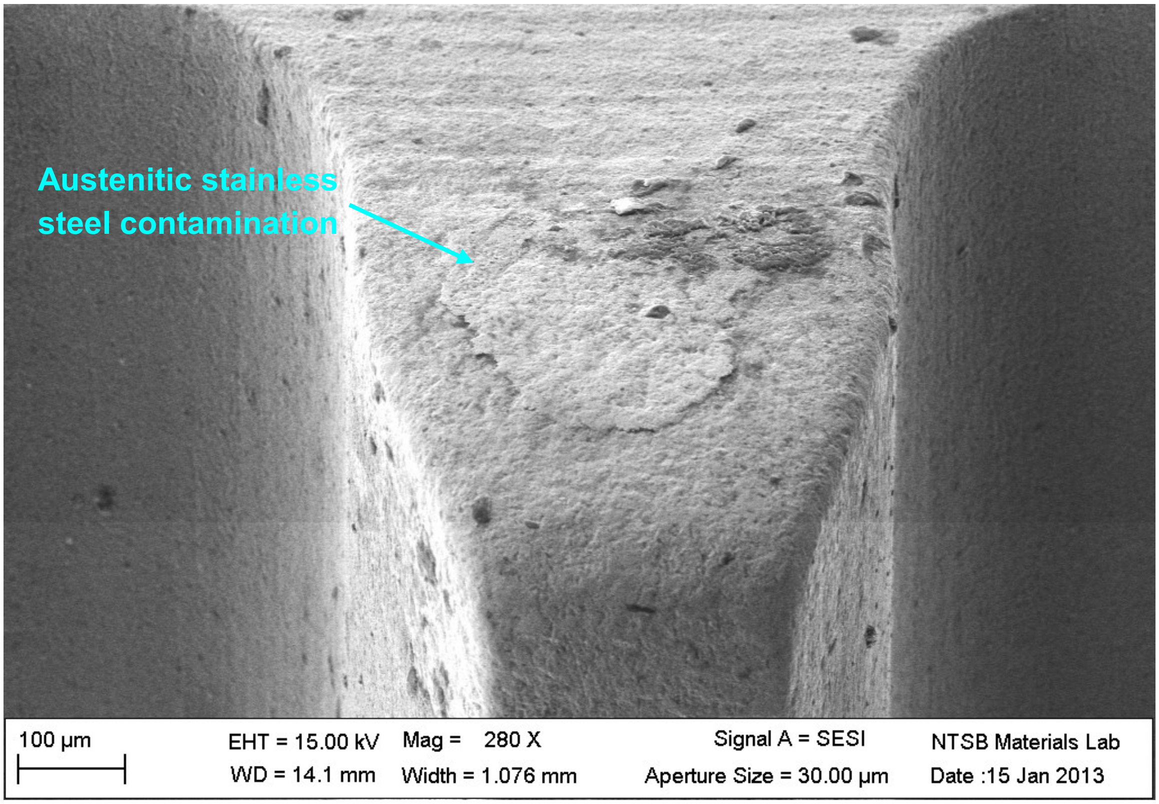

Figure 13 – SE micrograph of the dissimilar material on a gear tooth face.

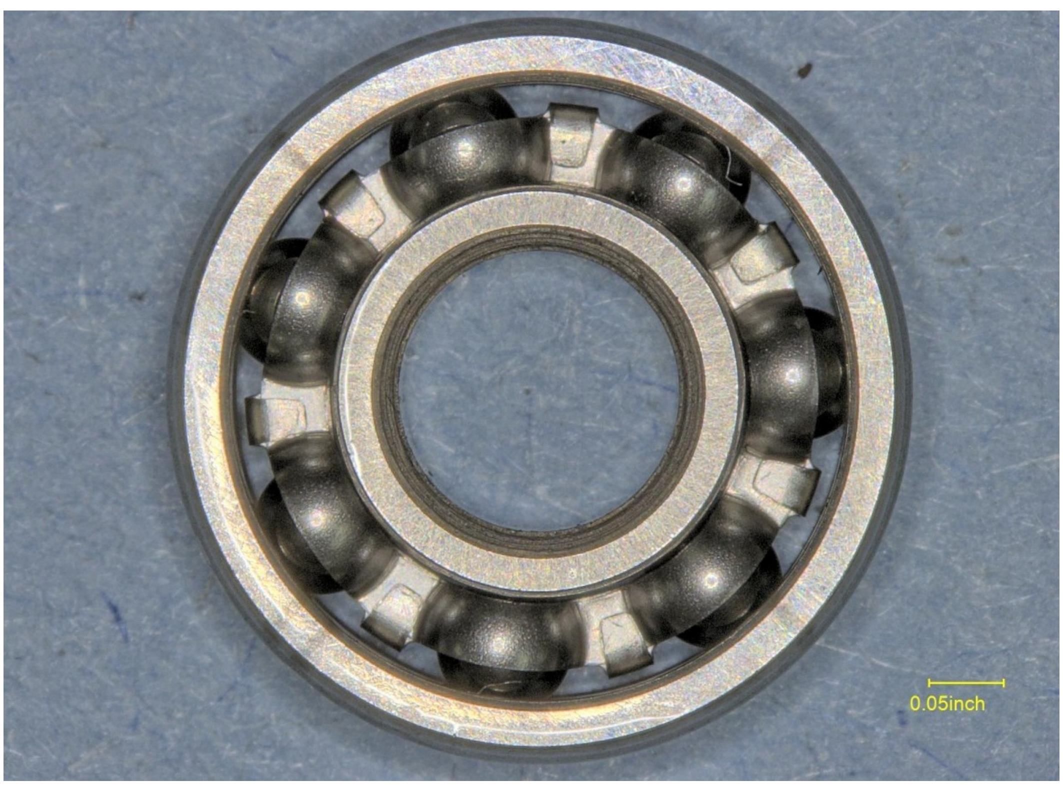

Figure 14 – The output gearshaft bearing, as received.

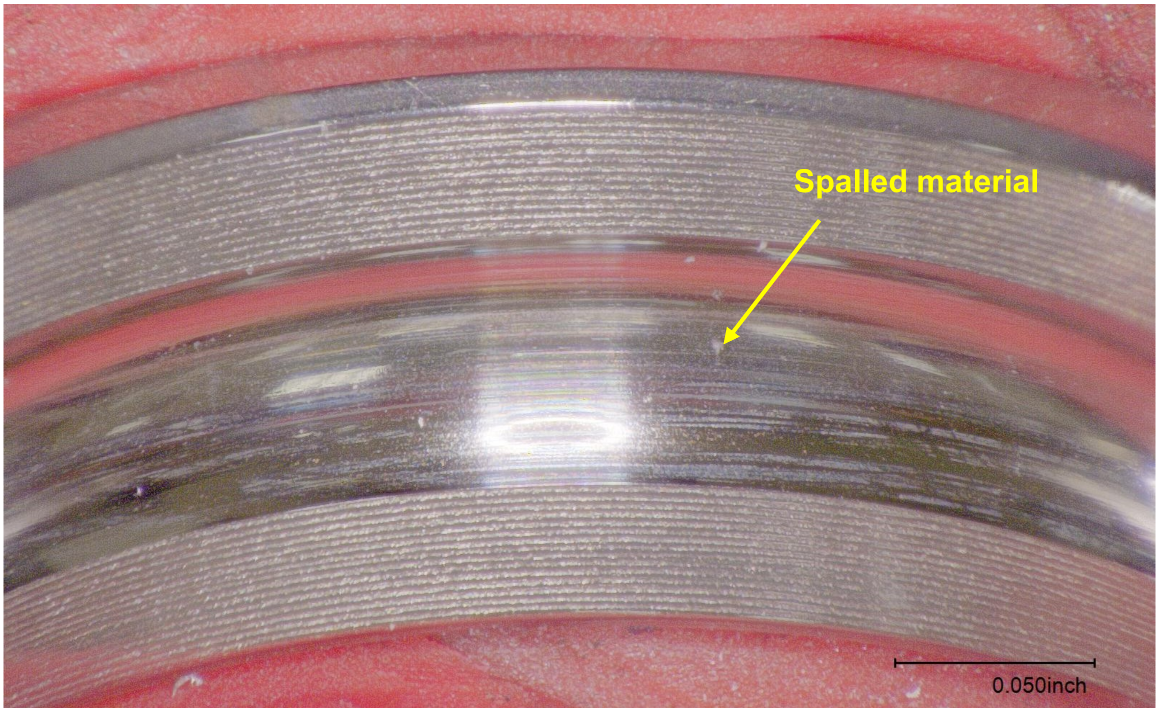

Figure 15 – The race of the outer bearing ring from the output gearshaft gearing, after disassembly. Isolated areas of material spalling were identified.

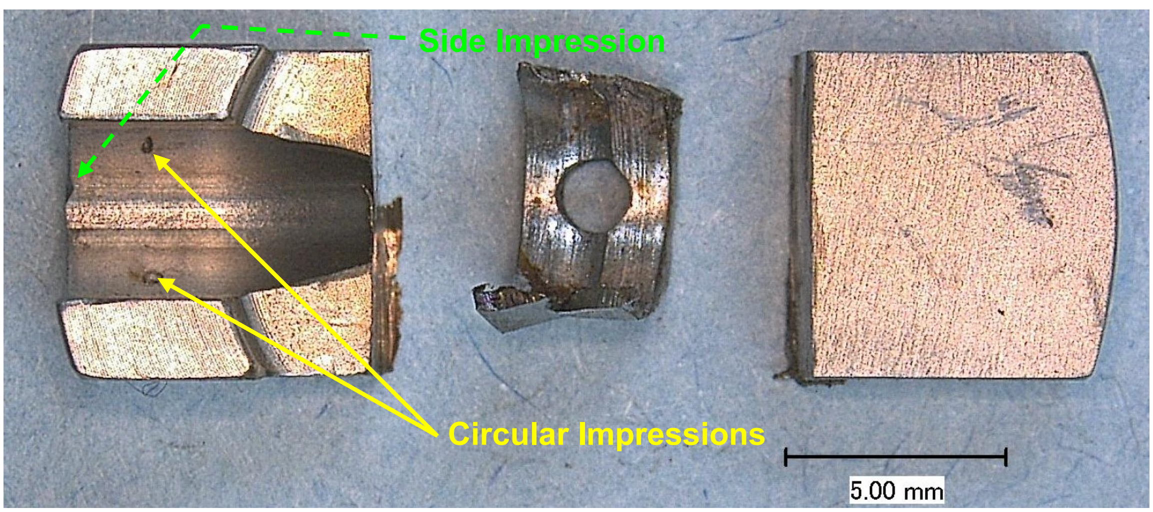

Figure 16 – Remnants of the lever arm, as positioned facing outside the stepper motor.

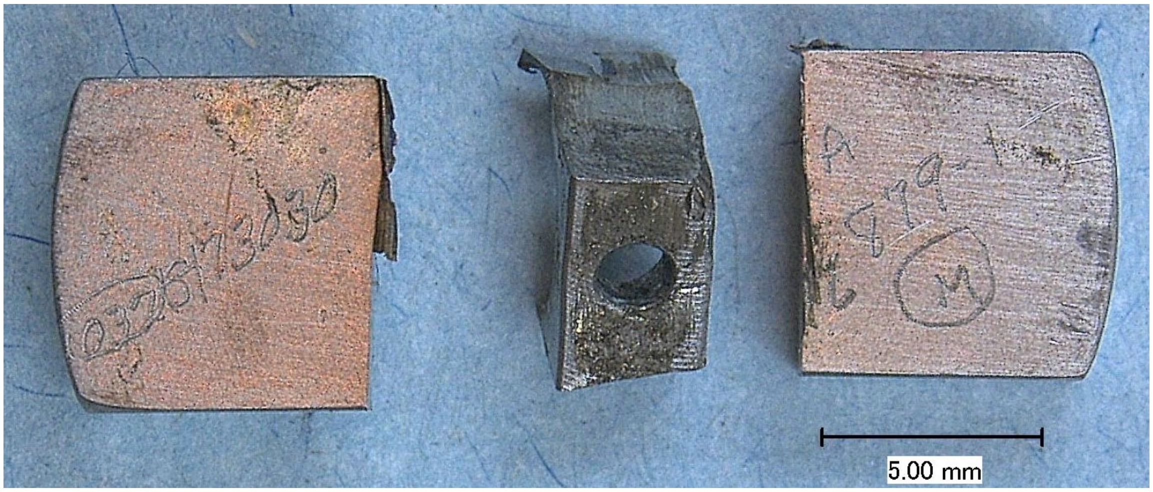

Figure 17 – The lever arm, reverse side of Figure 16 (faces towards motor housing).