NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

July 19, 2000

MATERIALS LABORATORY FACTUAL REPORT Report No. 00-071

A. ACCIDENT

Place	:	Nantucket, Massachusetts
Date	:	October 31, 1999
Vehicle	:	Boeing 767-366ER
NTSB No.	:	DCA0M-A006
Investigator	:	Scott Warren, AS-40

B. COMPONENTS EXAMINED

The following longitudinal control system components that were arbitrarily numbered during disassembly at Boeing:

1. PCA #3 – Servo Slide and Servo Sleeve, S/N 759; Bias Spring; Spring Guide; Servo Cap
2. PCA #4 -- Servo Slide and Servo Sleeve, S/N 1967
3. MH #1 -- Servo Slide and Servo Sleeve, S/N 1960
4. MH #3 – Portions of Separated Servo Slide and Servo Sleeve[1].
5. Bellcrank # 1 (4 pieces)
6. Bellcrank #2 (4 Pieces)
7. Bellcrank #3 (3 pieces)
8. Bellcrank #4 (3 pieces)
9. Bellcrank #5 (2 pieces)
10. Input Push-Pull Rods for Bellcranks No. 3, 4, and 5.

C. DETAILS OF THE EXAMINATION

The following party representatives participated in the examination of the above listed components:

Hani Salaheldin, Egypt Air;
Michael Marx, Consultant for the Egyptian Government.

[1] Portions of the sleeve and slide containing serial numbers were not submitted to the materials laboratory.

1. EXAMINATION OF PCA #3

An overall view of the servo slide, servo sleeve, bias spring, and spring guide from the elevator Power Control Actuator (PCA) labeled "#3" during disassembly at Boeing are shown in figure 1, as received. The servo cap from this PCA was submitted to the Materials laboratory after the other components and is shown in figure 2.

Bias Spring

The bias spring from PCA #3 is denoted by arrow "a" in figure 1. The spring had about 8 1/2 coils with ground flat ends. In the as received condition[2], two coils on one side (see arrow "a1") and one coil on the diametrically opposite side (see arrow "a2") were positioned over the head portion of the spring guide. The spring guide is indicated by arrow "b" in figure 1. The guide was carefully removed from between the coils for close up examinations and measurements (see next section).

The spring measured approximately 1.33 inches in free length, approximately 0.732 inch in outside diameter (OD), and was constructed from 0.0305-inch diameter wire. The engineering drawing for the part indicates the inside diameter of the coil -- 0.665 $\pm$ 0.005 inch, the wire diameter -- 0.031 $\pm$ 0.001 inch, the number of coils -- 5.474 to 9.973, and the free length – 1.233 inches to 1.457 inches. The measured dimensions on the bias spring were consistent with the dimensions specified by the manufacturer. Examination with the aid of a low power binocular microscope revealed no apparent impact, scraping, or abrasion marks on the surface of the spring wire. An X-ray Energy Dispersive Spectroscopic (EDS) analysis of the spring, after it was ultrasonically cleaned in acetone, generated a spectrum containing major peaks of iron, chromium, and nickel and minor peaks of carbon, manganese, aluminum, silicon, and oxygen[3]. The elemental composition (excluding oxygen) was consistent with the PH type 17-7 steel specified for the spring wire.

Spring Guide

A close up view of the spring guide is shown in figure 3. For reference purpose, the face denoted by arrow "t" in this figure will be further referred as the "top" face on the guide and the face denoted by arrow "b" will be referred as the "bottom" face. The spring guide is positioned at the end of the servo slide indicated by arrow "g" in figure 1 and is attached to the slide with a single rolled pin (see arrows "p" in figures 1 and 3). Axial measurements of the location of this pin on the slide showed that, when assembled, the tip of the slide is flush with the "top" face on the guide.

[2] The as-received condition may be different from the position of the spring when initially disassembled at Boeing.
[3] All spectra generated for this report are presented in the Appendix.

The pin for the guide sheared at the interface between the exterior surface of the slide and the bore of the guide creating three separated pieces. Two pieces of the pin were still contained within the corresponding holes in the guide, the third piece extended through the interior of the servo slide.

The pin fracture faces located on the bore of the guide were examined with a scanning electron microscope (SEM). SEM views of both fractures are shown in the two photographs of figure 4. The examination disclosed that at both fracture locations the layers of the rolled pin were deformed towards the “top” face on the guide as shown by unlabeled arrows in figures 3 and 4. The direction of deformation in combination with the appearance of scrape marks on the guide bore in the area between the pin holes and the top face were consistent with the servo slide moving through the hole in the guide in the direction indicated by arrow “md” in figure 1. The SEM examination of the two fracture faces at higher magnifications revealed that both were subjected to considerable mechanical damage after the separation. Undamaged portions of the fractures contained elongated dimples (see figures 5 and 6), typical of fractures created by direct shear overstress.

An EDS analysis of the guide material, performed at the exterior surface of the guide, generated a spectrum containing iron as a major peak with minor peaks of manganese, aluminum, silicon, and carbon, consistent with the specified 1215 steel. An EDS analysis of the pin generated a spectrum containing the major peaks of iron and chromium and minor peaks of manganese, silicon, and carbon.

Figure 7 depicts the bore surface in the spring guide, as viewed from the “bottom” face at an acute angle. Detailed binocular microscope examination revealed that some of the longitudinal scraping marks on the guide bore extended through an area located between the pin holes and the “bottom” face on the guide, see arrows “l” in figures 4 and 7. The examination of the guide bore also revealed the presence of a circumferential score mark that extended through an arc of about 120 degrees. This mark is shown by arrow “c” in figure 7.

The “top” face on the guide contained two narrow indentations. The indentations, denoted by unlabeled arrowheads in figure 8, were located at the periphery of this face and had an appearance consistent with contact by the bias spring.

Figure 9 illustrates a view of the “bottom” face on the spring guide. This face contained a series of curved impact marks (see arrowheads) as if from repeated contact with the end of the servo slide[4]. Most of these marks were located around the internal hole in the guide (see figure 10) and two marks (denoted by arrows “a” in this figure)

[4] The diameter of the servo slide in the area denoted by arrow “g” in figure 1 measured approximately 0.251 inches.

corresponded to the full diameter of the slide, as if the slide impacted the guide surface on a plane slightly offset from the guide centerline.

The two photographs in figure 11 show the sides of the spring guide adjacent to the ends of the rolled pin. The pin is reportedly intended to be inserted initially through the guide hole shown on the right in figure 11. (This hole tapers slightly to facilitate insertion of the pin, and it has a larger diameter than the opposite hole.) The insertion hole will be referred to as the larger diameter hole, and the opposite hole will be referred to as the smaller diameter hole. The examination revealed that the side of the guide in the vicinity of the smaller diameter hole contained a region of rubbing damage, see unlabeled white bracket in the left photograph of figure 11. The area of the rubbing damage was approximately 0.1 inch wide in the circumferential direction, 0.012 inch long (max.) in the axial direction and was located near the “top” edge of the hole. SEM examinations at higher magnifications revealed that the rub mark contained fine score lines that were oriented in the axial direction of the guide. An SEM view of the portion of the rub mark denoted by bracket “r” in the left photograph of figure 11 is depicted in figure 12 (see arrow “r”). The presence of a deformation lip (see arrow “l” in figure 12) indicated that the score lines extended toward the “top” face on the guide.

Various dimensions of the guide were measured as shown in figure 13. Table 1 compares these measurements with the specified dimensions. All measured dimensions were within the dimensions specified by the engineering drawing for the guide.

Servo Valve Cap

In the servo valve assembly, the cap (see figure 2) is positioned at the end of the servo sleeve shown by arrow “s” in figure 1. This end of the sleeve will be further referred as the “spring” end. The flat surface of the cap, denoted by arrow “f” in figure 2, butts up against the seating surface on the servo sleeve, which is indicated by arrow “ss” in figure 1. The internal diameter of the cap measured 0.872 inches and was within the range of 0.865 inches to 0.885 inches specified by the corresponding engineering drawing.

Examination with the aid of a low power binocular microscope revealed that the interior surface of the cap contained a number of foreign particles, see figure 14. The particles were collected using a double-sided adhesive carbon tape for EDS analysis of chemical composition. After most of the particles had been removed, the interior of the cap was cleaned with a cotton ball saturated in ethyl alcohol.

Examination of the internal surface of the cap after cleaning revealed several corrosion pits at the locations of former particles. Most of the corrosion pits were clustered on one side of the cap and are indicated by arrows “p1”, “p2”, “p3”, and “p4”, in figure 15. The corrosion pit indicated by arrow “p1” in this figure was located at a distance of about 0.31 inches from the seating face of the cap (denoted by arrow “f” in figure 15), the corrosion pits arrowed “p2” and “p3” were both located at a distance of about 0.45 inch from this face, and the largest corrosion pit (arrowed “p4”) was located in the radius between the bottom and the side surfaces of the cap.

EDS analysis indicated that there were 3 basic groups of particles on the internal surface of the cap. Views of these particles, together with the corresponding EDS spectra, are present in the appendix. The particles in the first group measured approximately 0.008 inch (200 microns) in the longest direction[5], had an appearance of a metal shaving or a chip, and had aluminum as a major element. The chemical composition of this group of particles was consistent with the chemical composition of the servo valve cap.

The particles in the second group ranged in size between 0.006 inch and 0.009 inch (150 microns and 230 microns) and contained silicon and oxygen as major peaks. The third “group” consisted of only one particle. This particle measured 0.012 inch by 0.010 inch (300 microns by 250 microns) and had iron as a major alloying element. The chemical composition of this particle was consistent with the chemical composition of the spring guide material.

The neutral position of the servo valve was reported as a position in which both metering holes in the servo sleeve are covered with the lands on the servo slide. Placing of the servo sleeve and slide next to each other indicated that in the neutral position of the valve, the top surface of the spring guide is located approximately 0.95 inches away from the flat face on the cap (indicated by arrow “f” in figure 2). The position of the spring guide inside the servo cap in the neutral position of the servo valve is illustrated in the sketch shown in figure 16. Also shown in this sketch are the longitudinal positions of major corrosion pits on the interior surface of the cap and a position of the spring guide when the “bottom” face on the guide is butted up against the end face on the servo sleeve. Optical microscopic examination of the internal surface of the servo cap disclosed no apparent damage other than the previously mentioned corrosion pits.

Servo Slide

The servo slide is labeled “1” in figure 1. A portion of the slide denoted by arrow “d” in this figure was darkly discolored and exhibited evidence of corrosion damage. Some corrosion damage was also noted in the increased diameter portions of the slide containing lands and groves.

Two photographs in figure 17 depict close up views of the servo slide in the areas of the fractured rolled pin. Magnified examinations revealed several discontinuous score marks on the surface of the slide (see unlabeled arrows in each photograph).

[5] Measured on the SEM photographs.

Measurements showed that the two longest score marks extended to a distance of approximately 0.357 inches and 0.342 inches, each, from the end face of the slide. The termini of four intermittent marks observed on the surface of the slide were located at the distances of approximately 0.203 inches, 0.213 inches, 0.254 inches, and 0.258 inches from the end face of the slide. The center of the hole for the rolled pin in the slide is positioned at a distance of 0.077 inch from the end, suggesting that the slide moved a maximum of about 0.28 inch (0.357 inch minus 0.077 inch) relative to the spring guide.

Figure 18 illustrates an oblique view of the input end of the slide from PCA #3 (on the left), and, for comparison, the similar areas on the slides from MH #1, and PCA # 4. The input end in the slide from MH # 3 was broken off and was not submitted to the materials laboratory. A magnified examination of the slide from PCA #3 revealed a wear mark in the bore of the input hole at the location indicated by arrow “a” in figure 18. The input hole in the slides from MH #1 contained a wear mark that was slightly less pronounce than the mark found on the slide from PCA #3. The input hole in the slide from PCA #4 was in a similar location but was much less noticeable.

Servo Sleeve

The servo sleeve is labeled “2” in figure 1. The external surface of the sleeve exhibited evidence of corrosion. The corrosion damage was most apparent on the outside diameter recesses containing metering ports (see brackets “m” and “n” in this figure) and on the land that contained return ports at the “spring” end of the sleeve (see bracket “p”).

An internal boroscope examination of the sleeve showed no evidence of impact damage or foreign particles being trapped at the metering edges of any of the metering ports. Portions of the internal surface of the sleeve in the areas denoted by brackets “m” and “n” in figure 1 were found to have well defined bands of what appeared to be corrosion stain. The corrosion bands averaged 0.025 inch in thickness, consistent with the average thickness of lands and grooves on the larger diameter portion of the servo slide.

A development view of the internal surface of the sleeve is shown in figure 19. Arrows “X” and ”Y” in this figure denote the “spring” and input ends on the sleeve, respectively. Red lines indicate positions of some of the corrosion stain bands. For reference purpose, all ports, including metering ports, return ports, and pressure ports in figure 19 are labeled “1” through “7”, starting from the input end on the sleeve. The metering edges on the metering ports are indicated by the unlabeled arrowheads in this figure.

Measurements performed during boroscope examination showed that the metering ports labeled “2” in figure 19 were intersected by only one corrosion band (see position “2a”). The maximum extent of this band was 0.032 inch from the metering edge towards the input end on the sleeve. The holes labeled “3” and the surrounding portions of the sleeve were intersected by numerous bands. The maximum extent of the bands from the metering edge of the port were 0.105 inches towards the “spring” end of the sleeve and 0.130 inches toward the input end (see positions “3a” and “3b” in figure 19). Portions of the sleeve in the areas of metering ports labeled “5” and “6” also contained numerous corrosion bands. The maximum extent of these bands from the metering edges of ports 5 and 6 towards the input end of the sleeve measured about 0.410 inches and 0.155 inches, respectively (see positions “5a” and “6a”).

2. EXAMINATION OF PCA #4

The servo slide and sleeve from PCA #4 are shown as received in figure 20. Visual magnified examination of both components revealed no apparent evidence of corrosion damage either on the slide or the spool. A boroscope examination of the internal surface of the sleeve revealed no impact damage to the metering edges of the metering ports.

3. EXAMINATION OF MH #1 AND MH #3

Figures 21 and 22 depict as received views of the components labeled “MH #1” and “MH #3”, respectively. Visual examination of the servo slide from MH #1 revealed corrosion damage on the land denoted by bracket “q” in figure 21. Extensive corrosion damage was also evident at the external surface of the sleeve, in recesses containing metering ports (see brackets “r” and “s”) as well as in the recess containing return ports at the “spring” end of the sleeve (see bracket “t”).

The servo sleeve from MH #3 separated through the return ports located at the input end of the unit. The fracture face on the sleeve is indicated by arrow “v” in figure 22. The servo slide separated adjacent to the increased diameter portion, in the area denoted by arrow “w” in this figure. When the slide and the spool were placed next to each other in the position corresponding to the neutral position of the servo valve, the fracture face on the sleeve was displaced approximately 0.4 inches towards the input end relative to the fracture face on the slide.

The spring guide was still attached to the servo slide from unit “MH #3”, see arrow “sg” in figure 22. The rolled pin positioning this guide at the end of the slide was intact.

The exterior surfaces of both the slide and the sleeve from “MH #3” contained extensive corrosion damage. A boroscope examination of the internal surface of the servo sleeves from both units showed no evidence of impact markings or foreign particles at the metering edges of metering ports.

4. EXAMINATION OF THE BELLCRANKS

Overall views of the bellcranks submitted to the materials laboratory are shown in figures 23, 24, 25, 26, and 27. As received, the bellcranks were labeled 1, 2, 3, 4, and 5. Reportedly, bellcranks No. 1 and No. 2 were from the left elevator. The bellcranks Nos. 3, 4, and 5 were from the right elevator: bellcrank No. 3 was from the outboard position, No. 4 was from the middle position, and No. 5 was from the inboard position. Only bellcranks from the right elevator were examined in detail.

Each bellcrank in the right elevator contains an inboard (yellow) arm and an outboard (green) arm[6]. The arms are rotationally connected to each other with two rivets that pass through the inboard arm and through a shaft that is part of the outboard arm. The shaft in the outboard arm contains a 0.15-inch deep circumferential recess between bearing surfaces that contact the inboard arm. The rivet holes are located in this recess. The inboard arm has no recess. Examination revealed that the rivets in all bellcranks were sheared. To remove grease, loose corrosion deposits, and other debris, the bellcrank arms in all units were cleaned ultrasonically in toluene and then in acetone. Subsequent examination of the bellcrank arms revealed that this cleaning removed most of the deposits from the fracture faces on the rivets.

The rivets in the bellcrank arms from units No. 3 and No. 4 separated flush with the recess surface in the shaft portion of the outboard arm. Examination with the aid of a low power binocular microscope and then at higher magnifications with the scanning electron microscope revealed that all fracture faces on the rivets from these units were grossly smeared and contained elongated dimples, typical of ductile shear overstress. The direction of the shear in all rivets from these two units was as if the bellcrank arms were moving to a lower relative angle.

Examination of the bellcrank arms in bellcrank #5 (figure 27) showed that one of the two rivets sheared flush with the recess surface in the outboard arm, similar to the rivets from units No. 3 and No. 4. However, the origin of the shear fracture in the second rivet was in line with the bearing surface on the outboard arm. A side view of this arm is shown in figure 28. Unlabeled arrowheads in this view denote the two bearing surfaces on the bell crank, bracket “r” indicates the recessed area, and arrow “rv” indicates the sheared rivet. The fracture in this rivet propagated on a slightly slant plane and terminated flush with the bottom of the recess. An SEM view of the fracture face on this rivet is shown in figure 29 with arrow “o” indicating the origin of fracture. The SEM examination also revealed the presence of a circumferential crack in the rivet. This crack propagated flush with the surface of the recess in the bellcrank arm, see arrow “c” in figure 29. What appeared to be an origin of this crack was obscured by the smeared over final portion of the fracture face on the rivet. The SEM examination of the fracture face on the rivet at higher magnifications disclosed elongated dimples, consistent with a

[6] In the left elevator, the yellow arm is an outboard arm and the green arm is an inboard arm.

direct shear overstress. Both rivets in the bellcrank No. 5 were sheared as if the bellcrank arms were moving to a higher relative angle.

5. EXAMINATION OF INPUT PUSH-PULL RODS

An overall view of the push-pull rods for the Nos. 3, 4, and 5 bellcranks is shown in figure 30. The positions of bellcranks No. 4 and No. 5 are shown by the corresponding arrows. All three rods were found to be deformed by bending. The most severe deformation was noted on the push-pull rod between bellcranks No. 3 and No. 4. The push-pull rod between bellcranks No. 4 and No. 5 was subjected to the least amount of deformation.

The outboard portion of the push-pull rod between the No. 3 and No. 4 bellcranks was broken off and remained attached to the No. 3 bellcrank (see figure 25). The inboard portion of the push-pull rod that was extending inboard of the No. 5 bellcrank was also broken off. This piece of the push-pull rod was not submitted for examination. The fractures in both push-pull rods had characteristic features of overstress.

[redacted]

Jean Bernstein
Senior Metallurgist

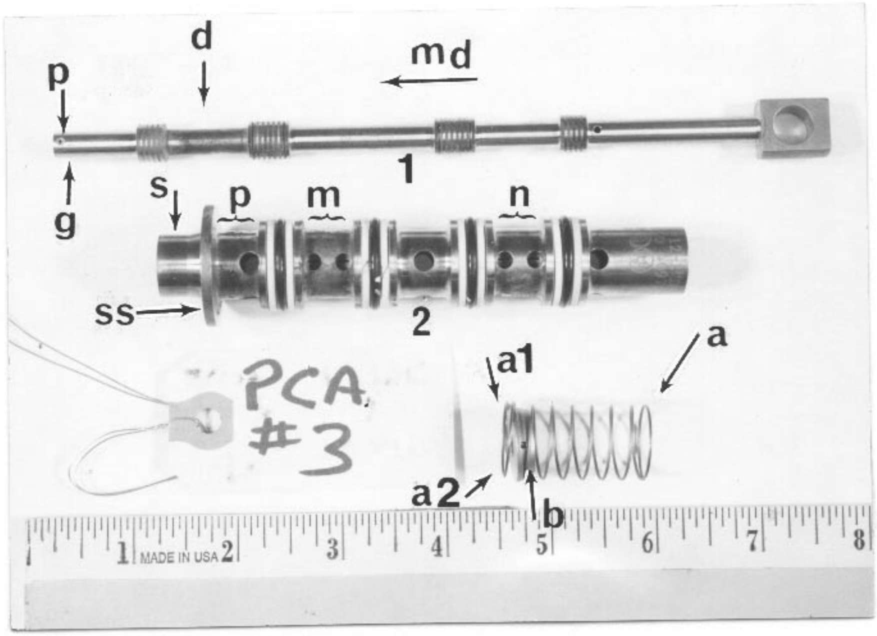


Figure 1. An overall view of the servo slide (1), servo sleeve (2), bias spring (arrow "a"), and spring guide (arrow "b") from PCA #3.

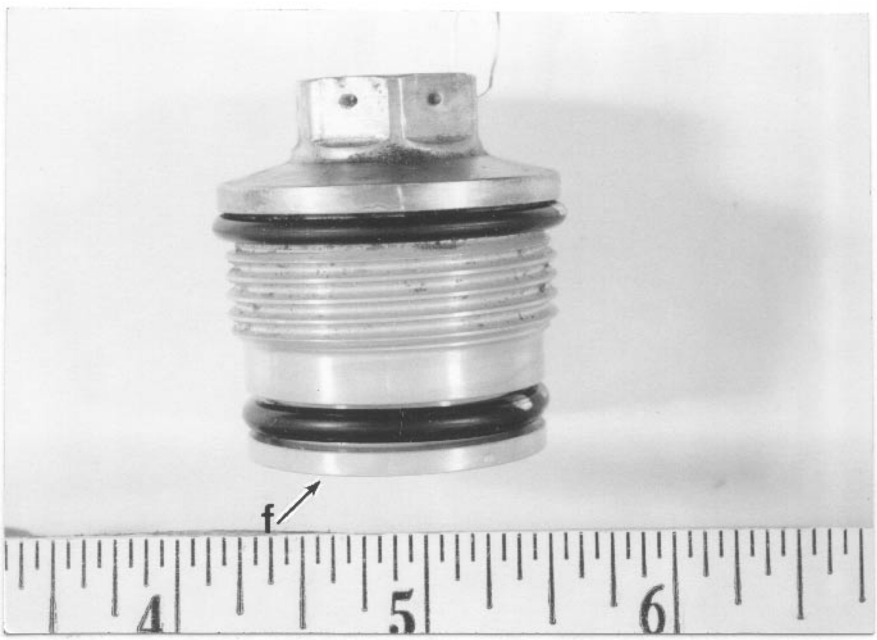


Figure 2. As received view of the servo cap. Arrow "f" indicates the face that in the servo valve assembly butts up against the seating surface on the servo valve (see arrow "ss" in figure 1).

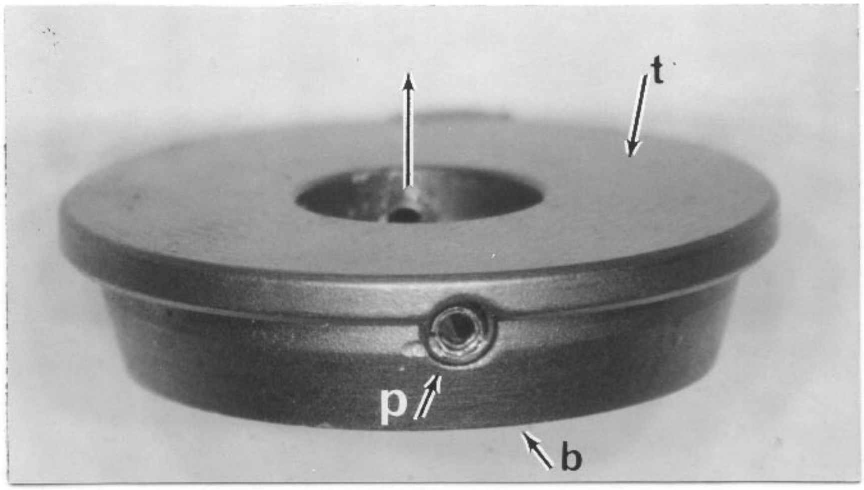
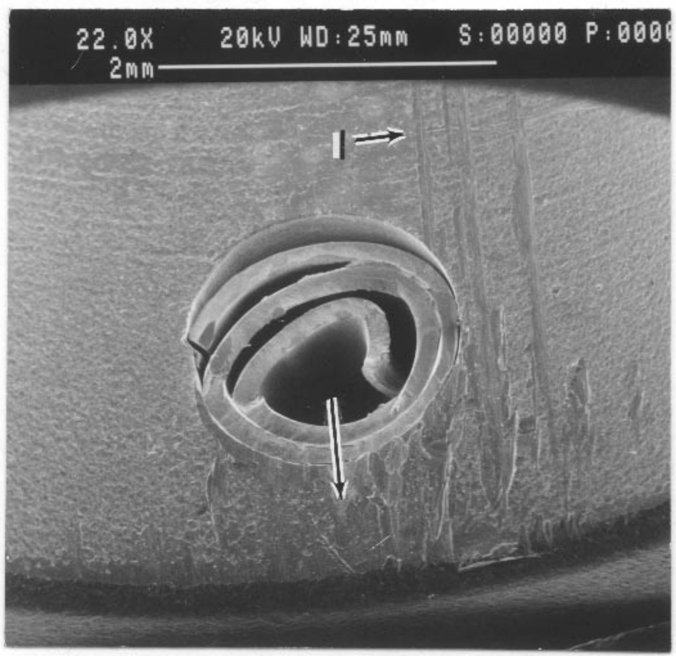


Figure 3. A close up view of the spring guide. The unlabeled arrow indicates the direction of deformation on the fracture surfaces of the separated pin. (5X).



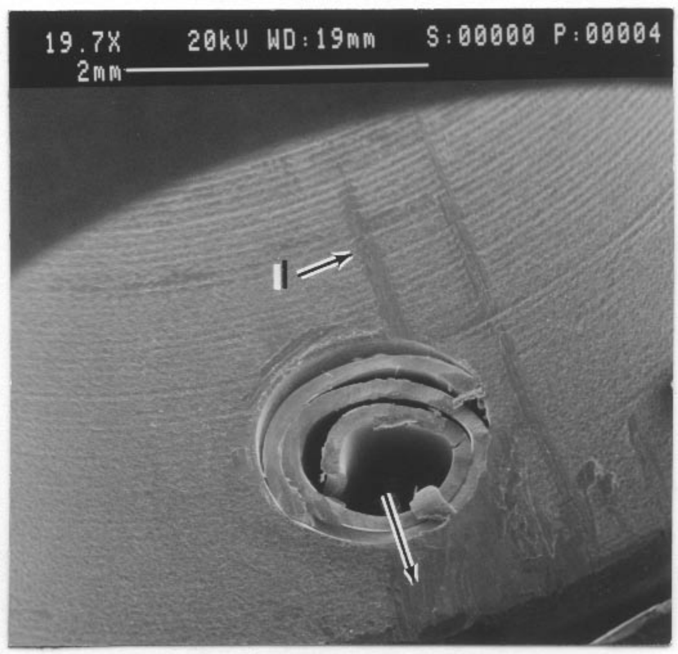


Figure 4. SEM views of the pin fracture faces on the bore of the spring guide. The unlabeled arrow on each fracture face shows the direction of deformation. Arrows "l" denote scrape marks on the bore surface of the guide. Magnification 22X -- left photograph and 19.7X – right photograph.

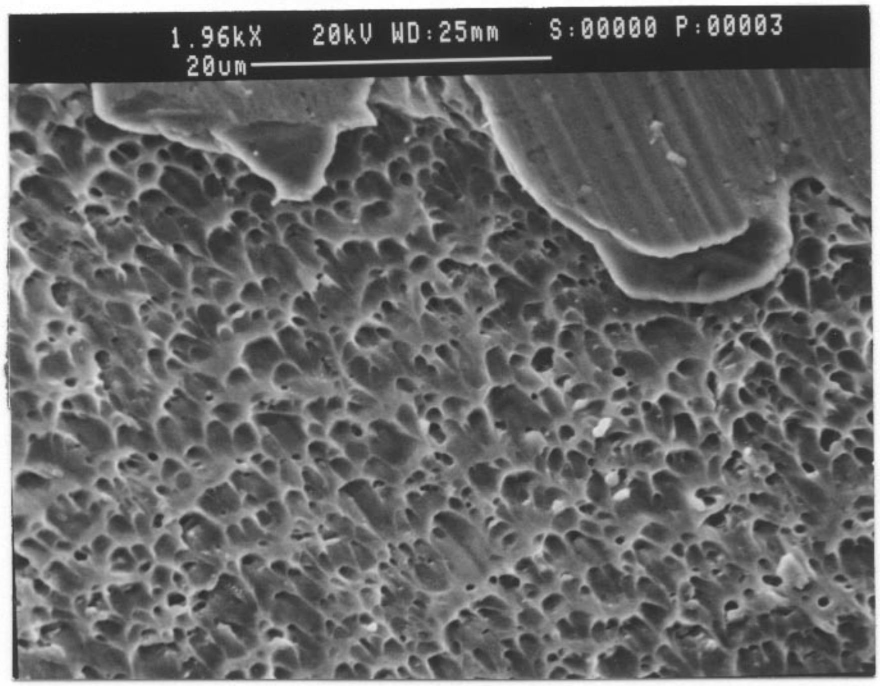


Figure 5. SEM view of typical microscopic features on the fracture face shown on the left photograph of figure 4. (1,960X).

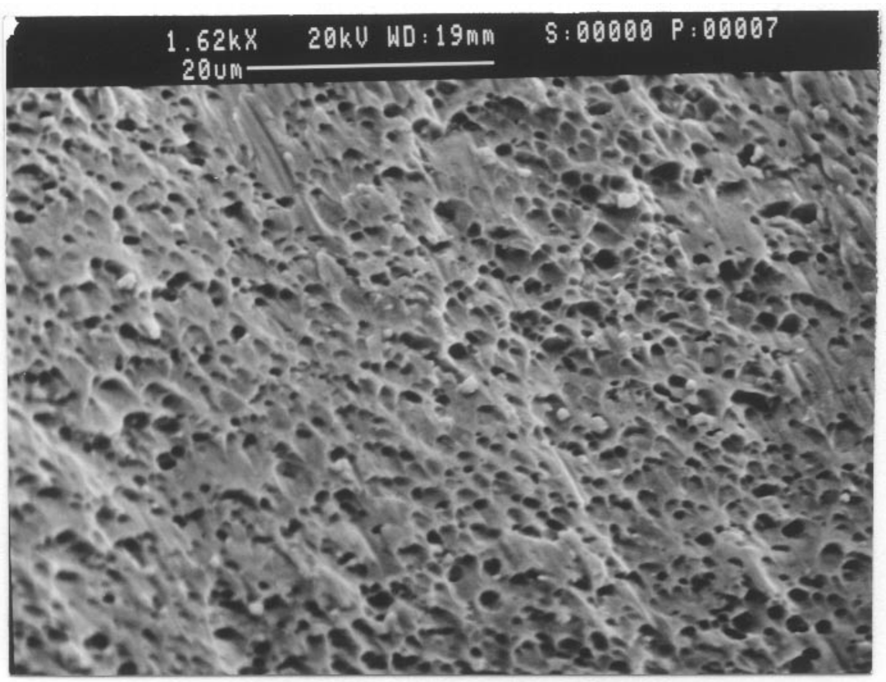


Figure 6. SEM view of typical microscopic features on the fracture face shown on the right photograph of figure 4. (1,620X).

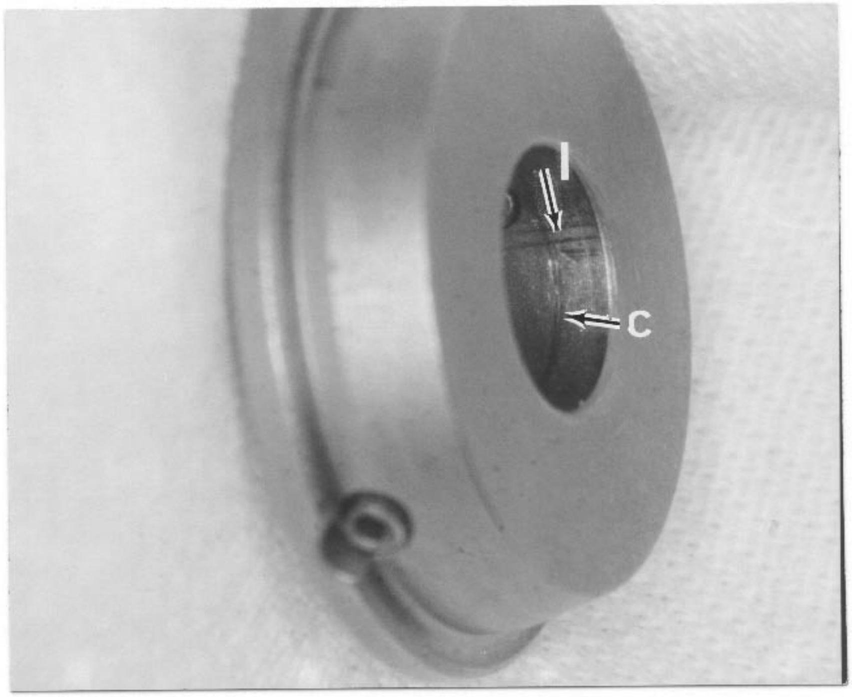


Figure 7. The bore surface of the spring guide as viewed at an angle from the "bottom" face. Arrow "l" shows the longitudinal scraping marks that extend up to the bottom face on the guide. Arrow "c" indicates the circumferential mark. (5X).

Figure 8. Indentations at the periphery of the top face on the spring guide (see arrowheads). (5X).

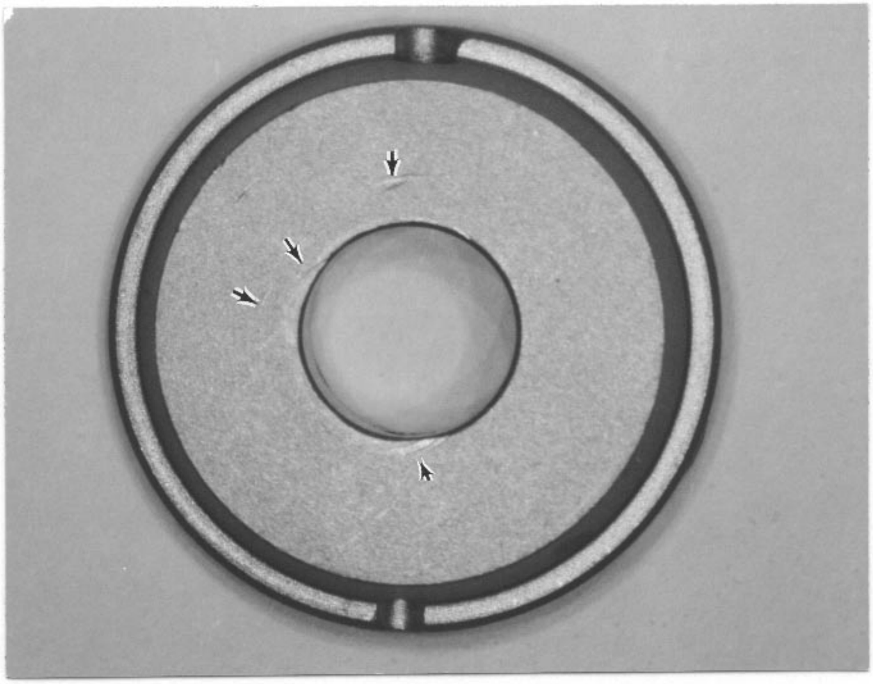


Figure 9. A view of the "bottom" face on the spring guide. Unlabeled arrowheads show the locations of curved impact marks. (5X).

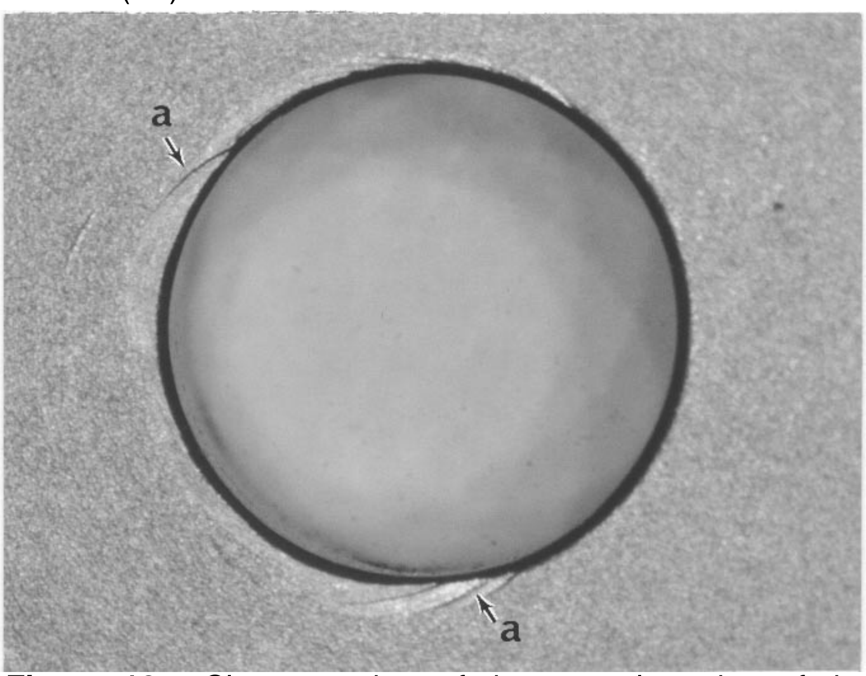


Figure 10. Close up view of the central portion of the "bottom" face on the guide. The marks indicated by arrows "a" correspond to the full diameter of the servo slide. (5X).

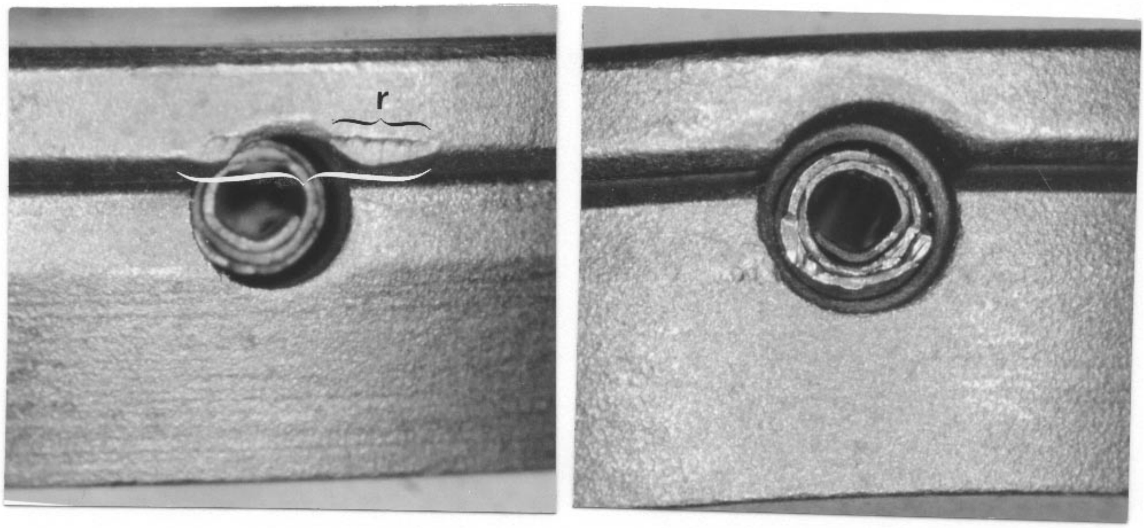


Figure 11. Close up views of the sides of the spring guide in the areas adjacent to the ends of the rolled pin. Unlabeled white bracket on the left photograph denotes the rub mark. Bracket "r" indicates the portion of the rub mark shown in figure 12. (15X).

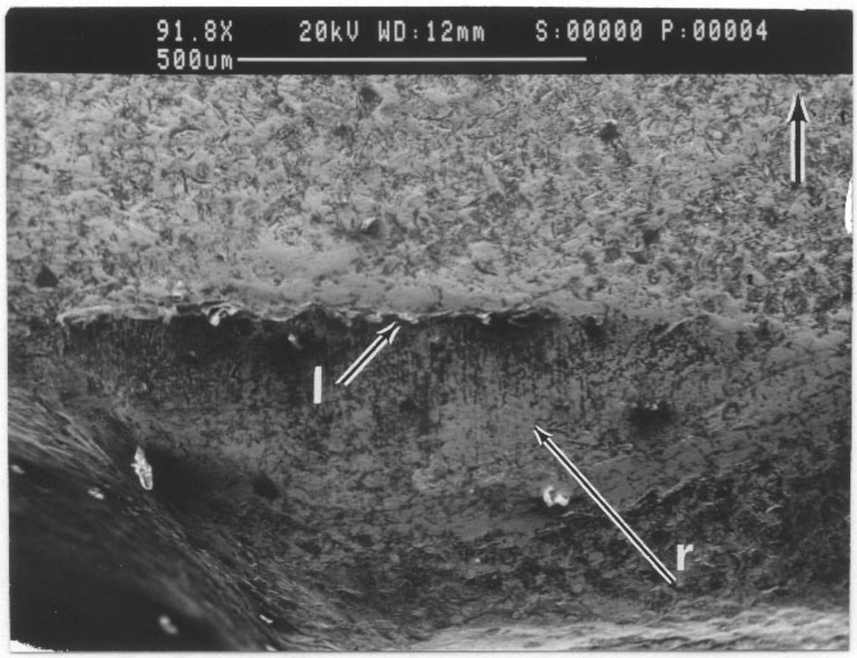


Figure 12. SEM view of the portion of the rub mark denoted by bracket "r" in figure 11. The unlabeled arrow in the right top corner of the photograph points in the direction of the "top" face on the spring guide. (91.8X).

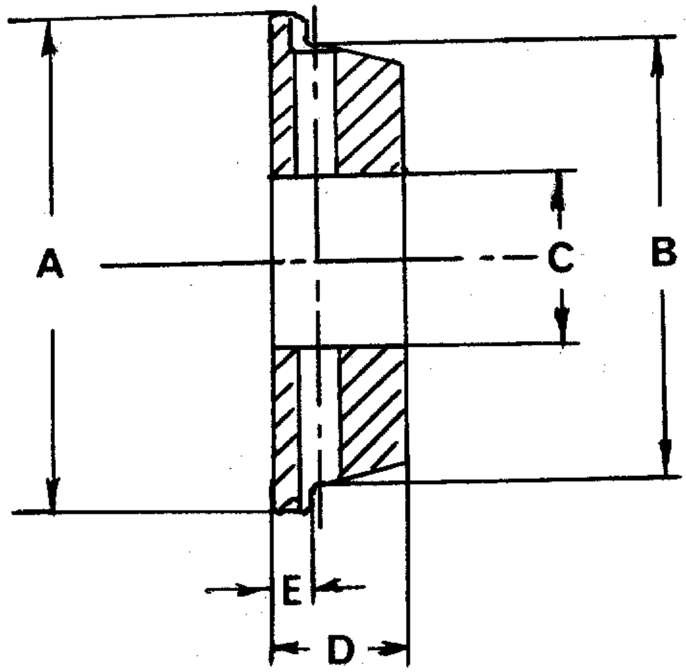


Figure 13. The dimensions measured on the guide.

TABLE 1

Dimension, see Figure 13	Measured, inch	Specified, inch
A	0.748, 0.749	0.750 ± 0.010
B	0.665	0.665 ± 0.005
C	0.256	0.257 + 0.006, - 0.001
D	0.18	0.18 ± 0.040
E	0.055	0.055 ± 0.010

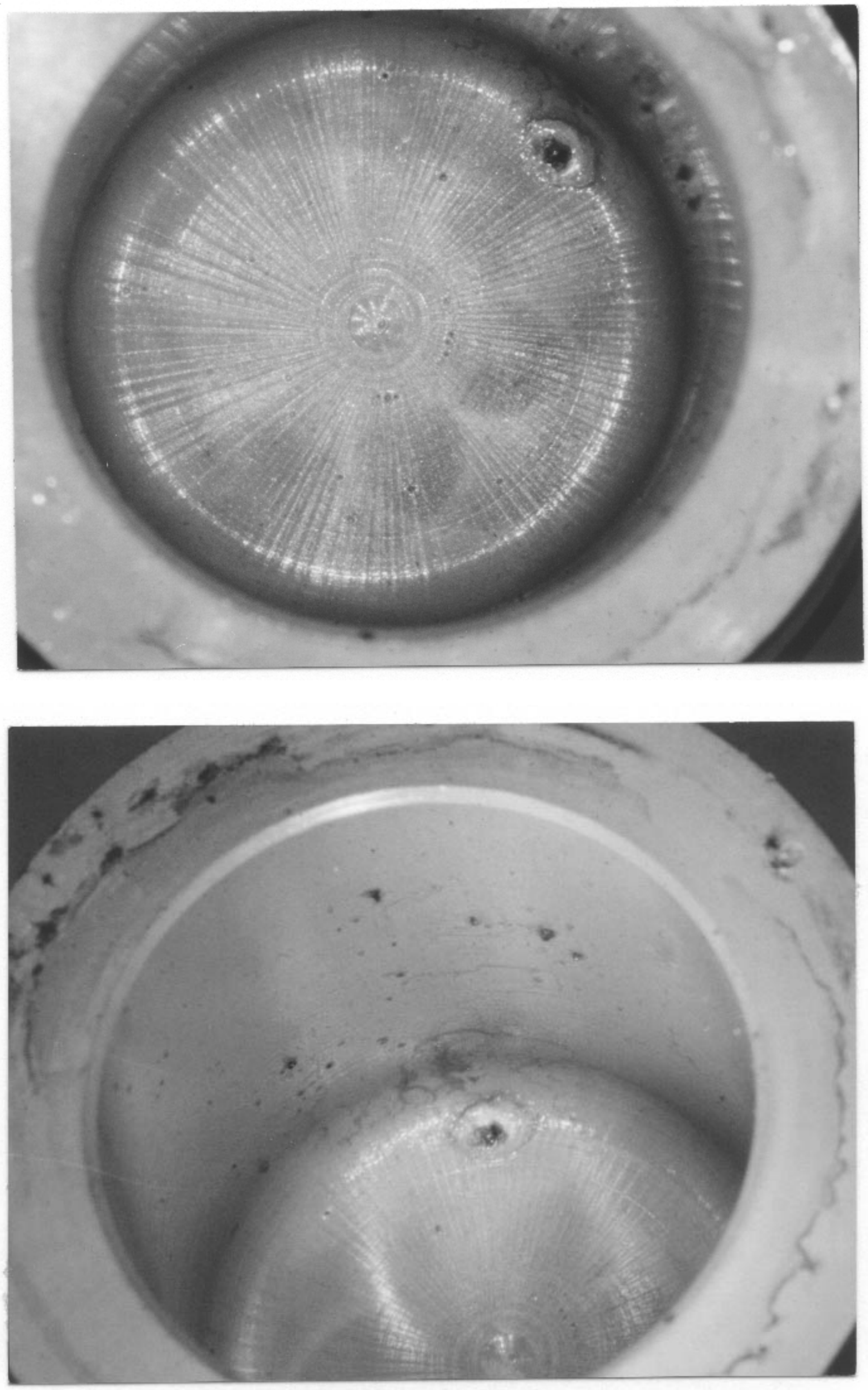


Figure 14. The interior of the servo cap showing foreign particles on the bottom surface (top photograph) and on the side surface (bottom photograph). (3.75X).

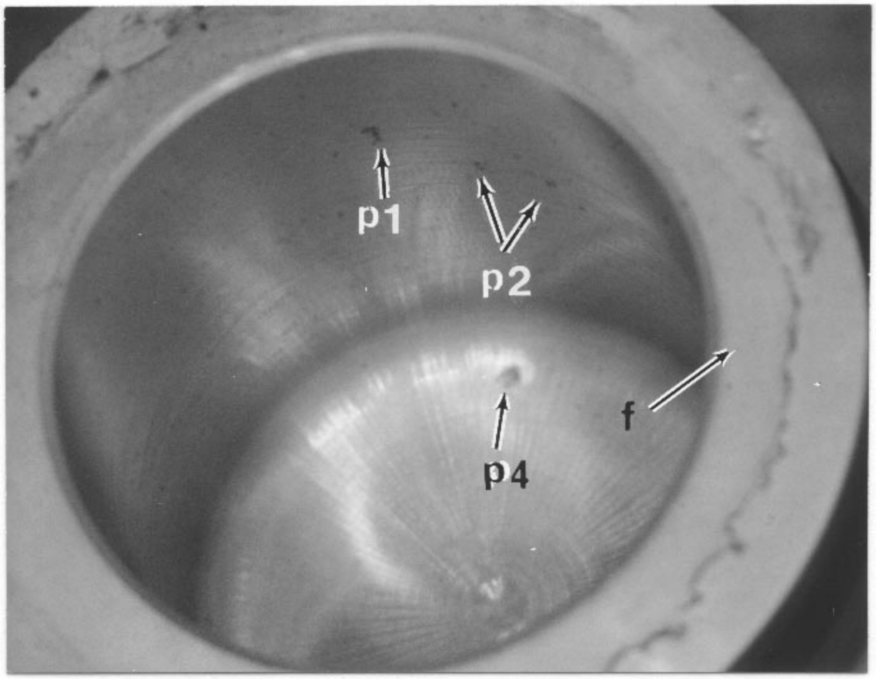


Figure 15. Appearance of the interior of the servo cap after the cleaning. Arrows “p1”, “p2”, and “p3” indicate corrosion pits on the interior surface of the cap. (3.75X).

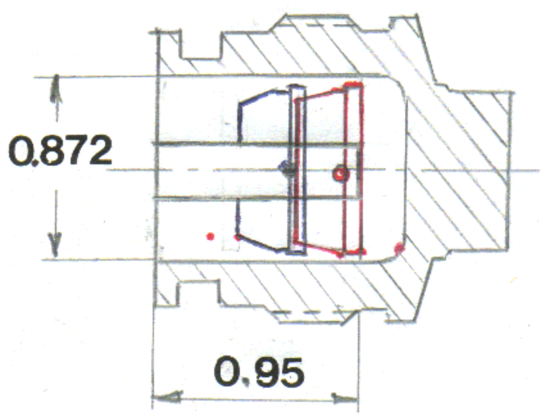
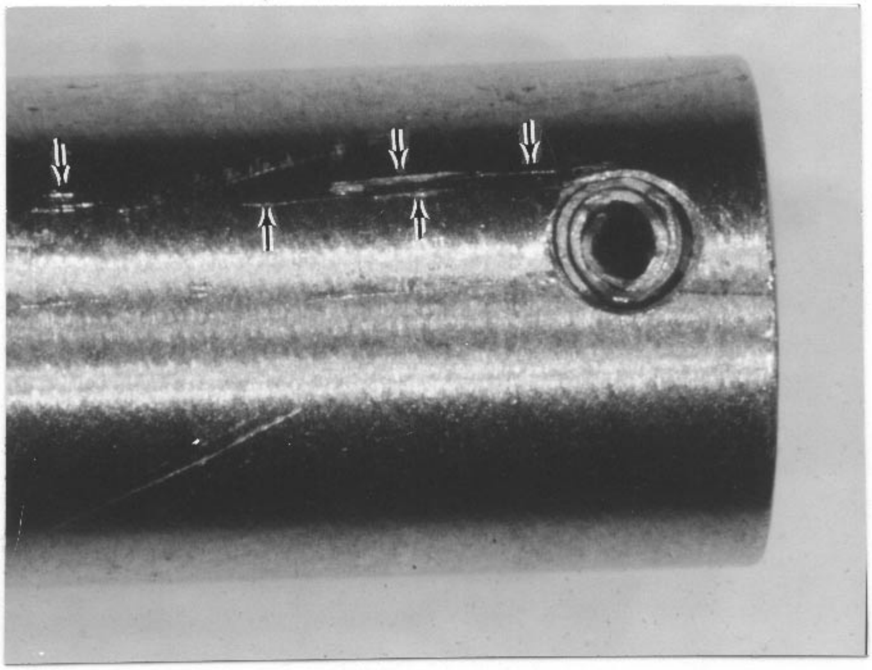


Figure 16. A sketch illustrating the position of the spring guide inside the servo cap in the neutral position of the servo valve (red outline) and in the condition when the bottom face on the guide is butted up against the end face on the servo sleeve (blue outline). The red dots indicate the longitudinal positions of the corrosion pits.



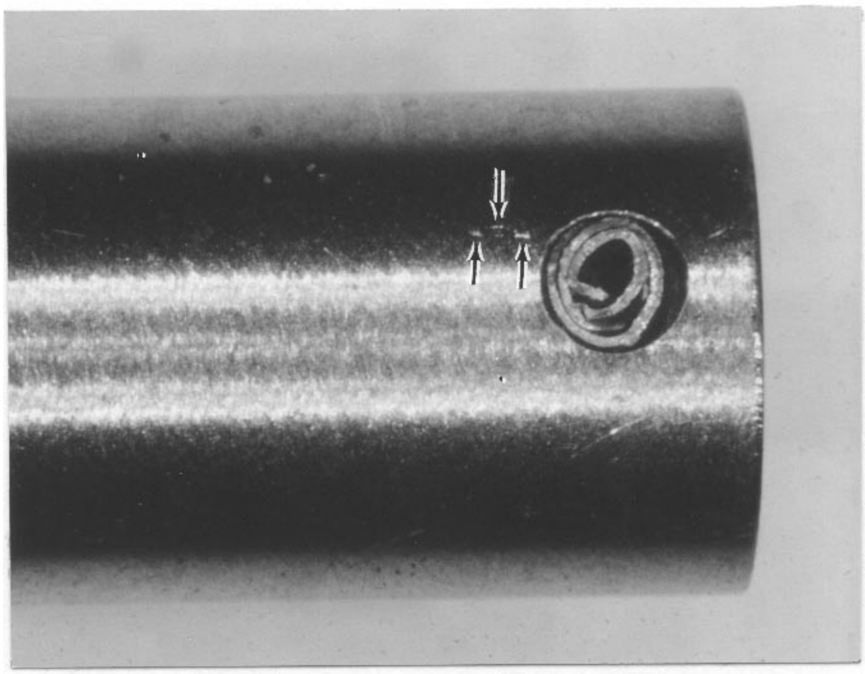


Figure 17. Close up views of the end of the servo slide denoted by arrow "g" in figure 1 showing areas of the slide surrounding the fracture faces on the pin. Unlabeled arrows indicate the score marks. (10X).

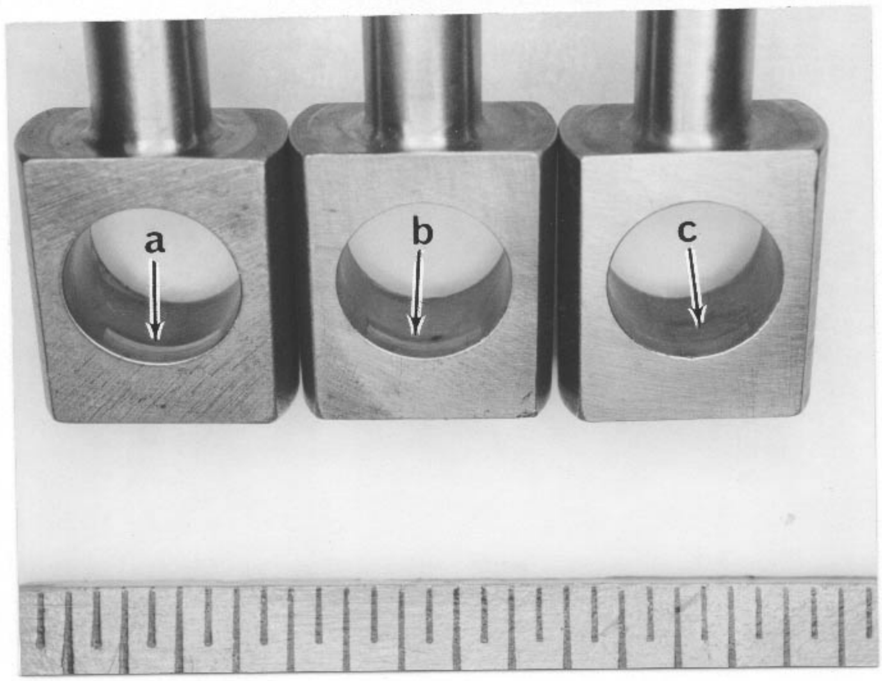


Figure 18. Oblique view of the input ends in the slides from PCA #3 (left), MH #1, (center), and PCA #4 (right) showing wear marks by arrows “a”, “b”, and “c”.

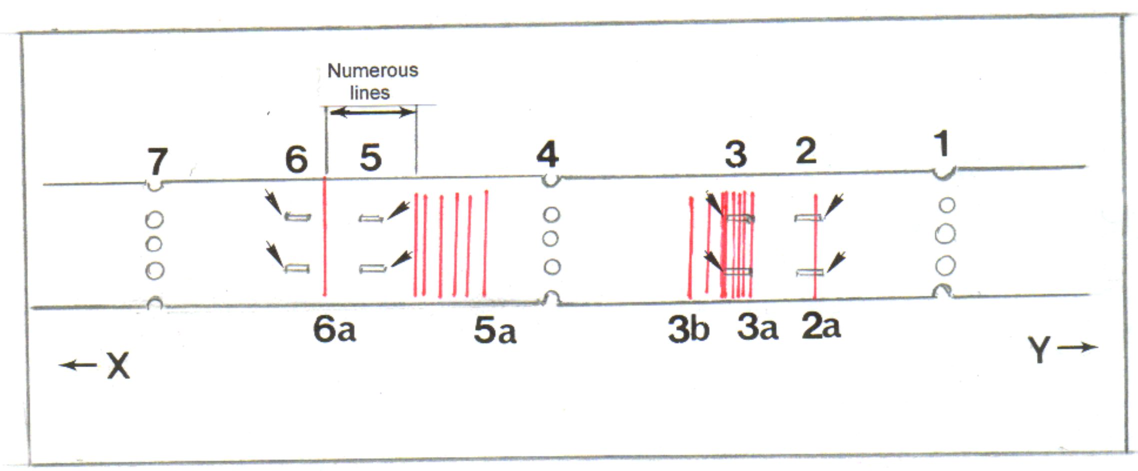


Figure 19. A development view of the internal surface of the servo sleeve from PCA #3. The ports for reference purpose are labeled “1” through “7” starting from the input end. Red lines illustrate positions of some of the corrosion stain bands. The metering edges in the metering holes are shown by unlabeled arrowheads. Not to scale.

Figure 20. As received view of the servo slide and sleeve from PCA #4.

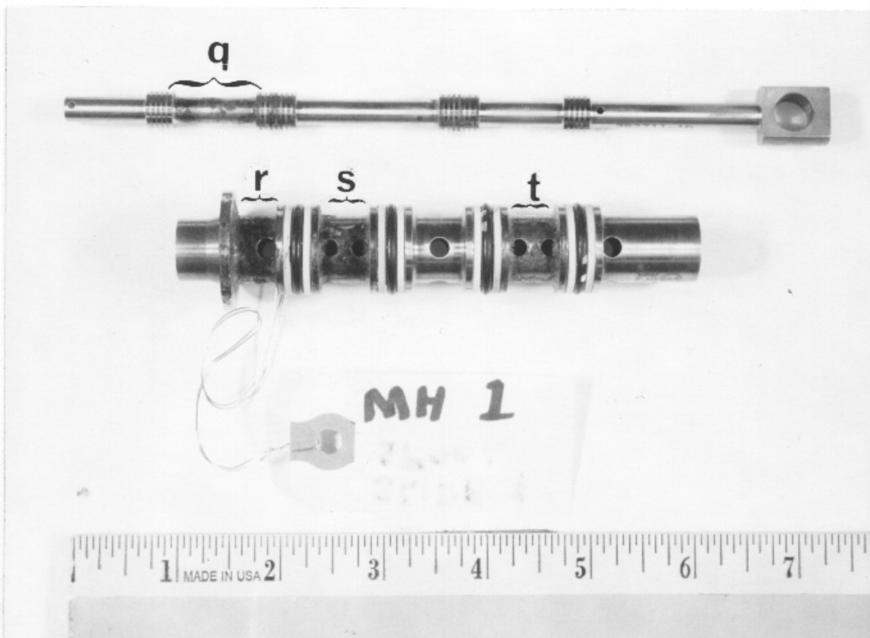


Figure 21. As received view of the servo slide and sleeve from the unit labeled MH #1. Brackets “q”, “r”, “s”, and “t” denote areas of the corrosion damage.

Figure 22. As received view of the slide and sleeve from the unit labeled MH #3. Arrow "v" indicates the fracture face on the sleeve and arrow "w" indicates the fracture face on the slide. Note that the longitudinal orientation of the servo sleeve in this view is reversed relative to the orientation of the slide.

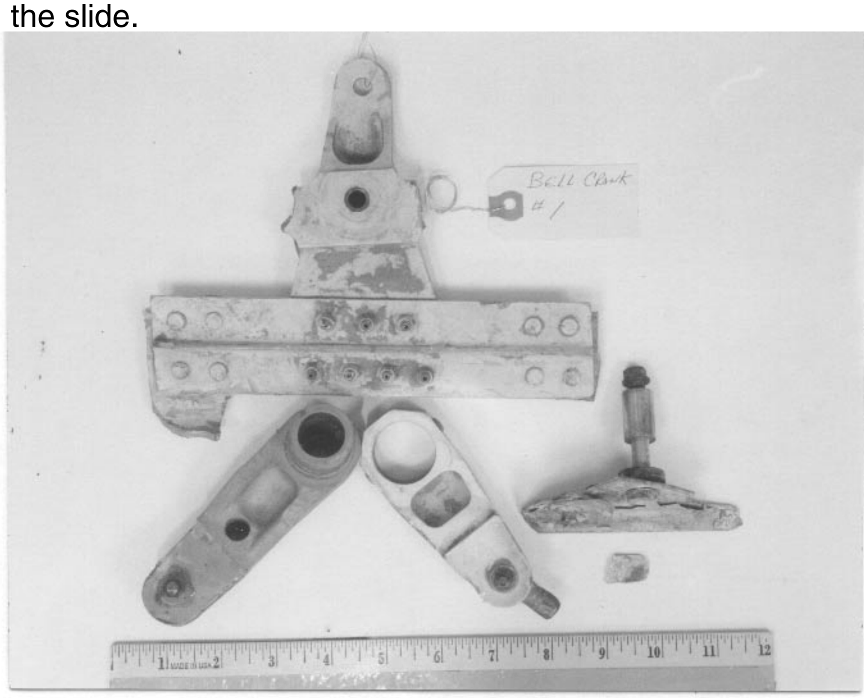


Figure 23. An overall view of bellcrank labeled # 1.

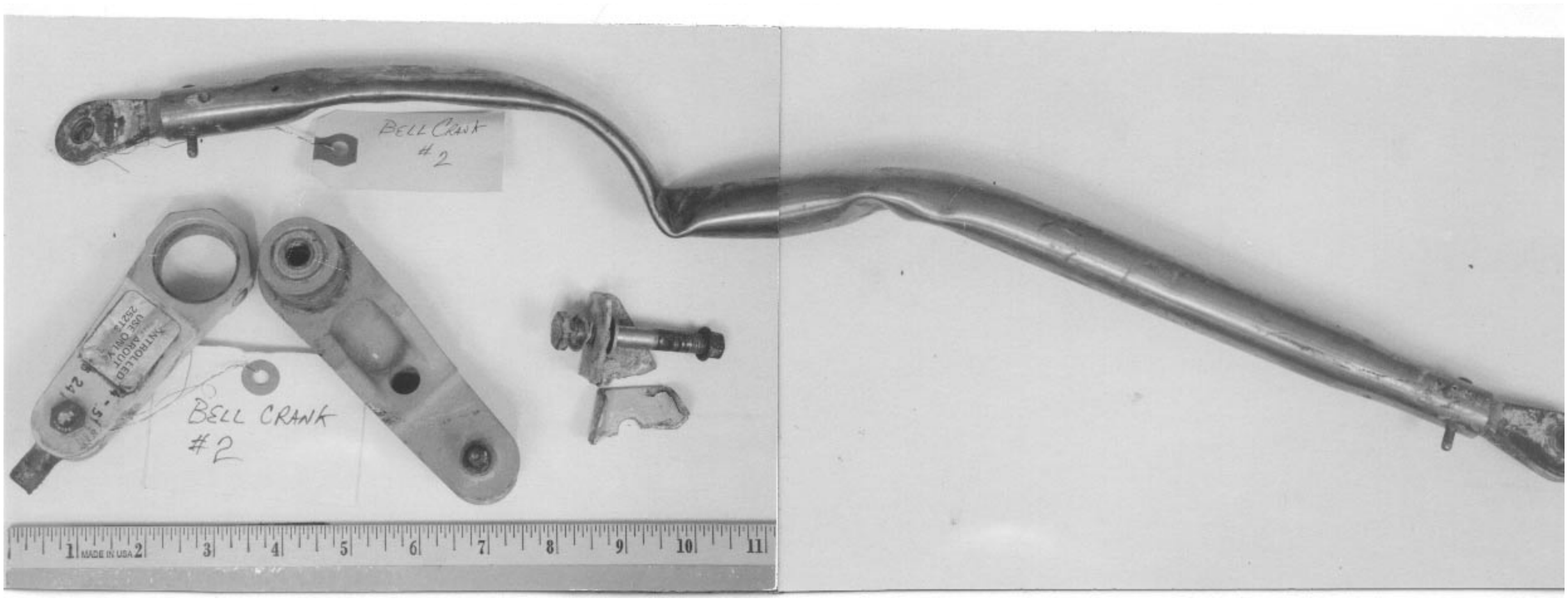


Figure 24. An overall view of bellcrank labeled # 2.

Figure 25. An overall view of bellcrank labeled # 3.

Figure 26. An overall view of bellcrank labeled # 4.

Figure 27. An overall view of bellcrank labeled # 5.

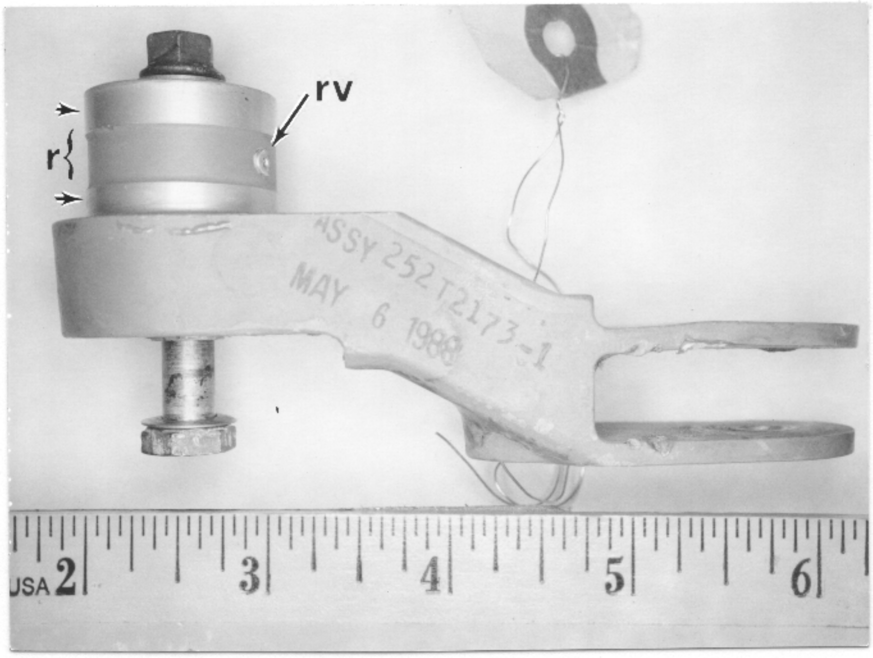


Figure 28. The side view of the outboard arm from bellcrank #5 showing the two bearing surfaces by unlabeled arrowheads, the recessed area by bracket "r", and the sheared rivet by arrow "rv".

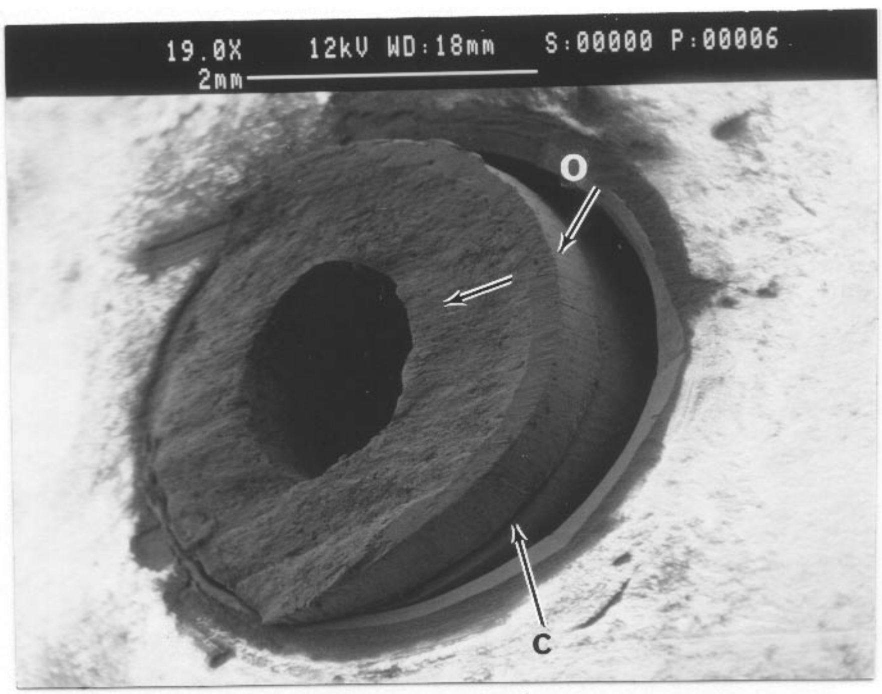


Figure 29. SEM view of the fracture surface on the rivet indicated by arrow "rv" in figure 26. Arrow "o" indicates the origin of fracture, the unlabeled arrow indicates the direction of the fracture, and arrow "c" indicates the circumferential crack. (19X).

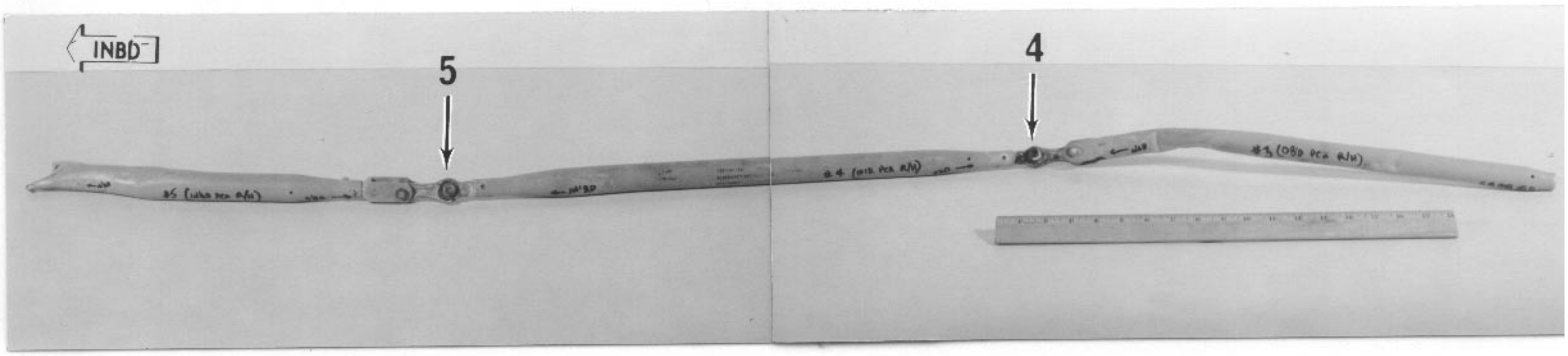
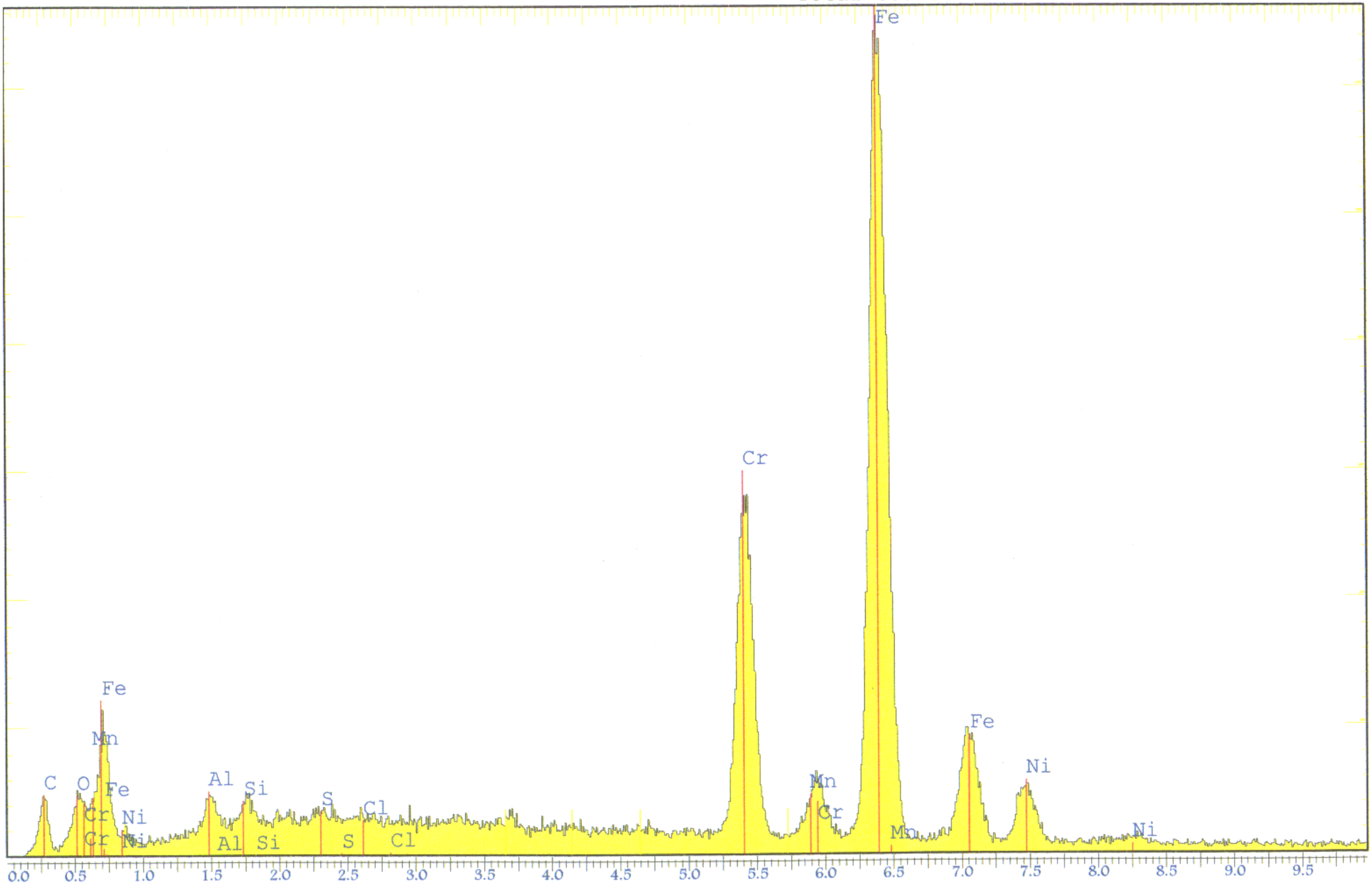


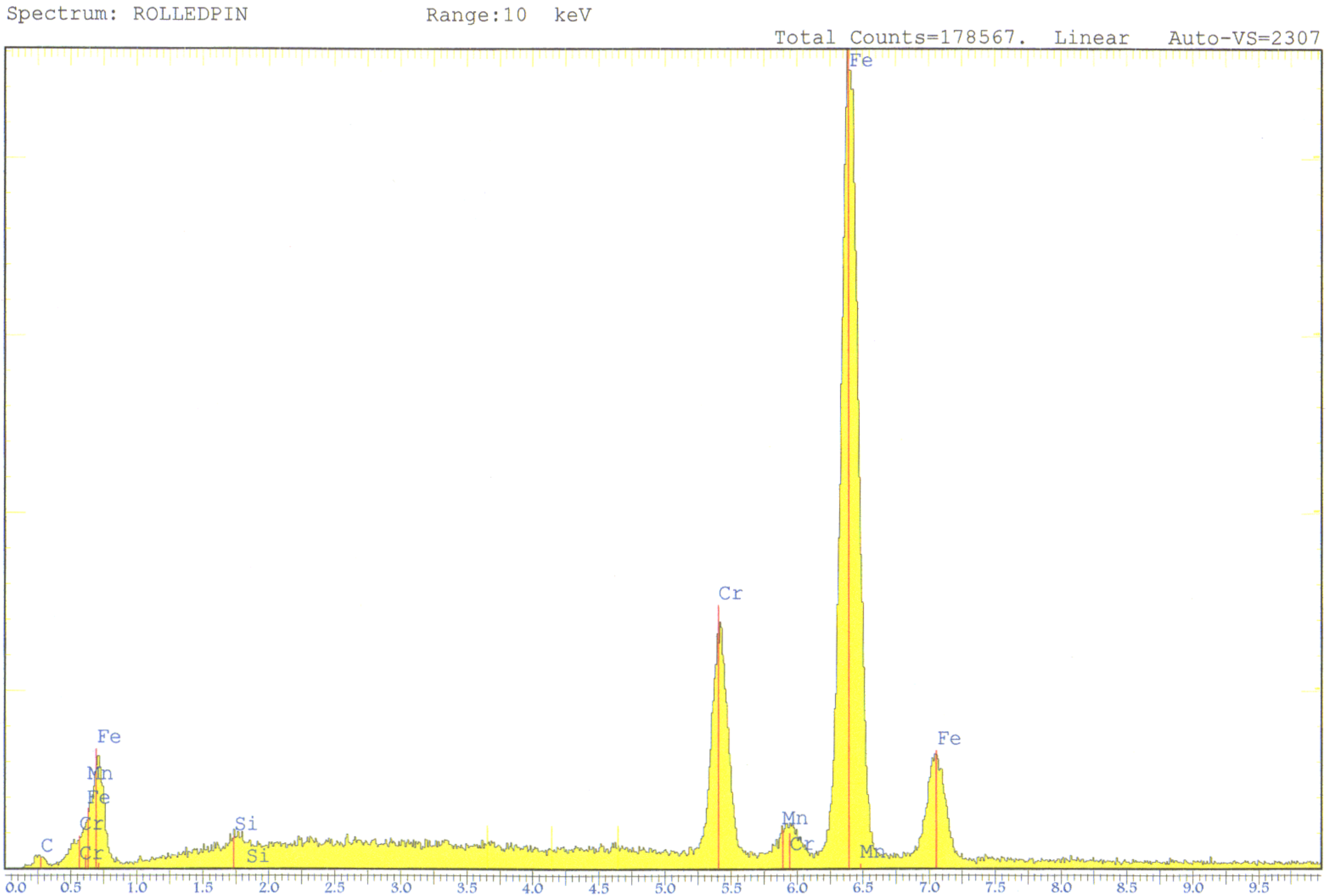
Figure 30. An overall view of the push-pull rods for the Nos. 3, 4, and 5 bellcranks. Arrows "5" and "4" indicate positions of bellcranks No. 5 and No. 4.

APPENDIX

Spectrum: SPRING Range:10 keV

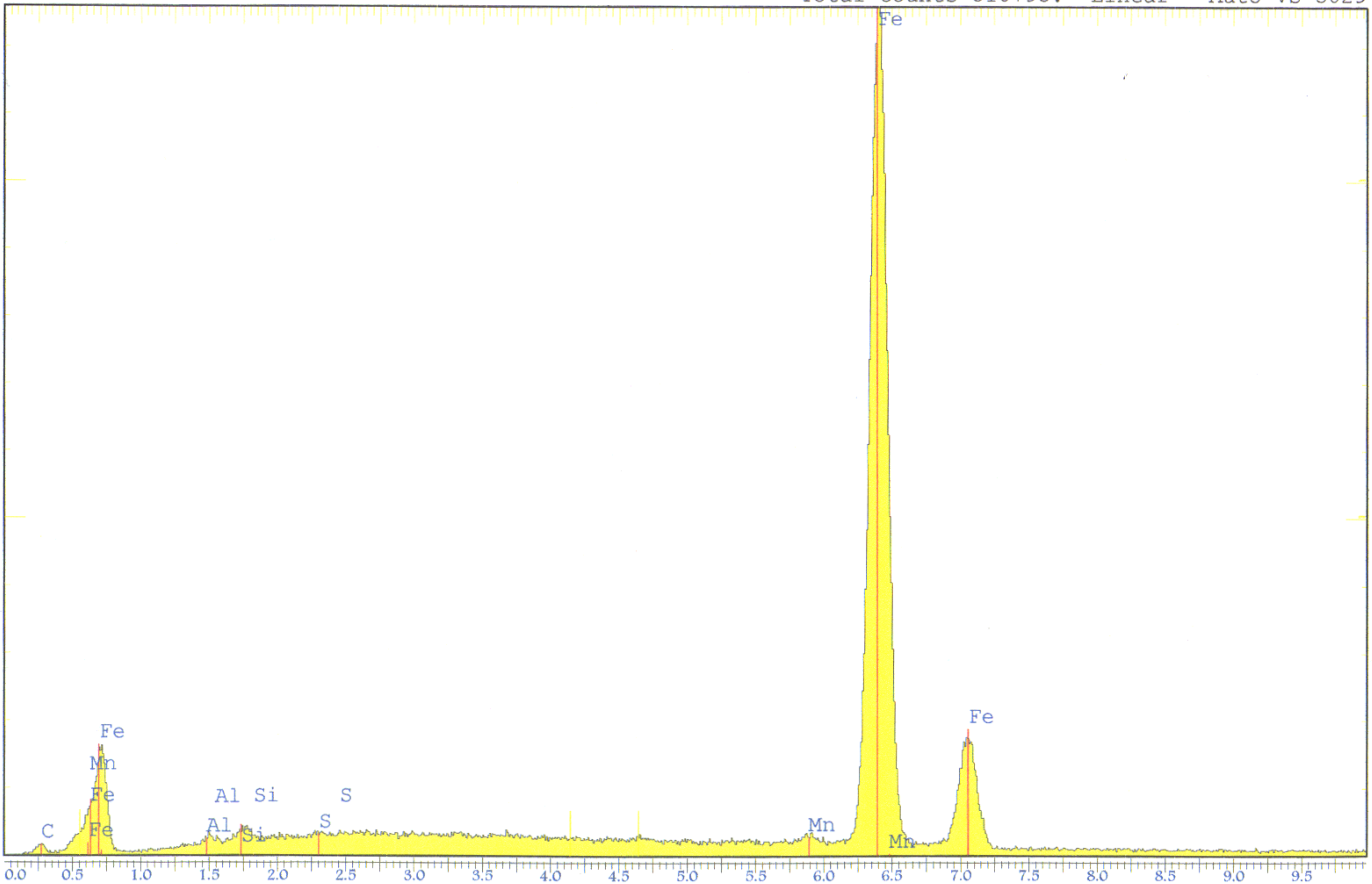
Total Counts=125025. Linear Auto-VS=1321




Spectrum: ROLLEDPIN
Range:10 keV
Total Counts=178567. Linear Auto-VS=2307
Fe
Cr
Fe
Fe
Mn
Fe
Cr
Cr
C
Si
Si
Mn
Cr
Mn
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5

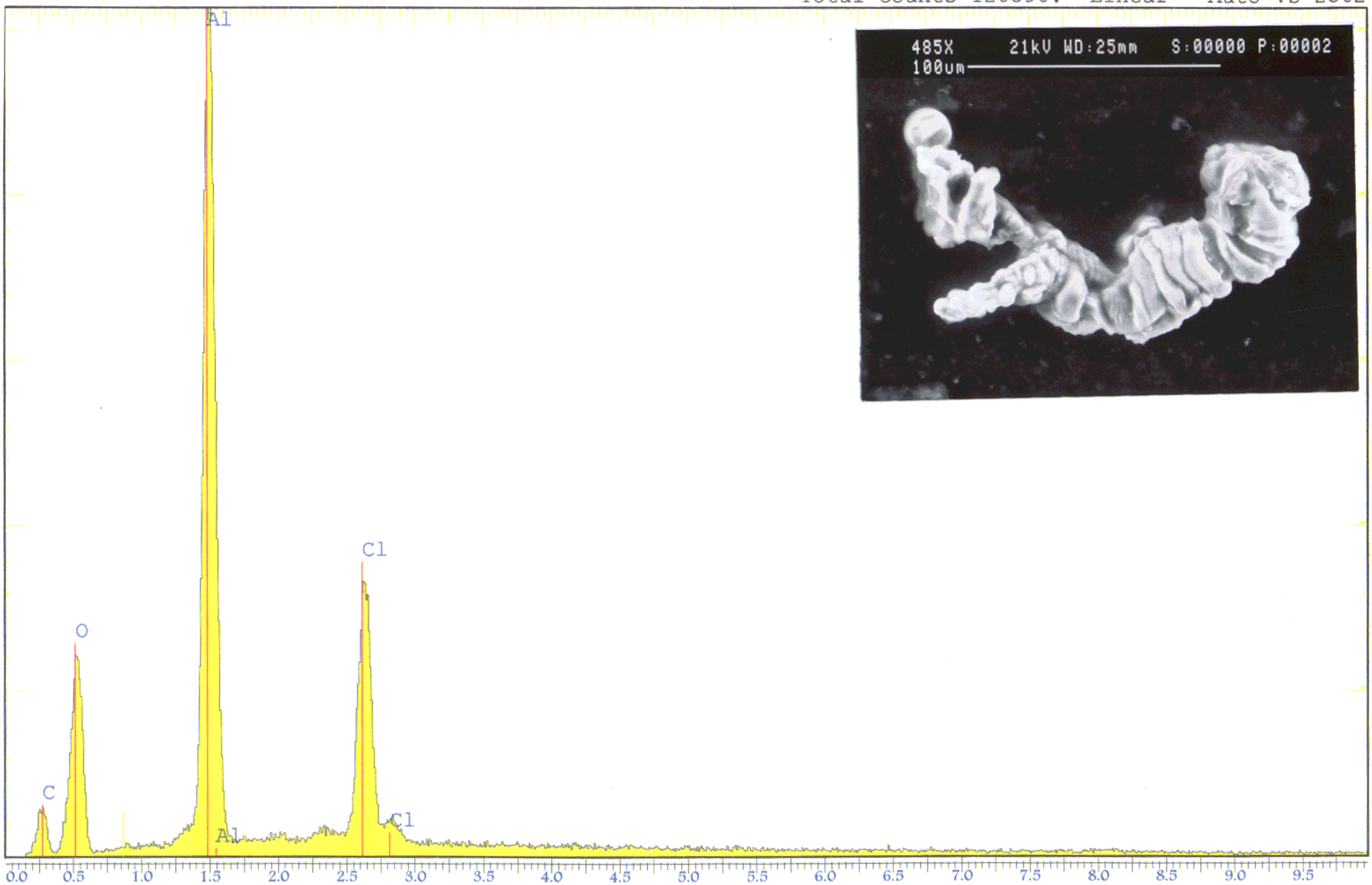
Spectrum: SPRING~~CAP~~GUIDE Range:10 keV

Total Counts=318793. Linear Auto-VS=5029



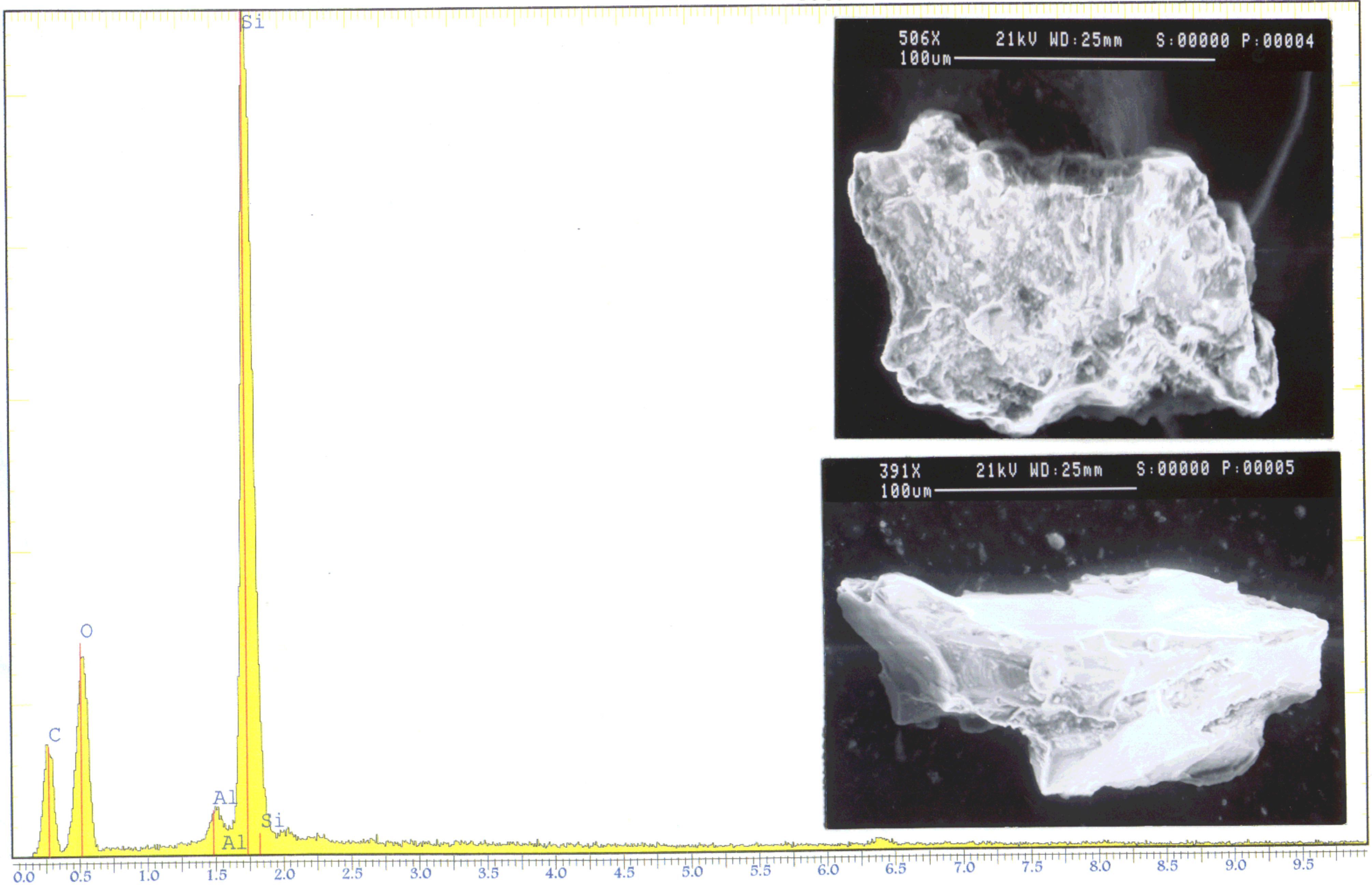
Spectrum: PARTICLESIDE2 Range:10 keV

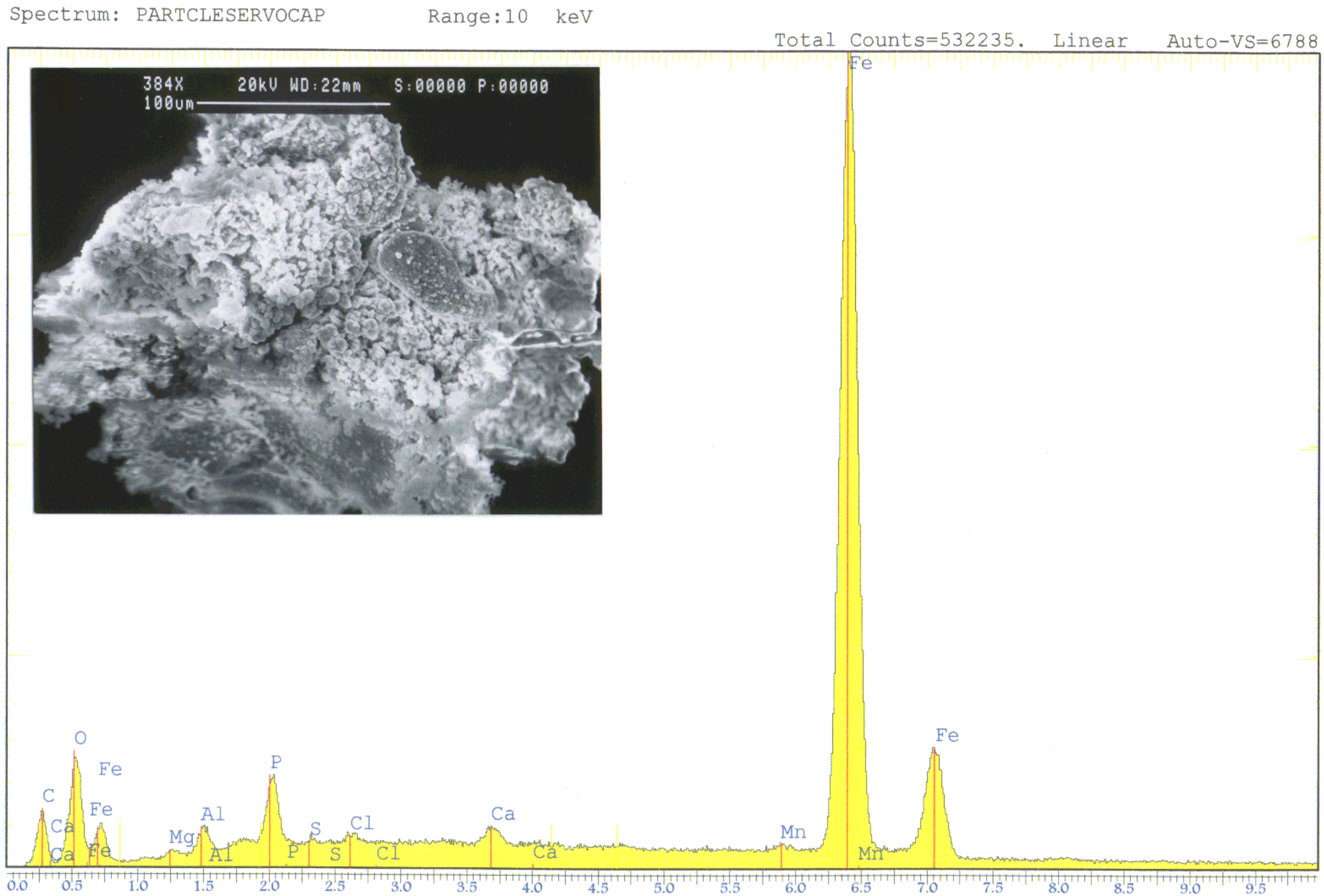
Total Counts=128398. Linear Auto-VS=2562



Spectrum: PARTICLESIDE3 Range:10 keV

Total Counts=117666. Linear Auto-VS=2771




Spectrum: PARTCLESERVOCAP
Range:10 keV
Total Counts=532235. Linear Auto-VS=6788
384X 20kV WD:22mm S:00000 P:00000
100um
C
O
Fe
Ca
Mg
Al
P
S
Cl
Mn
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5