NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, D.C. 20594

September 1, 1998

MATERIALS LABORATORY STUDY — Report No. 98-116

A. INTRODUCTION

A study was initiated to examine Boeing 737 rudder power control unit (PCU) servo valves that were involved in accidents and compare them to representative exemplar valves removed from service that were not involved in accidents. The primary reason for doing this study was to document the differences and/or similarities between non-accident and accident valves. Exemplar valves were obtained from Parker Hannifin that had known service histories. In addition a valve used in testing, referred to as the "minimum tolerance valve", was obtained and added for comparison.

B. COMPONENTS EXAMINED

1) Exemplar Rudder PCU Servo Valves, S/N's 2278X, 3167X, 3590X, 2108X, and 3403X
2) Rudder PCU Servo Valve S/N 1091 (DCA91-M-A023, Colorado Springs, CO, 3/13/91)
3) Rudder PCU Servo Valve S/N 2956 (DCA94-M-A076, Aliquippa, PA, 9/8/94)
4) Rudder PCU Servo Valve S/N 2567 (DCA96-I-A061, Richmond, VA, 6/10/96)
5) Rudder PCU Servo Valve S/N 5119 (DCA98-R-A013, Palembang, Sumatra, 12/19/97)
6) Rudder PCU Servo Valve S/N 5264 (Minimum Tolerance Test)

C. VALVE HISTORIES

The following table shows the reported histories of the exemplar valves

Serial Number *	Time Since Overhaul (hours)	Time Since Last Removal (hours)	New Primary	New Secondary
2108X	51,977	8,349	No	No
2278X	18,548	10,822	No	No
3167X	27,554	7,296	No	No
3403X	24,927	13,232	No	No
3590X	7,038	0	Yes	No

* All valve assemblies were P/N 68010-5005

The accident, incident, and test valves have the following histories

Serial Number *	Time Since Overhaul (hours)	Time Since Last Removal (hours)	New Primary	New Secondary
1091	26,050	26,050	No	No
2567	24,477	24,447	No	No
2956	21,077	21,077	No	No
5119	2,238	2,238	No	No
5264	0 - Test	0 - Test	No	No

* All valve assemblies were P/N 68010-5005

D. EXAMINATION PROCEDURE

Each servo valve assembly consists of many parts but only three parts were examined. These were the primary slide, secondary slide, and the housing (also referred to as the body). The surfaces examined were the outside diameter lands of the primary, the inside diameter of the secondary slide (also referred to as the primary inserts), outside diameter lands of the secondary slide, and the inside diameter of the housing (also referred to as the secondary inserts). All valves were identically examined with a borescope and a video tape record was made of the examination. The video tape examination set up and video documentation procedure are detailed in Appendix A.

The outside diameter land surfaces of the primary and secondary slides were also examined with the aid of a stereo microscope and characteristic markings were identified.

C. DETAILS OF THE EXAMINATION

Video Record

The individual video tapes made of each valve (total of 10 tapes) was approximately 1 3/4 hours standard recorded time of a 2 hour VHS formatted tape. One additional, much shorter, tape was also produced for the S/N 2956 valve, and one other for special examinations. All together there were 12 tapes produced and these tapes are considered part of this report.

During the video examination, notes were made of any distinguishing features. Also noted were the longitudinal[1] displacement positions of holes, both round and rectangular in shape, on the internal portions of the parts. In addition, the angular positions of the rectangular holes (metering ports) were noted for reference purposes to the mating slides. Appendix B displays the longitudinal and angular positions noted for each valve (for inside

[1] The longitudinal direction is along the centerline axis of the cylindrical shaped part

diameters only). The borescope probe was positioned on the primary and secondary to give the angular readings relative to each other. However, the valve housing in each case was inadvertently situated in the examination device to give angular readings (on videotape) that were 180 degrees out of phase. This was not discovered until all the initial 10 tapes were produced. In order to correct for this, the video recorded angular reading for the housing in Appendix "B" is shown in parenthesis and the actual angle relative to the secondary is shown without parenthesis. Also for the tables in Appendix "B", C1 through C4 describes areas in the hydraulic ram; Ra = Return hydraulic a-system; Rb = Return hydraulic b-system; Pa = Pressure hydraulic a-system; and Pb = Pressure hydraulic b-system.

Distinguishing Features

The outside diameters of the primary and secondary slides were examined with the stereo microscope for distinguishing features that would be representative of normal service. Also reviewed were any distinguishing marks found on the borescopic examination of the inside diameters. The following is a list of the markings or characteristics found.

Velocity marks

Fine longitudinally oriented marks on the outside diameter surface of the lands are defined as velocity marks. These are believed to be produced by small particulate matter in the hydraulic fluid scraping the surface during movement of the slide and/or by normal passage of fluid over the surface.

Honing Marks

Fine parallel but multi-diagonal markings oriented at angles that are neither longitudinal or circumferential to the part. These markings are those representative of fabricating the part to its final diameter.

Circumferential Marks

Marks orientated circumferentially to the part over a large angular area (in many cases completely around the circumference).

Burnishing Marks

Localized longitudinally oriented markings that are much broader then velocity marks. Such marks normally extend over relatively short longitudinal distance (approximately 0.1 inch maximum) and are in the neighborhood of 0.005 inches in breadth (circumferentially).

Chipping

Brittle fracturing of the surface at the corner of the land at the metering edge or balance groove. This chipping on the most part was small, over short circumferential distances, but in some cases was present nearly around the circumference.

Splotch or Deposit Marks

Appearance of surface contamination or mild corrosion on the outside diameter of the primary and secondary land surfaces.

Corrosion

Discoloration of the surface indicative of an oxide. In some cases the surface may contain evidence of etching.

Assembly or Disassembly Markings

Relatively long markings on the inside diameter that often have a change in angle relative to the longitudinal axis and have an appearance similar to burnishing marks. The length of the marking is far greater than the maximum travel of the mating spool during operation of the valve. These markings are believed to be associated with insertion or removal of the spools on assembly or disassembly.

Witness Markings

Etching, corrosion or erosion areas representative of mating features such as the metering ports and holes.

Exemplar Valve S/N 2108X Distinguishing Features

Primary

Valve S/N 2108X had the highest time since last overhaul (51,977 hours) and was the first to be examined, in detail, for distinguishing marks.

Figures 1 through 4 show selected areas of the primary outside diameter lands that contained a relatively large concentration of burnishing marks (shown as thin dark marks aligned longitudinally). Other areas also contained burnishing marks but were not as concentrated as those shown in these figures.

Areas of small chip outs of the land /metering cavity corner were noted at some of the metering edges. Two chip out areas (30 and 300 degree reference positions) are displayed in figures 5 and 6 on the metering edge associated with land 6+. Three other chip out areas (50, 160, and 235 degrees) are shown in figure 7 for land 11++.

In addition, significant chip out areas of the corner between the land and groove were noted that were associated with the first balance groove from the metering edge. One area was on land 7 as shown in figures 8 and 9. Other areas are shown in figures 10 through 13 for land 13, and figures 14 through 16 for the groove side of land 21. The chipped out portions were approximately 0.001 inch along the longitudinal land surface with a maximum of about 0.003 inch within the groove below the land. However, these chip out areas were of varying sizes circumferentially, some of which extended circumferentially over 0.04 inch (see figure 10 as an example). In the longer circumferentially chipped areas the chipping appeared to follow circumferential lines on the land as shown by the unmarked arrows in figures 10 and 11.

When first examined, the chip out area shown in figure 8 displayed a crack in the area of the arrow . It was noted that this same area had changed with more chipping (extension of crack) after the primary was rotational hand wiped with a Kimwipe (laboratory tissue) in attempts to remove what appeared to be contamination on the surface. Figure 9 displays the same area after this wiping (arrow in this figure indicates the identical area shown by the arrow in figure 8) The area of bracket "1" in figure 9 indicates the amount of the corner edge that was removed by this wiping.

Other superficial markings were also noted and are only mentioned for thoroughness. A few areas contained blemishes or splotches on the land surface as shown by the arrow in figure 17. These appeared to be a thin deposit on the surface. Figure 18 shows an area containing what appeared to be a scrape somewhat like a burnished area. The brackets in figure 19 locate two longitudinally roughened areas which were in contrast with the remaining polished surface. Small circular dark regions exhibiting a comet tail were also noted on the land surfaces in some areas (typical examples are shown in figure 20).

Secondary Slide Inside Diameter

The internal diameter surface contained evidence of long burnish type marks (in some cases in excess of about 0.4 inches in length) which were mostly in a straight line but were at varying angles to the longitudinal axis. These were located at longitudinal positions 0.1 to 0.5 inches between 180 and 220 degrees and between 1.2 and 1.5 inches at 120 to 190 degrees. Due to their length, these marks were probably produced by assembly and/or disassembly of the primary in the secondary.

Distinctive circumferential markings traversing the total diameter were found that intersected the Pa to C3 and Pb to C1 metering ports about mid length of the ports. A shiny area was also noted on the I.D. surface at the Ra aft metering port. This shiny area was in line with and corresponded to the width of the port with extension circumferentially from the port at the reference angular position of 80 degrees to about the position of 0 degrees. A 0.03 inch wide scratch on the I.D. surface intercepted the aft corner of the Pa to C3 metering port on an angle.

Secondary Outside Diameter

Concentrated burnishing marks were noted at two areas. One area was on land 1 at about 90 degrees (see figures 21 and 22) and the other was on land 11 at 30 degrees (see figures 23 and 24). In addition, two small areas of surface corrosion (arrowed in figure 22) had a reddish brown tint and were within the burnished areas on land 1. Figure 23 also show lands 8 through 10 where other less concentrated burnishing marks appeared.

Two areas of irregular staining and possible corrosion are shown in figures 25 and 26 for lands 6 and 10.

A probable witness shadow for the forward side of the C1 to Rb aft metering port is displayed in figure 27. This was determined by the angular position corresponding to the port position in the housing. The shadow was about 0.015 inch long (between arrows figure 27) and was about 0.002 inch from the metering edge (indicating overlap of land 7 to port while in neutral).

Only one chip out was noted, which is arrowed in figure 28. This chip out area was located about 105 degrees from the housing C1 to Rb aft port position (far removed from the port).

Housing Inside Diameter

Approximately 0.02 inch wide light corrosion band was found between 140 to 220 degrees at a longitudinal position around 0.1 inch. Some angular scratches were noted at 330 degrees located about angular position 330 degrees. Multiple circumferential marks were noted between reference positions 0.7 to 1.0 that extended most of the way around the circumference. Small dark pit-like areas were noted at 1.8 inches and 60 degrees.

The metering port Pb to C1 contained a darkened shadow aft of the port that was the same width and length of the port (0.015 by 0.045 inch).

Remaining Exemplars 2278X, 3167X, 3403X, 3590X

Similar features of those shown for exemplar 2108X were found in varying degrees for the remainder of the exemplars.

Accident Valve S/N 1091 (DCA91-M-A023, Colorado Springs, CO, 3/13/91)

For reference purposes an internal layout view of the inside diameters of the secondary and housing for this valve are shown in Appendix C.

Primary

The aft two metering cavities (corresponding to system "a" hydraulic system) were darkly discolored containing a thick deposit. Witness marks (see figure 29) representative

of the C3 to Ra aft metering port were found at about 260 degrees in two positions, one on land 6 is near its normal relative position (see bracket "a" and unmarked bracket) and another one on land 4 (arrowed "b"), is well removed from its normal position.

At the metering edge corresponding to land 6 the forward side of the 0.045 inch long metering port within the inside diameter of the secondary slide is approximately in line longitudinally with the metering edge[2] when the primary is at neutral relative to the secondary (port is essentially closed off or covered by land 6 and a portion of land 5). Measurements[3] obtained showed the unmarked bracket as well as the bracket "a " dimensions in figure 29 were 0.015 inch. These dimensions indicated that the metering port in this position was about 1/3 covered by land 6 when the witness mark was made. The mark shown by arrow "b" was the width of the metering port (0.015 inch) and was circumferentially in line with witness mark "a". The characteristic of the mark indicated that the line at arrow "b" witnessed the aft edge of the metering port at this point. Longitudinal measurement from the arrow "b" location to the metering edge at land 6 gave a value of 0.099 inch. The aft edge of the metering port at neutral relative to the primary would be approximately 0.045 inch from the metering edge. Therefore, the witness mark at point "b" indicated the primary had shifted forward approximately 0.054 inch (0.099 inch less 0.045 inch) from neutral when witness mark arrowed "b" was made.

Land 6 also contained six almost semi-circular witness marks that were equally spaced circumferentially around the land. These marks were indicative of the C3 round holes in the mating secondary being positioned over the land. One of these semi-circular marks is outlined by unmarked arrows in figure 29. Measurements showed that the diameter of the holes producing these marks was about 0.052 inch and that the mark extended 0.023 inches aft from the metering edge. Internal longitudinal measurements taken on the inside diameter of the secondary between the aft edge of the C3 round holes and the forward edge of the C3 to Ra aft metering port gave a value of 0.039 inch. The combined distance of 0.039 and 0.023 inch indicated that when the semi-circular marks were produced the primary had shifted forward about 0.062 inches relative to its neutral position with the secondary.

Other circular arc marks about 0.05 inch in diameter indicative of C4 holes in the secondary were found on lands 10 and 11 as shown in figure 30. In this area there appeared to be three sets of six equally spaced holes producing the witness marks, one set (lighter) is indicated by arrows "X", another set (dark) by arrows "Y" and a third set (less distinct and only one shown in figure 30) by arrow "Z".

On the "X" witness set there was a small but distinct band at the circumference indicative of a broader line around the mark circumference. A reference 0.050 inch

[2] In actuality there is a slight under lap of about 0.001 to 0.002 inch between the metering edge and the forward edge of the metering port at neutral. An under lap means that the port is slightly open or uncovered allowing partial flow of the fluid at neutral.

[3] Unless otherwise indicated all measurements taken were with the aid of an OGP Smart Scope (a non contact video measuring device)

diameter hole[4] appeared to match the diameter arc of the inner portion of the band for the "X" witness marks as well as the other witness marks "Y" and "Z". Longitudinal measurement from the inner band aft edge to the metering edge gave a value of 0.020 inch for holes "X". Similarly longitudinal dimensions of 0.052 and 0.055 inch were obtained for witness sets "Y" and "Z", respectively. Using the borescope examination set-up the rotational displacement between witness mark sets "X" and "Y" showed approximately 5.5 degrees. The rotational position of witness set "Z" was estimated to be approximately midway between the position set of witness "Y" (approximately 30 degrees).

Internal measurement of the secondary, using the borescope set-up, showed that the distance between the aft edge of the C4 holes and the forward edge of the Pa to C4 metering edge was 0.034 inch. At neutral the forward edge of the Pa to C4 metering port would be approximately longitudinally in line with the metering edge of land 11 (disregarding under lap). This measurement and the measurement obtained for the "X", "Y" and "Z" witness marks showed three separate witness positions of the primary relative to the secondary. The "X" witness marks indicated the primary was displaced relative to the secondary about 0.054 inch (0.034 plus 0.020) forward of neutral, the "Y" witness marks indicated a displacement of 0.086 inch (0.034 plus 0.052) forward of neutral and rotated about 5.5 degrees from witness "X", and the "Z" witness marks indicated a displacement of 0.089 inches (0.034 plus 0.055) forward of neutral and rotated about 30 degrees from witness "Y".

The metering edge on land 11 was notably irregular around the "X" witness mark locations as if the corner edge had corroded away. The most edge removal measured about 0.0015 inch longitudinally along land 11 and in all cases was associated with the regions encompassing the witness areas "X."

Secondary Inside Diameter

The secondary inside diameter contained light area circumferential bands of what appeared to be a smoothed out etched surface (normal velocity marks and machining marks smoothed out within the light areas) These bands were of the approximate width and in the approximate longitudinal positions corresponding to the system "a" metering cavities on the primary.

Secondary Outside Diameter

A distinct witness mark for the C4 to Ra fwd metering port was found on land 5 as shown in figure 31. The position of this witness mark indicated the primary was in a neutral position relative to the housing when the mark was made.

Figure 32 shows circular witness marks that were found on land 1 and land 6. In the left photograph of figure 32 the circular mark pairs shown (one slightly offset circumferentially from the other) were one of three circumferentially equally spaced pairs

+[4] Generated with the OGP Smart Scope.

found around the circumference of land 1. These marks measured[5] O.125 inch in diameter. The diameter, number of equally spaced pairs, and location corresponded to the Ra aft holes on the inside diameter of the housing. The circular pairs shown in the right photograph were one of four pairs found equally spaced around land 6. Their diameters measured about 0.1 inch which corresponded to the Ra fwd holes in the housing.

One of the three hydraulic b-system pressure (Pb) holes on the outside of the secondary contained what appeared to be metal particles in the area indicated by arrow "A" in figure 33. The particles were located well within the hole as shown in the close up view of figure 34. The particle location corresponded to the inside diameter of the secondary body where it interfaced with the annulus on the outside diameter of the primary insert. There appeared to be two particles as indicated by arrows "A1" and "A2" in figure 34. The visible area of particle "A1" was about 0.012 inch wide by 0.02 inch long. The visible portion of particle "A2" was somewhat smaller, roughly 0.01 by 0.01 inch.

Housing Inside Diameter

The inside diameter contained similar light bands as those found on the inside of the secondary. These lighter band areas corresponded to the system "a" cavities formed between the secondary slide and the housing when assembled. Areas corresponding to the land areas on the secondary when assembled displayed typical velocity and machining marks. Figure 35 illustrates the light banding at the Ra aft hole (see unmarked bracket) and also shows the annulus at the bottom of the hole for circumferential flow of fluid, arrowed "A3", and the side drilled hole, arrowed "A4", that leads to the C3 to Ra aft metering port, arrowed "A5".

Accident Valve S/N 2956 (DCA94-M-A076, Aliquippa, PA, 9/8/94)

This valve showed no unusual features. Only a few relatively small chip outs were noted on the metering edges of the primary. However, none of these chip outs appeared to correspond circumferentially to the metering port areas.

A light colored (whitish) particle was found in the Pa to C4 metering port off the inside diameter of the secondary slide as illustrated in figure 36. The particle appeared to be nearly flush to the interface with the 0.06 inch diameter side drilled hole (well within the port opening) and was adjacent to the forward side wall of the port. The particle had an approximate cross section of about 0.015 by 0.015 inch but its length could not be determined (due to visibility restraints by viewing with the borescope). Computer tomography (400 KV) could not detect the particle indicating that it was a low density material (not metallic). Before an attempt could be made to remove the particle it had dislodged from the port area. To this date the particle has not been recovered.

Additional selective viewing using a 15 degree borescopic probe (versus 90 degree that was used predominately in the examinations) was made in both directions on the

[5] By three point method using the OGP Smart Scope

metering ports for the secondary and housing inside diameters. This allowed for angled viewing of the forward and aft sides of the ports simultaneously with the inside diameter, which gave excellent viewing of the shearing surfaces. No evidence of deformation or distress was found in any of the ports. The extra video tape for this valve shows the examinations made using the 15 degree borescopic probe for the housing (15 degree probe examinations of the secondary ports are on the last part of the first tape).

Incident Valve S/N 2567 (DCA96-I-A061, Richmond, VA, 6/10/96)

Primary

A small chip out of the metering edge with an accompanying angled scratch was noted on land 11 (see figure 37). This rotational area of the land is in the immediate vicinity of the Pa to C4 metering port at 95 degrees reference. Other small chip out areas were noted that were not involved with metering ports.

Also noted were multiple small areas of what appeared to be corrosion pits on the surface of lands 12 and 13.

Secondary Inside Diameter

Examination disclosed no unusual features. The adjacent inside diameter surface of the Pa to C4 metering port contained shallow diagonal scratches oriented perpendicular to the scratch found on primary land 11 (see figure 38). No evidence of any distortion was found on this or any other metering port.

Secondary Outside Diameter

Nothing was found that was considered out of the ordinary.

Housing Inside Diameter

Faint multiple burnishes about 0.01 inch long were noted on the aft portion (0.1 to 0.2 longitudinal reference) between 270 to 290 degree reference positions. Similar burnishes were noted on the far forward end (2.2 longitudinal reference) between 50 and 90 degree reference.

Accident Valve S/N 5119 (DCA98-R-A013, Palembang, Sumatra, 12/19/97)

Primary and Secondary Outside Diameters

The input side into the a-system portion contained extensive corrosion products (resulting from water penetrating in from the summing lever cavities after the crash). However, stereo microscopic examination of the metering edges showed they were relatively free from any damage.

Secondary and Housing Inside Diameters

Extensive corrosion areas were found corresponding to those corroded on the outside diameters of the primary and secondary slides.

Test Valve S/N 5264 (Minimum Tolerance Test)

Primary and Secondary Outside Diameters

Longitudinal scratches about 0.1 inch long were noted across land 30 and part of land 31 for the primary and on the forward side of land 11 on the secondary. Both scratch areas were rotationally oriented at about the 0 degree position.

Secondary Inside Diameter

The far aft end contained numerous burnish marks between 80 and 105 degree reference positions that measured a maximum longitudinal length of 0.13 inch. Other isolated burnish marks were found at the 0.3 inch longitudinal position (75 degrees, approximately 0.12 inch long), at the 0.5 inch position at 200 and 240 degrees (both of these marks about 0.085 inch long), and at the 2.1 longitudinal (far forward position) within 10 to 20 degrees of the 0 degree reference position (multiple marks around 0.070 inch long).

The exemplars and S/N 2956 were reviewed again specifically for any evidence of burnishing marks on the inside diameter of the secondary slides. Most exemplars showed no similar evidence. However S/N's 2278X, 3167X, and 2956 showed some faint burnishing that was far less distinct and of a lesser quantity.

Multiple burnishes about 0.09 inch long were noted in the vicinity of the C3 to Ra aft metering port (80 to 105 degree reference).

Housing Inside Diameter

No unusual marks were found.

[redacted]

Michael L. Marx
Chief Technical Advisor
Metallurgy & Failure Analysis

[redacted]

Derek Nash
Engineering Technician

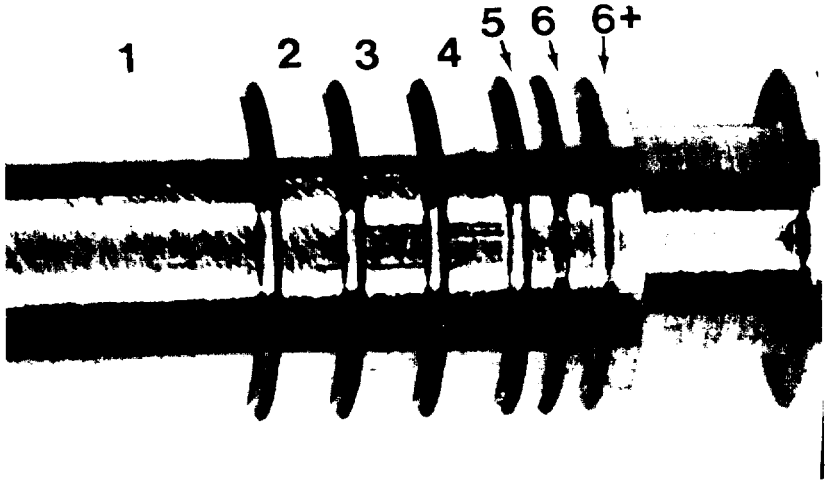


Figure 1. Primary for exemplar 2108X showing a location of concentrated burnishing marks. Lands 1 through 6+ reference angular position about 130 degrees. X7.5

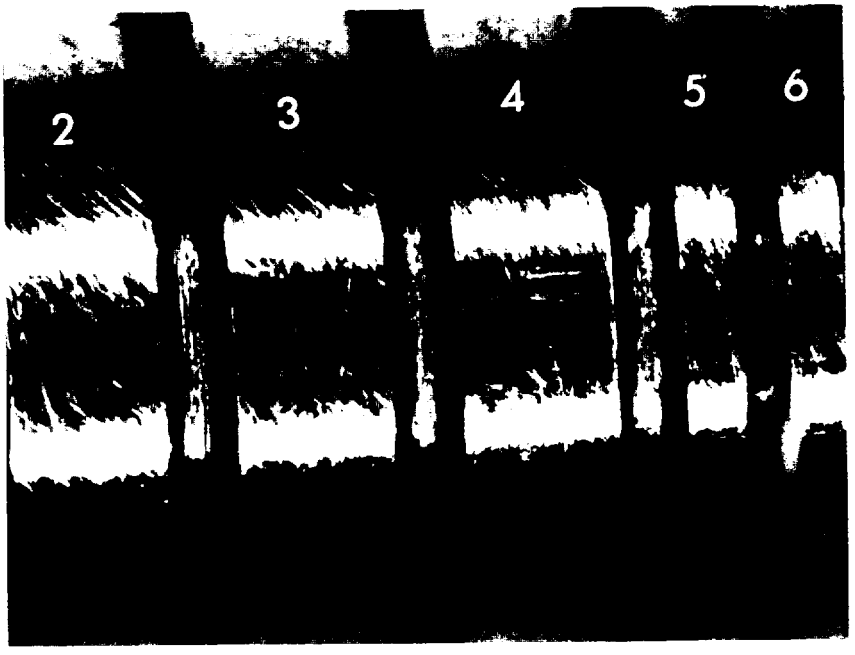


Figure 2. Higher magnification view of figure 1 in area of burnishing marks. X 20

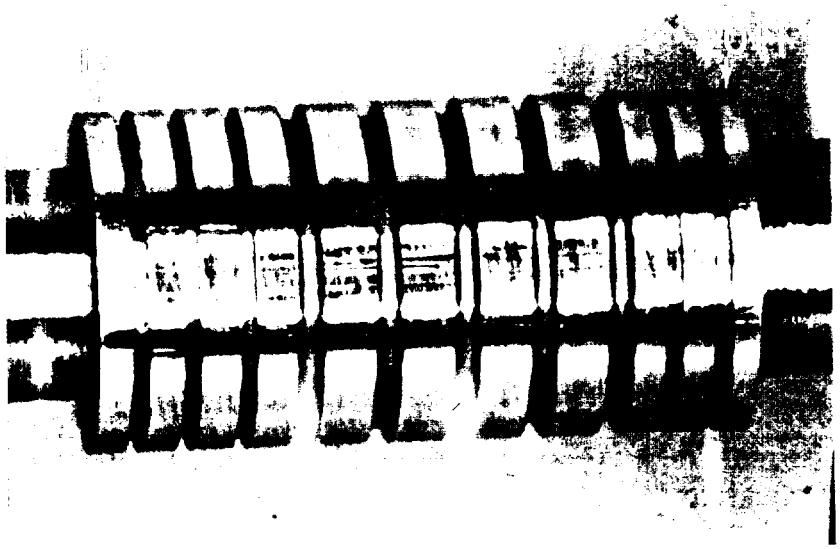


Figure 3 Another area showing a high concentration of burnishing marks. Exemplar 2108X primary lands 12 to 20+ at 30 degrees X7 5

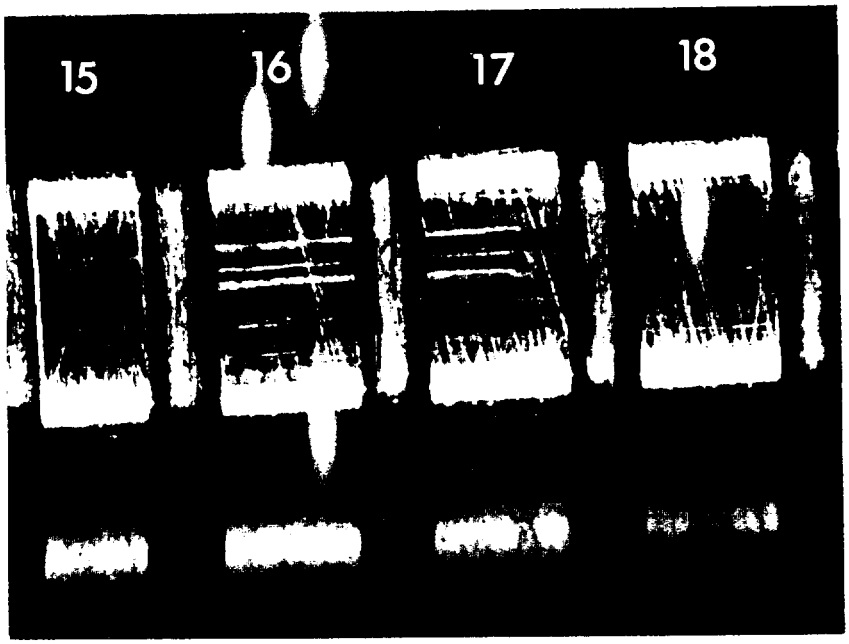


Figure 4 Higher magnification view of burnish mark area shown in figure 3 X 20

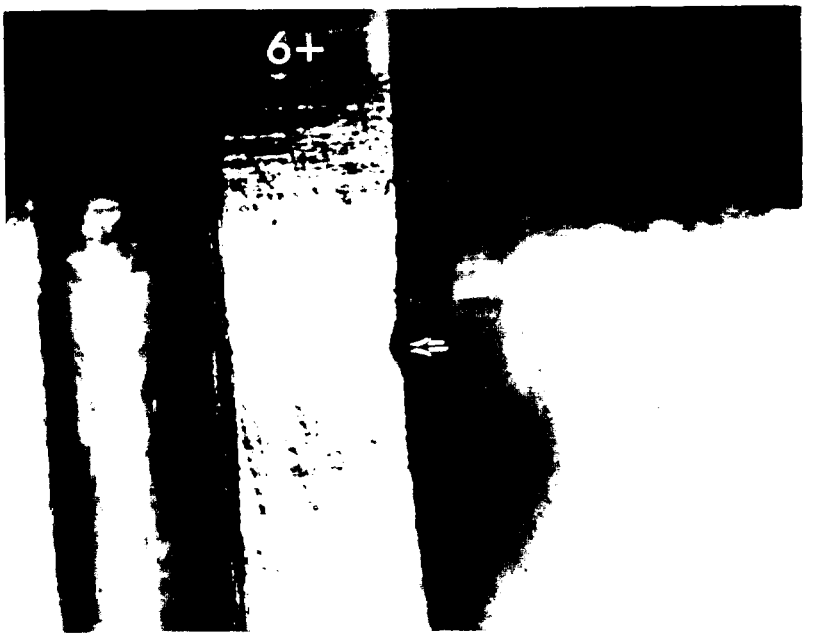


Figure 5 Small area of chip out (arrowed) of metering edge Exemplar 2108X primary land 6+ at 30 degrees X50

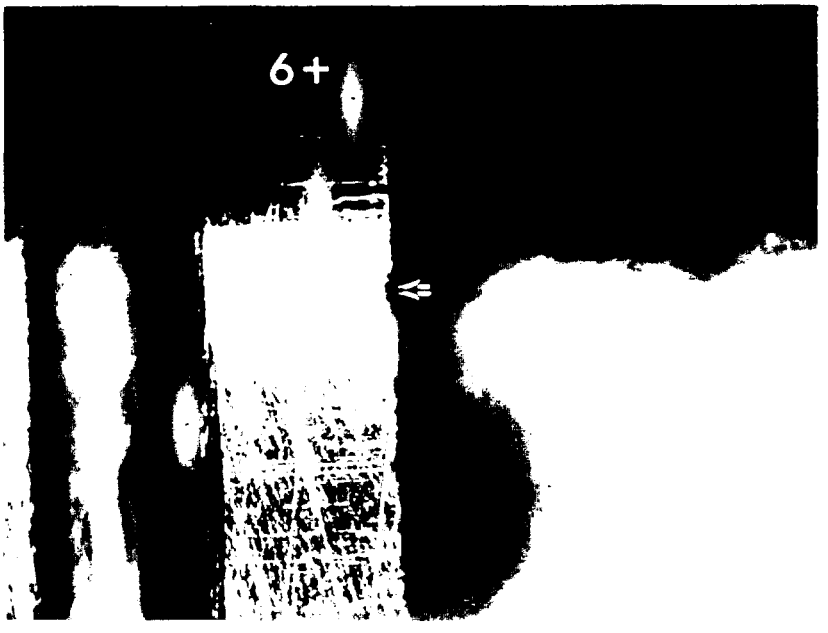


Figure 6 Another small area of chip out (arrowed) of metering edge Exemplar primary 2108X land 6+ at 30 degrees reference X50

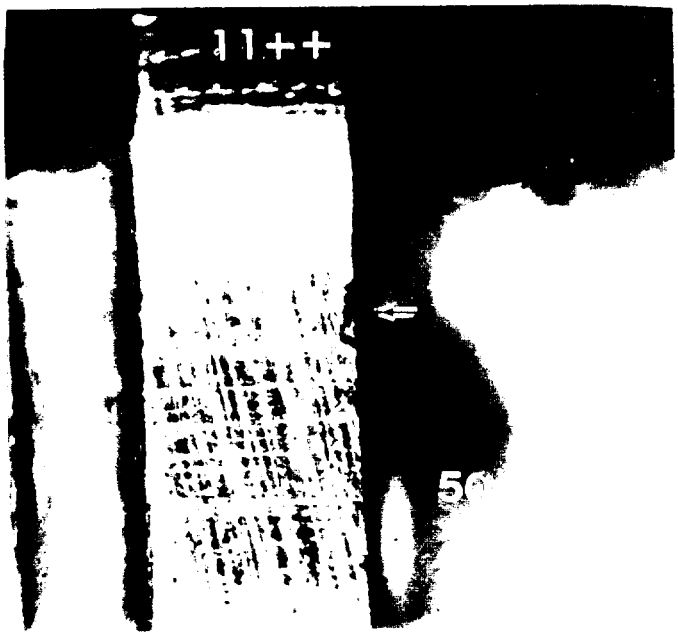
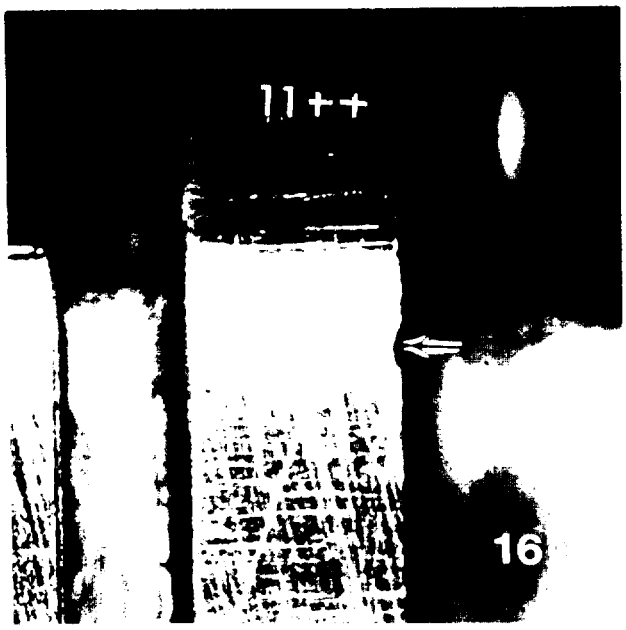
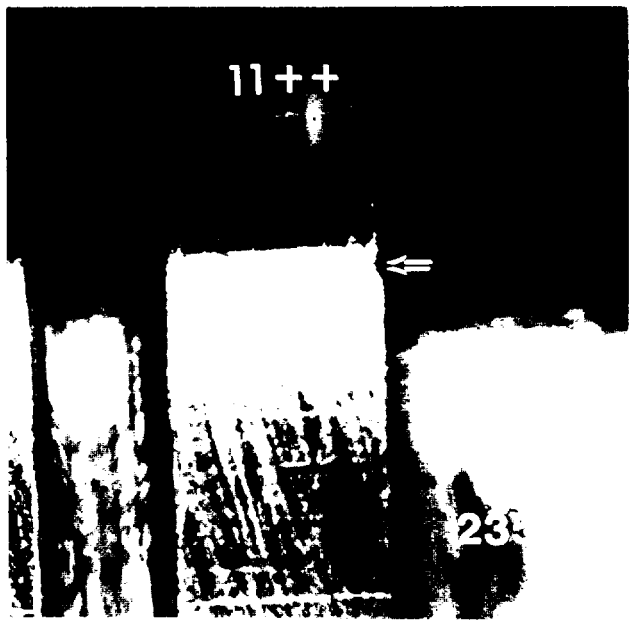


Figure 7. Three areas of small chip outs (arrowed) at metering edge 11++. Approximate angular positions shown to right of metering edge. All photos X50.





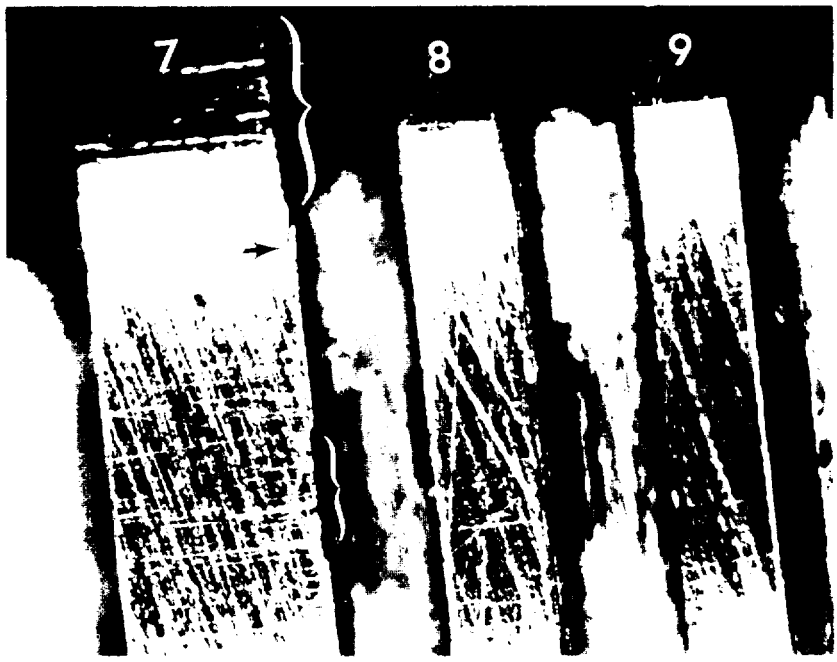


Figure 8 Chip out areas (bracketed) of the corner between the land and balance groove Arrow denotes a small crack Exemplar S/N 2108X, land 7 at 200 degrees X50

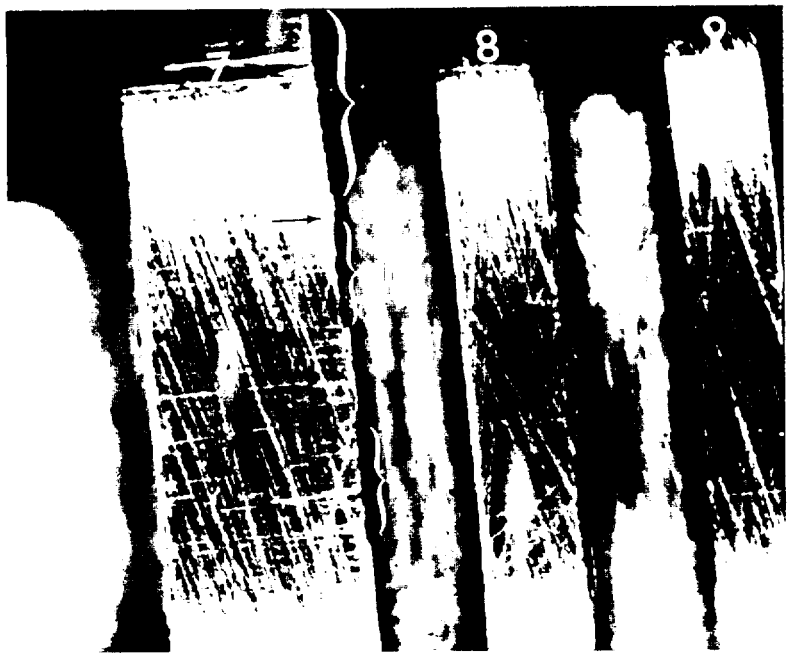


Figure 9 Same as above except photograph taken after the primary was rotational wiped with a Kimwipe tissue Arrow locates same area as that shown by the arrow in figure 8 above Note small area of additional chip out produced in the area of bracket "1" X50

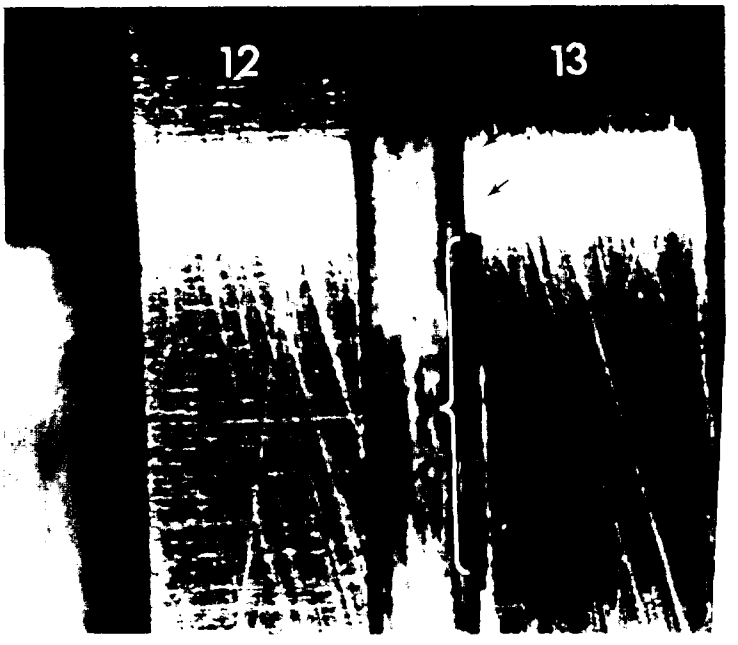


Figure 10 Larger chip out area (bracket area) of the land / balance groove corner found on exemplar 2108X at about 45 degrees for land 13 Note circumferential mark located by arrowheads X50

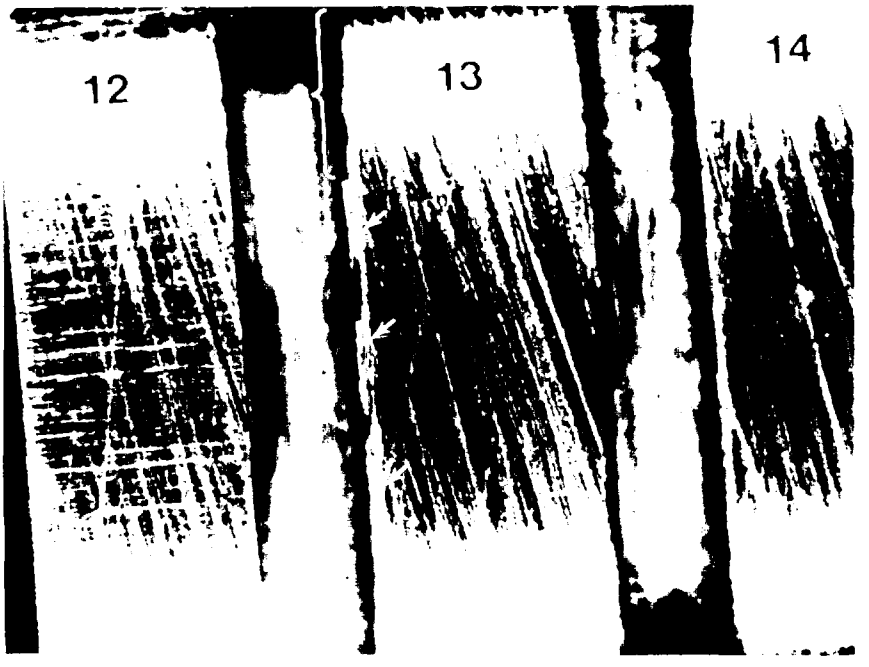


Figure 11 Same area as that shown in figure 10 except just below area of chipping (about 40 degrees) showing continuance of circumferential marking on land (arrowed) X50

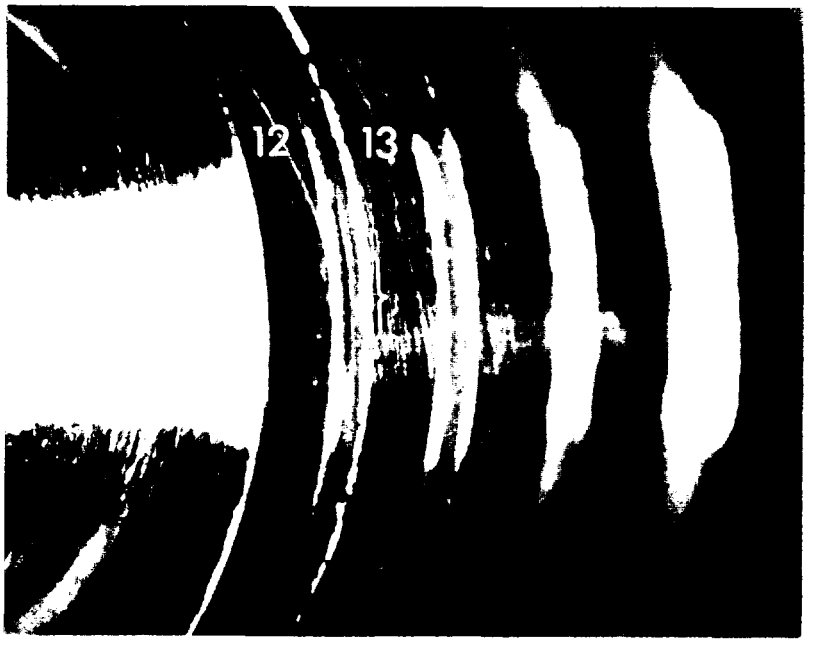


Figure 12. Lower magnification view of a corner chip area (bracketed) on S/N 2108X at about 120 degrees with primary tilted to indicate depth of chipping along balance groove surface. X20

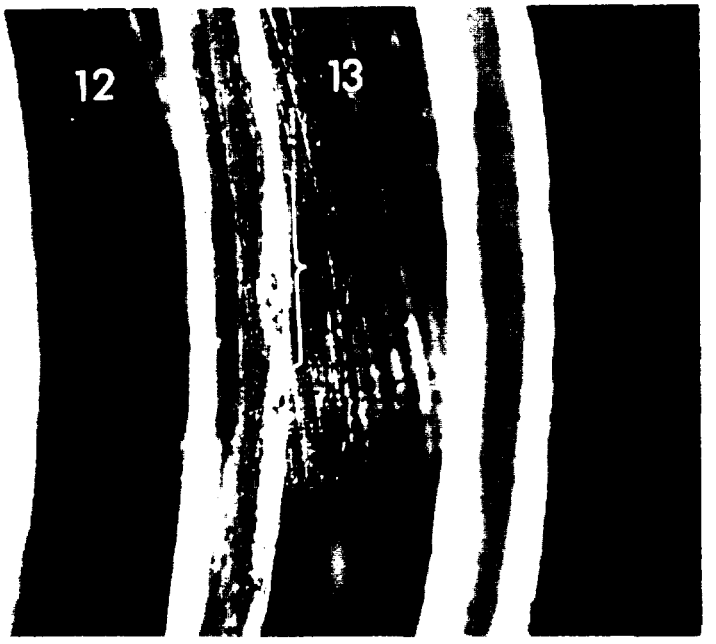


Figure 13. Same as that shown above except at higher magnification. Side wall of the balance groove is about 0.010" deep and the chipping was estimated to be about 0.003 inch along wall. X50

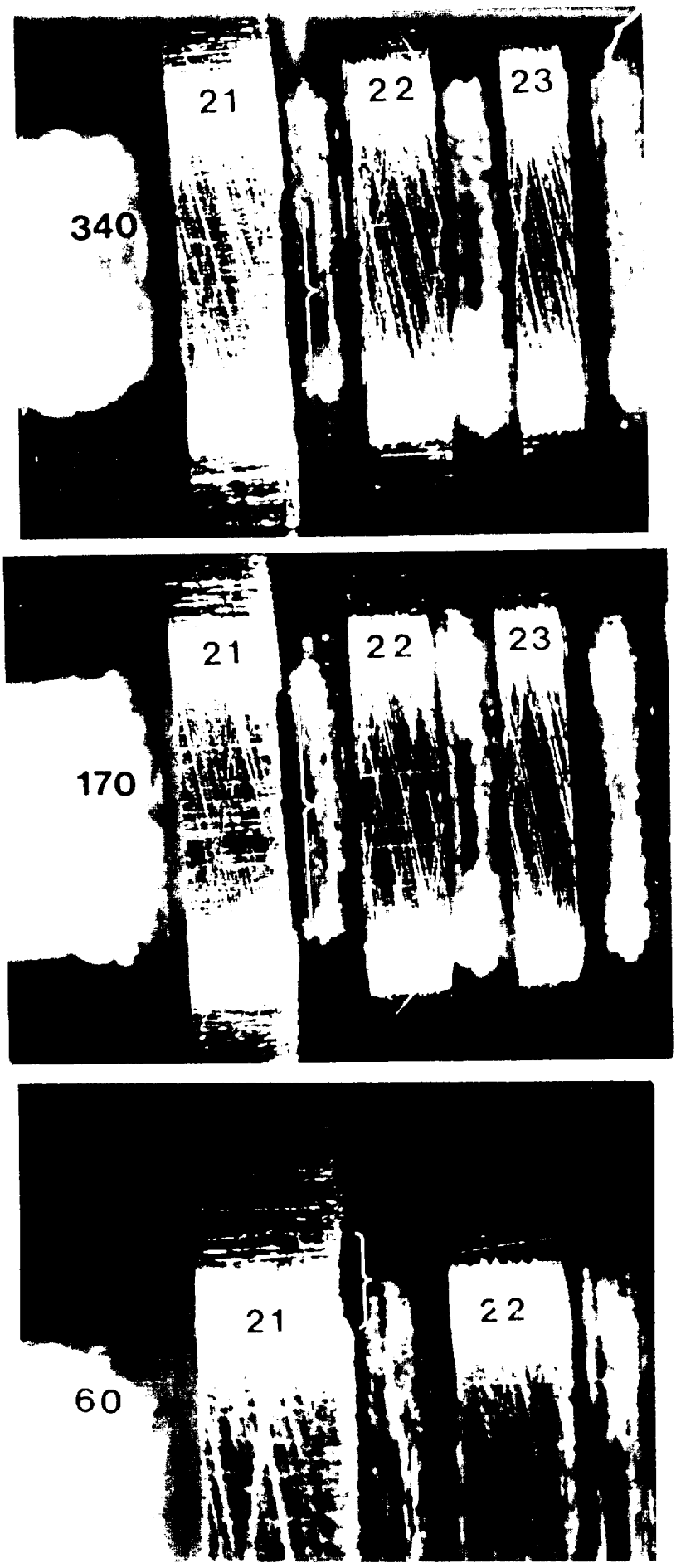


Figure 14. Three areas displaying corner chip outs (at brackets) along balance groove interface with land 21 on S/N 2108X exemplar. Reference angular position indicated to left of metering edge. All photos X50.

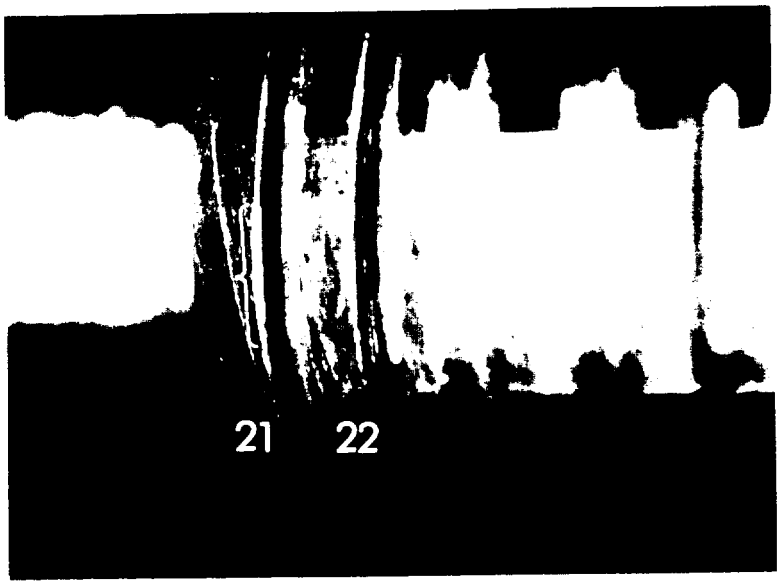


Figure 15 Low magnification angled view of chip out shown in figure 14 at 340 degrees X20

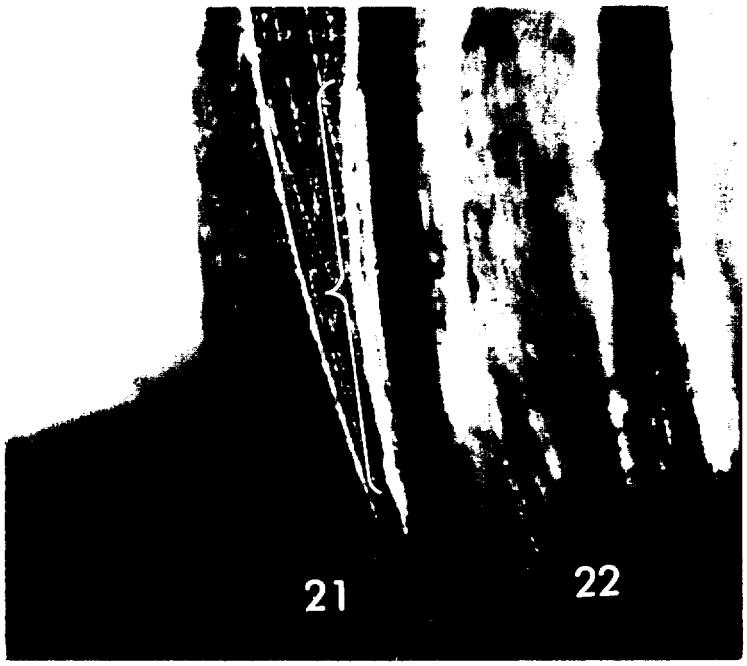


Figure 16 Same as in figure 15 above only at higher magnification X50

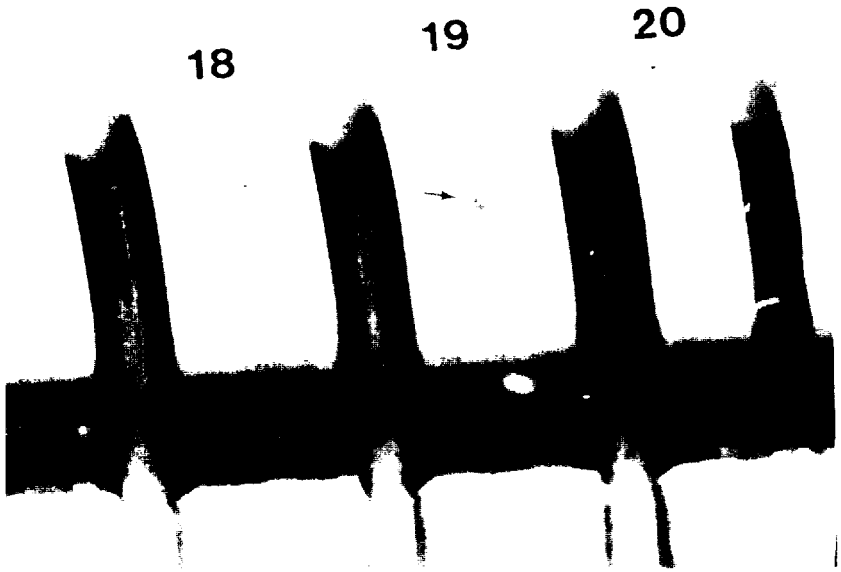


Figure 17. Splotching (probably deposit) found on land 19. Photograph taken after alcohol wiping with a Kimwipe to try to remove the deposit. About X20.

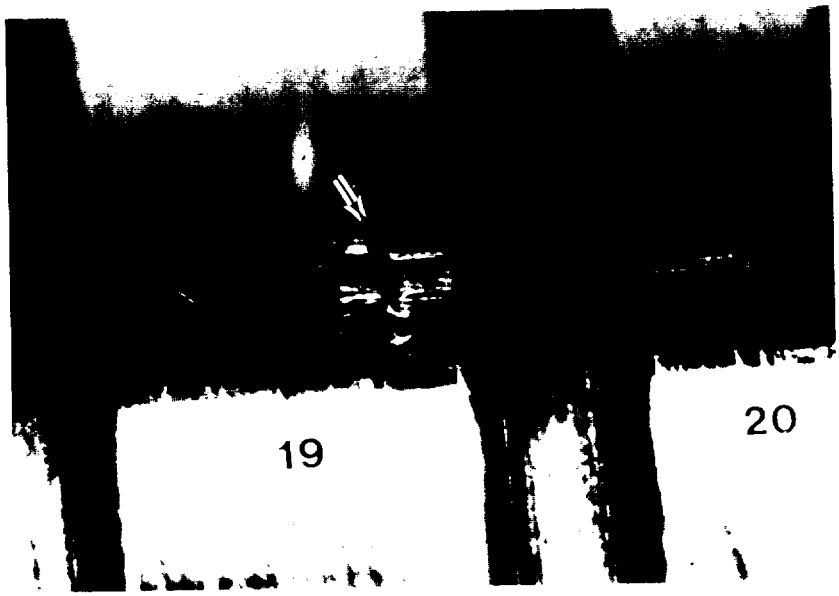


Figure 18. Irregular marking (arrowed) on land surface of S/N 2108 primary. X50.

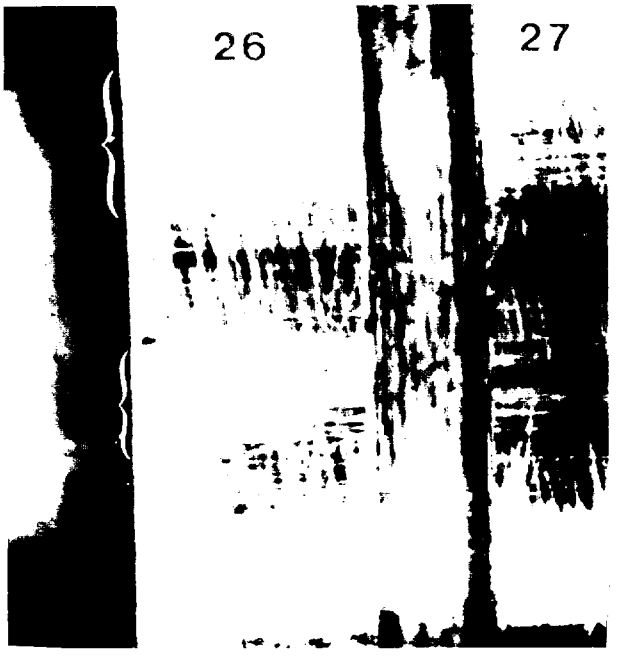


Figure 19 Roughened surface band areas (bracketed) located on S/N 2108X exemplar X50 at 260 degrees

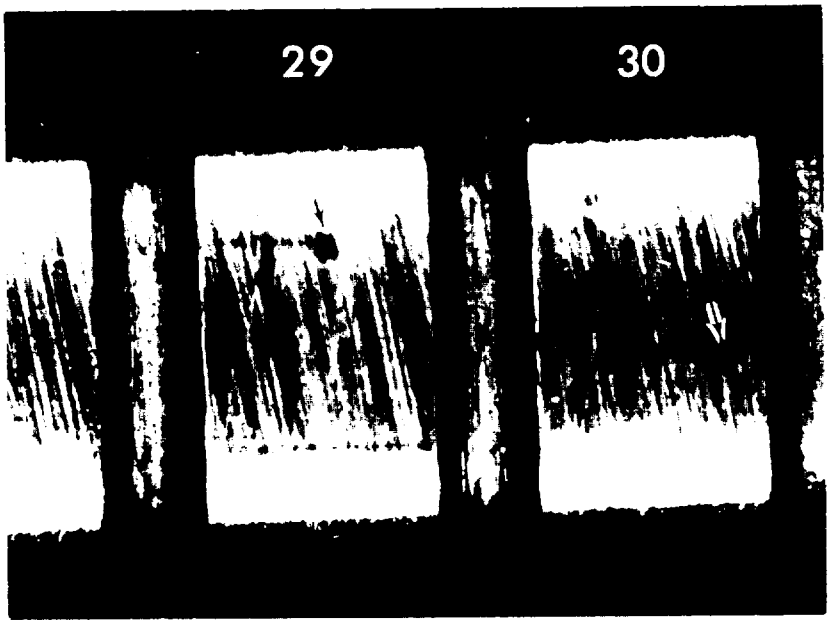


Figure 20. Dark circular areas with tails found on exemplar 2108X on lands 29 and 30 at 340 degrees X30

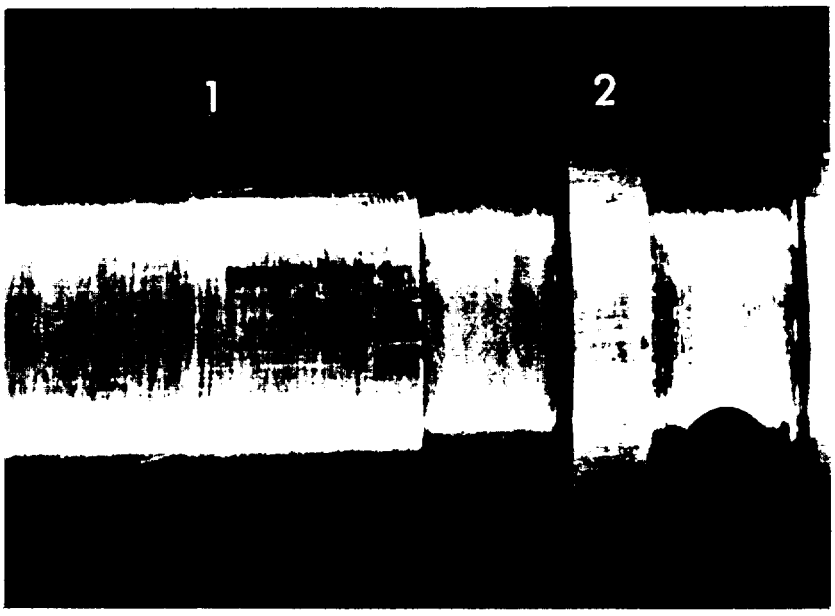


Figure 21 Typical high concentration burnish found on secondary slide outside diameter Exemplar 2108X, lands 1 and 2 at 90 degrees X7 5

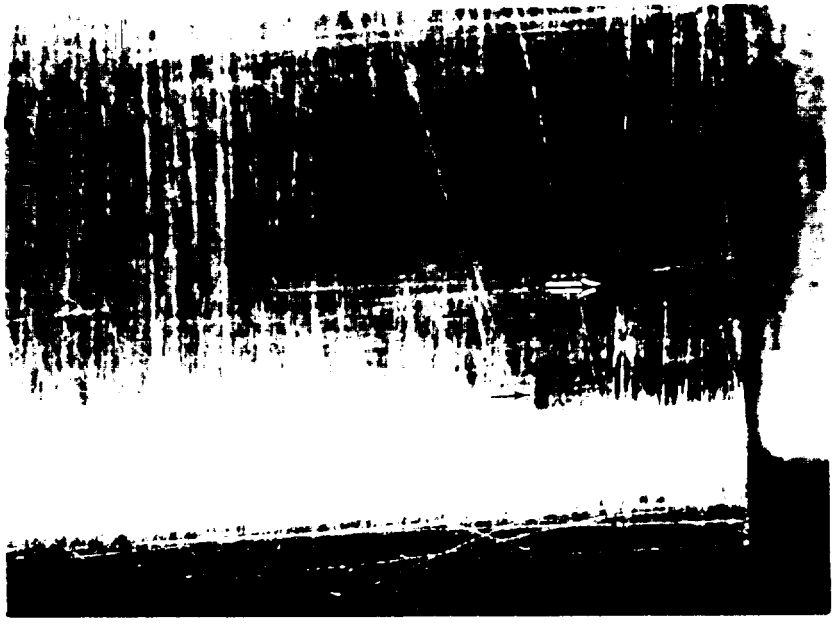


Figure 22. Higher magnification view (X20) of burnished area shown in figure 21 Arrows locate areas of corrosion Exemplar 2108X, land 1 at 90 degrees

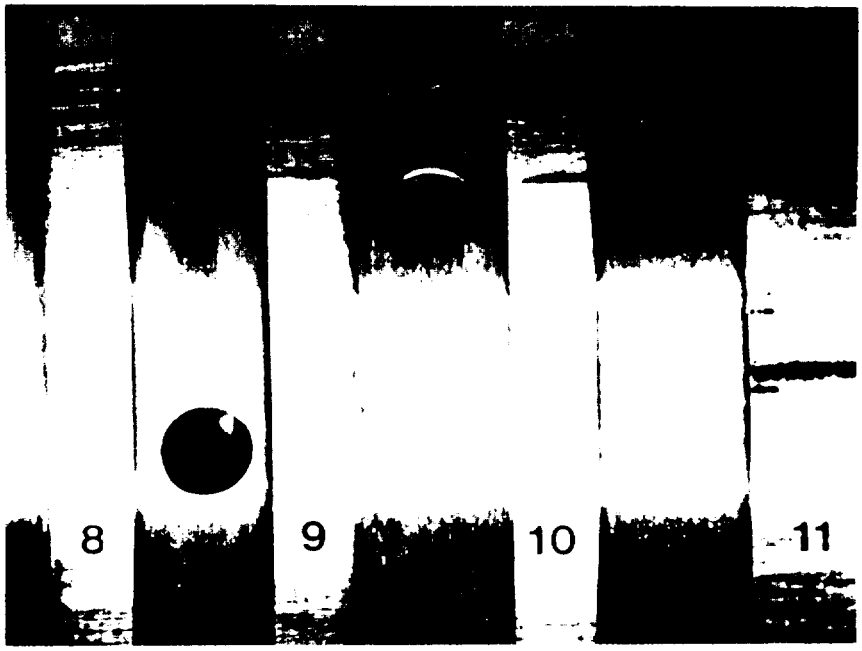


Figure 23 Another area of typical burnishing found on the secondary Exemplar 2108X, lands 8 through 11 at 30 degrees X7.5

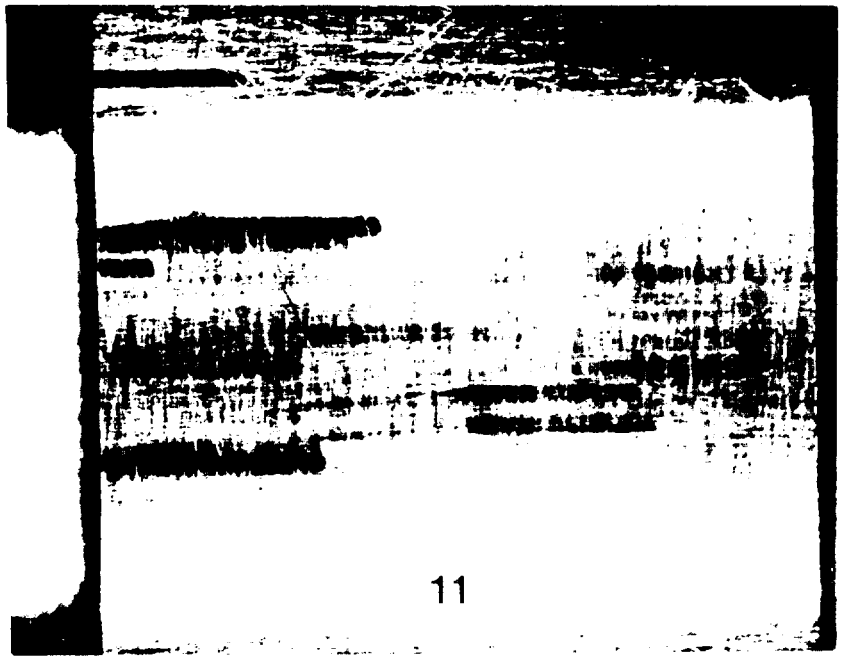


Figure 24 Higher magnification of area showing concentrated burnishing See far right middle of figure 23 for location Exemplar 2108X, land 11 at 30 degrees X15

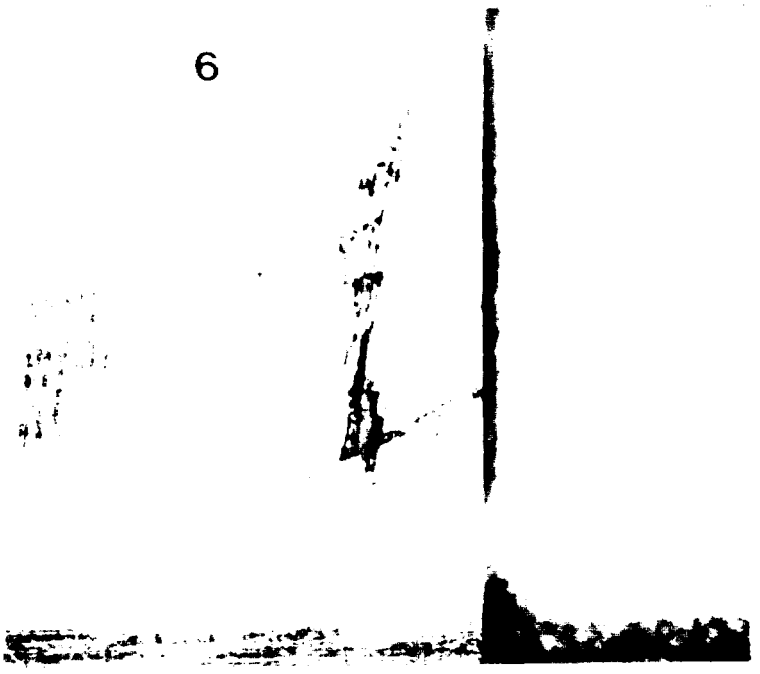


Figure 25 Area of irregular staining or possible corrosion on secondary exemplar Exemplar 2108X land 6, at 290 degrees X18

Figure 26 Another area of irregular staining or possible corrosion on secondary exemplar Exemplar 2108X land 10 at 240 degrees X35

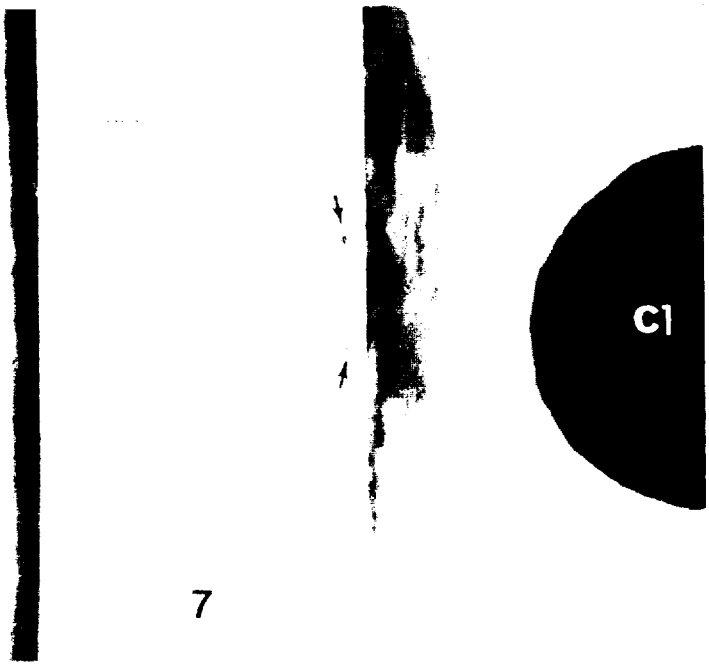


Figure 27 Probable witness mark (between arrows) on secondary outside diameter signifying the forward edge of the C1 to Rb aft metering port Exemplar 2108X land 7 at 110 degrees X30

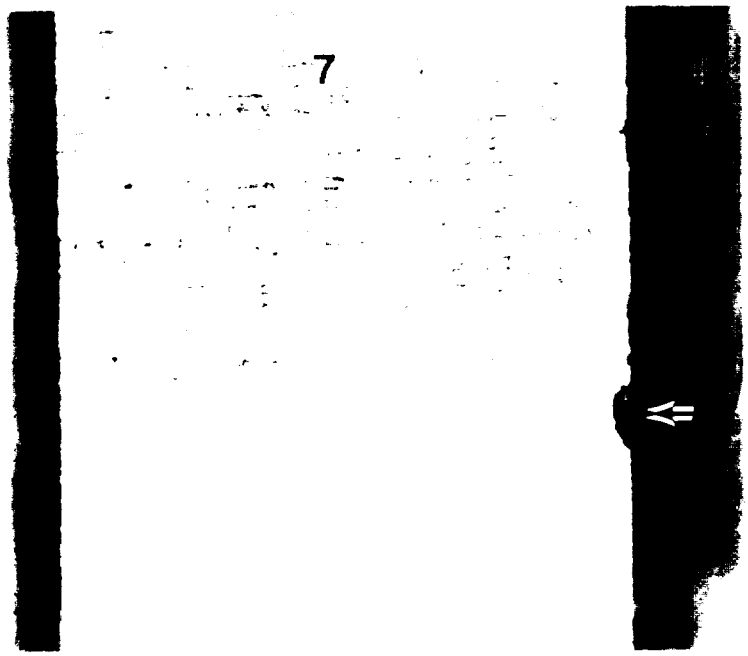


Figure 28 Small chip out of metering edge Exemplar 2108X land 7 at 10 degrees X50

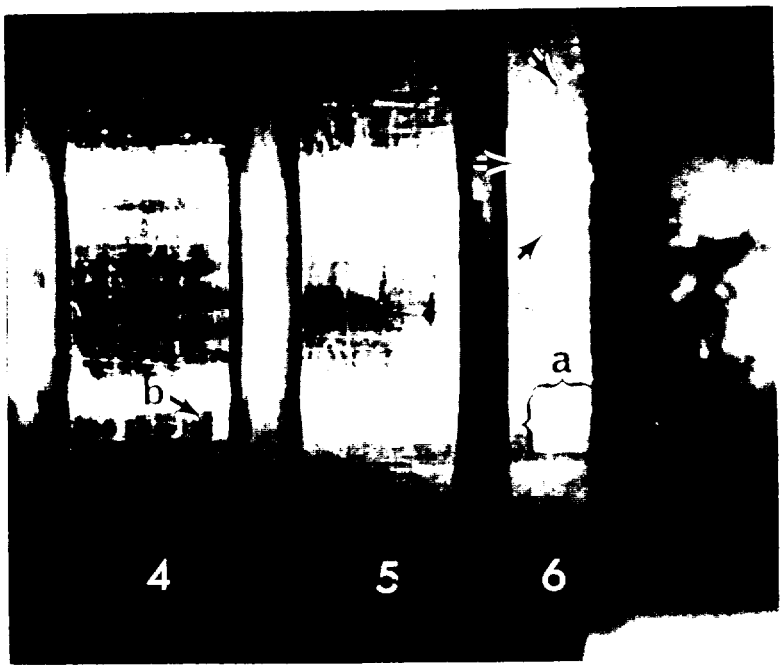


Figure 29 Witness marks from C3 to Ra aft metering port (bracket "a" and arrow "b") and C3 round port (unmarked arrows) on the primary. Accident S/N 1091 lands 4 through 6 at 265 degrees X20

Figure 30 C4 housing port witness marks on primary Accident S/N 1091 primary lands 9 through 11 at 120 degrees X20

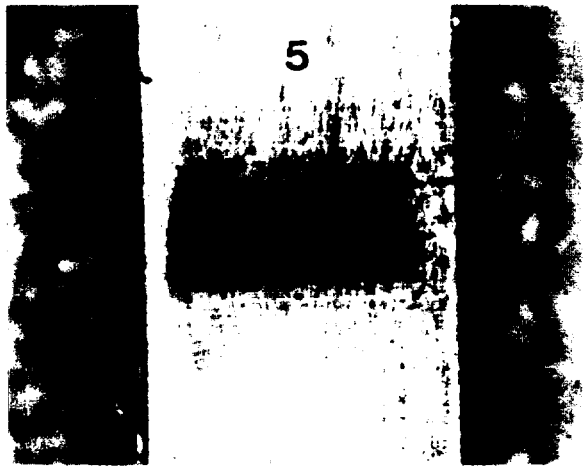


Figure 31 Witness mark indicative of the C4 to Ra fwd metering port found on land 5 S/N 1091 secondary at 325 degrees X30

Figure 32 Circular arc witness marks found on the forward edge of land 1 (left photo at X25) and aft edge of land 6 (right photo at X30) S/N 1091 secondary at 85 degrees (left) and 325 degrees (right)

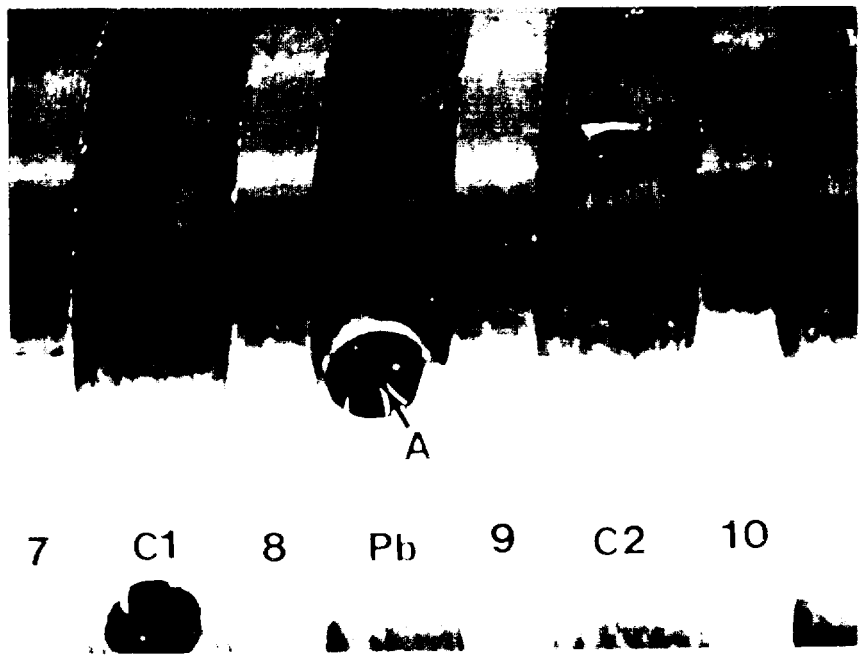


Figure 33 Arrow "A" shows the location of particles found within one of the three Pb holes on the outside of the S/N 1091 secondary at 10 degrees X7 5

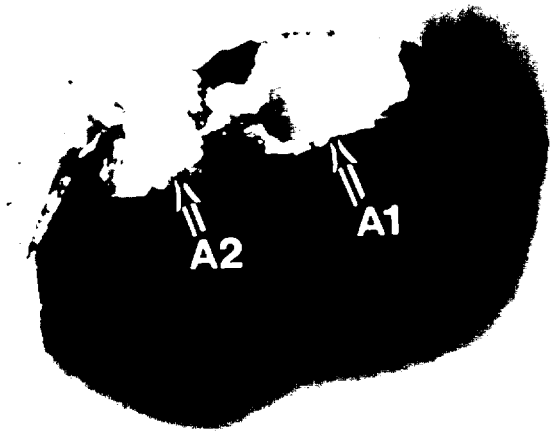


Figure 34 Higher magnification view of particles indicated by arrow "A" in figure 33 X50

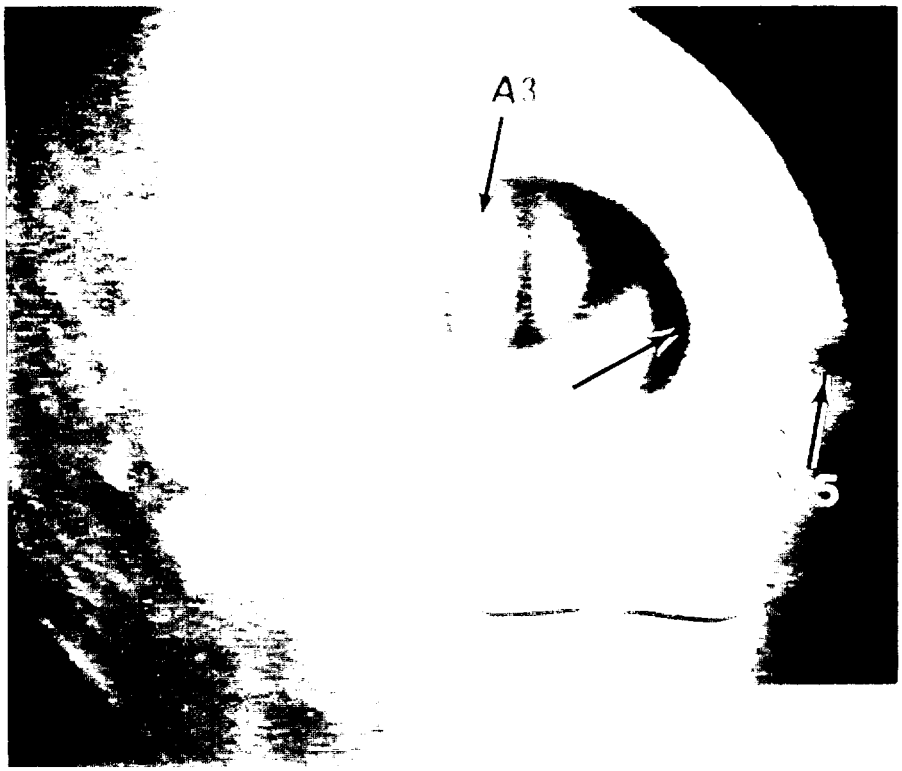


Figure 35 The Ra aft hole in the S/N 1091 housing illustrating the light banding (bracket), the annulus "A3" and the solenoid "A4", to the metering port, "A5"

Figure 36 Particle (arrowed) found in the [illegible] on the inside diameter of S/N [illegible] "spot" in area "X".

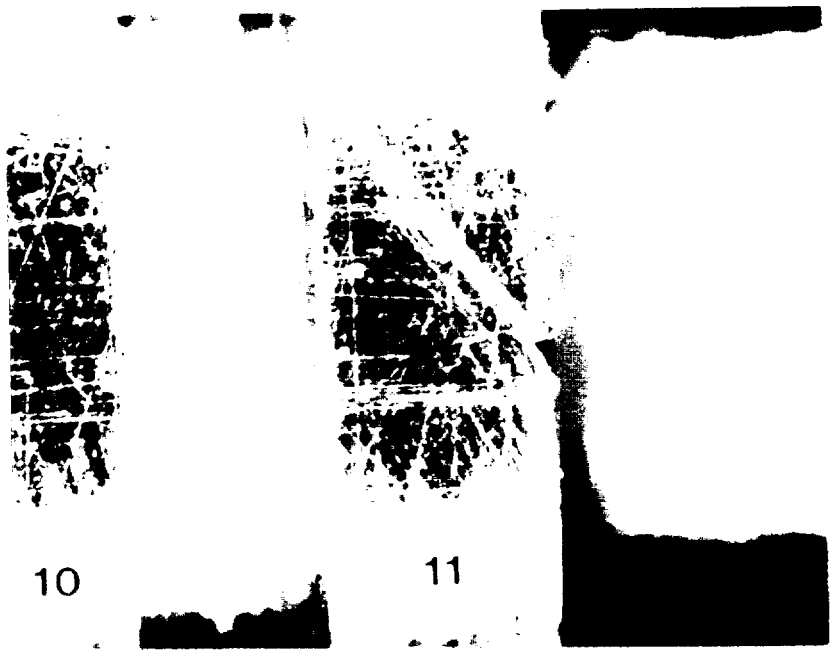


Figure 37. Chip out and angled scratch found on land 11 of S/N 2567 primary at 95 degrees. X50

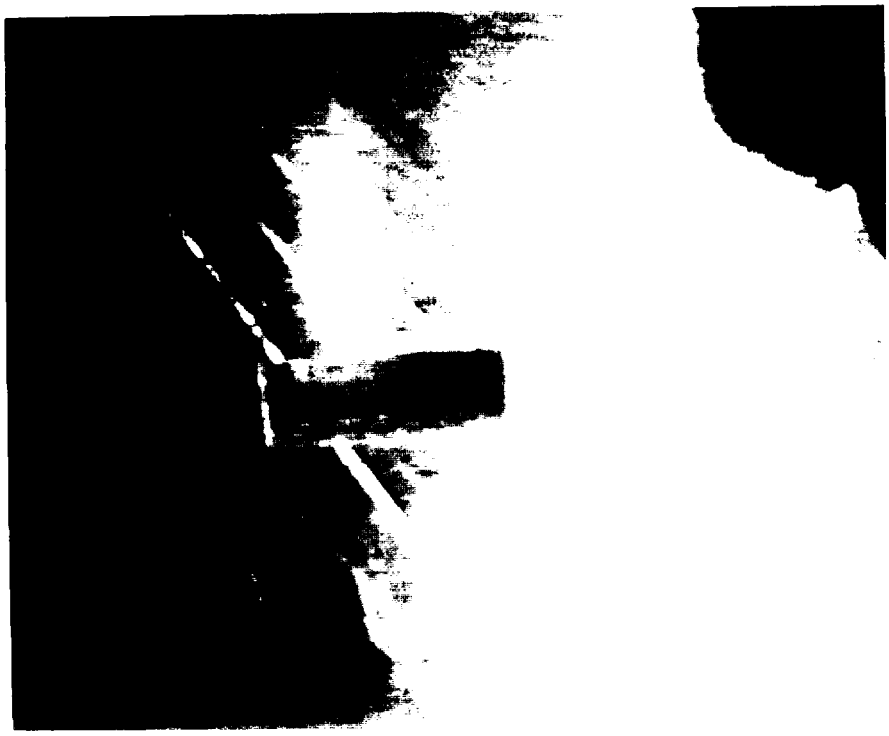


Figure 38. Scratches at the Pa to C4 metering port on the inside diameter of S/N 2567 secondary that would correspond to the approximate area containing the chip out and scratch on the primary shown in figure 37. X25

APPENDIX A. Video Examination Set Up and Procedure

Video Examination Device

A examination device was fabricated that horizontally positioned a 2.77 mm diameter borescope (Olympus P/N K27-18-90-62) in line with a horizontally positioned part. The part was positioned in a three jaw chuck of an indexing head graduated in degrees with an operating handle graduated in minutes. The indexing head was mounted at one end of a frame and an X-Y table was mounted on the other end of the frame. The borescope was attached to the X-Y table allowing for precise movement of the borescope along the longitudinal length of the part and laterally relative to the centerline of the part.

A video camera was attached to the borescope and a second video camera was arranged to record the degree positioning of the index head. Both video camera signals were fed into a special effects generator that allowed for placing the angular degree position view in the lower right corner of the image. The generator output was then fed into a VCR recorder and the VCR output was fed into a monitor.

Angular Reference on Parts

To maintain consistent longitudinal and angular references on each valve piece examined the assembly was angularly and longitudinally positioned as if located on the airplane. For practical purposes the centerline of the valve was considered to run horizontally fore and aft (in actuality it is inclined somewhat to the horizontal plane). The input side of the valve is forward and the cap end of the body is aft. Longitudinal start and longitudinal end reference points were established for the individual pieces to easily find positions on the pieces while viewing the borescopic image.

Longitudinal Reference

Figure A1 shows a cross sectional view of the valve as assembled with the primary slide shaded blue, secondary slide shaded yellow and the housing shaded red. Figures A2 through A4 depict the reference positions and land numbering system utilized during the examination.

The longitudinal start positions for video taping and referencing were at the aft points (reference "A") and the stop or end positions were at the forward end (reference "B"). On the outside diameter of the primary and secondary slides a numerical sequence was established for the lands starting at 1 on the "A" end. The lands are the maximum outside diameter surfaces between references "A" and "B" that are separated by balance grooves and/or metering cavities. Not all the primaries contained an equal number of lands since some of the primaries contained more balance grooves. However, there was a minimum amount of lands (31) that were present for each primary. The minimum number would compose of 6 lands (numbered 1 through 6)

between reference "A" and the first metering cavity, 5 lands (numbered 7 through 11) between the first and second metering cavity, 9 lands (numbered 12 through 20) between the second and third metering cavity, 5 lands (numbered 21 through 25) between the third and fourth metering cavity, and 6 lands (numbered 26 through 31) between the fourth metering cavity and reference "B". The numbering was kept consistent beginning after every metering cavity. If there were more than the minimum lands per segment a + sign was used, such as 6+ for the seventh land between reference "A" and the first metering cavity and 6 ++ for the eighth land between the same reference.

Procedure

Each valve piece was identically examined with the borescope at an equivalent magnification of about X50 on a 17 inch monitor. Simultaneously the image could be viewed at approximately X130 on a 35 inch television screen. The beginning point was set at reference "A" and the valve was rotated 360 degrees with the indexing head. The piece was then sequentially repositioned longitudinally (0.1 inches) and rotated through 360 degrees until all land surfaces (for the outside diameters) and all inside surfaces were examined and video taped. During the procedure selective notes were taken of hole positions and any noteworthy characteristics encountered. The positions of internal holes both longitudinally and angularly were recorded. These hole positions are shown in the tables of appendix B for each valve.

In addition, the accident valves were reexamined at the metering ports (.015 by .045 inch rectangular holes) on the inside diameters of the secondary slide and housing. During this examination the borescope was put closer to the port to increase magnification, and the slide was rotated and moved longitudinally about the port location to view it from different perspectives. Particular attention was given to the metering edge, looking for any damage to the edge.

For the accident valve S/N 2956, the metering ports were also examined with a 15 degree borescope which allowed for angular viewing of the metering face. The valve piece was then reversed to view the opposite metering face.

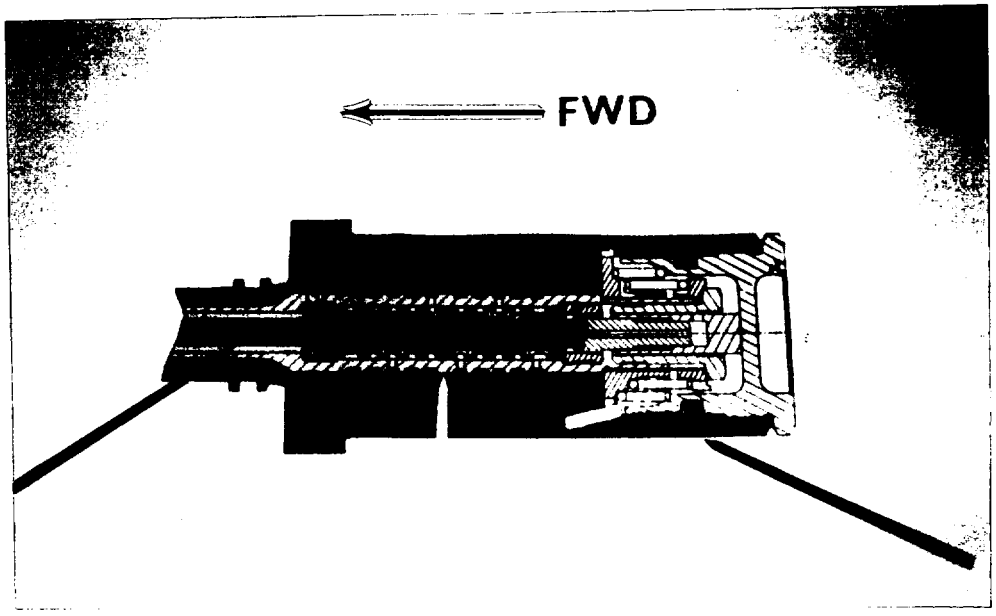


Figure A1. Representative cross section through a PCU servo valve. Primary-blue; secondary-yellow; housing-red.

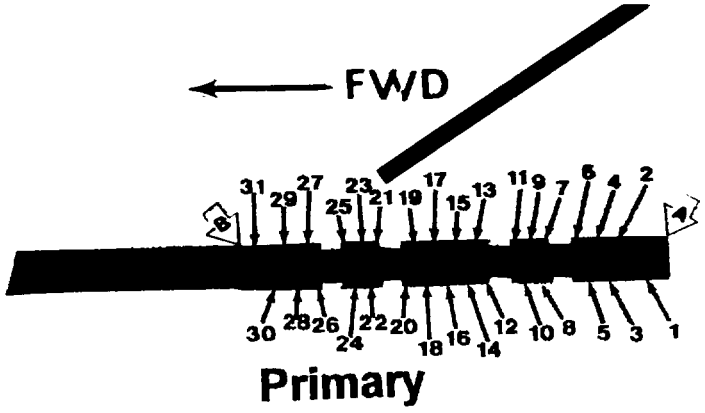


Figure A2. Primary slide referencing positions and land numbering system used during examinations.

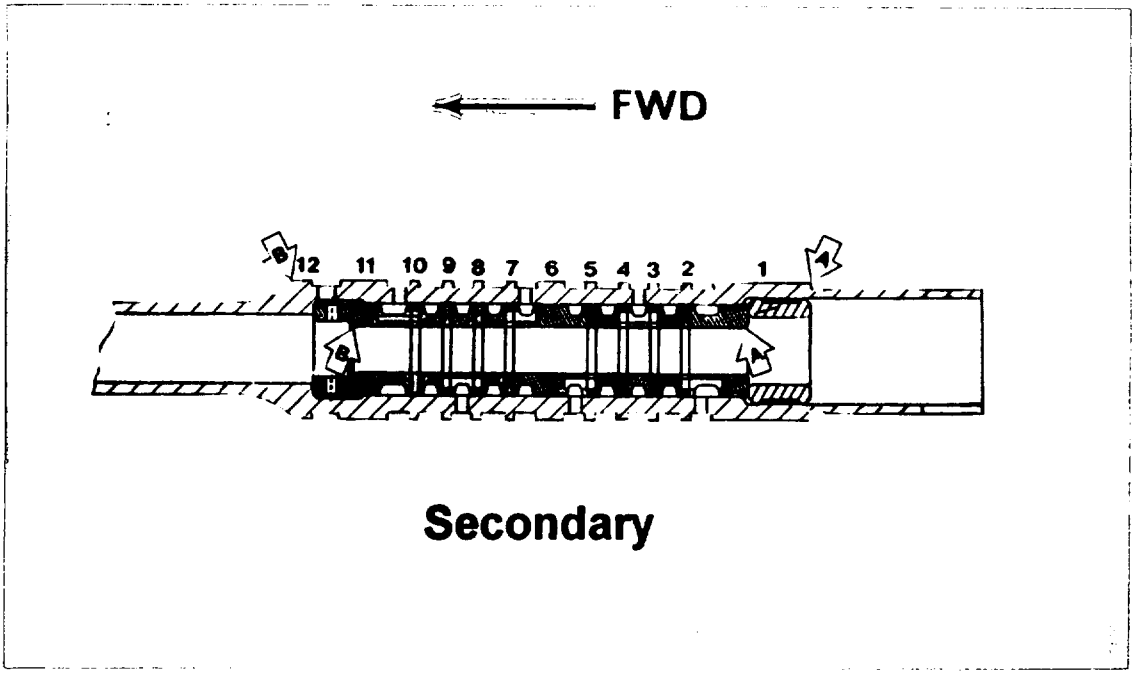


Figure A3. Secondary slide referencing positions and land numbering system used during examinations.

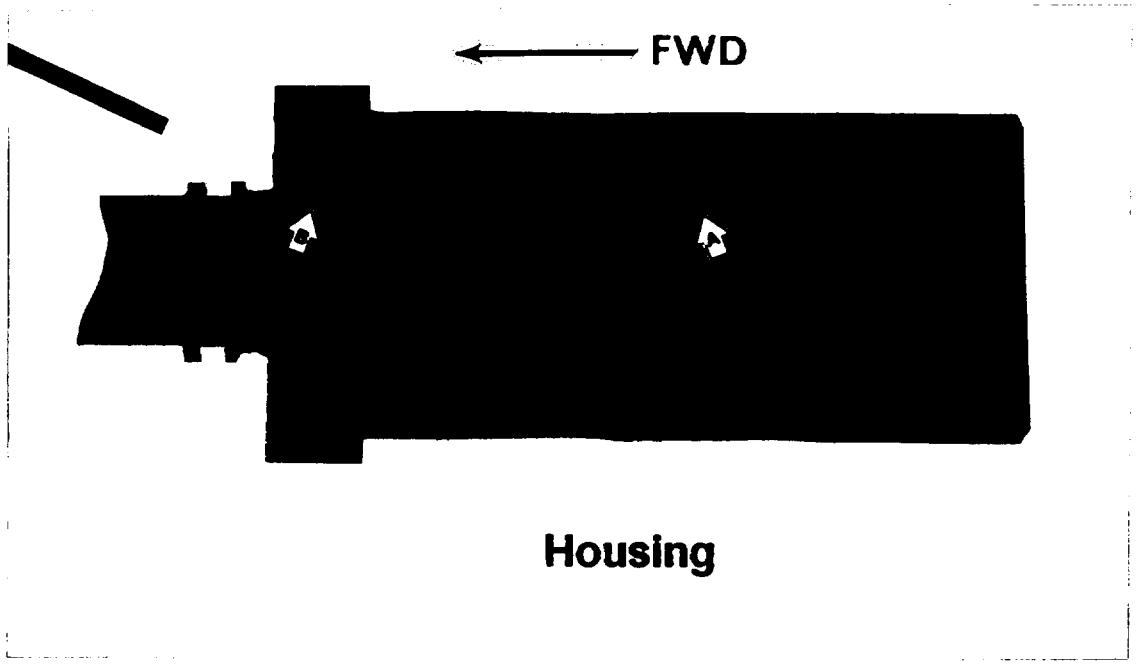


Figure A3. Housing referencing positions and land numbering system used during examinations

APPENDIX B. Longitudinal and Angular Positioning of Holes

Accident Valve S/N 2956 Secondary Inside Diameter (primary inserts)

From Reference "A" (inches)	Angular Reference (degrees)	Type of Hole	Port Representing
.32	80	.015 X .045 inch	Metering C3 to Ra aft
.40	6 evenly spaced	.053 inch Round	C3
.48	260	.015 X .045 inch	Metering Pa to C3
.65	265	.015 X .045 inch	Metering Pa to C4
.74	6 evenly spaced	.053 inch Round	C4
.82	85	.015 X .045 inch	Metering C4 to Ra fwd
1.25	260	.015 X .045 inch	Metering C1 to Rb aft
1.34	6 evenly spaced	.053 inch Round	C1
1.42	80	.015 X .045 inch	Metering Pb to C1
1.58	80	.015 X .045 inch	Metering Pb to C2
1.66	6 evenly spaced	.053 inch Round	C2
1.75	260	.015 X .045 inch	Metering C2 to Rb fwd

Accident Valve S/N 2956 Housing Inside Diameter (secondary inserts)

From Reference "A" (inches)	Angular Reference (degrees) *	Type of Hole	Port Representing
.20	3 evenly spaced	.125 inch Round	Ra aft
.31	(105) 285	.015X.045 inch Rectangular	Metering C3 to Ra aft
.39	6 evenly spaced	.070 inch Round	C3
.48	(240) 100	.015X.045 inch Rectangular	Metering Pa to C3
.56	6 evenly spaced	.070 inch Round	Pa
.64	(240) 100	.015X.045 inch Rectangular	Metering Pa to C4
.72	6 evenly spaced	.070 inch Round	C4
.81	(105) 285	.015X.045 inch Rectangular	Metering C4 to Ra fwd
.90	4 evenly spaced	.105 inch Round	Ra fwd
1.14	4 evenly spaced	.105 inch Round	Rb aft
1.24	(285) 105	.015X.045 inch Rectangular	Metering C1 to Rb aft
1.32	6 evenly spaced	.070 inch Round	C1
1.40	(60) 240	.015X.045 inch Rectangular	Metering Pb to C1
1.48	6 evenly spaced	.070 inch Round	Pb
1.57	(60) 240	.015X.045 inch Rectangular	Metering Pb to C2
1.65	6 evenly spaced	.070 inch Round	C2
1.73	(285) 105	.015X.045 inch Rectangular	Metering C2 to Rb fwd
1.83	6 evenly spaced	.095 inch Round	Rb fwd

* (XXX) recorded degrees. Degrees relative to secondary no parenthesis.

Appendix B. Longitudinal and Angular Positioning of Holes (Continued)

Accident Valve S/N 1091 Secondary Inside Diameter (primary inserts)

From Reference "A" (inches)	Angular Reference (degrees)	Type of Hole	Port Representing
.32	75	.015 X .045 inch	Metering C3 to Ra aft
.39	6 evenly spaced	.053 inch Round	C3
.48	255	.015 X .045 inch	Metering Pa to C3
.64	255	.015 X .045 inch	Metering Pa to C4
.73	6 evenly spaced	.053 inch Round	C4
.81	75	.015 X .045 inch	Metering C4 to Ra fwd
1.24	250	.015 X .045 inch	Metering C1 to Rb aft
1.33	6 evenly spaced	.053 inch Round	C1
1.41	70	.015 X .045 inch	Metering Pb to C1
1.57	70	.015 X .045 inch	Metering Pb to C2
1.65	6 evenly spaced	.053 inch Round	C2
1.74	250	.015 X .045 inch	Metering C2 to Rb fwd

Accident Valve S/N 1091 Housing Inside Diameter (secondary inserts)

From Reference "A" (inches)	Angular Reference (degrees) *	Type of Hole	Port Representing
.19	3 evenly spaced	.125 inch Round	Ra aft
.31	(145) 325	.015X.045 inch Rectangular	Metering C3 to Ra aft
.39	6 evenly spaced	.070 inch Round	C3
.48	(275) 95	.015X.045 inch Rectangular	Metering Pa to C3
.56	6 evenly spaced	.070 inch Round	Pa
.64	(280) 100	.015X.045 inch Rectangular	Metering Pa to C4
.73	6 evenly spaced	.070 inch Round	C4
.81	(145) 325	.015X.045 inch Rectangular	Metering C4 to Ra fwd
.90	4 evenly spaced	.105 inch Round	Ra fwd
1.14	4 evenly spaced	.105 inch Round	Rb aft
1.24	(325) 145	.015X.045 inch Rectangular	Metering C1 to Rb aft
1.32	6 evenly spaced	.070 inch Round	C1
1.40	(100) 280	.015X.045 inch Rectangular	Metering Pb to C1
1.49	6 evenly spaced	.070 inch Round	Pb
1.57	(100) 280	.015X.045 inch Rectangular	Metering Pb to C2
1.65	6 evenly spaced	.070 inch Round	C2
1.73	(325) 145	.015X.045 inch Rectangular	Metering C2 to Rb fwd
1.83	6 evenly spaced	.095 inch Round	Rb fwd

* (XXX) recorded degrees. Degrees relative to secondary no parenthesis.

Appendix B. Longitudinal and Angular Positioning of Holes (Continued)

Accident Valve S/N 5119 Secondary Inside Diameter (primary inserts)

From Reference "A" (inches)	Angular Reference (degrees)	Type of Hole	Port Representing
.32	270	.015 X .045 inch	Metering C3 to Ra aft
.40	6 evenly spaced	.053 inch Round	C3
.48	90	.015 X .045 inch	Metering Pa to C3
.65	90	.015 X .045 inch	Metering Pa to C4
.73	6 evenly spaced	.053 inch Round	C4
.81	270	.015 X .045 inch	Metering C4 to Ra fwd
1.24	90	.015 X .045 inch	Metering C1 to Rb aft
1.33	6 evenly spaced	.053 inch Round	C1
1.41	270	.015 X .045 inch	Metering Pb to C1
1.57	265	.015 X .045 inch	Metering Pb to C2
1.66	6 evenly spaced	.053 inch Round	C2
1.74	85	.015 X .045 inch	Metering C2 to Rb fwd

Accident Valve S/N 5119 Housing Inside Diameter (secondary inserts)

From Reference "A" (inches)	Angular Reference (degrees) *	Type of Hole	Port Representing
.20	3 evenly spaced	.125 inch Round	Ra aft
.32	(110) 290	.015X.045 inch Rectangular	Metering C3 to Ra aft
.40	6 evenly spaced	.070 inch Round	C3
.49	(250) 70	.015X.045 inch Rectangular	Metering Pa to C3
.57	6 evenly spaced	.070 inch Round	Pa
.65	(250) 70	.015X.045 inch Rectangular	Metering Pa to C4
.73	6 evenly spaced	.070 inch Round	C4
.82	(110) 290	.015X.045 inch Rectangular	Metering C4 to Ra fwd
.91	4 evenly spaced	.105 inch Round	Ra fwd
1.15	4 evenly spaced	.105 inch Round	Rb aft
1.25	(290) 110	.015X.045 inch Rectangular	Metering C1 to Rb aft
1.33	6 evenly spaced	.070 inch Round	C1
1.42	(65) 245	.015X.045 inch Rectangular	Metering Pb to C1
1.49	6 evenly spaced	.070 inch Round	Pb
1.58	(65) 245	.015X.045 inch Rectangular	Metering Pb to C2
1.66	6 evenly spaced	.070 inch Round	C2
1.74	(290) 110	.015X.045 inch Rectangular	Metering C2 to Rb fwd
1.85	6 evenly spaced	.095 inch Round	Rb fwd

* (XXX) recorded degrees. Degrees relative to secondary no parenthesis.

Appendix B. Longitudinal and Angular Positioning of Holes (Continued)

Incident Valve S/N 2567 Secondary Inside Diameter (primary inserts)

From Reference "A" (inches)	Angular Reference (degrees)	Type of Hole	Port Representing
.32	290	.015 X .045 inch	Metering C3 to Ra aft
.40	6 evenly spaced	.053 inch Round	C3
.48	115	.015 X .045 inch	Metering Pa to C3
.65	115	.015 X .045 inch	Metering Pa to C4
.73	6 evenly spaced	.053 inch Round	C4
.81	290	.015 X .045 inch	Metering C4 to Ra fwd
1.24	105	.015 X .045 inch	Metering C1 to Rb aft
1.33	6 evenly spaced	.053 inch Round	C1
1.41	290	.015 X .045 inch	Metering Pb to C1
1.57	290	.015 X .045 inch	Metering Pb to C2
1.66	6 evenly spaced	.053 inch Round	C2
1.74	100	.015 X .045 inch	Metering C2 to Rb fwd

Incident Valve S/N 2567 Housing Inside Diameter (secondary inserts)

From Reference "A" (inches)	Angular Reference (degrees) *	Type of Hole	Port Representing
.21	3 evenly spaced	.125 inch Round	Ra aft
.33	(125) 305	.015X.045 inch Rectangular	Metering C3 to Ra aft
.41	6 evenly spaced	.070 inch Round	C3
.49	(260) 80	.015X.045 inch Rectangular	Metering Pa to C3
.57	6 evenly spaced	.070 inch Round	Pa
.66	(260) 80	.015X.045 inch Rectangular	Metering Pa to C4
.74	6 evenly spaced	.070 inch Round	C4
.82	(125) 305	.015X.045 inch Rectangular	Metering C4 to Ra fwd
.92	4 evenly spaced	.105 inch Round	Ra fwd
1.16	4 evenly spaced	.105 inch Round	Rb aft
1.25	(305) 125	.015X.045 inch Rectangular	Metering C1 to Rb aft
1.34	6 evenly spaced	.070 inch Round	C1
1.42	(80) 260	.015X.045 inch Rectangular	Metering Pb to C1
1.50	6 evenly spaced	.070 inch Round	Pb
1.59	(80) 260	.015X.045 inch Rectangular	Metering Pb to C2
1.67	6 evenly spaced	.070 inch Round	C2
1.75	(305) 125	.015X.045 inch Rectangular	Metering C2 to Rb fwd
1.85	6 evenly spaced	.095 inch Round	Rb fwd

* (XXX) recorded degrees. Degrees relative to secondary no parenthesis.

Appendix B. Longitudinal and Angular Positioning of Holes (Continued)

Exemplar Valve S/N 2108 Secondary Inside Diameter (primary inserts)

From Reference "A" (inches)	Angular Reference (degrees)	Type of Hole	Port Representing
.31	70	.015 X .045 inch	Metering C3 to Ra aft
.39	6 evenly spaced	.053 inch Round	C3
.47	250	.015 X .045 inch	Metering Pa to C3
.64	260	.015 X .045 inch	Metering Pa to C4
.72	6 evenly spaced	.053 inch Round	C4
.80	60	.015 X .045 inch	Metering C4 to Ra fwd
1.23	240	.015 X .045 inch	Metering C1 to Rb aft
1.32	6 evenly spaced	.053 inch Round	C1
1.40	70	.015 X .045 inch	Metering Pb to C1
1.56	50	.015 X .045 inch	Metering Pb to C2
1.64	6 evenly spaced	.053 inch Round	C2
1.73	250	.015 X .045 inch	Metering C2 to Rb fwd

Exemplar Valve S/N 2108 Housing Inside Diameter (secondary inserts)

From Reference "A" (inches)	Angular Reference (degrees) *	Type of Hole	Port Representing
.20	3 evenly spaced	.125 inch Round	Ra aft
.32	(115) 295	.015X.045 inch Rectangular	Metering C3 to Ra aft
.39	6 evenly spaced	.070 inch Round	C3
.48	(250) 70	.015X.045 inch Rectangular	Metering Pa to C3
.56	6 evenly spaced	.070 inch Round	Pa
.65	(250) 70	.015X.045 inch Rectangular	Metering Pa to C4
.73	6 evenly spaced	.070 inch Round	C4
.81	(115) 295	.015X.045 inch Rectangular	Metering C4 to Ra fwd
.90	4 evenly spaced	.105 inch Round	Ra fwd
1.14	4 evenly spaced	.105 inch Round	Rb aft
1.24	(295) 115	.015X.045 inch Rectangular	Metering C1 to Rb aft
1.33	6 evenly spaced	.070 inch Round	C1
1.40	(65) 245	.015X.045 inch Rectangular	Metering Pb to C1
1.49	6 evenly spaced	.070 inch Round	Pb
1.57	(65) 245	.015X.045 inch Rectangular	Metering Pb to C2
1.65	6 evenly spaced	.070 inch Round	C2
1.73	(295) 115	.015X.045 inch Rectangular	Metering C2 to Rb fwd
1.84	6 evenly spaced	.095 inch Round	Rb fwd

* (XXX) recorded degrees. Degrees relative to secondary no parenthesis.

Appendix B. Longitudinal and Angular Positioning of Holes (Continued)

Exemplar Valve S/N 2278 Secondary Inside Diameter (primary inserts)

From Reference "A" (inches)	Angular Reference (degrees)	Type of Hole	Port Representing
.32	110	.015 X .045 inch	Metering C3 to Ra aft
.41	6 evenly spaced	.053 inch Round	C3
.48	290	.015 X .045 inch	Metering Pa to C3
.65	290	.015 X .045 inch	Metering Pa to C4
.74	6 evenly spaced	.053 inch Round	C4
.82	110	.015 X .045 inch	Metering C4 to Ra fwd
1.25	290	.015 X .045 inch	Metering C1 to Rb aft
1.33	6 evenly spaced	.053 inch Round	C1
1.41	110	.015 X .045 inch	Metering Pb to C1
1.58	110	.015 X .045 inch	Metering Pb to C2
1.66	6 evenly spaced	.053 inch Round	C2
1.74	290	.015 X .045 inch	Metering C2 to Rb fwd

Exemplar Valve S/N 2278 Housing Inside Diameter (secondary inserts)

From Reference "A" (inches)	Angular Reference (degrees) *	Type of Hole	Port Representing
.20	3 evenly spaced	.125 inch Round	Ra aft
.31	(130) 320	.015X.045 inch Rectangular	Metering C3 to Ra aft
.39	6 evenly spaced	.070 inch Round	C3
.48	(270) 90	.015X.045 inch Rectangular	Metering Pa to C3
.56	6 evenly spaced	.070 inch Round	Pa
.64	(270) 90	.015X.045 inch Rectangular	Metering Pa to C4
.73	6 evenly spaced	.070 inch Round	C4
.81	(130) 320	.015X.045 inch Rectangular	Metering C4 to Ra fwd
.90	4 evenly spaced	.105 inch Round	Ra fwd
1.14	4 evenly spaced	.105 inch Round	Rb aft
1.24	(310) 130	.015X.045 inch Rectangular	Metering C1 to Rb aft
1.32	6 evenly spaced	.070 inch Round	C1
1.41	(85) 265	.015X.045 inch Rectangular	Metering Pb to C1
1.49	6 evenly spaced	.070 inch Round	Pb
1.57	(85) 265	.015X.045 inch Rectangular	Metering Pb to C2
1.65	6 evenly spaced	.070 inch Round	C2
1.74	(305) 125	.015X.045 inch Rectangular	Metering C2 to Rb fwd
1.84	6 evenly spaced	.095 inch Round	Rb fwd

* (XXX) recorded degrees. Degrees relative to secondary no parenthesis.

Appendix B. Longitudinal and Angular Positioning of Holes (Continued)

Exemplar Valve S/N 3167 Secondary Inside Diameter (primary inserts)

From Reference "A" (inches)	Angular Reference (degrees)	Type of Hole	Port Representing
.32	270	.015 X .045 inch	Metering C3 to Ra aft
.40	6 evenly spaced	.053 inch Round	C3
.47	90	.015 X .045 inch	Metering Pa to C3
.64	90	.015 X .045 inch	Metering Pa to C4
.72	6 evenly spaced	.053 inch Round	C4
.81	260	.015 X .045 inch	Metering C4 to Ra fwd
1.24	90	.015 X .045 inch	Metering C1 to Rb aft
1.32	6 evenly spaced	.053 inch Round	C1
1.41	260	.015 X .045 inch	Metering Pb to C1
1.57	265	.015 X .045 inch	Metering Pb to C2
1.65	6 evenly spaced	.053 inch Round	C2
1.73	90	.015 X .045 inch	Metering C2 to Rb fwd

Exemplar Valve S/N 3167 Housing Inside Diameter (secondary inserts)

From Reference "A" (inches)	Angular Reference (degrees) *	Type of Hole	Port Representing
.19	3 evenly spaced	.125 inch Round	Ra aft
.31	(115) 295	.015X.045 inch Rectangular	Metering C3 to Ra aft
.39	6 evenly spaced	.070 inch Round	C3
.47	(250) 70	.015X.045 inch Rectangular	Metering Pa to C3
.55	6 evenly spaced	.070 inch Round	Pa
.64	(250) 70	.015X.045 inch Rectangular	Metering Pa to C4
.71	6 evenly spaced	.070 inch Round	C4
.80	(115) 295	.015X.045 inch Rectangular	Metering C4 to Ra fwd
.90	4 evenly spaced	.105 inch Round	Ra fwd
1.14	4 evenly spaced	.105 inch Round	Rb aft
1.24	(290) 110	.015X.045 inch Rectangular	Metering C1 to Rb aft
1.31	6 evenly spaced	.070 inch Round	C1
1.40	(70) 250	.015X.045 inch Rectangular	Metering Pb to C1
1.48	6 evenly spaced	.070 inch Round	Pb
1.56	(70) 250	.015X.045 inch Rectangular	Metering Pb to C2
1.64	6 evenly spaced	.070 inch Round	C2
1.73	(290) 110	.015X.045 inch Rectangular	Metering C2 to Rb fwd
1.84	6 evenly spaced	.095 inch Round	Rb fwd

* (XXX) recorded degrees. Degrees relative to secondary no parenthesis.

Appendix B. Longitudinal and Angular Positioning of Holes (Continued)

Exemplar Valve S/N 3403 Secondary Inside Diameter (primary inserts)

From Reference "A" (inches)	Angular Reference (degrees)	Type of Hole	Port Representing
.31	250	.015 X .045 inch	Metering C3 to Ra aft
.39	6 evenly spaced	.053 inch Round	C3
.47	70	.015 X .045 inch	Metering Pa to C3
.64	70	.015 X .045 inch	Metering Pa to C4
.72	6 evenly spaced	.053 inch Round	C4
.80	250	.015 X .045 inch	Metering C4 to Ra fwd
1.23	70	.015 X .045 inch	Metering C1 to Rb aft
1.31	6 evenly spaced	.053 inch Round	C1
1.40	240	.015 X .045 inch	Metering Pb to C1
1.56	245	.015 X .045 inch	Metering Pb to C2
1.64	6 evenly spaced	.053 inch Round	C2
1.72	70	.015 X .045 inch	Metering C2 to Rb fwd

Exemplar Valve S/N 3403 Housing Inside Diameter (secondary inserts)

From Reference "A" (inches)	Angular Reference (degrees) *	Type of Hole	Port Representing
.20	3 evenly spaced	.125 inch Round	Ra aft
.31	(115) 295	.015X.045 inch Rectangular	Metering C3 to Ra aft
.39	6 evenly spaced	.070 inch Round	C3
.47	(250) 70	.015X.045 inch Rectangular	Metering Pa to C3
.55	6 evenly spaced	.070 inch Round	Pa
.64	(250) 70	.015X.045 inch Rectangular	Metering Pa to C4
.72	6 evenly spaced	.070 inch Round	C4
.80	(115) 295	.015X.045 inch Rectangular	Metering C4 to Ra fwd
.90	4 evenly spaced	.105 inch Round	Ra fwd
1.14	4 evenly spaced	.105 inch Round	Rb aft
1.24	(295) 115	.015X.045 inch Rectangular	Metering C1 to Rb aft
1.32	6 evenly spaced	.070 inch Round	C1
1.40	(70) 250	.015X.045 inch Rectangular	Metering Pb to C1
1.49	6 evenly spaced	.070 inch Round	Pb
1.56	(70) 250	.015X.045 inch Rectangular	Metering Pb to C2
1.65	6 evenly spaced	.070 inch Round	C2
1.73	(295) 115	.015X.045 inch Rectangular	Metering C2 to Rb fwd
1.84	6 evenly spaced	.095 inch Round	Rb fwd

* (XXX) recorded degrees. Degrees relative to secondary no parenthesis.