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# TECHNICAL MEMORANDUM

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TITLE: Evaluation of SNAP-8 Alternator P/N 094069, S/N 481490 after 23,130 Hours of Endurance Testing in the Electrical Component Test Facility (ECTF).

## ABSTRACT

The alternator endurance testing was terminated by an automatic shutdown of the test facility due to an undervoltage signal from the alternator.

It was ascertained that the undervoltage was caused by a reduction in alternator speed as a result of friction in the alternator screw seals. By the time the shutdown had occurred, the alternator rotor had completely seized.

An examination of the alternator was made to ascertain the cause of seizure and also to determine the condition of the alternator and its suitability for further service.

It was concluded that the seizure occurred due to a loss of preload in the angular contact ball bearings supporting the rotor, resulting in the rotor orbiting due to the increased bearing radial clearance. This effect was compounded by rotor deflections as a result of the large centrifugal forces causing a rub to occur between the rotor and the stationary parts of the screw seals.

Failures of this nature had occurred previously and a modified design with improved bearing preload system had already been made, but not implemented in existing hardware.

With the exception of this already known deficiency the alternator was in a highly satisfactory condition and capable of a greatly extended life, probably for at least 5 years without maintenance.

This report describes the condition of the alternator including its bearings and also the bearings of the drive adapter. The drive adapter consists of the housing, shaft and bearing assembly for a SNAP-8 turbine which was used as a convenient method for mounting and coupling the alternator to the gearbox drive.

APPROVED:

DEPARTMENT HEAD

AEROJET-GENERAL CORPORATION

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## I. INTRODUCTION

An alternator (P/N 094069, S/N 481490) was used for endurance testing in the Electrical Component Test Facility (ECTF). In conjunction with the alternator, a drive adapter consisting of a housing, shaft, bearings and other parts which are essentially SNAP-8 turbine parts were tested simultaneously. This arrangement made a simple and convenient coupling between the gearbox drive and the alternator and also enabled endurance tests to be conducted on the turbine bearings as well as the alternator. The arrangement for testing is shown in Figure 1. The purpose of these tests was to determine if there might be any weaknesses in the alternator or other simultaneously tested electrical components that would show up under long-term testing (see Reference 1 for a detailed report on the other electrical components).

The alternator was first installed in the Electrical Component Test Facility in 1966. After 2553 hours an inspection was made, at which time the drive end bearing, the drive end shaft components and the adjacent drive adapter parts were found to be corroded. This was attributed to the ingestion of moisture laden air into the unit during long shutdown periods. The alternator rotor had enlarged by 0.005 inch on the large diameter across the lobes. The unit was reassembled with the drive end bearing in the alternator and the drive adapter replaced. All other elements were judged to be suitable for continued testing although there was some corrosion on the antidrive end bearing of the alternator and the outboard bearing of the drive adapter. The unit was reassembled and returned to test, and at this time a nitrogen cover gas system was incorporated to provide protection for the alternator during long periods of down time. The condition of the alternator and drive adapter parts is described in Reference 2.

At 12,679 hours, the drive adapter was inspected (see Reference 3) and the outboard bearing was found to have become pitted at the site of the heaviest corrosion spot on one of the balls. The bearing was assessed as having limited life (less than 5,000 hours) remaining and was replaced. All other elements were considered to be satisfactory and the drive adapter was reassembled and the unit was returned to test. Details of this inspection are contained in Reference 4. At 23,130 hours the test was terminated due to a seizure of the alternator rotor. The unit was removed from the test stand and disassembled. This report is written to document the examination of the alternator and drive adapter following the endurance testing and to evaluate the causes for the termination of testing.

## II. DESCRIPTION OF ALTERNATOR

The alternator is a hermetically-sealed, homopolar-inductor machine with radial air gaps (Figure 2). It has a solid rotor straddle mounted on spring preloaded angular-contact ball bearings. Cooling is accomplished by a heat exchanger in the stator housing and lubrication is effected by direct lubricant injection onto the bearing inner race. Dynamic seals are provided to scavenge the rotor-stator cavity and outboard sides of the ball bearings. Heat from the rotor is removed by radiation to the stator and surrounding parts and by conduction to the inboard slinger seals, where it is rejected to the lubricating oil. The lubrication and cooling (L/C) fluid is a polyphenyl ether (Shell Co. Mix-4P3E). The electrical insulation is a DuPont aromatic polyimide combined with a General Electric Company epoxy resin compound, NOVALAC.

### A. STATOR

The stator consists of two laminated stack assemblies with a toroidal field coil in between. The laminations are made of cold-rolled, 3.25% silicon, electrical steel (AISI type M19). The laminated stacks are back welded and also bonded with an epoxy resin. Form-wound conductors of electrical grade copper are used for the coils.

### B. FRAME AND END BELLS

The frame housing of the alternator is low-carbon steel. Cooling of the alternator is accomplished with machined cooling passages in the housing. The end bells are made of nonmagnetic Inconel and 316 stainless steel.

### C. ROTOR

The rotor is made from a forging of AISI 4620 steel. Teeth are machined in the rotor to concentrate the air-gap flux and reduce pole-face losses. Extra teeth are provided to overlap the stator cores so that magnetic forces are not created when there is an axial misalignment between the rotor and the stator. The rotor is also contoured between the poles to minimize the flux leakage in the region between rotor teeth.

### D. BEARINGS

The bearings are angular-contact ball bearings with a counterbored outer race. They are size 208 with a bore of 40 mm (1.5748 inch). The rings and balls are made from triple-melted consumable electrode vacuum melted M-50 steel. The retainer is made of an iron-silicon bronze in accordance with AMS 4616.

### E. MISCELLANEOUS PARTS

The shaft collars and the screw seals are made of AISI 4340 steel. The screw seals are Teflon coated for improved seal performance.

## III. DESCRIPTION OF DRIVE ADAPTER

The SNAP-8 Alternator was designed to operate in a vacuum with zero gravity. In order to close the driving pad and closely approximate the system thermal condition, a SNAP-8 turbine bearing housing was employed as a drive adapter. Thus, the alternator would be mounted during the ECTF testing in a similar manner to system testing. One condition that was deliberately created to aggravate spline wear and stresses to the quill shaft, was to mount the drive adapter .005 inch eccentric in lieu of the normal tolerance of .0005 inch.

The adapter bearing housing was cast 9% chromium - 1% molybdenum steel alloy. The shaft and slingers were AISI 4340 steel. The bearings were identical to the alternator bearings except that those identified by P/N 36A226199 S/N -G$\underline{XX}$ were of an earlier origin being fabricated from single vacuum melted M-50 tool steel. The material used in the later bearings was triple vacuum melt, being identified as P/N 095355 S/N A $\underline{XX}$. The female spline mating with the alternator quill male spline was nitride AISI 4340 steel.

## IV. HISTORY

### A. DESIGN

The alternator was developed in two phases. In the first phase, the emphasis was on designing the alternators to meet the electrical performance requirements. The alternators made during this phase of development were called "pre-prototypes."

In the second phase of the alternator development, design changes were made to improve the performance. These included changes that reduced magnetic flux leakage and lowered temperatures in the windings. The alternators made during this phase of development were called "prototypes."

Alternator S/N 481490 was the second of five prototype alternators produced. During this alternator's qualification tests, it was found that the winding temperature was slightly higher than the maximum allowable design temperature. The subsequent machines were modified by increasing the internal lead area to the terminals, but alternator S/N 481490 was not changed.

## B. TEST SYSTEM, PROCEDURE, AND PROFILE

### 1. Test System

The ECTF consisted of the alternator drive stand, a lubrication and cooling system, instrumentation, and the required Test Support Equipment (TSE) for control of the facility. The equipment and test components were installed as shown schematically on P&I Diagram 1264242 (Figure 3). The alternator-bearing housing assembly was as shown in AGC Drawing 1264243 (Figure 1).

### a. Alternator drive stand

The alternator drive stand consisted of an eddy current coupling and speed-increaser gear box driven by an electric motor. The motor rating is 150 hp, 3550 rpm, 440 volts, 3-phase, 60 Hz.

The alternator was connected to the drive stand through a modified turbine bearing assembly with a flexible drive shaft. An eddy current coupling was used for adjusting shaft speed into the low speed side of the gear box from 0 to 3500 rpm. The coupling was equipped with an electronic speed controller which supplied excitation to the eddy current coupling to maintain a preselected output speed. If higher than design speeds were desired, the step-up gear box could be used to increase the output speed to a maximum of 14,000 rpm. At 12,000 rpm, the maximum continuous output power from the drive was 120 hp.

### b. Lubrication and coolant system

The lubrication and cooling (L/C) system provided lubricant to the alternator and the turbine bearing assembly and coolant to the alternator and its voltage regulator and static exciter. The system included a pump, a water-cooled heat exchanger, line heaters, filters and control valves (see Figure 3). A glass-walled supply reservoir was used to indicate the quantity and the condition of the L/C fluid. The reservoir was evacuated during operation to remove any trapped gas from the L/C fluid.

c. Instrumentation

Instrumentation was used to measure the functions for the control and evaluation of the system. The functions are shown on Figure 3.

d. Electrical test support equipment

Electrical test support equipment was used to control the system and to automatically shut down the system if abnormal operating conditions existed. This equipment included load banks for absorbing the alternator output, controls for the alternator drive, controls for the L/C system, and a system for automatic shutdown.

e. After the 2553 hour inspection a, nitrogen blanket system was installed to protect the interior of the alternator from corrosion during long shut-down periods. This was done to preclude corroding of the parts as noted during the 2553 hour inspection.

2. Test procedure

The test procedure for the ECTF is described in detail in Reference 2. A summary of the more significant events is as follows:

a. Startup

(1) Start L/C pump
(2) Turn on line heaters and vacuum pump on L/C reservoir
(3) Maintain temperature control of L/C system at 200 ± 10°F
(4) Pre-lubricate bearings if necessary
(5) Start alternator drive and apply alternator field flashing power
(6) Increase alternator speed to 8000 rpm and stabilize the L/C flows
(7) Increase alternator speed to 12,000 rpm and turn off field flashing power
(8) Set the alternator load
(9) Turn off line heater.

b. Shutdown

(1) Reduce alternator speed to 8000 rpm

(2) Stop bearing lubricant flow

(3) Stop alternator and shut off motor drive

(4) Shut down L/C pump and vacuum pump when the L/C temperature drops below 150°F

c. Steady-state running conditions

The alternator was tested under the following conditions:

| | |
|---|---|
| Alternator power | $60^{+1}_{-4}$ kwe |
| Alternator power factor | 0.9 ± 0.02 lagging |
| Alternator voltage | 120 ± 3.6 volts |
| Alternator frequency | 400 ± 4 Hz |
| L/C inlet temperature | 200 ± 10°F |
| Alternator coolant | 1600 ± 40 lb/hr |
| Lube fluid - each bearing | 200 ± 6 lb/hr |

# V. DISASSEMBLY AND INSPECTION

## A. ALTERNATOR

Disassembly and inspection was initiated after 23,130 hours due to a seizure of the alternator rotor and termination of the test. The alternator was frozen and the rotor would not rotate with up to 100 inch ounces of torque although it could be oscillated 5 to 10° with a gritty feel. Disassembly was normal except for some extra force being required to separate the rotor from the drive end screw seal. Fits between shaft elements and fits between housing elements appeared normal and no galling occurred except for the quill shaft fit in the rotor which was damaged in removal.

The stator heat exchanger and main stator shell including the terminal seals were helium leak tight. No new corrosion was found and the original corrosion damage found at the 2553 hours inspection had not progressed.

The rotor was heavily wiped at the inboard drive end screw seal and less heavily at the outboard drive end seal which faces a sleeve on the rotor. A light contact had occurred at the anti-drive end screw seal. The damage at the drive end was so extensive that the rotor was noticeably bent in line with the heaviest damage. The area in contact apparently heated up severely and yielded under compression thermal stresses. Maximum shaft runout was found to be .0052 inches. This prevented a balance reading of the shaft from being meaningful since the bending and displaced metal would cause forces an order of magnitude greater than the balancing tolerances. Figure 4 is a plot of shaft runouts. Figure 5 is a table of rotor diameter at each inspection and shows that one half of the rotor growth occurred in the first 2553 hours. The largest growth was in the undercut portions of the lobes which suggests that both dynamic stresses and manufacturing stress relaxation may have occurred. Since no balance measurement would be meaningful with the shaft bent, only the balance data from the 2553 hours inspection is available. This had indicated a moderate change which would increase the bearing loads but still not significantly effect the bearing life. Since only half of the geometric changes occurred in the first 2553 hours of the test, we can assume that changes in rotor balance during the 2553 hours to 23,130 hours portion of the testing were similar to the changes in the early part of testing. Five pounds change in total unbalance load on each bearing would be a good estimate. In addition, visual inspection of the bearings showed no evidence of unbalance loading. However, unbalance loading of less than 10 pounds might not be distinguishable because of the relatively large load capacity of these bearings.

The visual inspection of the stator insulation showed heavy discolorations and coking which proved to be of polyphenyl ether (Mix-4P3E) origin when analyzed by spectrographic methods (see Figures 6 and 7 and Appendix A). The insulation material had darkened but had not apparently degenerated mechanically. Electrical resistance checks showed the entire system to be very satisfactory. Figure 8 is a table comparing resistance values at various times during the testing.

An evaluation of the test facility was made to determine if it contributed in any way to the alternator seizure (see Appendix B). In order to determine the cause of the rotor seizing, particular emphasis was placed on the preload system parts examination. The wavy preload springs were found to be in average condition with the drive end slightly under tolerance with respect to load at operating height and the antidrive end was in tolerance. The free height of the spring lobes was normal in variation (less than .030 inches) and therefore excessive spring cocking was judged not to be a major cause for failure. The bearing outer rings and the lubrication jet rings were a sliding fit in the housing and no binding varnish was found on the outer diameter of these parts or in their normal seat positions in the housings. No surface finish damage or galls were found. However, a ridge of varnish or 4P3E residual was found at the edge of the oil groove on the outboard drive end bell that would mate with the corner radius of the bearing outer ring. See Figures 9, 10 and 11. This ridge had been flattened in the normal sequence of disassembly of the unit where significantly more than 60 pounds force (the preload spring value) is applied. No other attribute was found to explain lack of preload. See Figures 12 through 26 for the condition of major parts of the unit.

## B. BEARINGS

<u>S/N A54 Alternator Drive End Bearing</u>.- Prior to disassembly, this bearing had a slightly gritty feel when rotated by hand using axial pressure. No major particles were located by ultrasonic cleaning however. The general appearance was of a well-used bearing with varnish stains and darkened balls. No damage was visible.

The inner ring bore was clean. There were very minimum axial scratches found and no signs of ring rotation on the shaft. The low shoulder face was lightly stained. The thrust face was clean except at the outer edge where an irregular stain appeared. The ball track had dirt damage dents up to .010 inches axially by .005 inches circumferential. These ball tracks were of no measurable depth and were found singularly and in groups. Most of them appeared to be new. The lubrication of the ball tracks was very good. The average track width was .070 inch and in the normal contact angle position. Although the bottom edge was wavy there was no unbalance pattern.

The outer ring faces were varnish stained with a distinct contact pattern on the jet ring side. The outer ring showed no cause for restricted sliding in the housing although the outboard corner radius and the varnish stains wiped away. One circumferential scratch extending for approximately 60° was found around the bearing at about 0.27 inches from the non-thrust or outboard face. The raceway showed superficial rust dating to before the last run. This covered approximately 7% of the raceway. The shoulder above the ball track contained two or three partial sets of old mounting marks. These marks occur when high nonrotating loads or vibrations are applied axially during assembly. A random scattering of dirt vents was found in the ball path. None of these were considered critical.

The balls were stained dark brown with a blue cast. One ball had a flat or dent .030 inches in diameter with a heat stain in the center. One ball showed two elliptical dents .045 inches long in close proximity. One ball was scratched equatorially .020 inches wide. The scratch was rough and very bright but of no significant depth. No signs of fatigue or heavy ball banding were noted. The separator was normal in every respect. There were no outside diameter or inside diameter contact patterns in the heat stain. The ball pockets had the "dumb bell" contact pattern with a minimum height of .030 inches. The site of the ball scratch particle was not located (see Table IV for inspection details).

<u>S/N A48 Alternator Antidrive End Bearing</u>.- In the assembled condition, this ball was very smooth to hand "feel". The inner ring bore was clean with no rotation marks. Some light axial mounting marks were found. The inner ring faces had a light stain. The high shoulder had a dark stain. The ball track stain was wavy but the relatively wide .080 inch ball track was not unbalanced. Old rust pits and dents from the first 2553 hours of operation were filled with varnish. There was no sign of fatigue.

The outer ring outer diameter was smooth with light staining but it showed intermittent light chatter patterns over the non-thrust half. The thrust face had intermittent stains. The non-thrust face had dark stains. The ball track was uniform with good lubrication. There were many ball spaced chatter marks in the raceway and new high shoulder ball contacts from dismounting.

The balls had very minor scratches and were lightly stained all over. Banding could be discerned on some balls. One ball was distinctly banded and 40 micro-inches out of round with wear occurring in an equatorial path. Another ball was similarly but less extensively banded and was 28 micro-inches out of round. The remaining balls were in good condition measuring less than 20 micro-inches out of round.

The separator had normal stains and showed no outisde diameter or inside diameter contact patterns. The ball pocket contact patterns were dumb-belled and .030 inches minimum height. (See Table V for inspection details.)

S/N G18 Drive Adapter Bearing at the Alternator or Inboard End.- This bearing was smooth to hand feel in the assembled condition. It appeared relatively clean and bright with no visible damage. The inner ring bore was clean showing no rotation marks and very light axial mounting scratches. The high shoulder face was lightly stained and the low shoulder was clean. The ball track had no distinct edges and showed very minor pits which could be dirt damage or manufacturing imperfections. The raceway has a washboard appearance to the stain. The raceway varnish deposits are soft above the track and could be displaced with a fingernail.

The outer ring outer diameter was very clean and undamaged. The raceway had light staining with no distinct track showing.

The balls were lightly stained with one ball showing a pit 45 micro inches deep.

The separator was stained as commonly seen with these bearings after operation. The ball pockets contact pattern was dumbbell-shaped with a minimum height of .030 inches. (See Table VI for inspection details.)

S/N A25 Drive Adapter Bearing at the Outer End.- In the assembled condition, this bearing was smooth to hand feel. No significant debris was washed from the bearing. The general appearance was stained but undamaged. The inner ring bore was clean with light axial scratches but no rotation marks. A narrow band of heat stain was found at the thrust end of the bore. The face showed varicolored heat stains. The non-thrust face was clean except for stains at the outer 10 percent of the face. The ball track is uniform, narrow (.050 inches) and clean. The raceway above the ball track had an unusual feathery stain or etching which would not clean with acetone.

The outer ring outside diameter was lightly varnish stained with some local blotching but no appreciable buildup. There were no indications of rotation. Old axial scratches were filled with varnish stain. The non-thrust face had varicolored stains. The thrust face had blotchy stains with some buildup. The raceway was varicolored outside the ball track which was very clean, bright, wide, (0.170 inches) and multipathed. There were several dirt dents in the track. Lubrication was very good.

The balls were bright with almost no loss of finish. There was no banding. A few superficial scratches were noted. The separator was normally stained with contact marks on the outside diameter in several places. The ball pocket wear was light and had not progressed to dumbbelling or widening at the edges. (See Table VII for inspection details.)

## VI EVALUATION OF COMPONENTS

### A. ROTOR

Rotor growth occurred in all operational SNAP-8 alternators. The ECTF alternator, S/N 481490, was found to have a rotor enlarged by .002 inches in diameter at the 2553 hour inspection. At the final inspection the growth had increased to .0058 inches, maximum. Figure 5 shows various rotor diameters at different inspections.

There are two possible deleterious effects of rotor growth. First, the rotor could rub against the stator. However, the maximum diametral growth was .0058 inches and minimum radial air gap was .054 inches when originally built. Second, the growth could result in high unbalance forces which would effect bearing life. However, there have been no SNAP-8 alternator rotor imbalance loads measured resulting in more than 13 pounds force on a bearing. No SNAP-8 alternator bearings have shown noticeable signs of imbalance loading in the ball tracks after service. The rotor growth phenomena is therefore judged not to be a potential problem area at the service conditions tested.

### B. STATOR

The alternator stator appeared to be in good condition, (see Figures 6 and 7). The darkening of the insulation material had progressed. The electrical resistance inspections at various stages of assembly are tabulated in Table I. These show no degradation. Figure 8 shows a plot of field to frame resistance and stator to frame resistance versus time displaying a wide spread of values over the test period. Moisture presence and lubricant effects soaking the stator are known to cause some differences in the ground resistance measurements.

### C. SPLINE

The spline on the quill shaft is subject to wear. The inspection data reveals that this was only minor in nature (see Table II). This inner shaft is one of a batch which was manufactured with a chrome flash (electrolizing) on the teeth which were nitrided Nitralloy. Some of the batch became badly chipped and flaked under light loading and due to light impact loads. The teeth on this shaft were only moderately worn or chipped after long service. The major portion of the plating wear had occurred in the first test period. The overall condition of the spline was considered satisfactory even with the loss of chrome plating (see Figures 27, 28, and 29).

## D. BEARINGS

Total operating times for each bearing described in this report are:

| ALTERNATOR | | DRIVE ADAPTER | |
|---|---|---|---|
| DRIVE END | ANTI-DRIVE END | ALTERNATOR END | TURBINE END |
| S/N A54 | S/N A48 | S/N G18 | S/N A25 |
| 20,630 HRS | 23,130 HRS | 20,630 HRS | 10,451 HRS |

All the bearings both in the alternator and in the drive adapter were found to be in satisfactory condition. See Figures 30 through 59. The rust on the antidrive bearing of the alternator has caused no progressive damage since it occurred prior to the 2553 hour inspection. The scratches on the drive end alternator bearing balls from seal failure debris are not considered critical.

In general, lubrication and ball pocket wear on all the bearings was satisfactory. The only serious defect is the out-of-roundness of two balls (40 and 28 micro inches) in the antidrive end bearing of the alternator. These balls are heavily banded in comparison to the other balls in the bearing and are worse than would normally be reassembled for extended use in testing. See Table III for a tabulation of ball roundness. The remaining balls range in sphericity up to 20 micro inches with the 10,451 hour bearing, S/N A-25 showing less wear than the 20,630 hour bearings S/N A-54 and S/N G-18.

## VII. DISCUSSION OF CAUSES OF FAILURE

The ECTF alternator incorporates two angular contact ball bearings supporting the rotor. In order to reduce geometric radial excursions and prevent ball spinning when they enter an unloaded zone, a preload system was included to maintain nominally a sixty pound axial load on each bearing at all times. This load is the result of axial compression of two wavy spring washers, one at each bearing. Bearing stops restrict the axial motion to a total of .012 inches when the unit is cold. At operating temperature, differential expansion of the rotor and the stator reduces the possible end play to an estimated 0.008 inches. As axial loading changes, the net force may reverse in direction. The bearing outer rings and jet rings normally slide axially in the end bells. When the lead bearing causes the jet ring to bottom on the bearing stop, the axial sliding motion of the rotor ceases. Meanwhile the opposite bearing outer ring is being pushed axially by the 60 pound preload spring force acting thru the jet ring. If the following bearing outer ring fails to follow the rotor displacement, the rotor will orbit due to the relatively large radial bearing clearance which is nominally .0008 inches. The result of this condition could be a total indicated runout of as much as .002 inches at normal speed and loads. When bearing deflections and mounting eccentricities are added to this the total, eccentricities become on the order of .002 inches. The buildup clearance at the screw seals was .0027 inches. This is reduced by adverse temperature differential expansion of .0006 to .0012 inches and by varnish buildup of .001 to .002 inches. The probability of contact is greatly increased. The Teflon coating employed on the screw seal threads tends to ball and gall when rubbed. Any local rotor heating from contact is self-aggravating since the shaft would bend thus increasing the runout and contact loading.

Previously, two alternators in Power Conversion System (PCS) service failed by similar seal seizing patterns. These occurred during inadvertent overspeeds (see references 5, 6 and 7). In one case, distinct evidence indicated a probable loss of preload due to foreign particles preventing the outer race from sliding.

The ECTF alternator ball tracks do not show operation without preload which would be indicated by a path in the center of the raceways. However, in the case of a loss of preload causing an immediate failure, the wear track at $0^{\circ}$ contact angle would not have time to develop.

There are several significant differences between operation of the ECTF and the PCS with respect to the lubricant coolant fluid Mix-4P3E. Generally speaking, stability of lubricants is affected by oxygen, elevated temperatures and certain materials. ECTF was known to have air leaks into the system during operation and vacuum was maintained with a vacuum pump. The sump tank normally showed foam on the liquid. Upon shutdown, either planned or inadvertent, air immediately flooded the system and was dissolved into the lubricant such that considerable degassing was necessary on startup.

In order to judge the magnitude of the sludge and varnish found in this alternator, a comparison between the operation in ECTF and the PCS tests were made. The ECTF is considered to be a less sophisticated test operation whereas the PCS test, which is actually a complete SNAP-8 ground test breadboard, contains a high degree of sophistication including much tighter vacuum conditions and temperature controls in the Mix-4P3E lubrication system. The ECTF contained heaters for controlling temperature of the lubricant. These would provide local hot spots with possible lubricant deterioration. The ECTF had three carbon face seals operating flooded with Mix-4P3E. One of these, the drive adapter outboard carbon seal, was a chronic maintenance problem due to buildup of coke and gum material on the carbon noise. The combination of friction and air obviously accelerated the breakdown of the fluid. Upon emergency shutdown, the ECTF system allows flooding of the alternator cavity with fluid. The hot rotor parts and the end turn hot spots become oil coated. However, both the PCS alternator (long duration test unit) and the ECTF alternator both showed varnish and coke buildup on the screw seals and mating rotor parts. The PCS used a 5 micron oil filter and the ECTF used a 10 micron oil filter. Neither of these trapped any significant sludge or varnish. The preceding differences could explain the observed variation in total mass of sludge and varnish seen in the 10,822 hour PCS alternator. It is estimated that the ECTF component contained about ten times as much sludge and varnish as the PCS-1 components. However, the deposition of sludge at the bottom edge only of the outboard oil grooves is not easily explained. The bearing slinger imparts considerable velocity to the fluid in this area.

## VIII. CONCLUSIONS

A. The alternator failed due to malfunction of the spring preload system which permitted the rotor to orbit and close the tight clearances at the drive end inboard screw seal. The screw seals wiped and dragged the rotor causing an alternator underspeed where low voltage controls terminated the test. The seal overheated the rotor locally causing yielding due to thermal stresses. The seal and rotor welded together upon stopping producing screw seal thread patterns on the rotor.

B. The spring preload system in the alternator has been previously identified as being deficient in that it is susceptible to jamming. In this case, it is believed that decomposition products of the Mix-4P3E lubricant deposited at the drive end bearing outer ring corner radius aggravated this situation and provided enough restraint to allow rotor displacement without the outer ring following the motion. The geometry of an angular-contact bearing does not permit operation without preload, due to radial clearances. Bearing deflections due to the resultant heavy loading and mounting eccentricities compounded the problem and allowed the seal clearance to close up and contact to occur thus initiating the seizure.

C. It is worthy of note that the SNAP-8 turbine which employs bearings identical to the alternator described herein has never suffered a loss of preload, nor did the drive adapter used in conjunction with the alternator described herein. This suggests that the spring preload system in the turbine is more dependable than that of the alternator.

D. No definite reason for rotor shifting has been determined but the drive system was thought to be noisier than normal at the time of failure due to some vibrations in the drive system.

E. The bearing examination showed no failure modes. Lubrication was good. No fatigue was found. The ball wear rate measured indicates a minimum life of at least 5 years. Separator modifications could reduce this wear and permit even greater wear life.

F. The other components of the alternator are in good working condition and no life limiting modes were identified.

G. Correction of the aforementioned problem areas should result in a life of 5 to 10 years without maintenance when operated under similar loading conditions and within a controlled environment.

H. The unusual amounts of polymerized or decomposed varnish and sludge found after the extensive endurance test were undoubtedly produced to a major extent by the uncontrolled operation of the testing thus allowing air-in leaks, moisture, etc. These effects would be eliminated in a cleaner, vacuum-tight test operation.

## IX. RECOMMENDATIONS

A. The following recommendations are made primarily to minimize the probability of the occurrence of the loss of alternator bearing preload.

1. Install the redesigned spring preload system as designed previously (reference 8) to improve the length to diameter ratio of sliding parts and reduce the cocking moment of the spring force (see Figure 60). The design proposed in Figure 60 is almost identical to that used in the SNAP-8 turbine (and in the drive adapter tested with the alternator). It is noted that belleville spring washers are employed, whereas the current alternator design (as tested) uses wavy spring washers. The latter tend to present an uneven preload to the bearing.

2. Replace the polyphenyl ether Mix-4P3E with a lubricant less likely to sludge and varnish the parts.

B. The following recommendations are designed to reduce the probability of failure when the alternator suffers a temporary loss of bearing preload.

1. Increase the nominal radial seal clearances from .003 to .004 inches.

2. Remove the Teflon coating on the screw seal threads. This coating is difficult to apply to threads uniformly, and to measure accurately. Also it is subject to damage during assembly and tends to ball up when rubbed during high speed contact with the rotor.

The original purpose for the Teflon was to provide a non wetting barrier to eliminate liquid film creepage thru the seal. These have shown the non wetting characteristic to be temporary in nature.

3. Hard surface the rotor surfaces that mate with the screw seals. Also hard surface the sleeves that mate with the outboard screw seals.

C. Redesign the ball bearing separator as described in Appendix C in order to further increase the wear life of the bearing. This recommendation would be applicable to both the alternator and the turbine bearings.

D. In the event that further testing in this facility is planned, an attempt should be made to improve the control of testing such as sealing, vacuum tight conditions, and improving the method of heating the oil.

## X. REFERENCES

1. Electrical Component Test Facility, Phase I Checkout Test and Phase II 2500 Hour Endurance Test. Test Report TM 4936:67-498

2. Mechanical Evaluation of the Alternator from ECTF after 2553 hours, TM 4932:67-494

3. Inspection Results on ECTF Drive Adapter including Bearings P/N 36A226199, S/N G-14 at 12,679 hours, Memo 4932-69-0606

4. SNAP-8 Turbine Alternator (TAA) 5/4 Bearing Inspection and Evaluation after 10,823 hours in PCS-1

5. SNAP-8 Failed Alternator P/N 094069, S/N 481492 Bearing Evaluation TM 4931:67-465

6. SNAP-8 Failed Alternator P/N 094069, S/N 481491 Bearing Evaluation TM 4932:66-413

7. Alternator P/N 094069, S/N 481492, Failure Analysis TM 4932:67-478

8. Design Review Information for Proposed Modifications for SNAP-8 Alternator P/N 094069, TM 4932:68-529

TABLE I Electrical Inspection Data

| Test Hours / Electrical Characteristic | 0 Time | 2553 | 23130 |
|---|---|---|---|
| Stator Winding Resistance $T_1$-$T_4$ (Ohms) | .00573 | .00571 | .005694 |
| $T_2$-$T_4$ | .00572 | .00568 | .005768 |
| $T_3$-$T_4$ | .00567 | .00571 | .005688 |
| Field Winding Resistance $F_1$-$F_2$ (Ohms) | 1.45 | 1.48 | 1.442 |
| Stator Insulation (K Megohms) | 9 | 4.9 | 40 |
| Field Insulation Resistance (K Megohms) | 200 | 4.5 | 200 |

## TABLE II Inner Shaft

Spline Diameter over 0.0960 pins for S/N 481490

Manufacturing tolerance 1.1417 to 1.1432 inches

| New | Measurements After Endurance Testing | |
|---|---|---|
| | 2553 HOURS | 23130 HOURS |
| 1.1435/1.1417 | 1.1426 | 1.1427 |
| | 1.1426 | 1.1427 |
| | 1.1425 | 1.1427 |
| | 1.1424 | 1.1426 |
| | 1.1424 | 1.1427 |
| | 1.1425 | 1.1428 |
| | 1.1424 | 1.1427 |
| | 1.1425 | 1.1427 |
| | 1.1426 | 1.1427 |
| ↓ | 1.1426 | 1.1427 |
| | 1.1425 average | 1.1427 average |

Note: The apparent growth of spline diameters is attributed to metrology differences not real growth.

## TABLE III Bearing Ball Roundness

| | | Roundness (micro inches) | | Ball Diameter (inches) | Comments |
|---|---|---|---|---|---|
| ALTERNATOR ANTI DRIVE-END | | | | | |
| S/N A-48 | A | 20 | 15 | .47055 | |
| (23135 hrs) | B | 18 | 17 | .47054 | |
| | C | 40 | 18 | .47056 | heavily banded |
| | D | 20 | 14 | .47055 | |
| | E | 28 | 8 | .47056 | heavily banded |
| | F | 20 | 10 | .47053 | |
| | G | 6 | 2 | .47051 | |
| | H | 14 | 11 | .47050 | |
| | I | 20 | 9 | .47051 | |
| | J | 13 | 10 | .47052 | |
| | K | 18 | 8 | .47050 | |
| | L | 10 | 10 | .47052 | |
| | M | 18 | 8 | .47054 | |
| ALTERNATOR DRIVE END | | | | | |
| S/N A-54 | 1 | 16 | 15 | .47051 | bright equatorial scratches |
| (20630 hrs) | 2 | 12 | 10 | .47051 | |
| | 3 | 20 | 15 | .47052 | |
| DRIVE ADAPTOR TURBINE END | | | | | |
| S/N A-25 | 1 | 10 | 10 | .46873 | |
| (10630 hrs) | 2 | 12 | 8 | .46873 | |
| | 3 | 7 | 6 | .46876 | |
| DRIVE ADAPTOR ALTERNATOR END | | | | | |
| S/N G-18 | 1 | 8 | 6 | .47217 | |
| (20630 hrs) | 2 | 14 | 6 | .47218 | |
| | 3 | 19 | 8 | .47218 | pit 45 micro inches deep |

TABLE IV Bearing S/N A-54 Inspection Data Versus Time (Alternator A.D.E.)

| Alternator Time<br>Characteristic | New at 2553 hrs. | 12679 hrs. | 23130 hrs. |
|---|---|---|---|
| DIAMETRAL PLAY | .00165 | NOT INSPECTED | .0017 |
| BALL DIAM | .47068 | | .47047 |
| FLUSHNESS | .0001 | | -.0004 |
| CONTACT ANGLE | 15°53' | | 15° 50.25' |
| OUTER RING HARDNESS-Rc | 64 | | 62.7 |
| INNER RING HARDNESS-Rc | 63.6 | | 62.4 |
| OUTER RING OUTSIDE DIAMETER | 3.14951 | | 3.14950/3.14957 |
| INNER RING BORE | 1.57470 | | 1.57474 |

TABLE V Bearing S/N A-48 Inspection Data Versus Time (Alternator D.E.)

| Alternator Time<br>Characteristic | New | 2553 | 12679 | 23130 |
|---|---|---|---|---|
| DIAMETRAL PLAY (inches) | .00165 | | | .0015 |
| BALL DIAM (inches) | .47068 | .47055 | | .47044 |
| FLUSHNESS (inches) | .0005 | | | .00015 |
| CONTACT ANGLE | 15°53' | | | 15°30.25' |
| OUTER RING HARDNESS (Rc) | 63.6 | Not available | Not taken | 62.3 |
| INNER RING HARDNESS (Rc) | 64 | | | 61.7 |
| OUTER RING OUTSIDE DIAMETER (inches) | 3.14942 | | | 3.149450<br>3.149500 |
| INNER RING BORE (inches) | 1.57470 | | | 1.57470 |

TABLE VI Bearing S/N G-18 Inspection Data Versus Time

| Alternator Time<br>Characteristic | | New at 2553 hrs | 12679 hrs | 23130 hrs |
|---|---|---|---|---|
| DIAMETRAL PLAY (inches) | NOT INSTALLED | .0016-.0021 | .0016 | .0016 |
| BALL DIAM (inches) | | .472 | .472 | .47215 |
| FLUSHNESS (inches) | | ±.0002 | -.00011 | -.00005 |
| CONTACT ANGLE | | $14^\circ$-$18^\circ$ | 14.575 | $14^\circ 45'$ |
| OUTER RING HARDNESS-Rc | | | | 63.7 |
| INNER RING HARDNESS-Rc | | | | 61.9 |
| OUTER RING OUTSIDE DIAMETER (inches) | | | 3.149525/<br>3.149600 | 3.149530/<br>3.149570 |
| INNER RING BORE (inches) | | 1.57470/<br>1.57475 | 1.574840/<br>1.57487 | 1.57478 |

TABLE VII <u>Bearing S/N A-25 Inspection Data Versus Time</u>

| Alternator Time / Characteristic | New at 12679 hrs. | 23130 hrs. |
|---|---|---|
| DIAMETRAL PLAY (inches) | .00165 | .0016 |
| BALL DIAM (inches) | .46877 | .46872 |
| FLUSHNESS (inches) | .0002 | -.0001 |
| CONTACT ANGLE | 14°43' | 14°7' |
| OUTER RING HARDNESS-Rc | 64 | 63.7 |
| INNER RING HARDNESS-Rc | 63.6 | 61.9 |
| OUTER RING OUTSIDE DIAMETER (inches) | 3.14946 | 3.14948/3.14944 |
| INNER RING BORE (inches) | 1.57466 | 1.5746 |

2

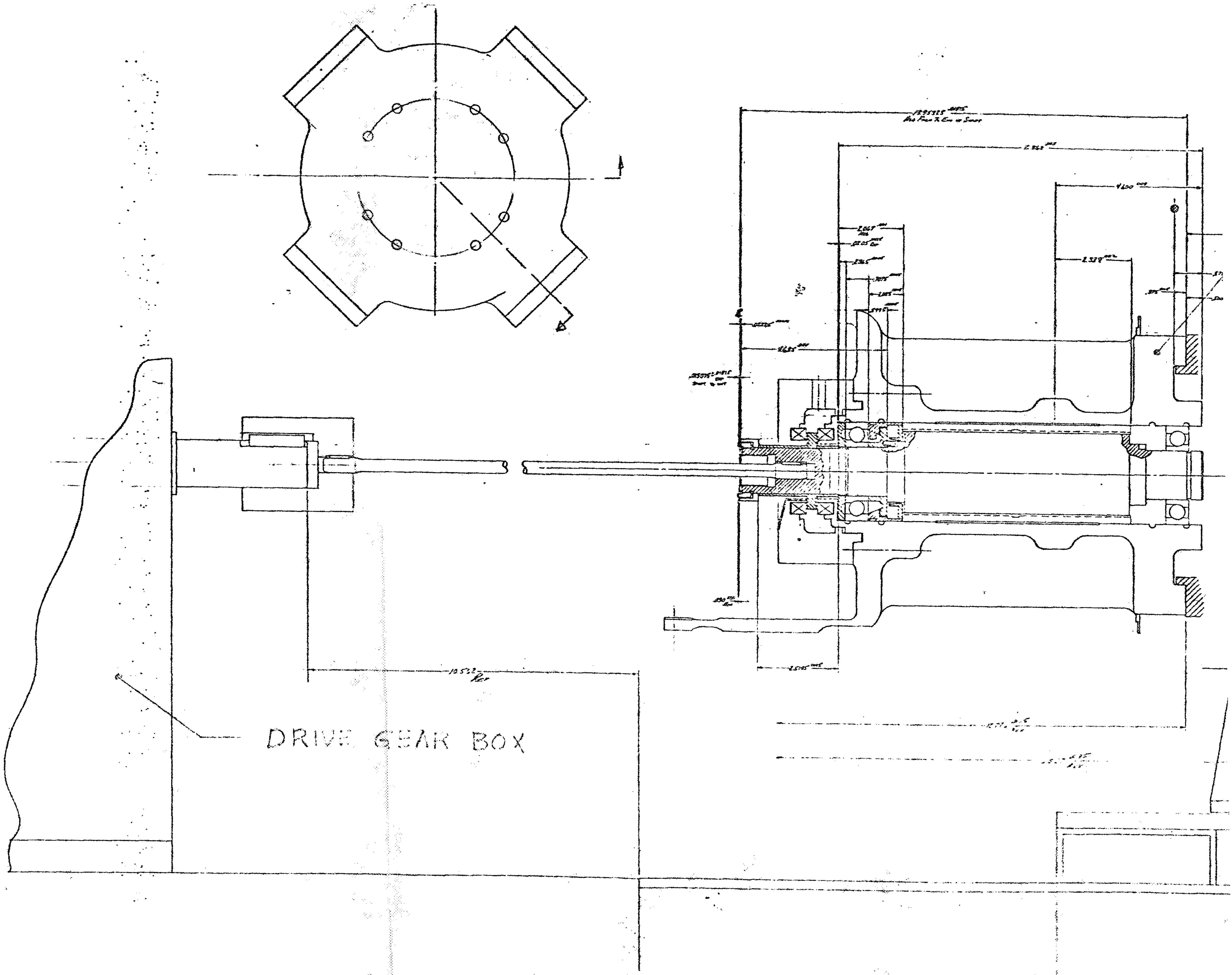


Figure 3

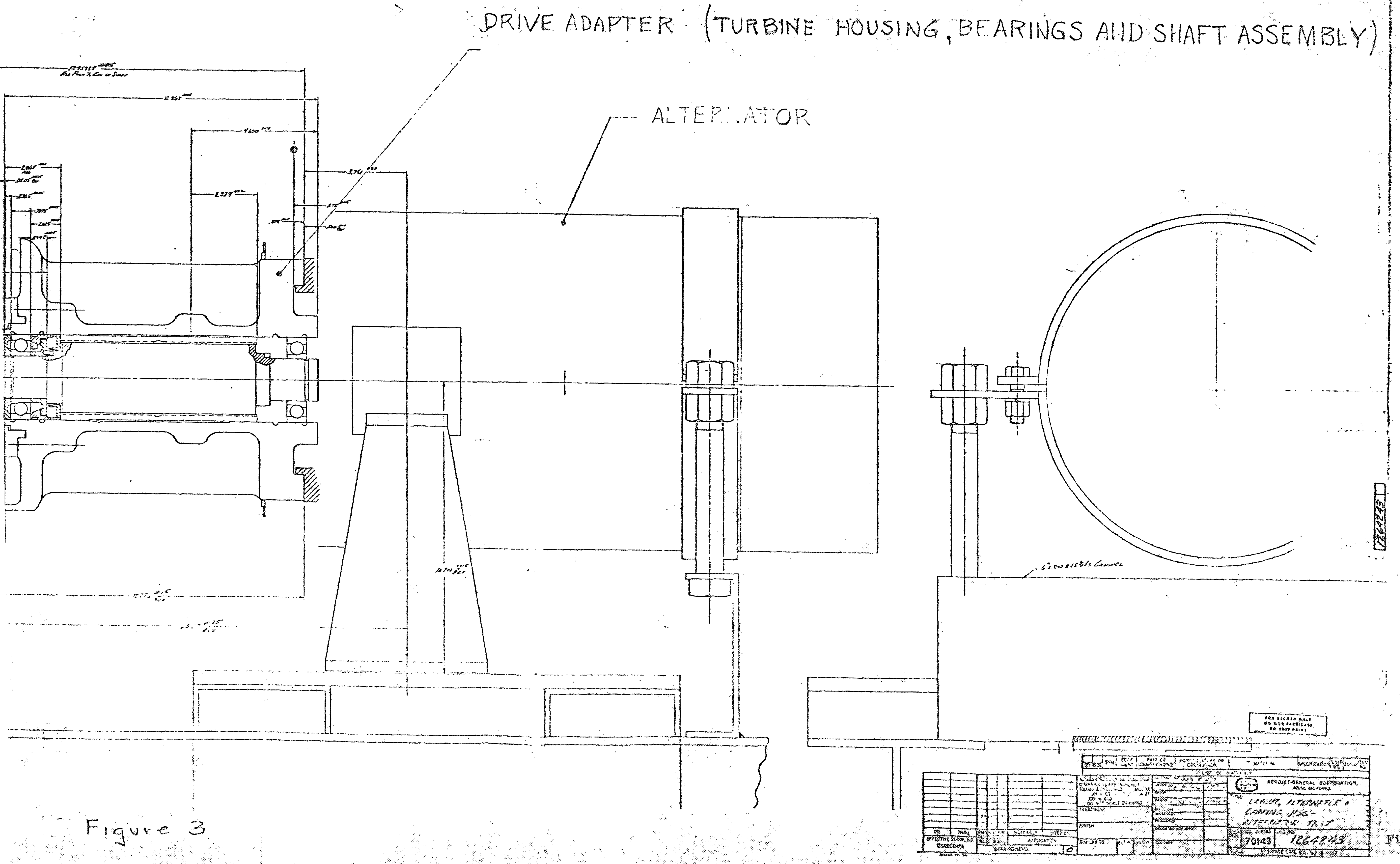


Figure 3

Figure 1
27

# SNAP-8 ALTERNATOR ASSEMBLY

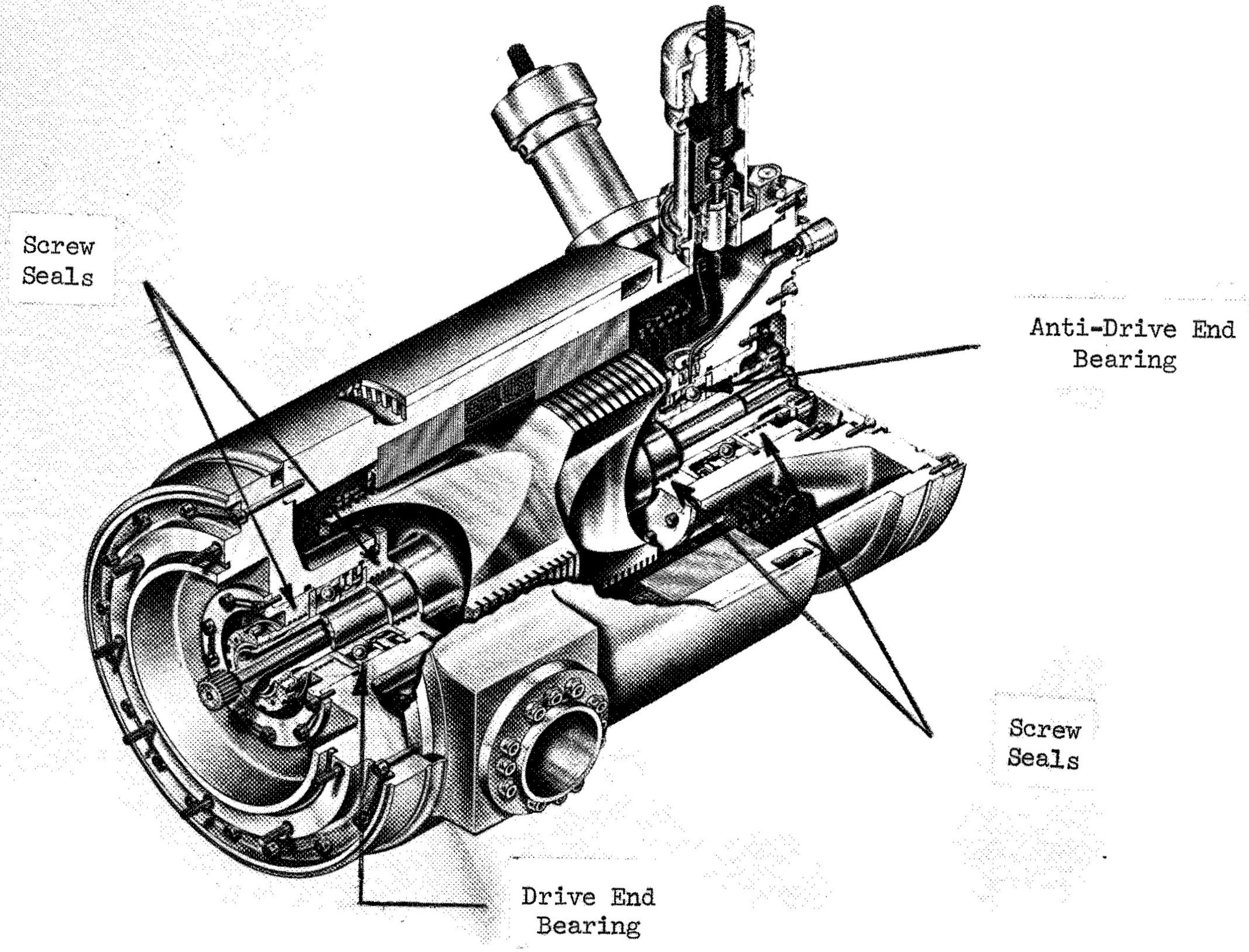


Figure 2

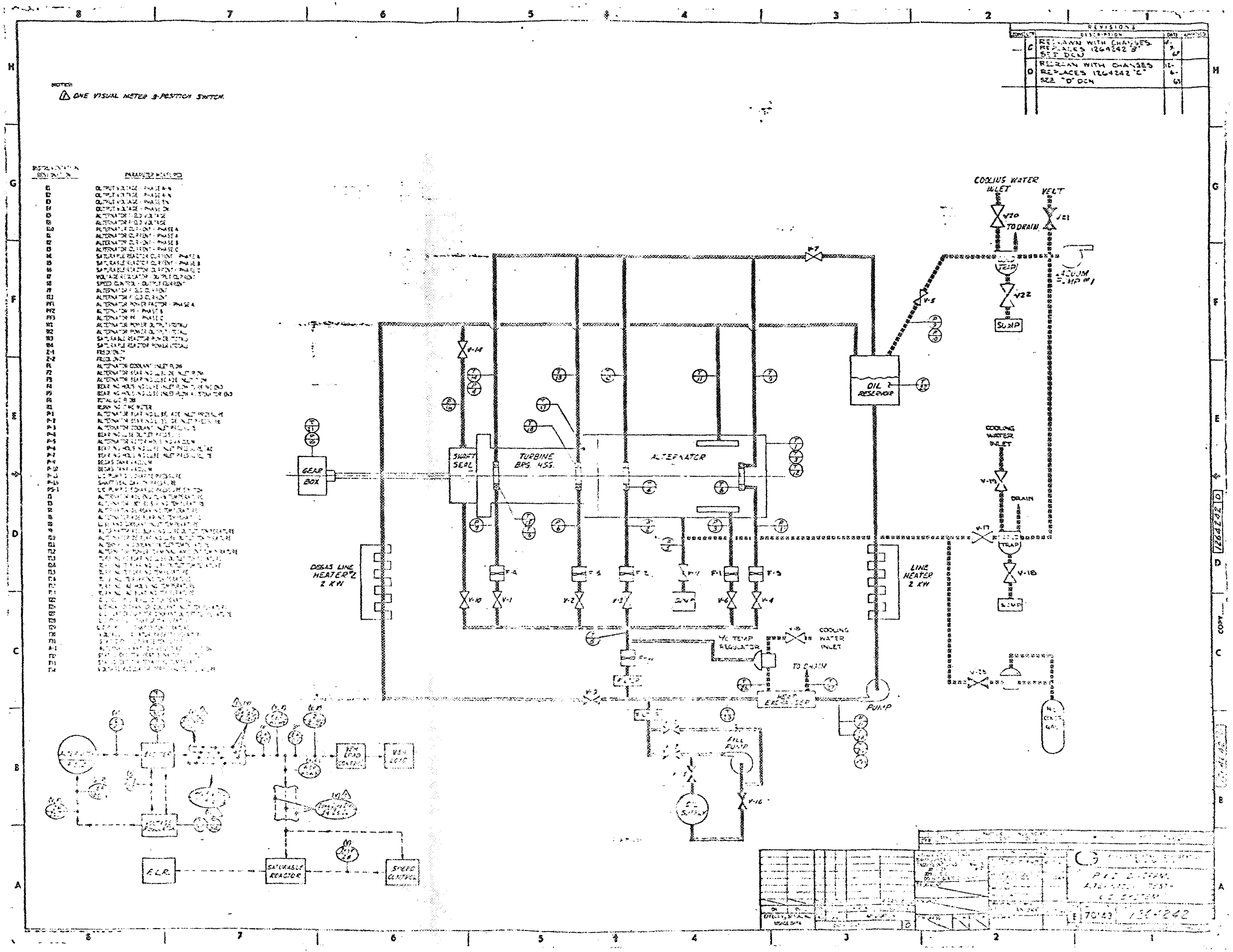
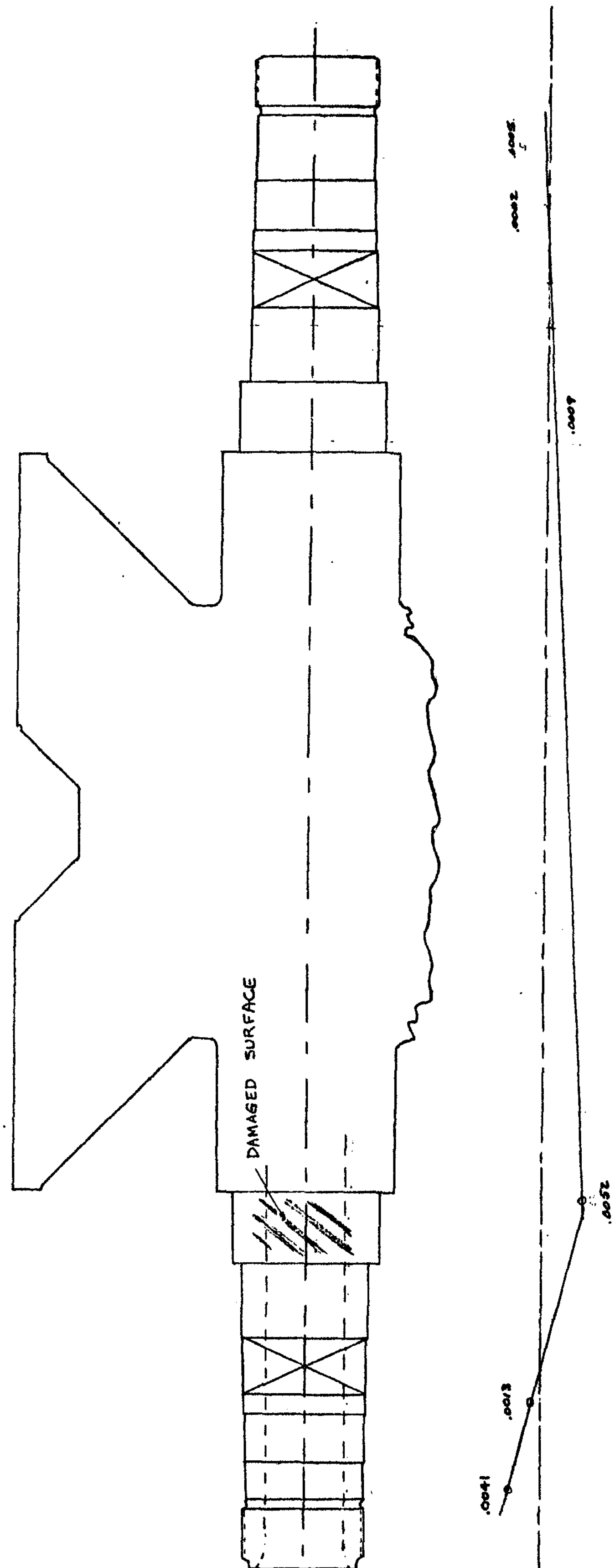

REVISIONS
C REDRAWN WITH CHANGES REPLACES 1264242 "B" SEE DCN
D REDRAWN WITH CHANGES REPLACES 1264242 "C" SEE "D" DCN
NOTES:
1 ONE VISUAL METER 3-POSITION SWITCH
INSTRUMENTATION DESIGNATION
PARAMETER MEASURED
COOLING WATER INLET
VENT
V-20
V-21
V-22
TO DRAIN
TRAP
SUMP
VACUUM PUMP #1
V-5
OIL RESERVOIR
V-7
COOLING WATER INLET
V-19
DRAIN
V-17
V-18
V-14
SHAFT SEAL
TURBINE BPS 4SS.
ALTERNATOR
GEAR BOX
DEGAS LINE HEATER #2 2 KW
LINE HEATER 2 KW
F-4
F-5
F-2
F-1
F-3
V-10
V-1
V-2
V-3
V-6
V-4
V-8
V-9
V-15
V-16
H/C TEMP REGULATOR
TO DRAIN
HEAT EXCHANGER
PUMP
FILL PUMP
OIL SUPPLY
F.L.R.
SATURABLE REACTOR
SPEED CONTROL
VEH. LOAD
70143
1264242

Figure 3



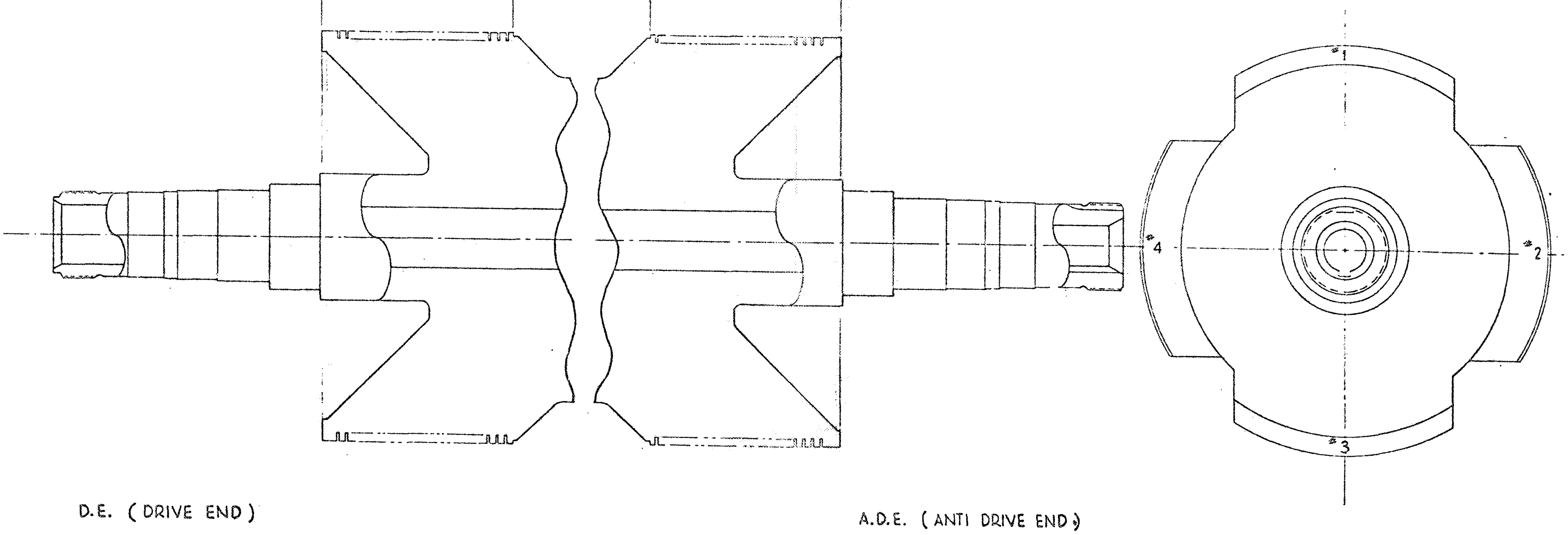
ALTERNATOR S/N 481490
PLOT OF ROTOR DEFORMATIONS - INCHES TIR
AT 23130 HOURS

Figure 4

Figure 4

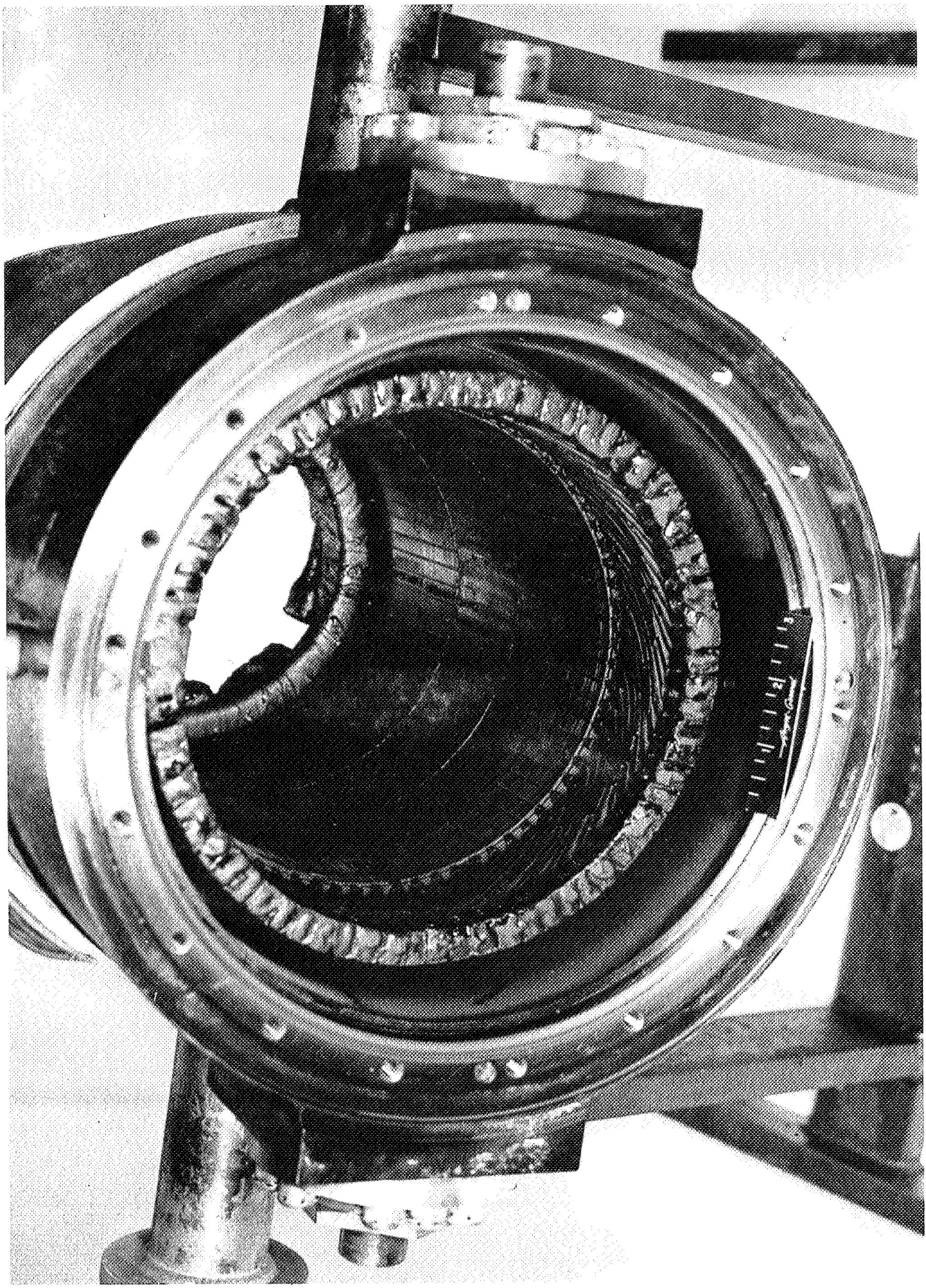
| TEST HRS | DIA'S | | |
|---|---|---|---|
| | 7.3800 | | |
| 0 | 7.3812 | 7.3806 | 7.3807 |
| 2553 | 7.3816 | 7.3813 | 7.3810 |
| 2430 | 7.3820 | 7.3810 | 7.3800 |
| 0 | 7.3812 | 7.3806 | 7.3805 |
| 2553 | 7.3817 | 7.3812 | 7.3807 |
| 23130 | 7.3823 | 7.3814 | 7.3803 |
| 0 | 7.3817 | 7.3808 | 7.3805 |
| 2553 | 7.3817 | 7.3806 | 7.3811 |
| 23130 | 7.3813 | 7.3812 | 7.3809 |

| TEST HRS | DIA'S | | |
|---|---|---|---|
| | 7.3800 | | |
| 0 | 7.3817 | 7.3812 | 7.3810 |
| 2553 | 7.3803 | 7.3811 | 7.3818 |
| 23130 | 7.3820 | 7.3810 | 7.3808 |
| 0 | 7.3810 | 7.3812 | 7.3821 |
| 2553 | 7.3812 | 7.3812 | 7.3817 |
| 23130 | 7.3822 | 7.3820 | 7.3820 |
| 0 | 7.3802 | 7.3810 | 7.3805 |
| 2553 | 7.3811 | 7.3815 | 7.3821 |
| 23130 | 7.3815 | 7.3812 | 7.3845 |



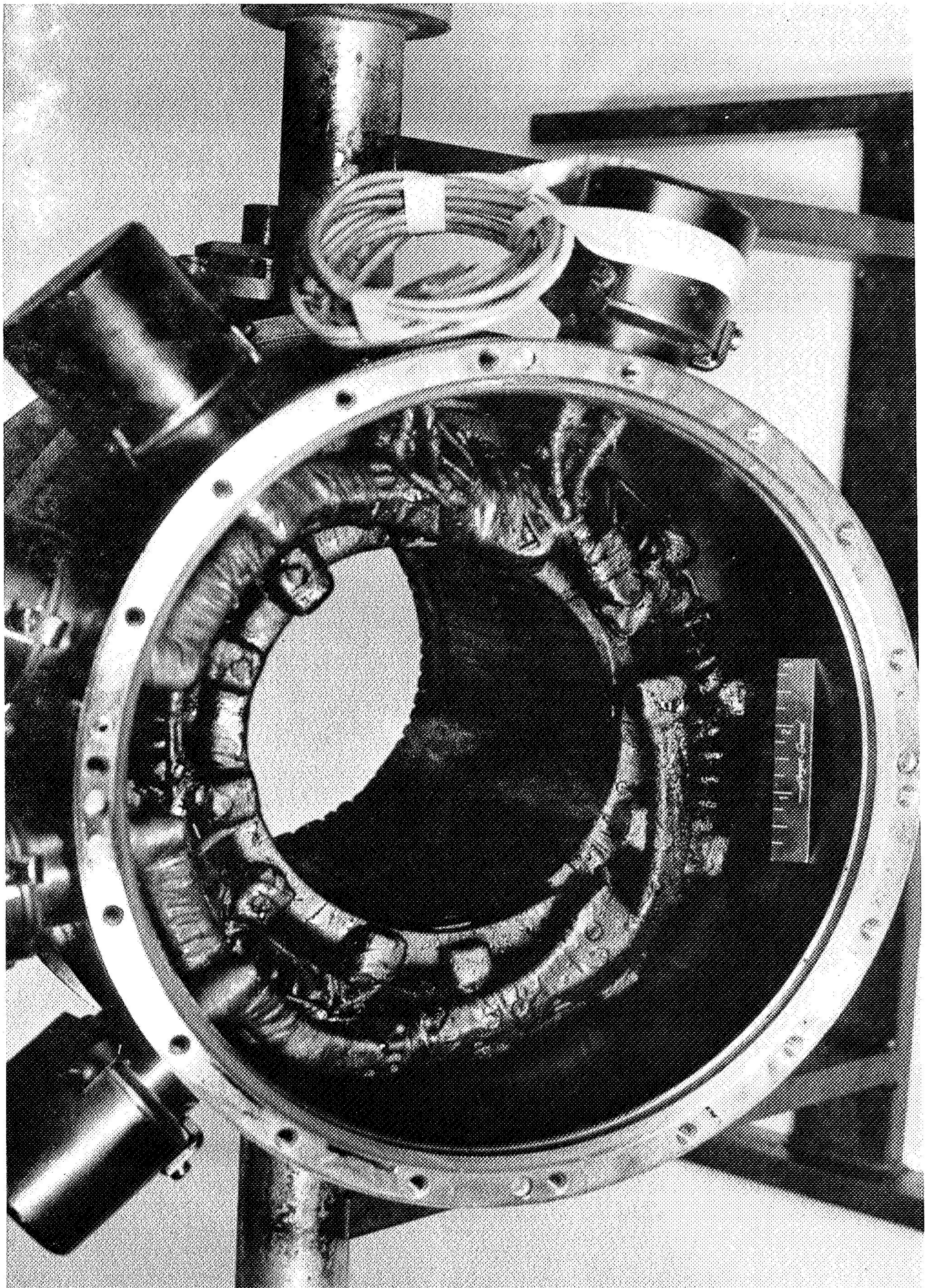
S/N 481490 ROTOR DIAMETER VERSUS OPERATING TIME

Figure 5



SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
VIEW OF DRIVE END OF THE STATOR

Figure 6



SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
VIEW OF ANTIDRIVE END OF THE STATOR

Figure 7

Aerojet-General®
CORPORATION

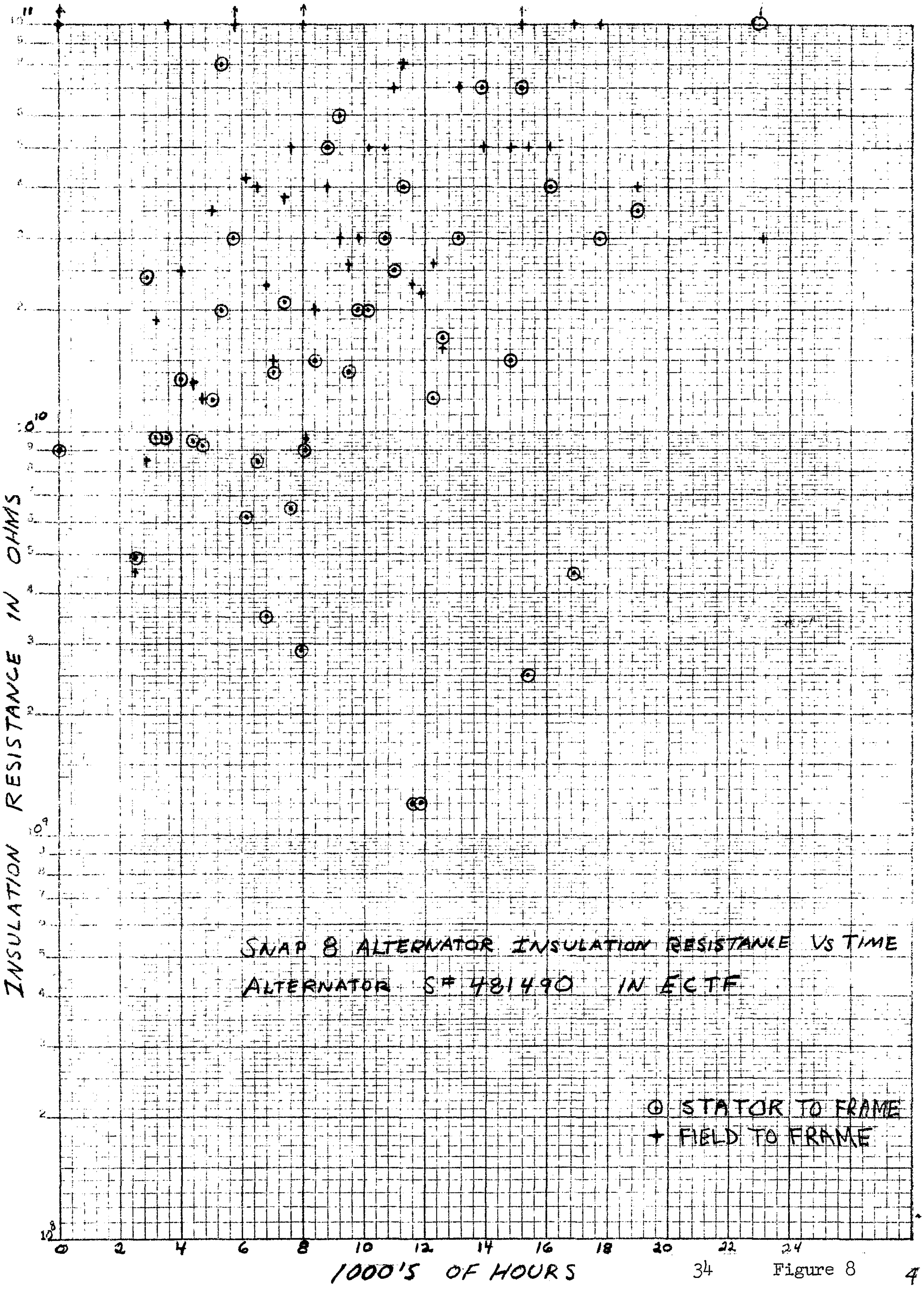
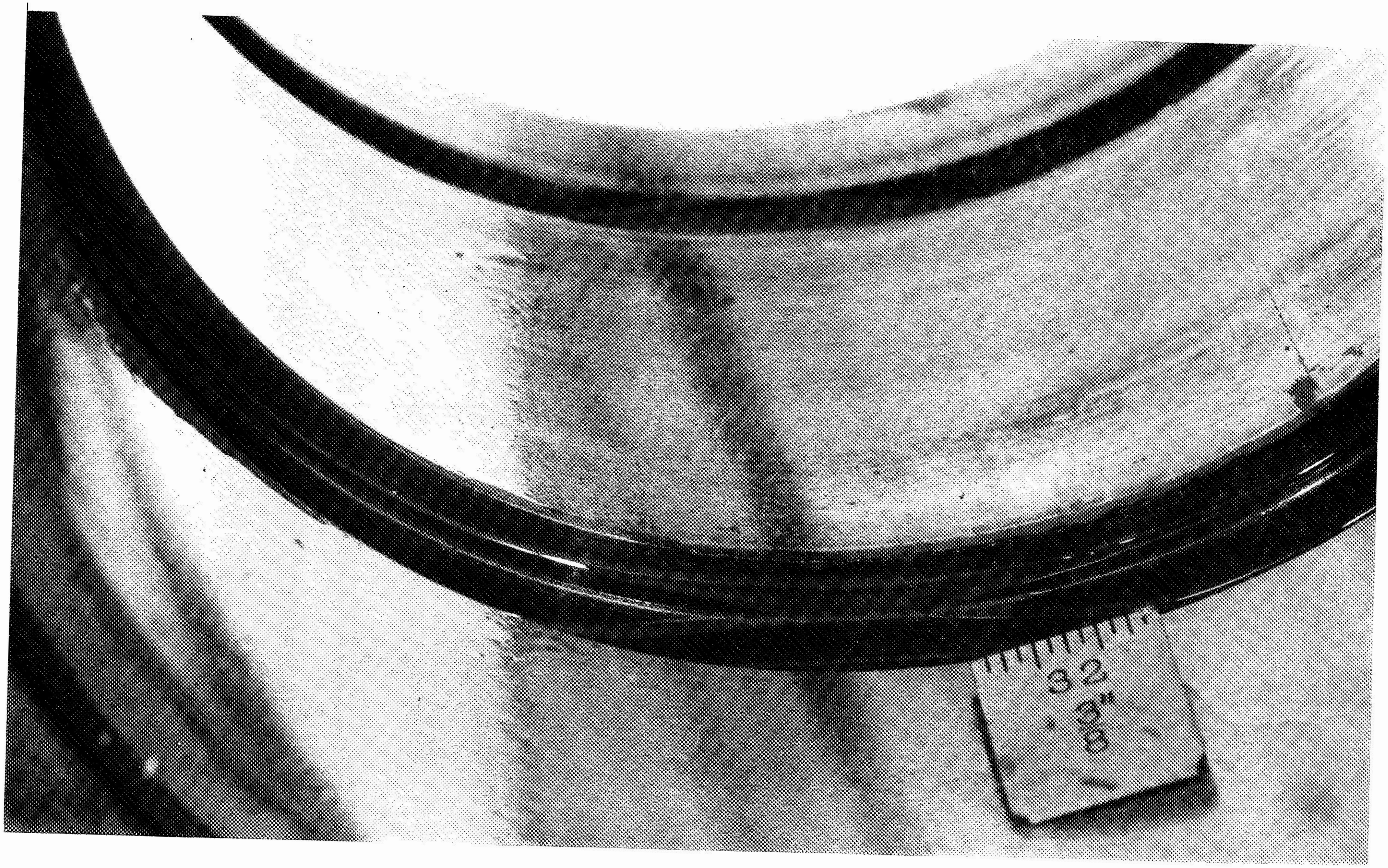


Figure 8



SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
CLOSE UP VIEW OF END BELL FOR D. E.
SHOWING VARNISH ACCUMULATION AT SLINGER DISCHARGE GROOVE

Figure 9

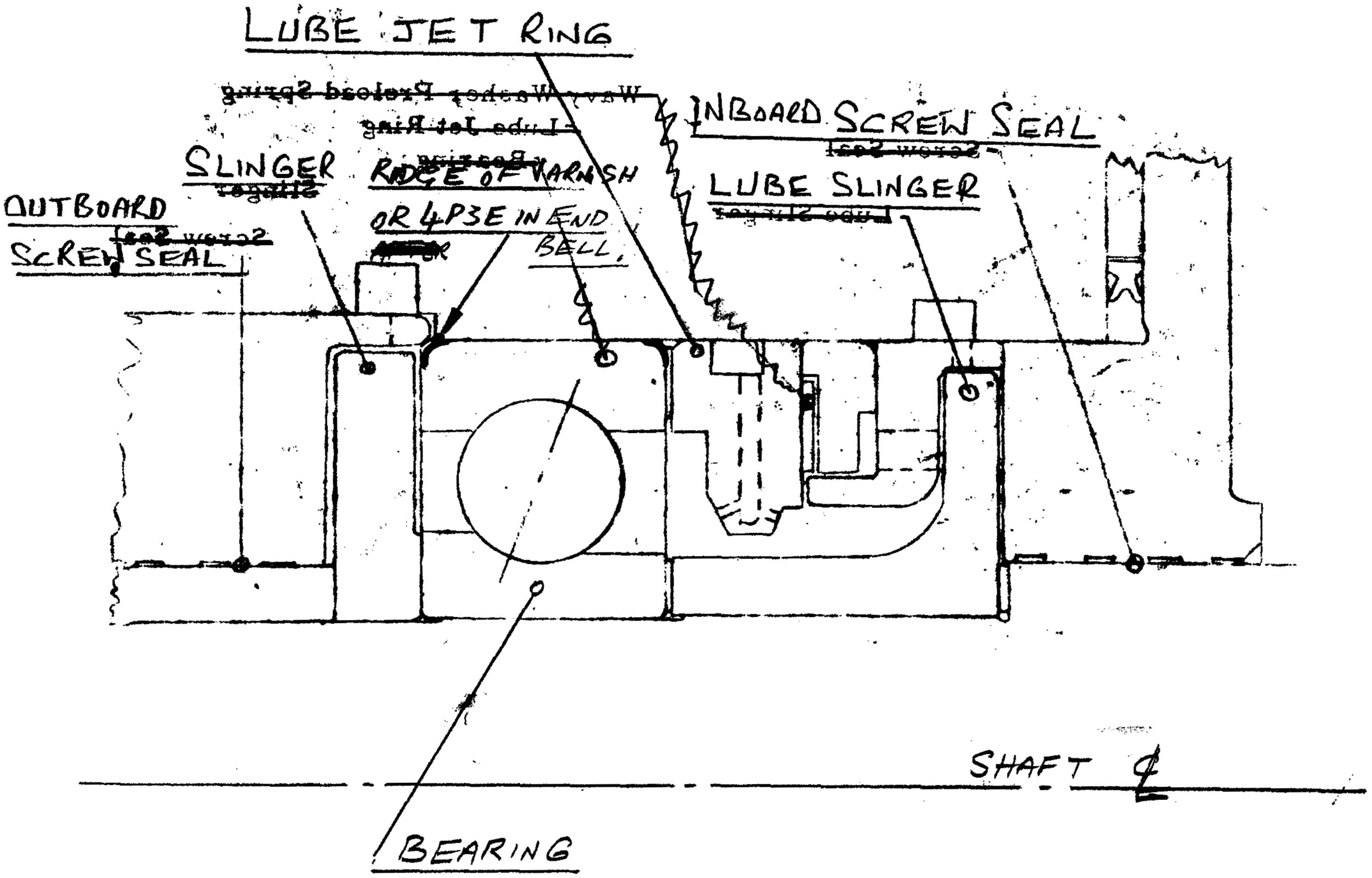
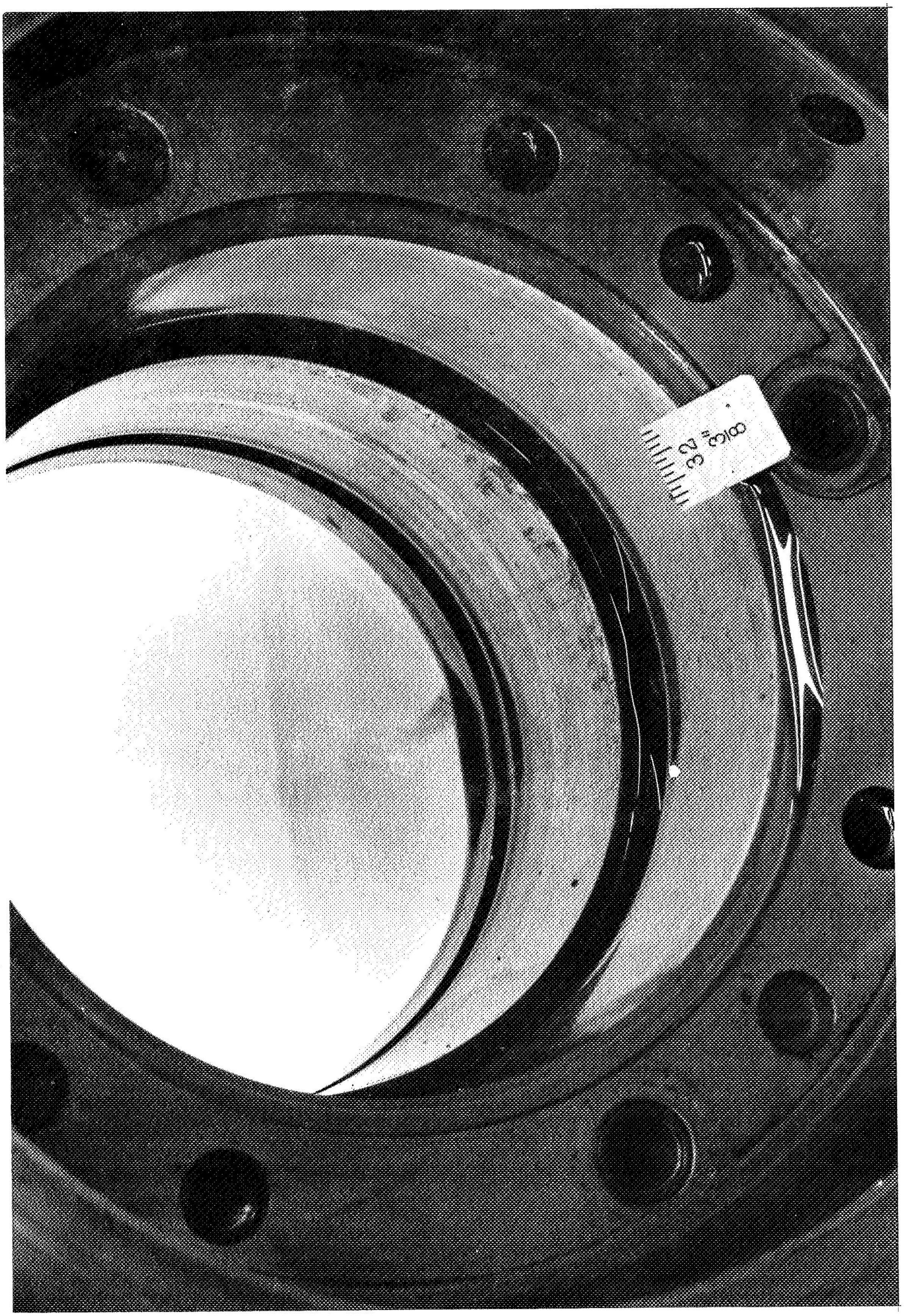


FIG 10 ALTERNATOR DRIVE END SHOWING LOCATION OF RIDGE OF VARNISH OR 4P3E RESIDUAL OBSERVED AFTER 23,130 HOUR ENDURANCE TEST.

Figure 10



SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
VIEW OF END BELL FOR [redacted]. AOC
SHOWING VARNISH ACCUMULATION AT SLINGER DISCHARGE GROOVE

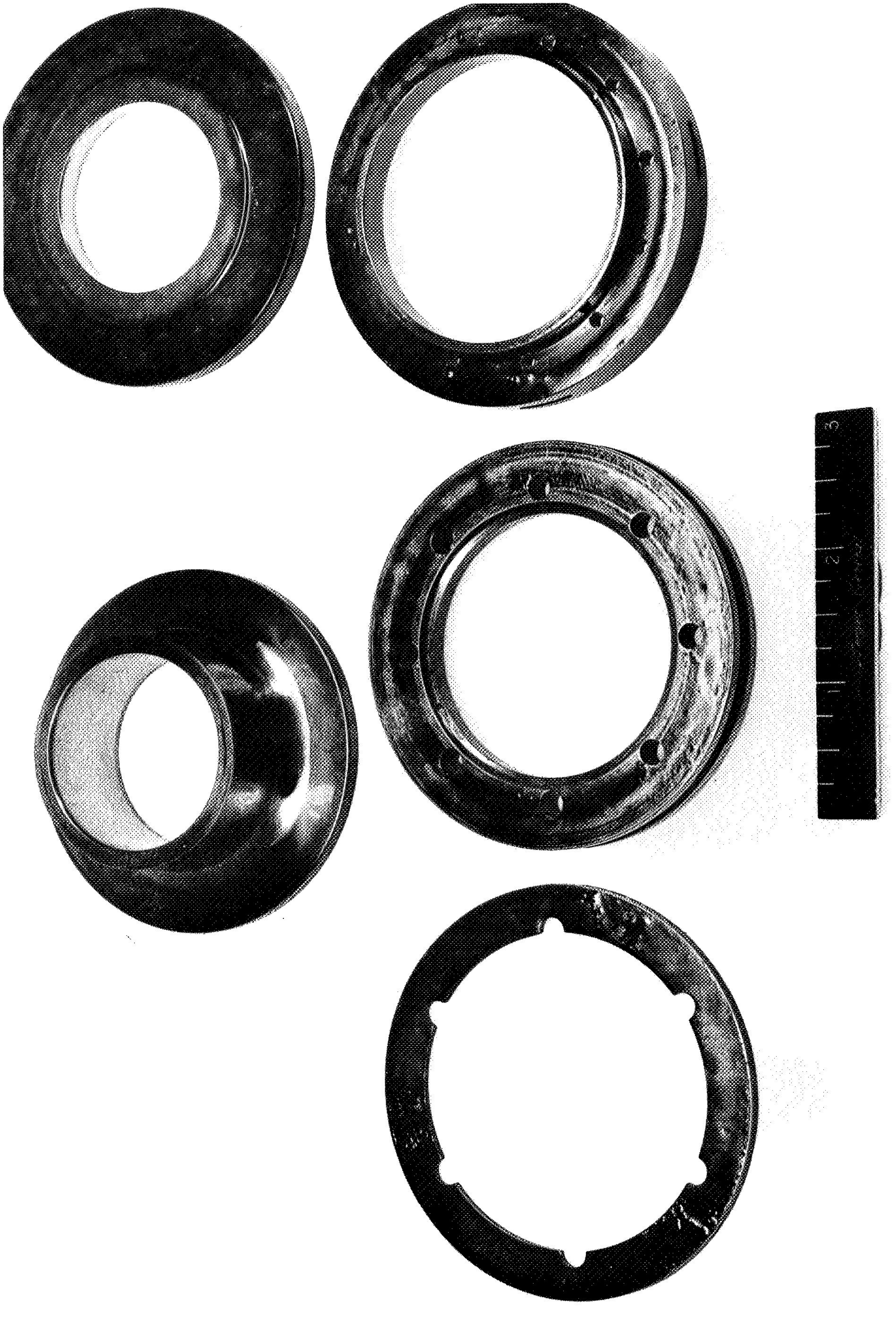
Figure 11

SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
INBOARD SCREW SEAL FOR D.E. SHOWING OUTBOARD FACE AND DAMAGED THREADS

Figure 12

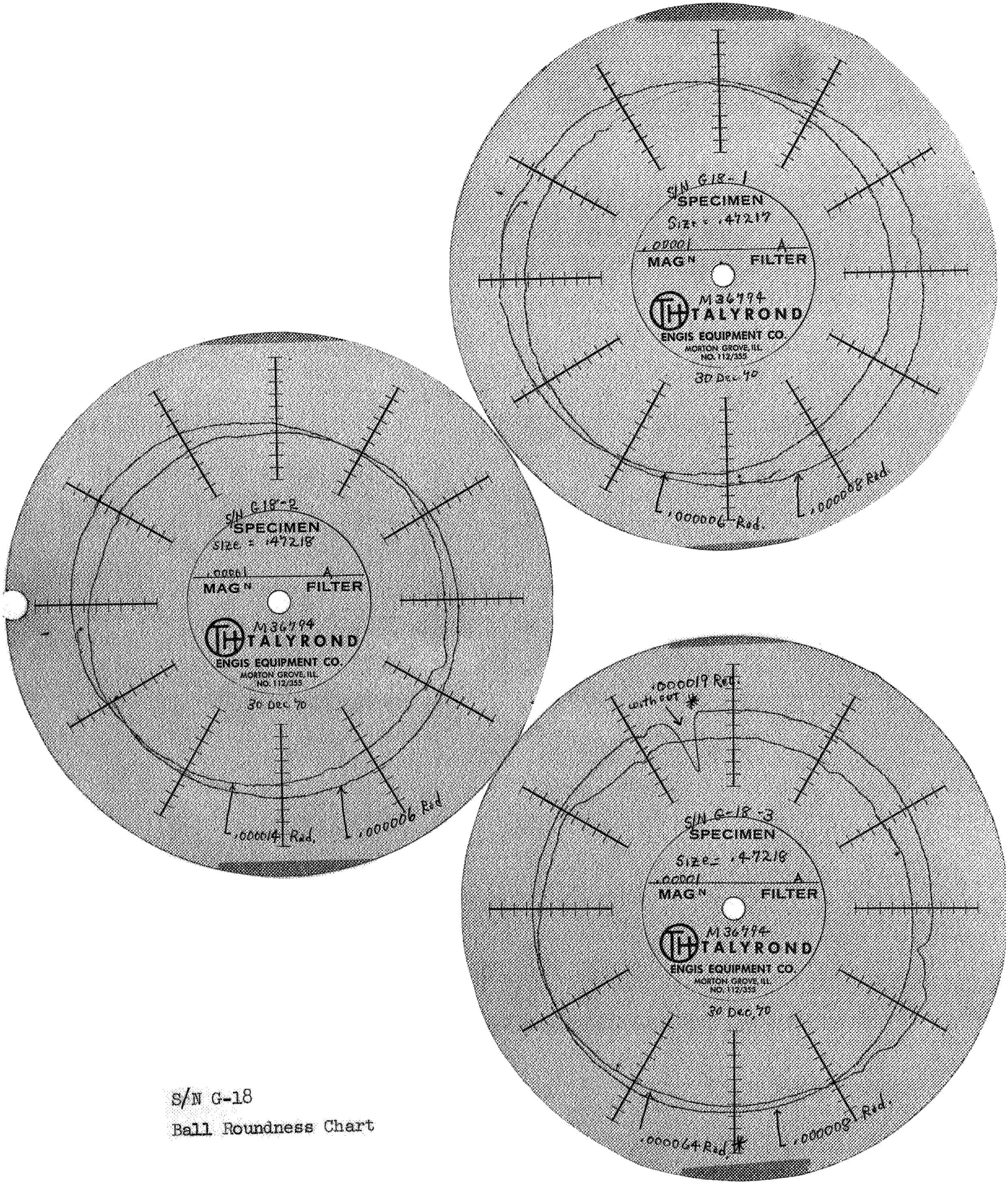
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
SLINGERS AND OIL RINGS FOR D. E.

Figure 13



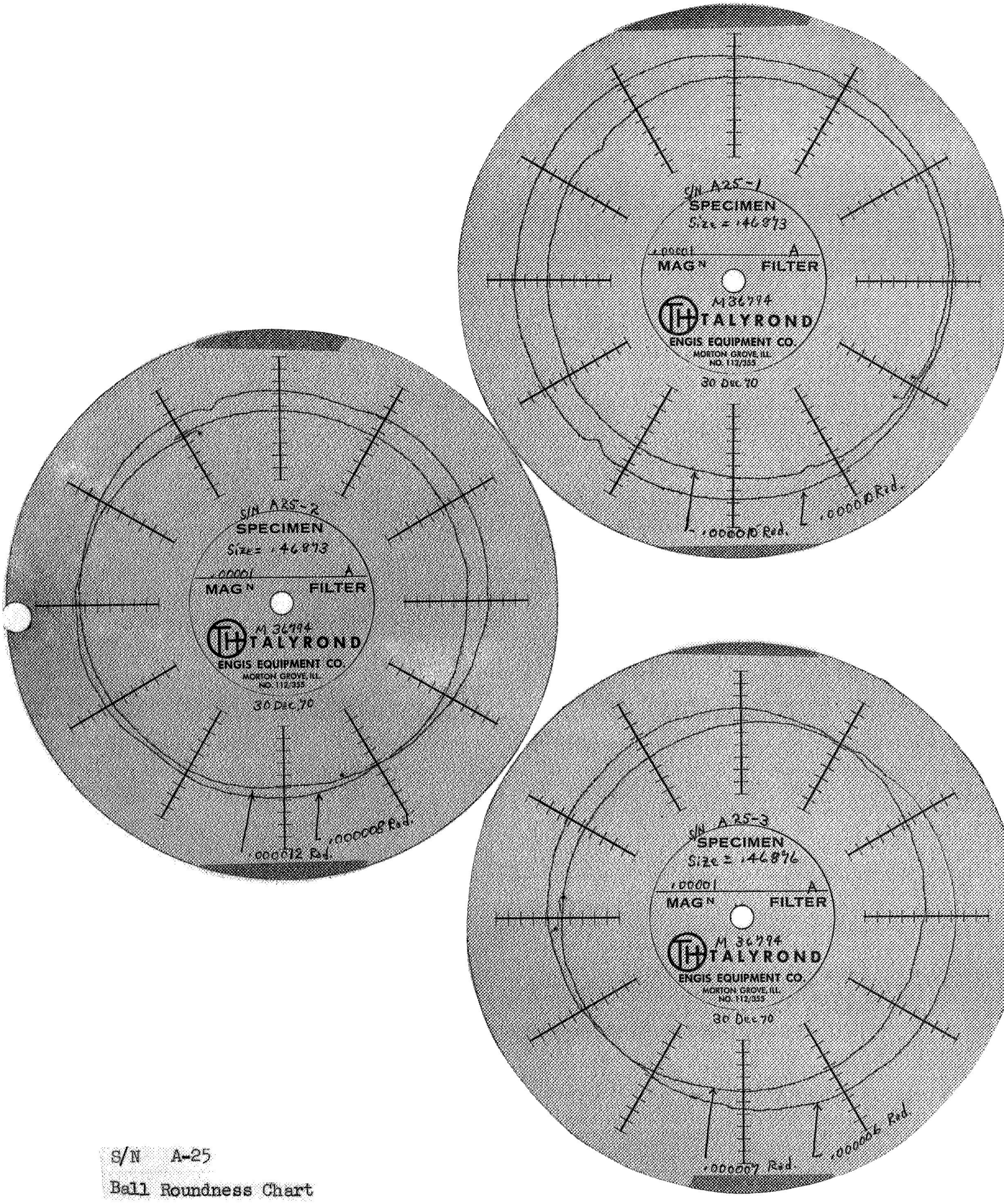
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
SLINGERS AND OIL RINGS FOR A. D. E.

Figure 14



S/N G-18
Ball Roundness Chart

Figure 15



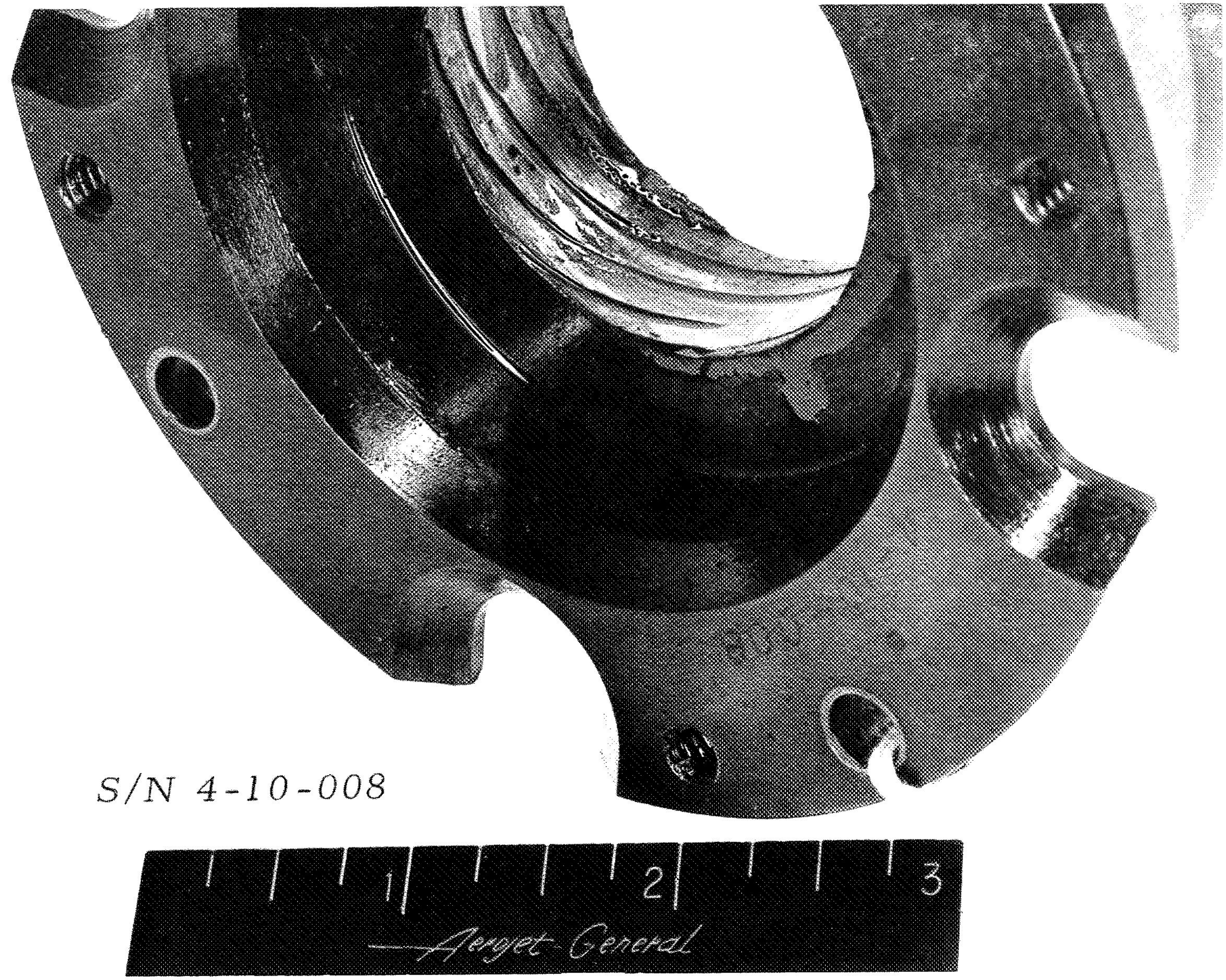
S/N A-25

Ball Roundness Chart

Figure 16

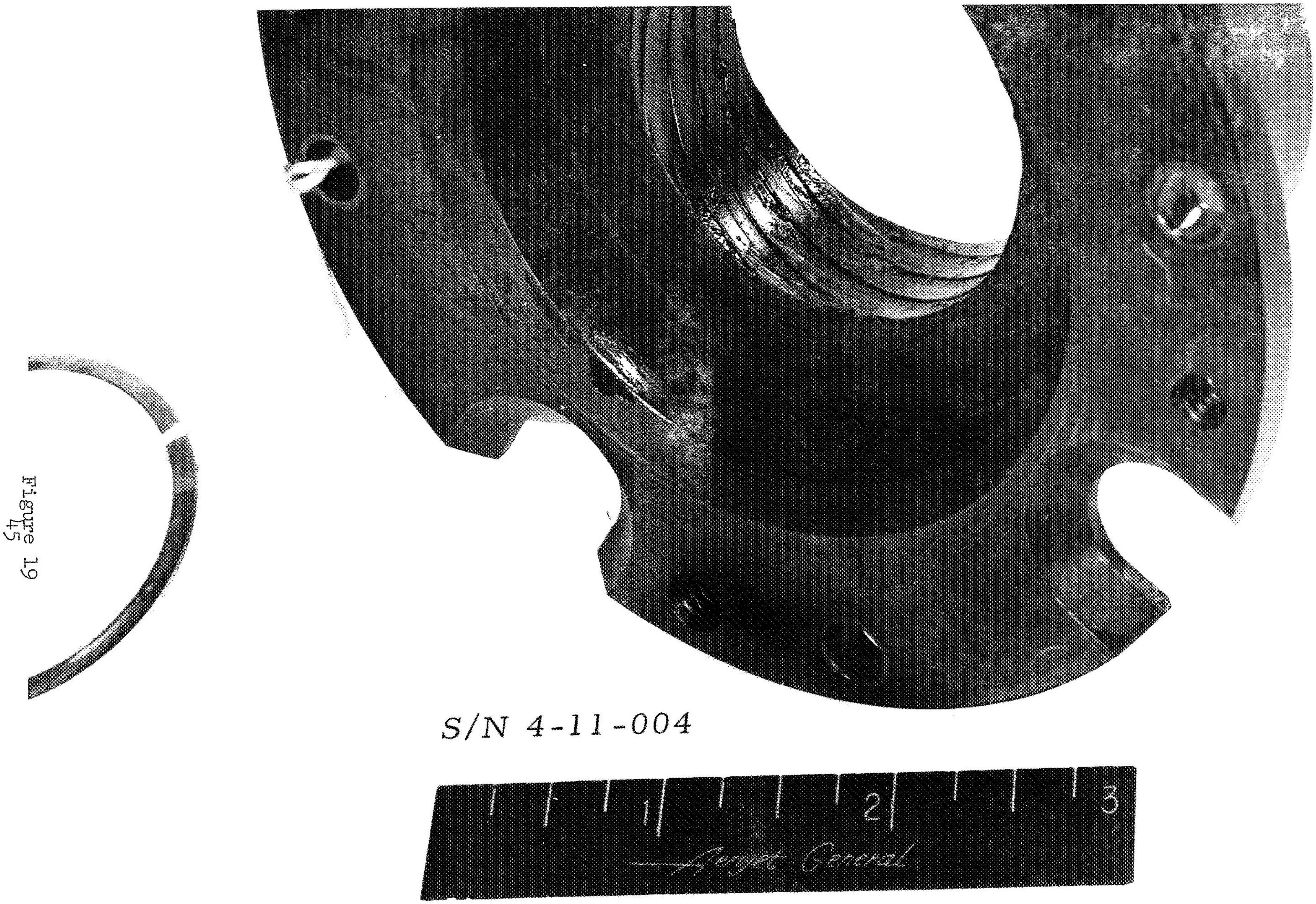
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
INBOARD SCREW SEAL FOR D.E. SHOWING VARNISH BUILDUP ON OUTBOARD FACE

Figure 17



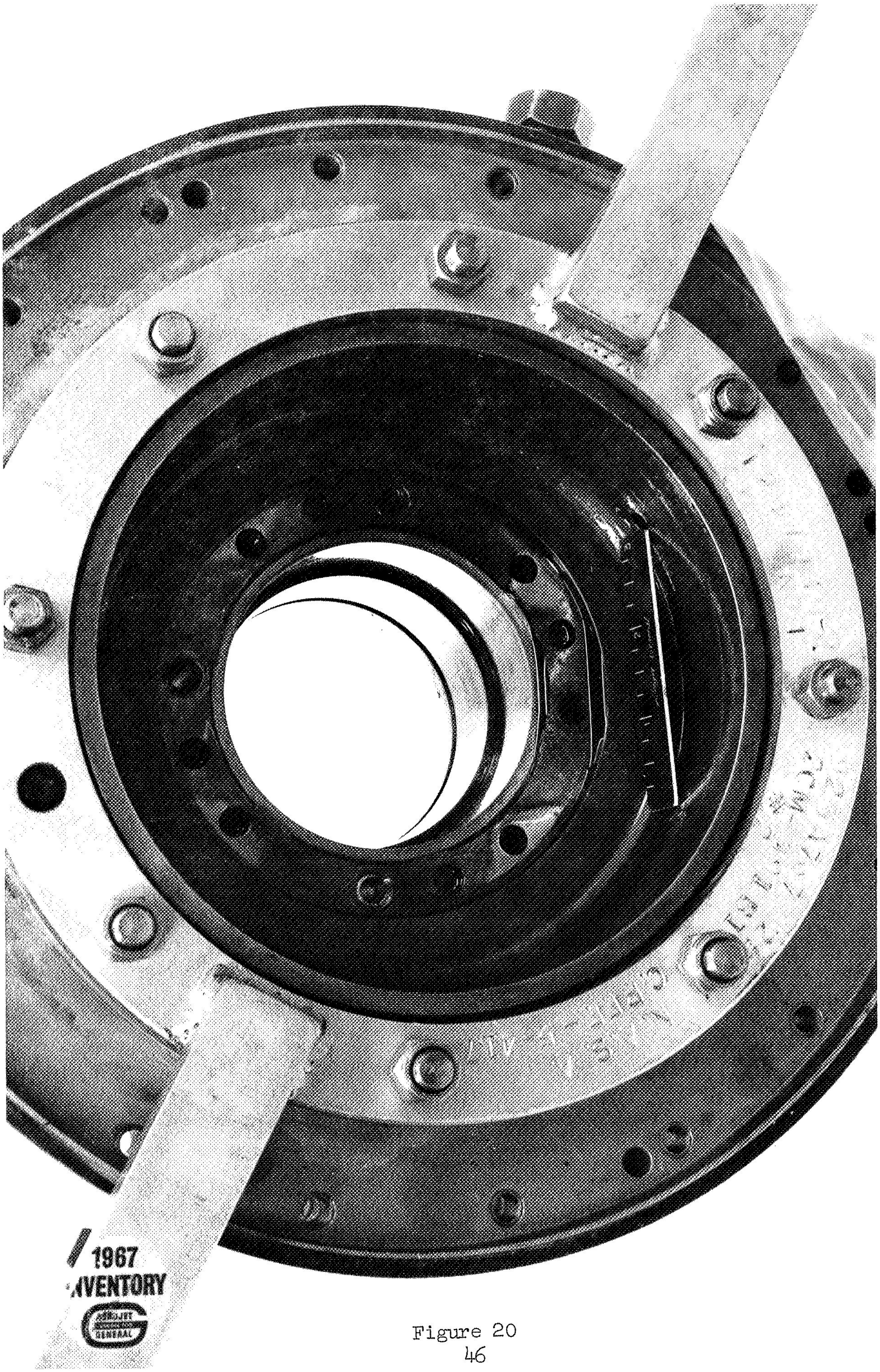
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
OUTBOARD SCREW SEAL FOR D.E.

Figure 18



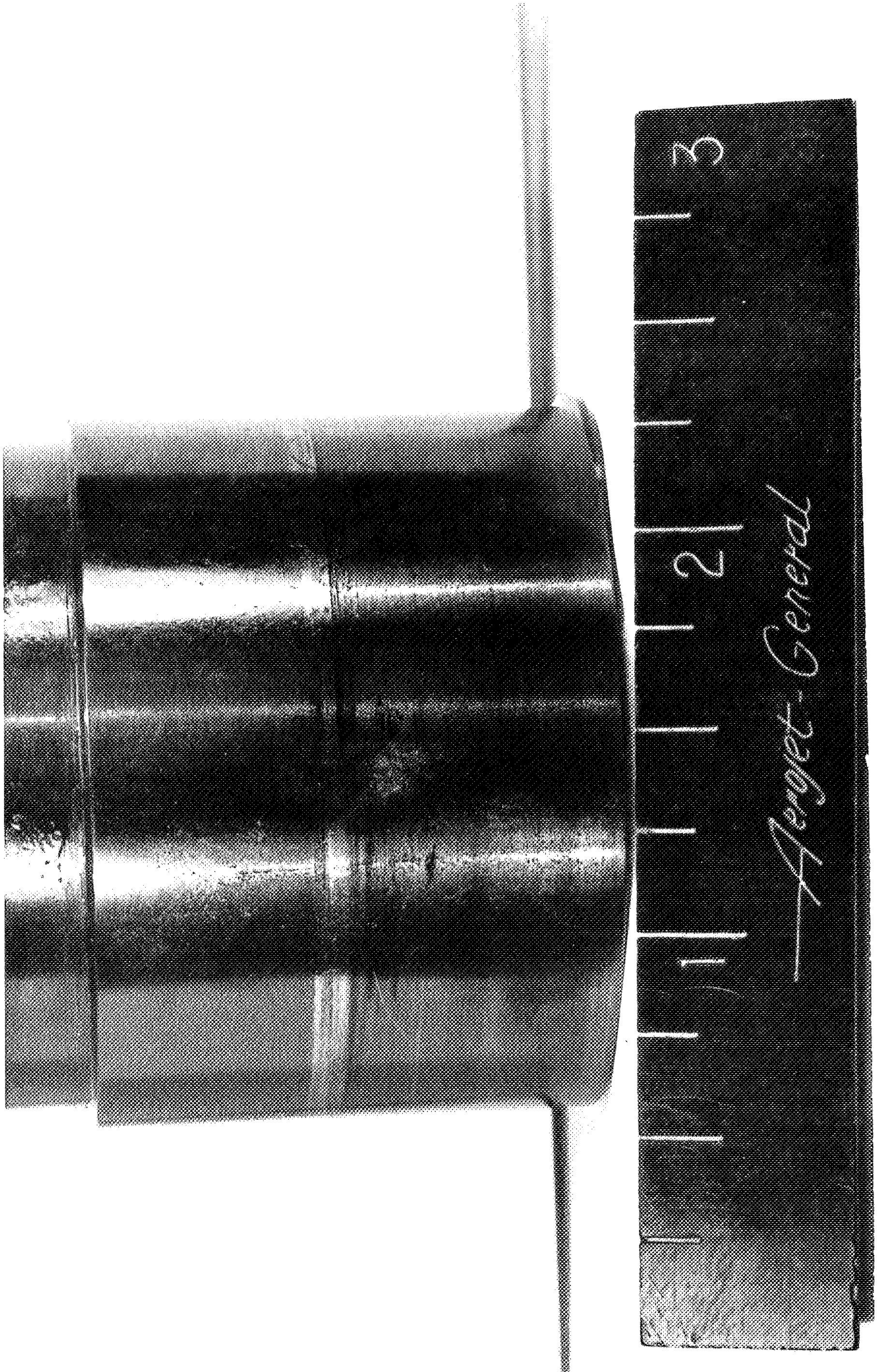
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
A. D. E. OUTBOARD SCREW SEAL SHOWING DAMAGED THREADS

Figure 19



SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
END BELL FOR D.E.

Figure 20



SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
SHAFT SLEEVE FOR A.D.E. OUTBOARD SCREW SEAL SHOW LIGHT CONTACT DAMAGE

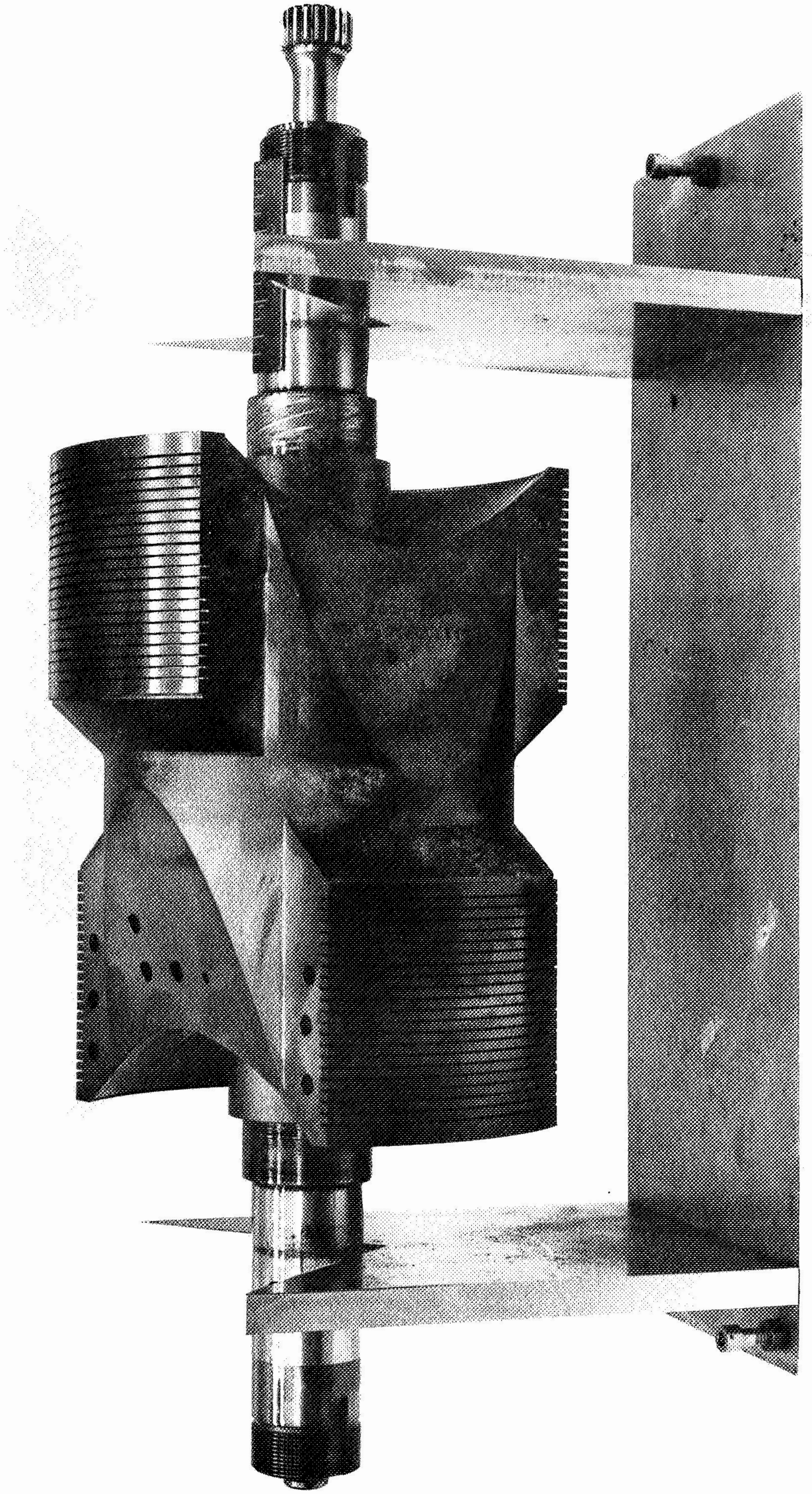
Figure 21

SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
SHAFT SLEEVE FOR D.E. OUTBOARD SCREW SEAL SHOWING DAMAGE

Figure 22

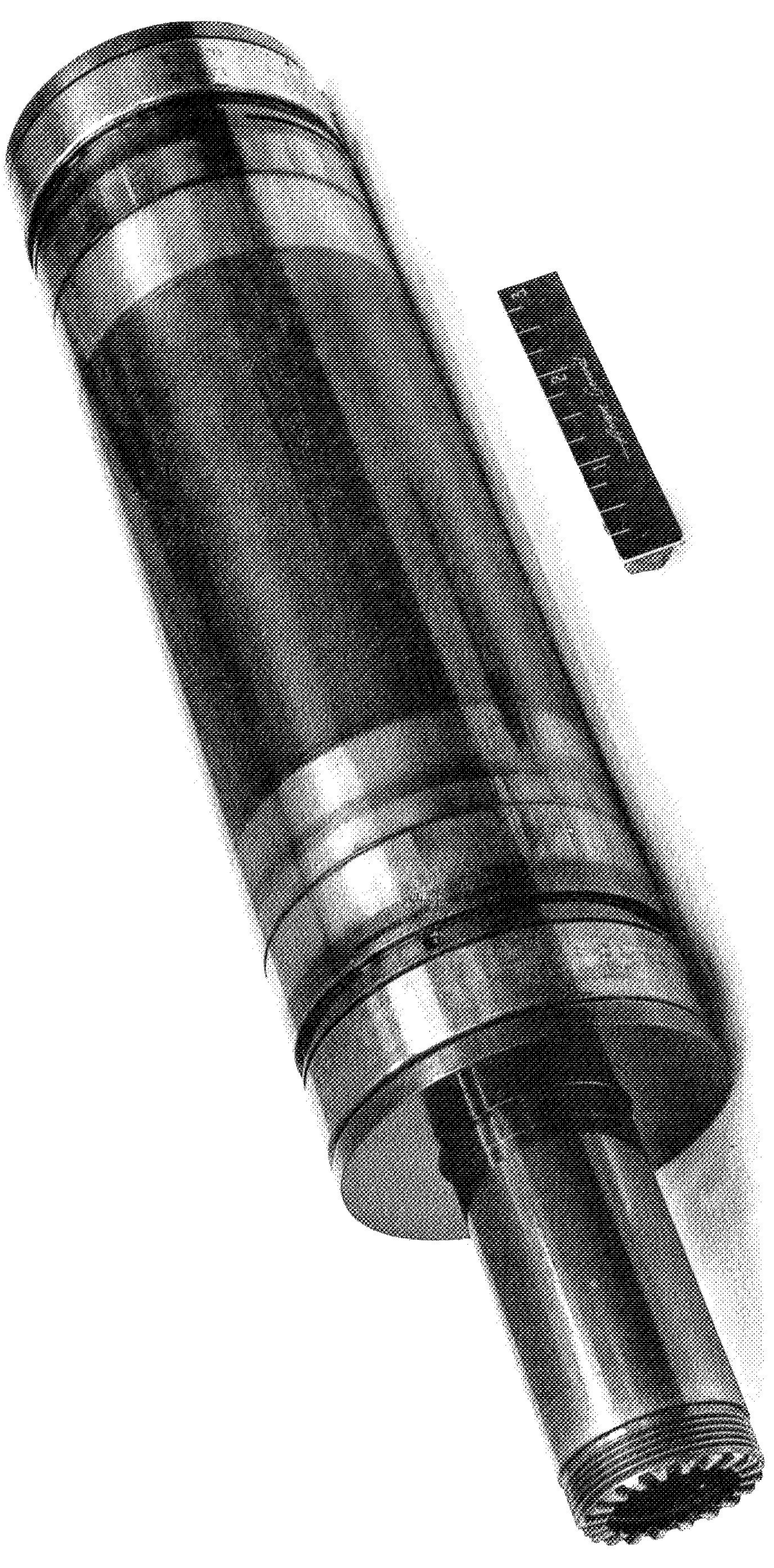
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
CLOSE UP VIEW OF ROTOR DAMAGE

Figure 23



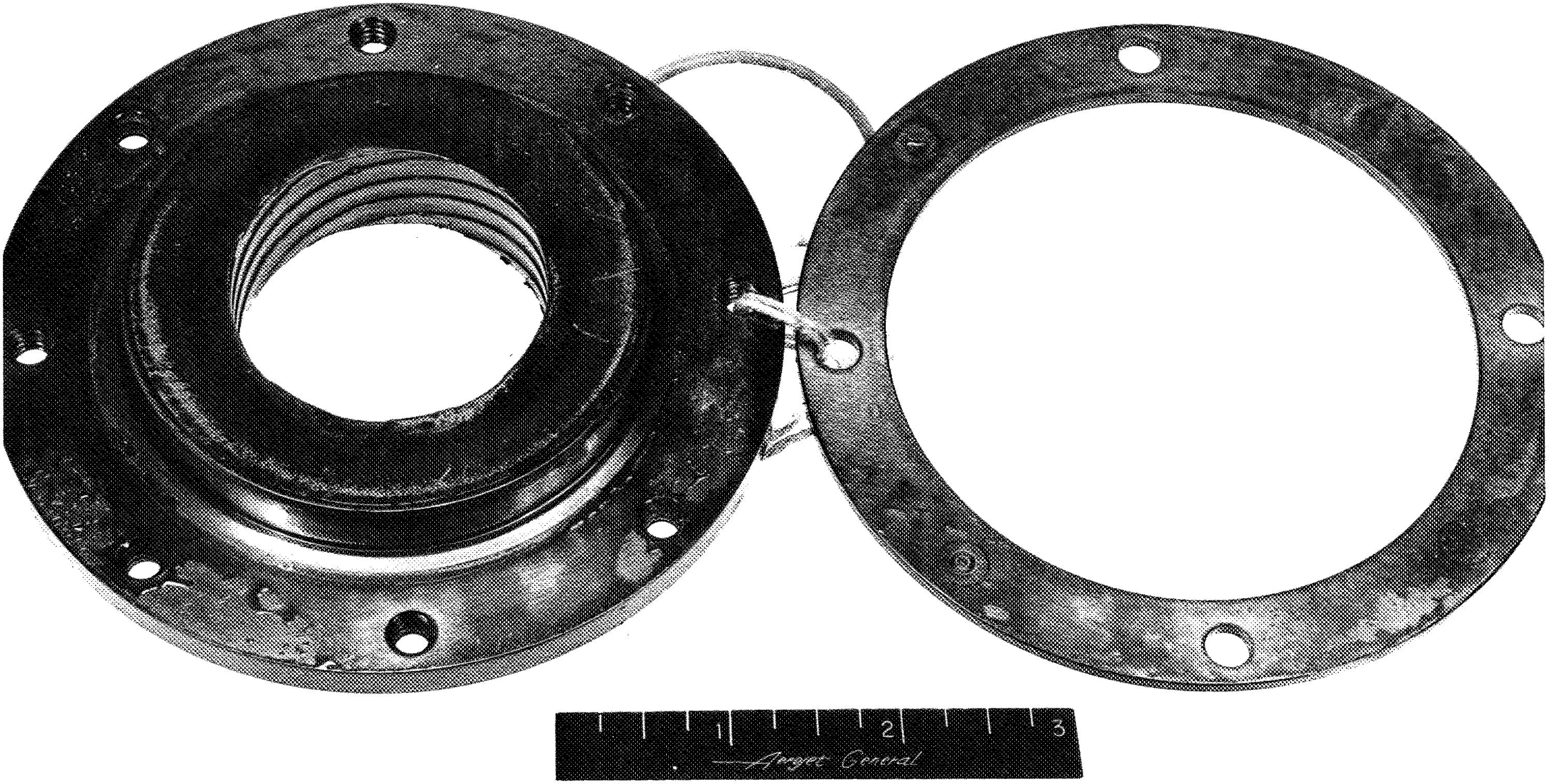
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF - ROTOR

Figure 24



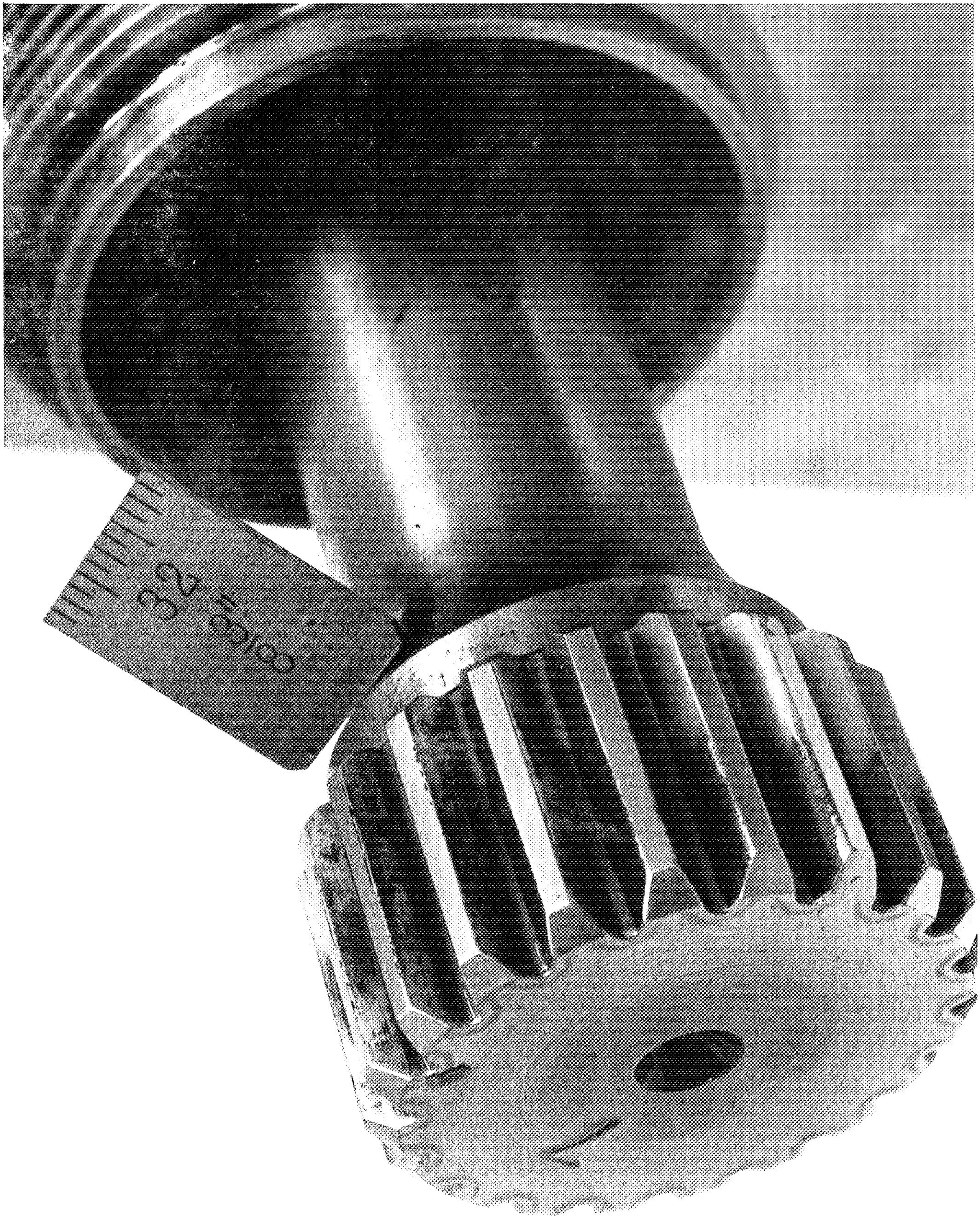
SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS - VIEW OF ROTOR

Figure 25



SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
INBOARD SCREW SEAL FOR D.E. SHOWING VARNISH BUILDUP
ON OUTBOARD FACE AND DAMAGED THREADS
A.D.E.

Figure 26

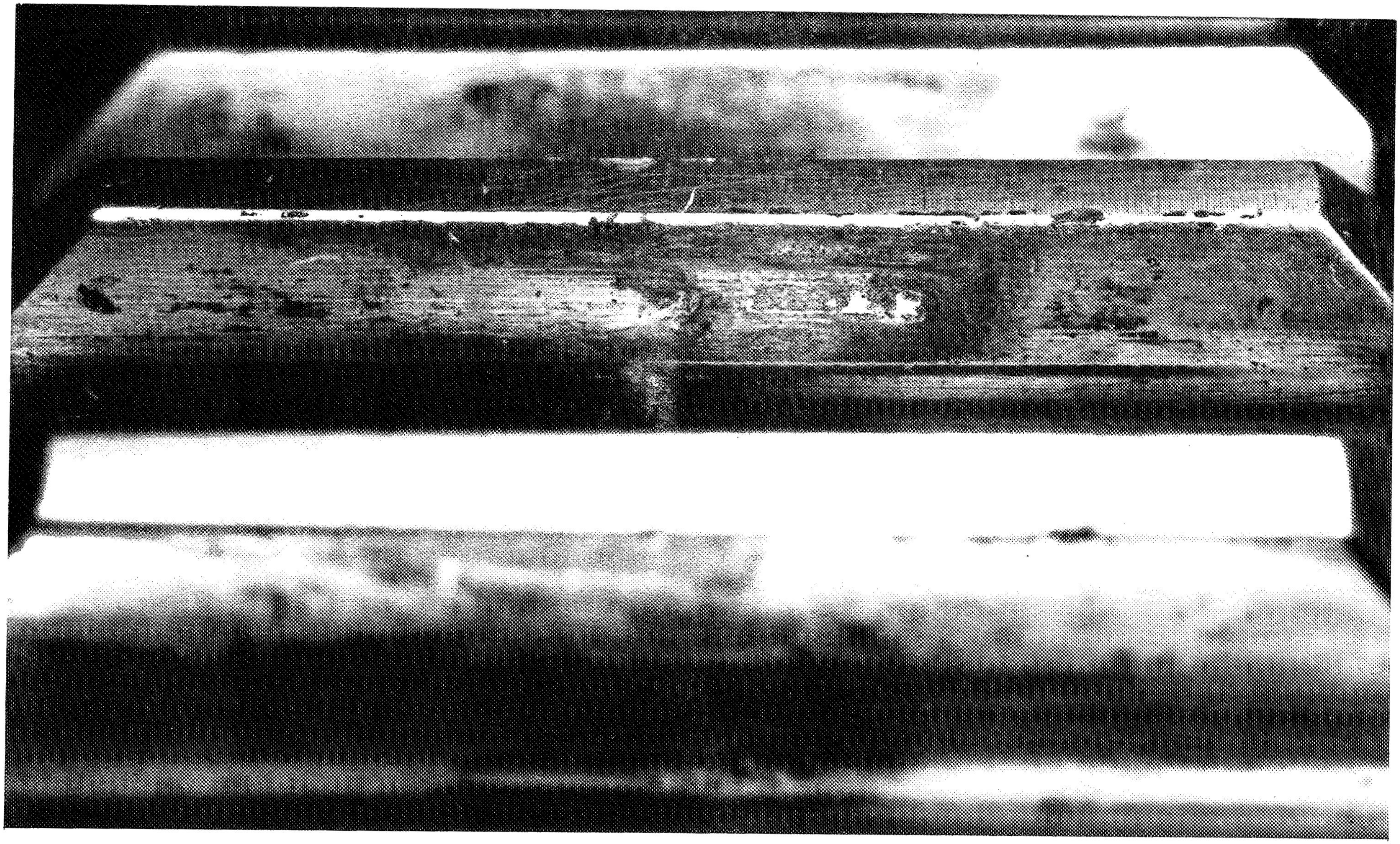


SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
VIEW OF SPLINE TEETH ON QUILL SHAFT

Figure 27

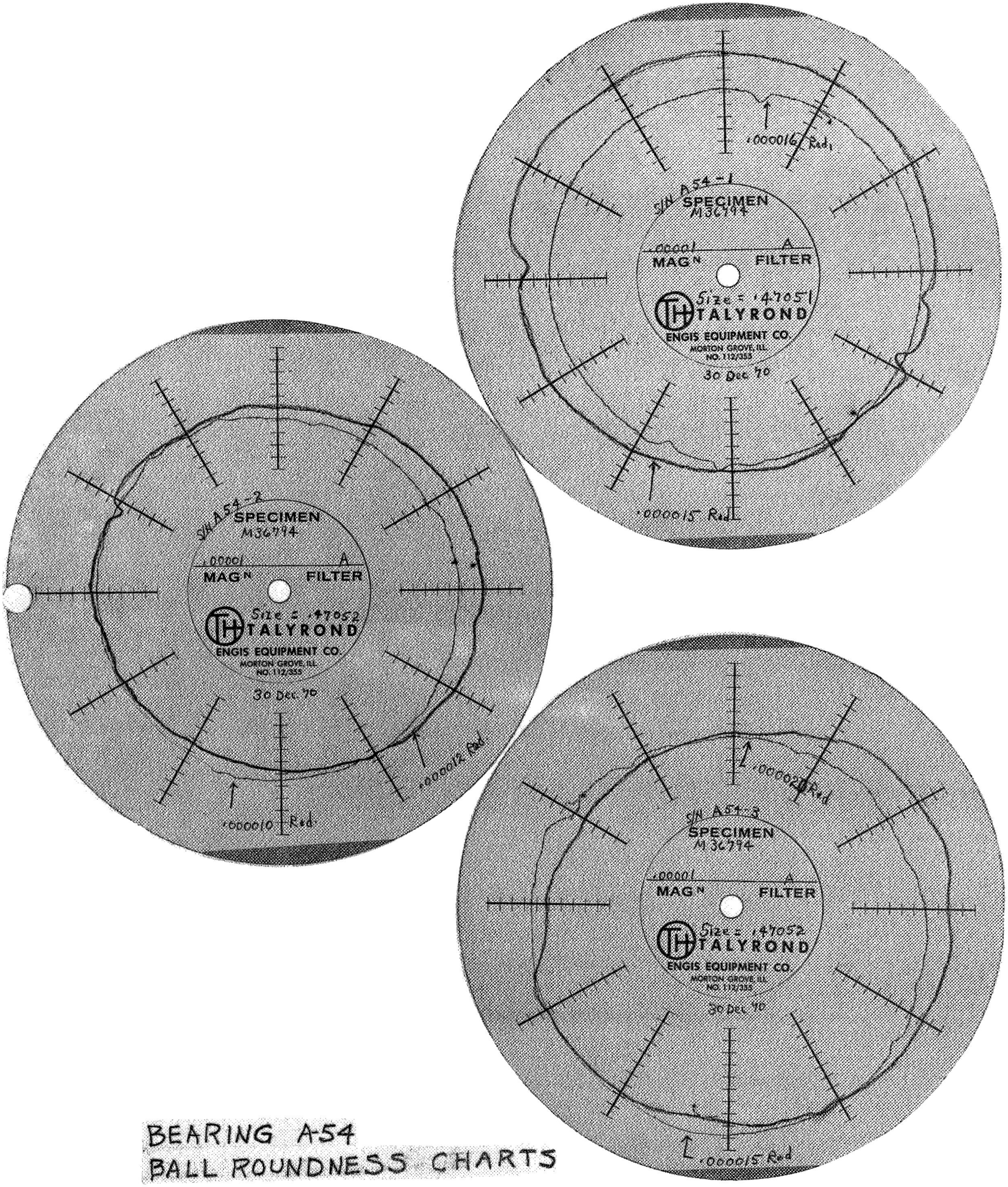
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
SPLINE TOOTH WEAR

Figure 28



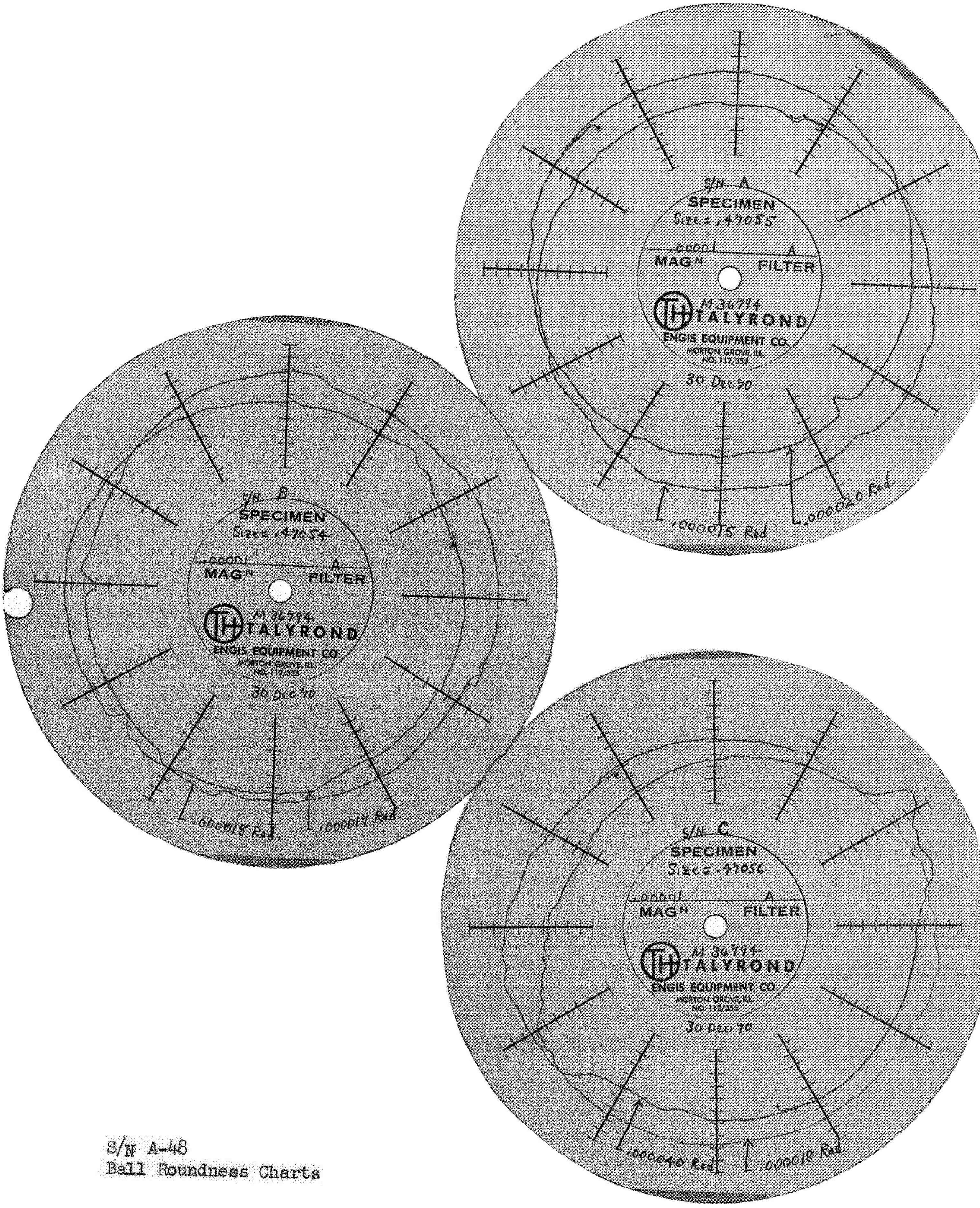
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
SPLINE TOOTH WEAR

Figure 29



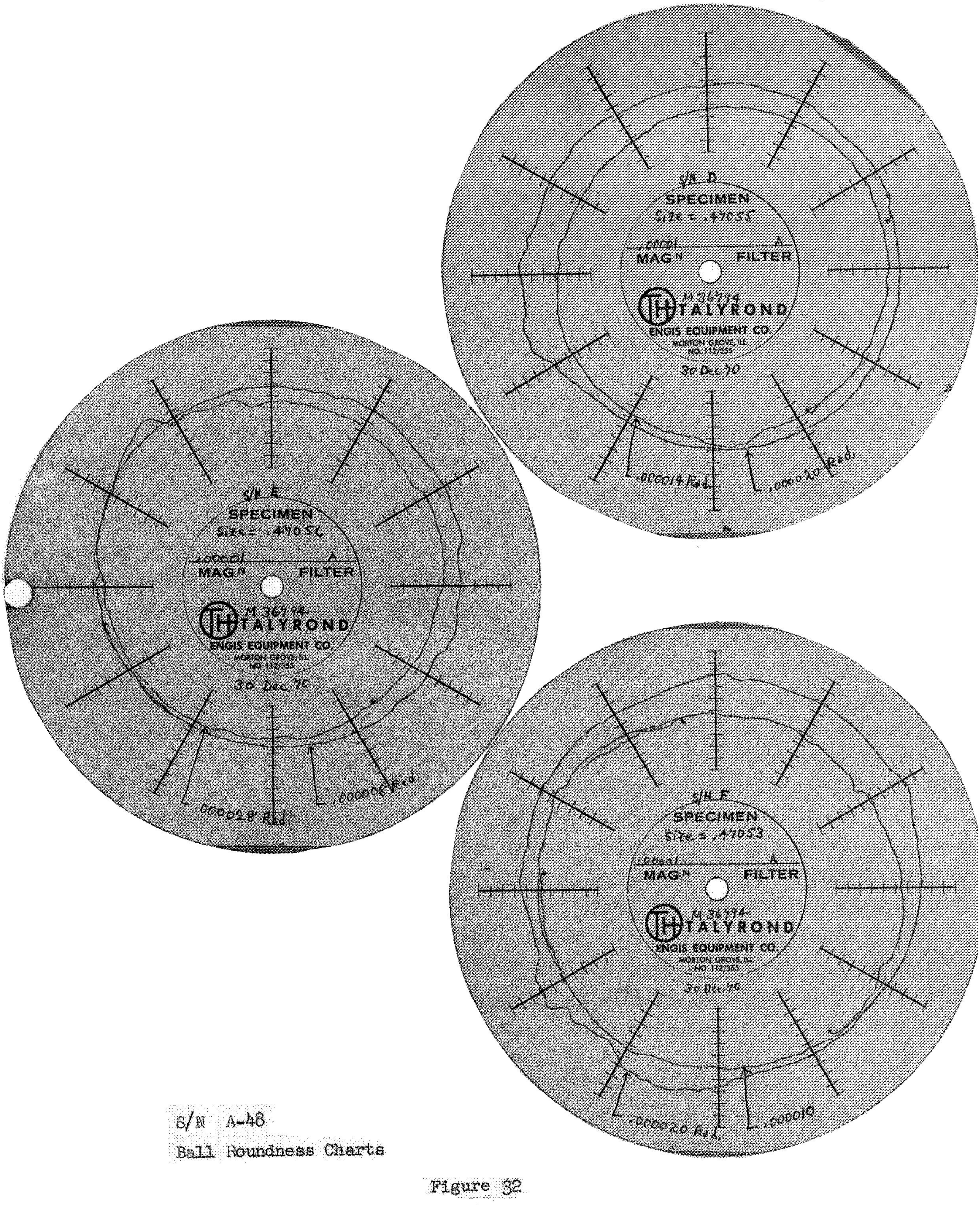
BEARING A-54
BALL ROUNDNESS CHARTS

Figure 30



S/N A-48
Ball Roundness Charts

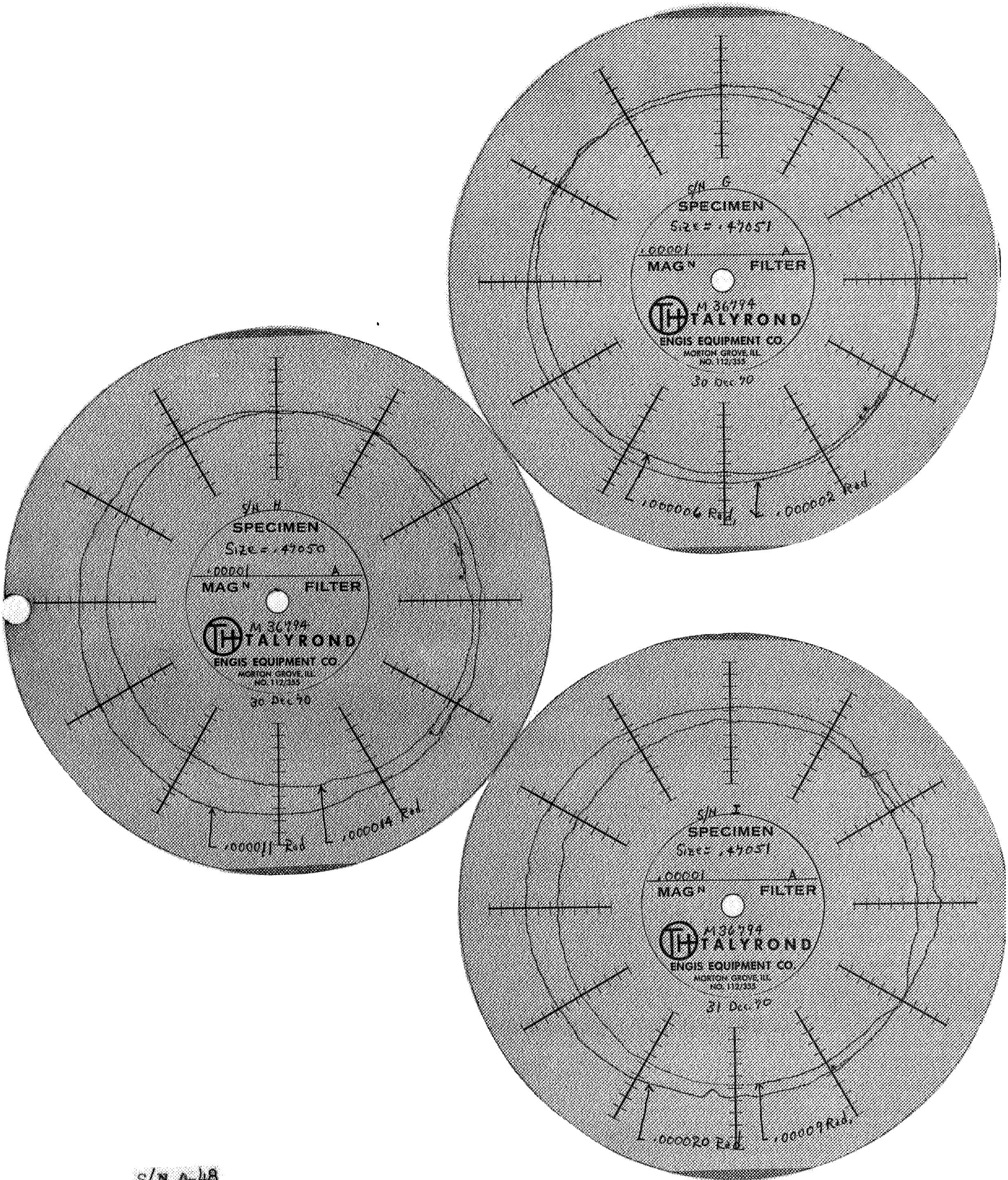
Figure 31



S/N A-48

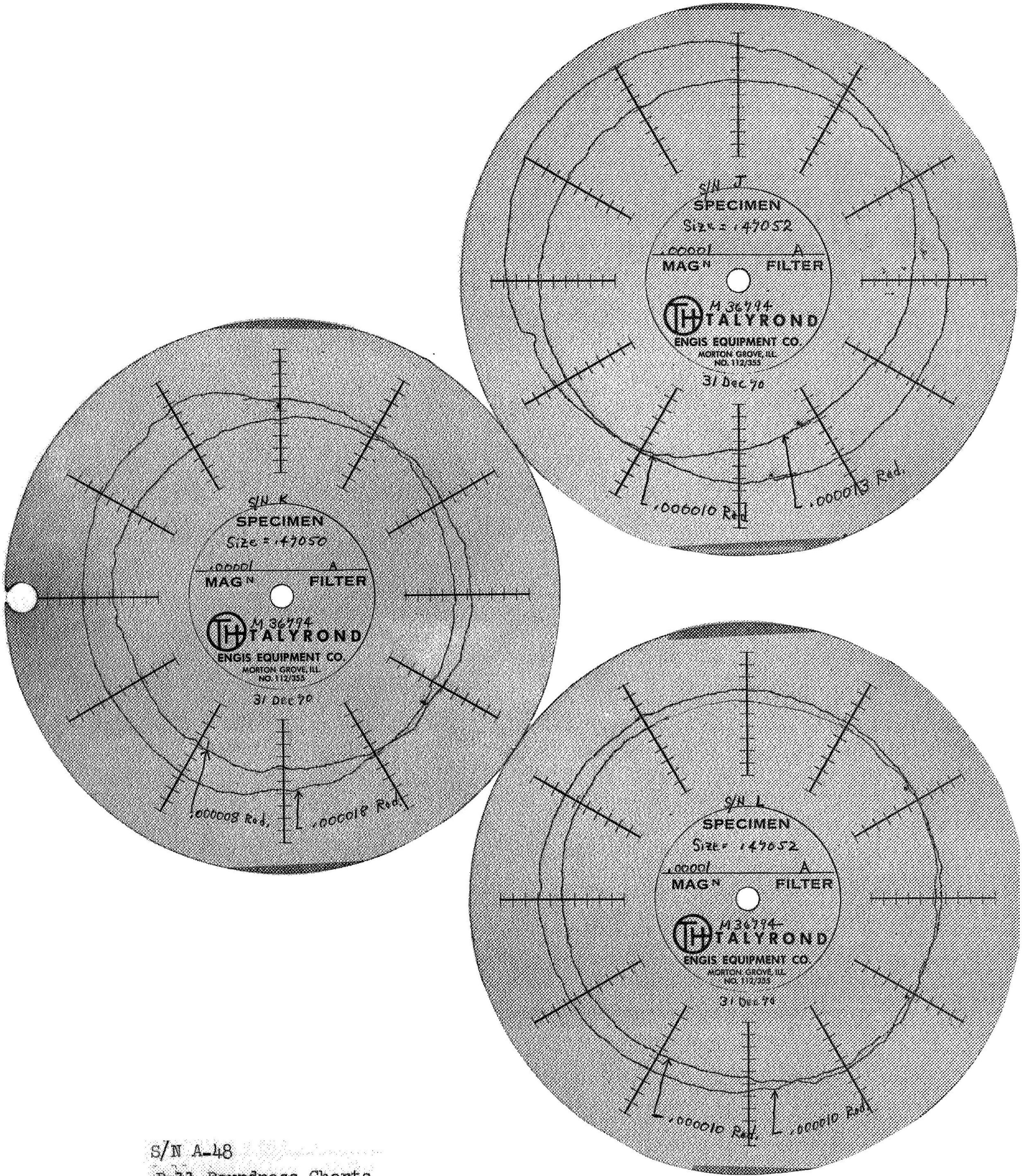
Ball Roundness Charts

Figure 32



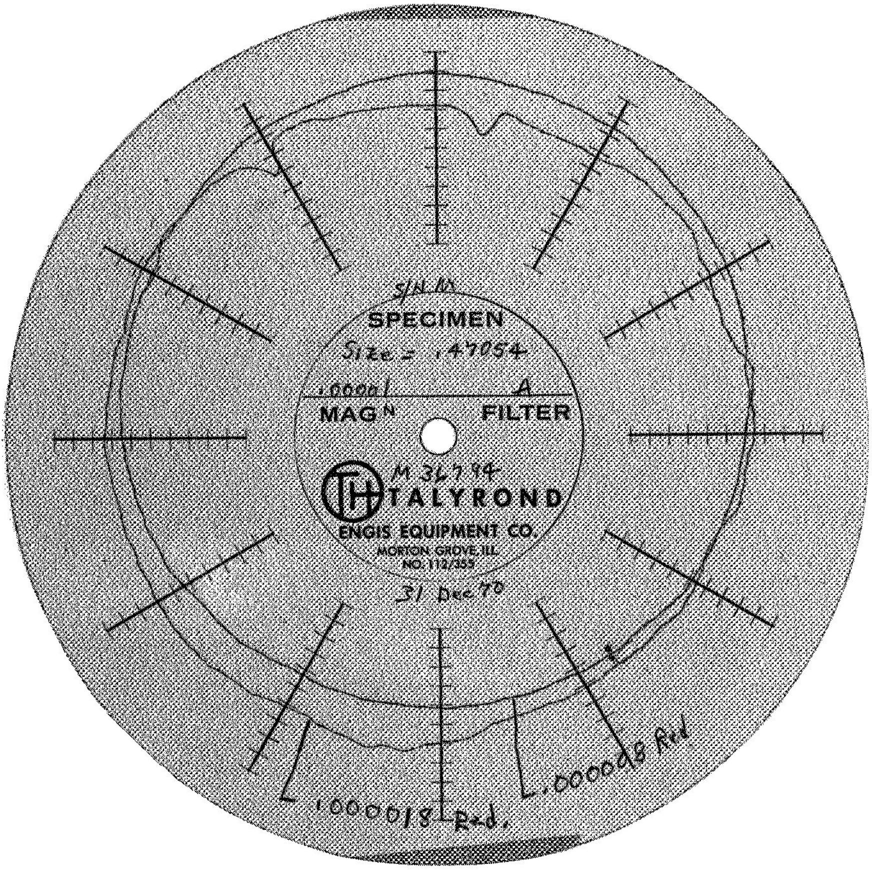
S/N A-48
Ball Roundness Charts

Figure 33



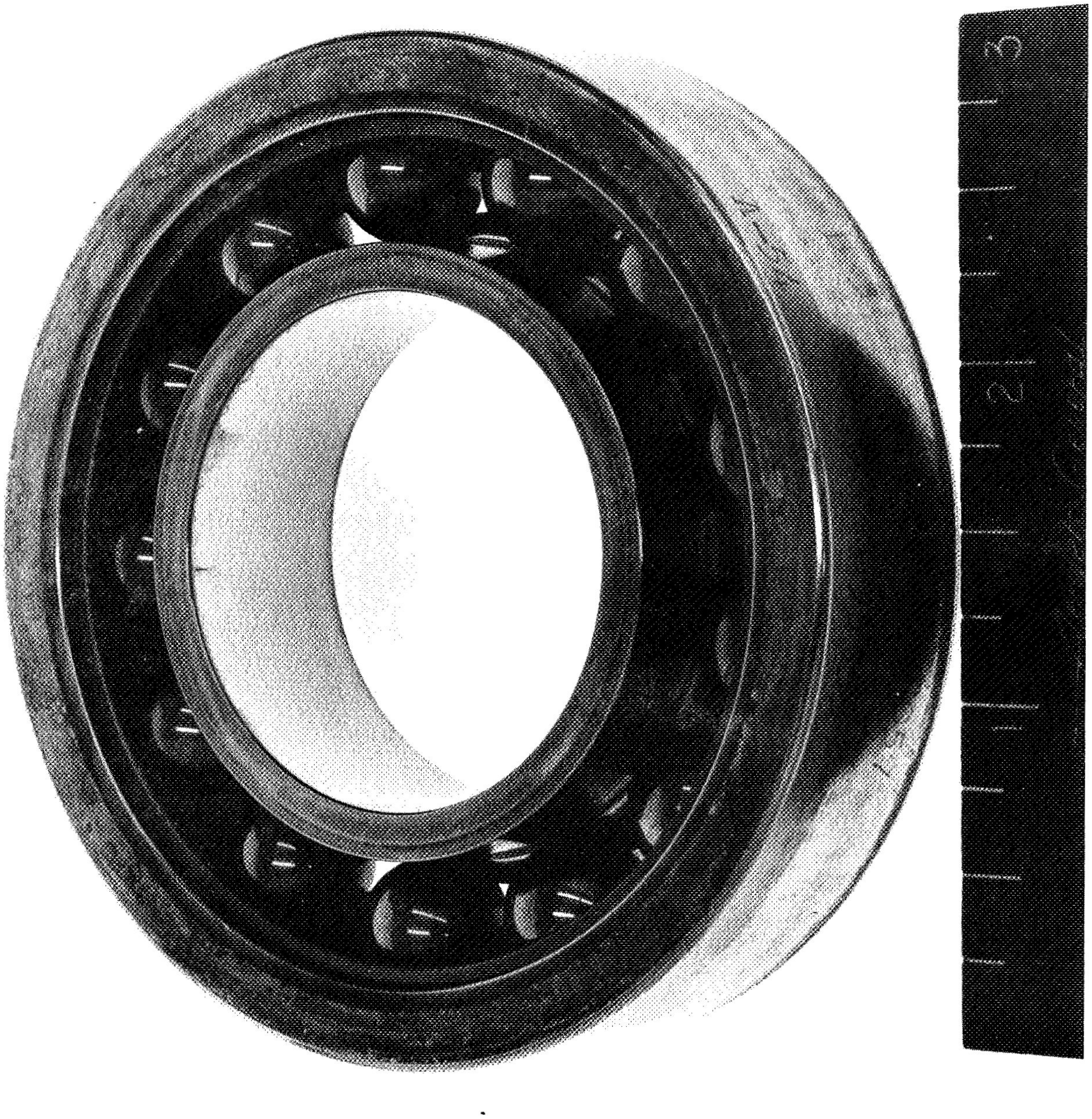
S/N A-48
Ball Roundness Charts

Figure 34



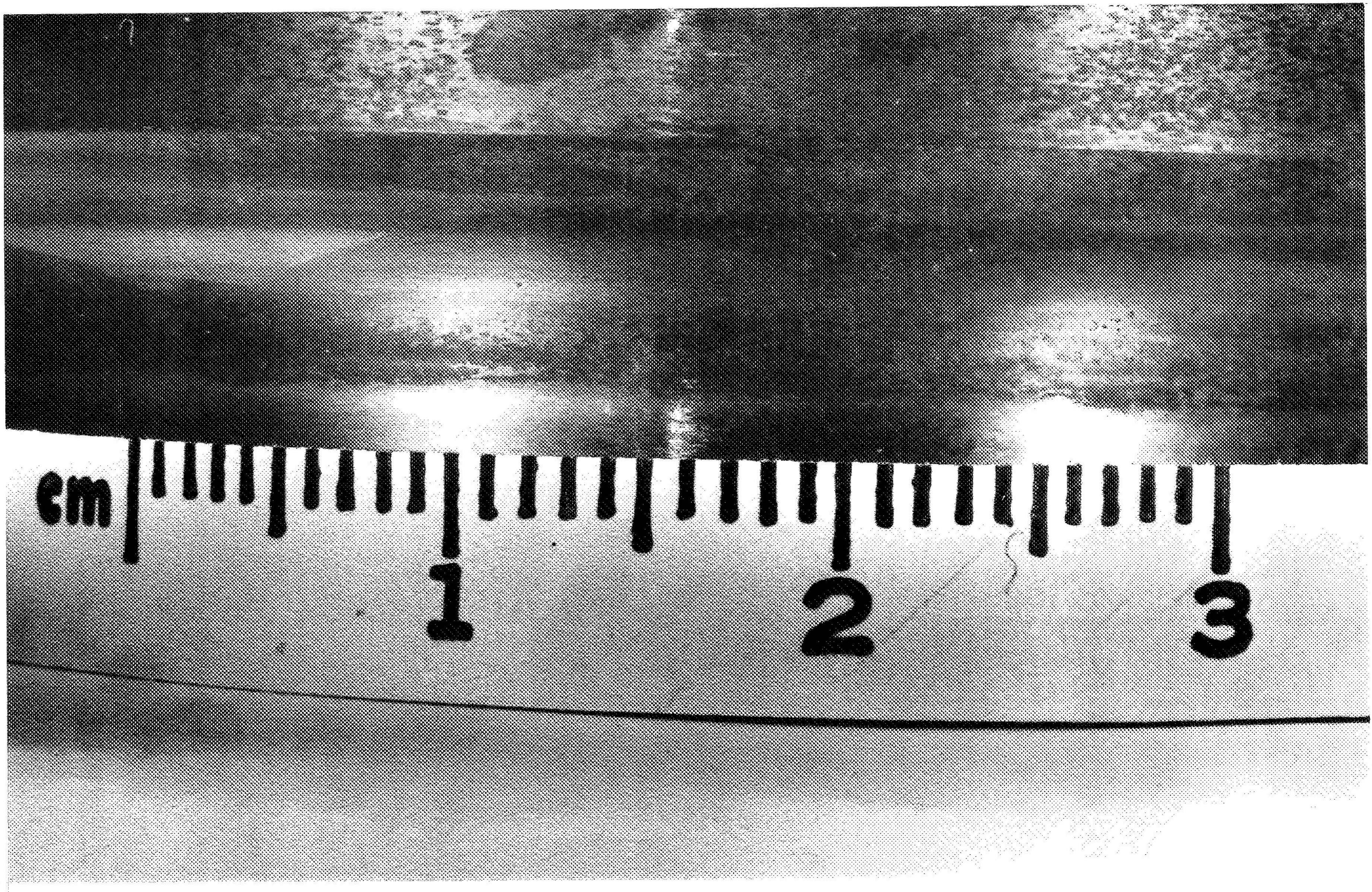
S/N A-48
Ball Roundness Chart

Figure 35



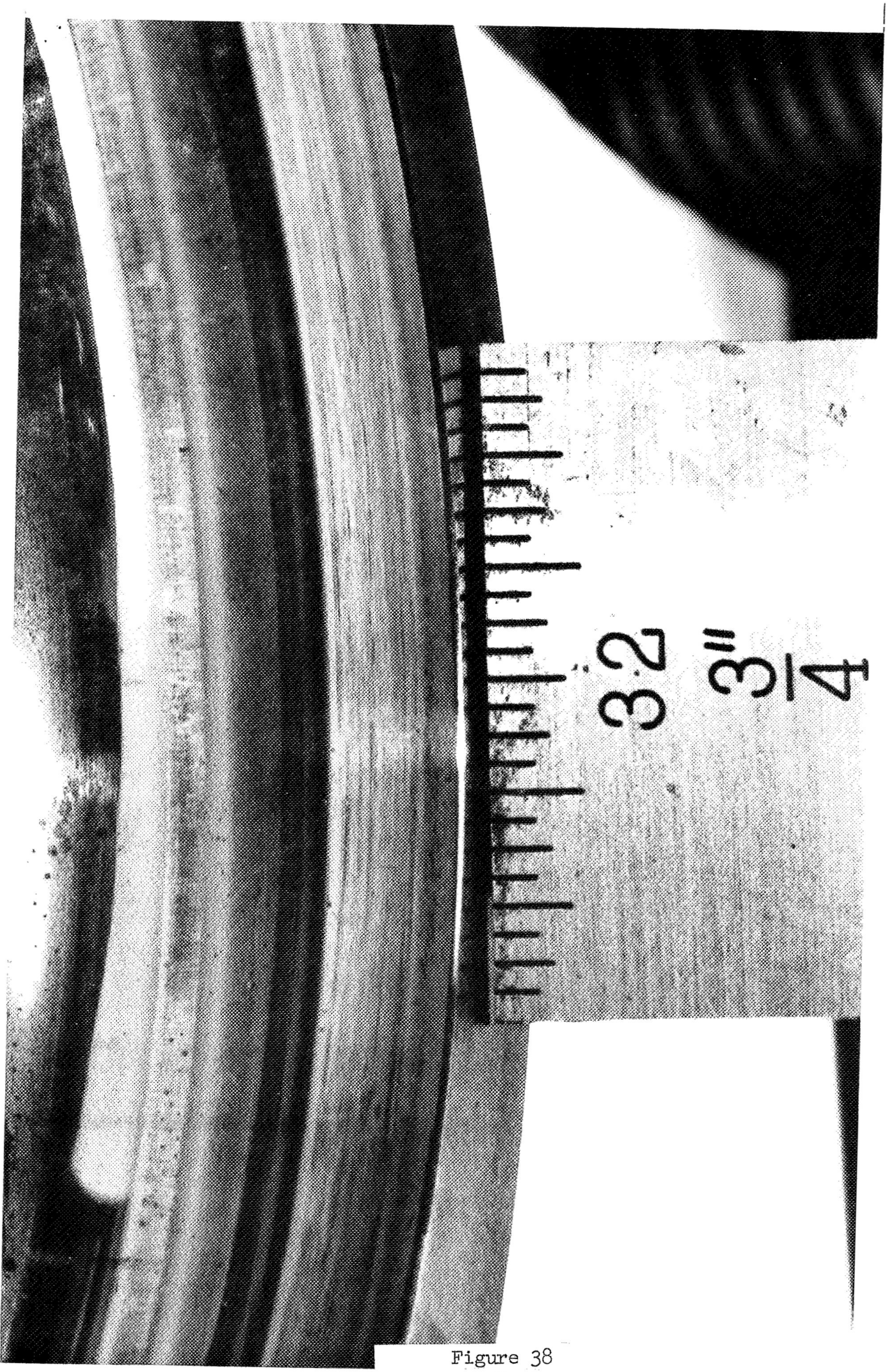
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-54 D.E. VIEW OF ASSEMBLED BEARING (20630 HOURS)

Figure 36



SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-54 D. E. INNER RACE (20630 HOURS)

Figure 37

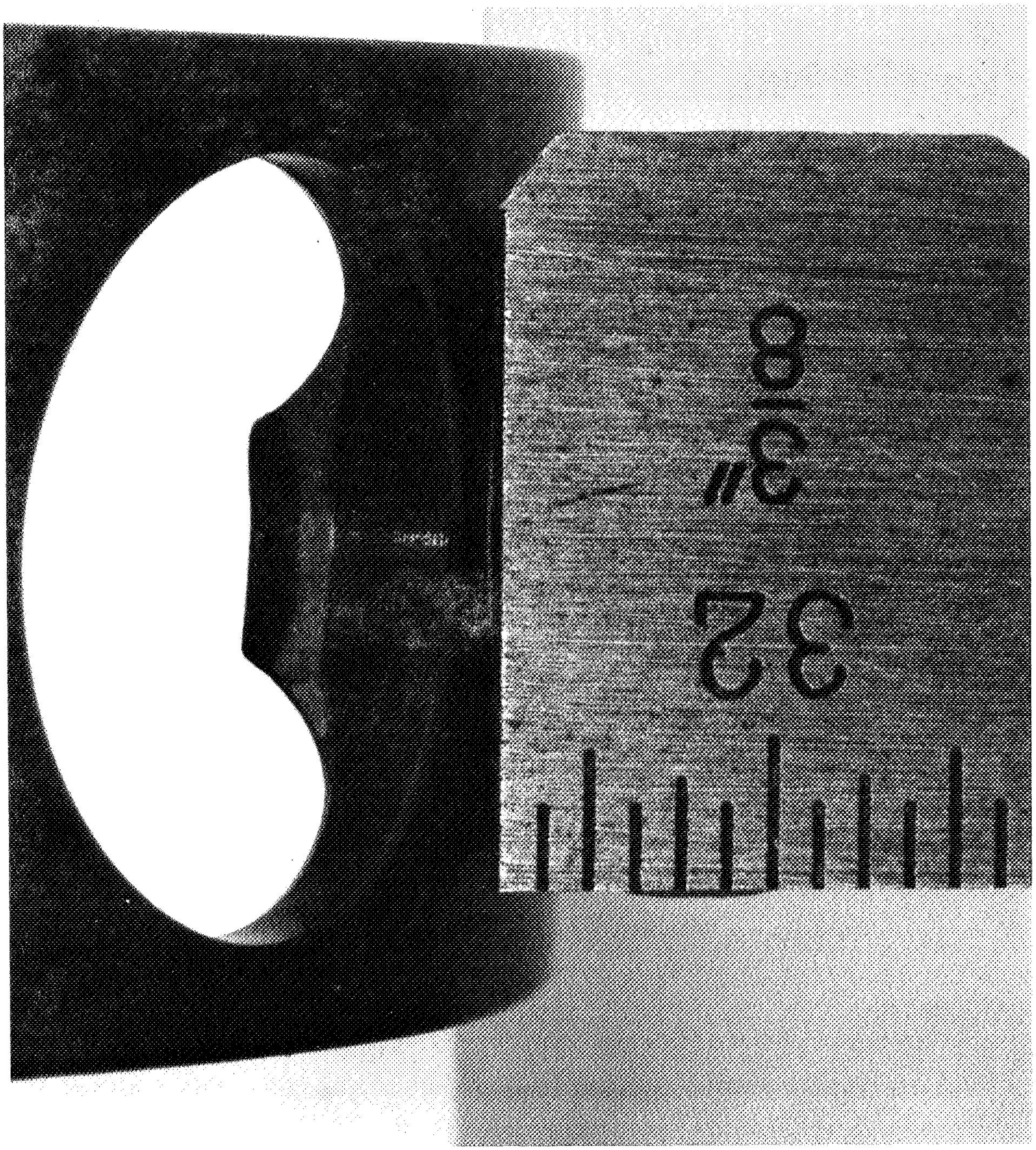


SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-54 D.E. OUTER RACE (20630 HOURS)

Figure 38

SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-54 D.E.
VIEW OF THREE BALLS INCLUDING SCRATCHED BALL (20630)

Figure 39

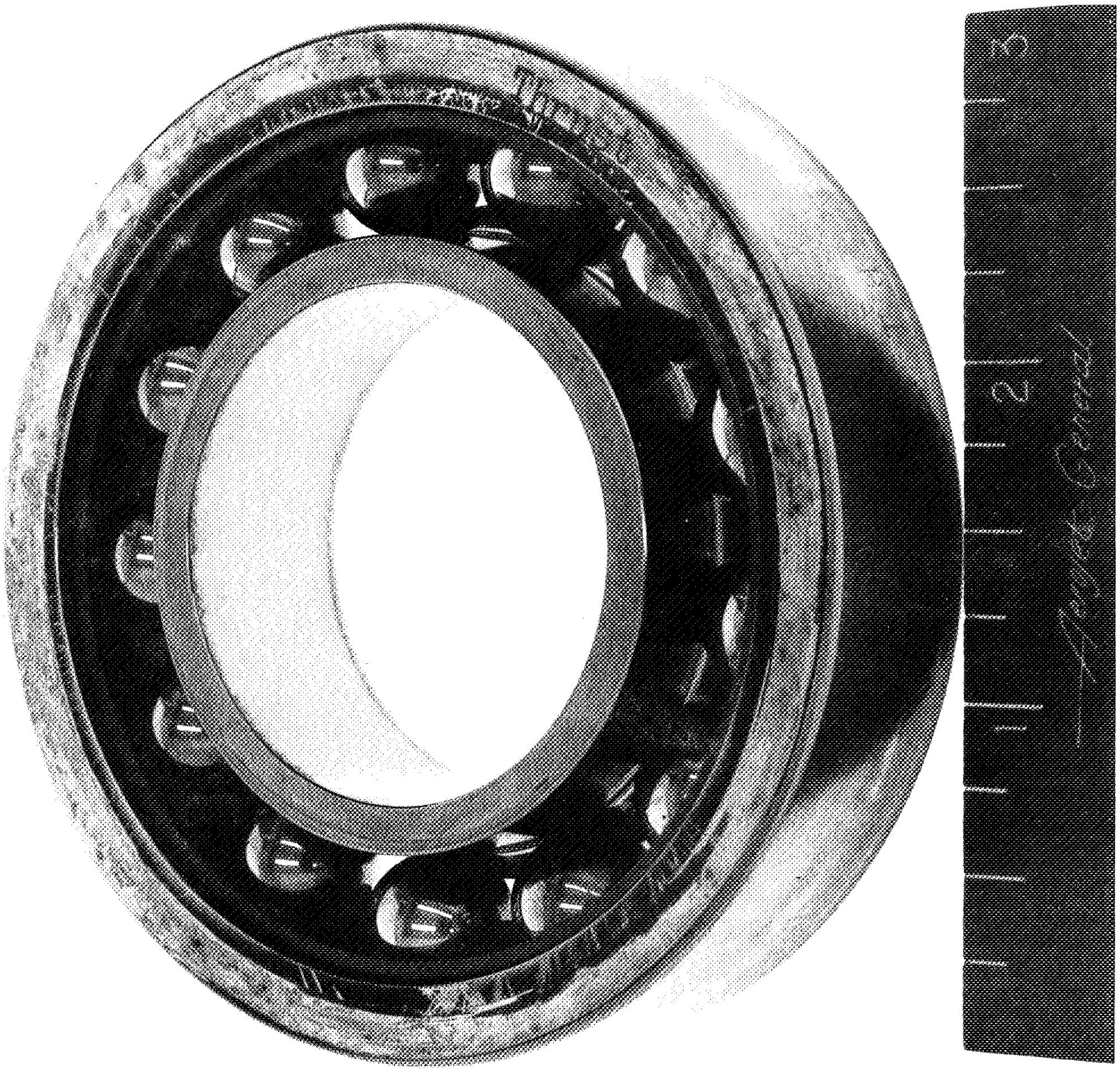


SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-54 D.E. VIEW OF TYPICAL SEPARATOR POCKET (20630 HOURS)

Figure 40

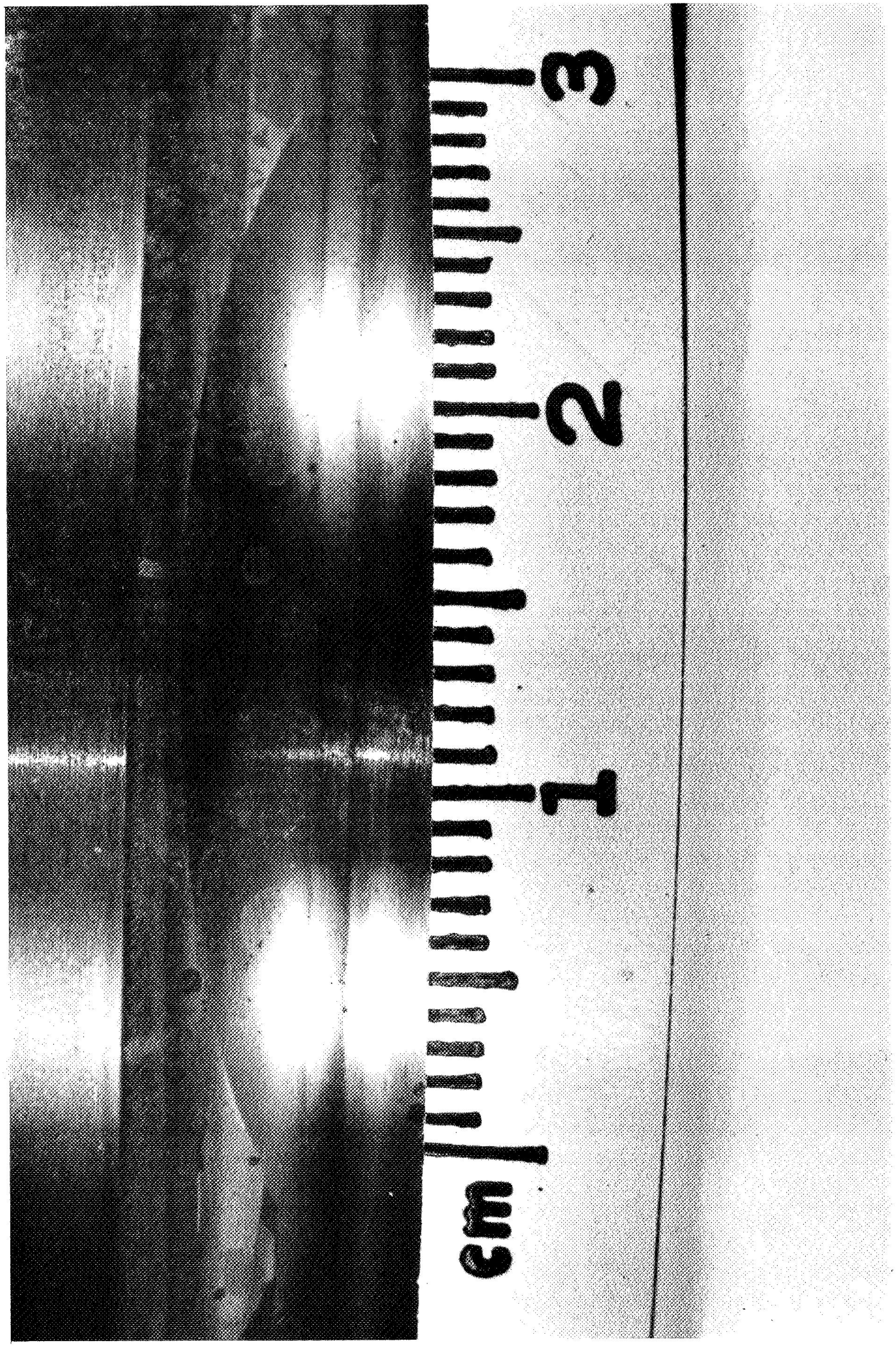
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-54 D.E. VIEW OF DISASSEMBLED BEARING (20630 HOURS)

Figure 41



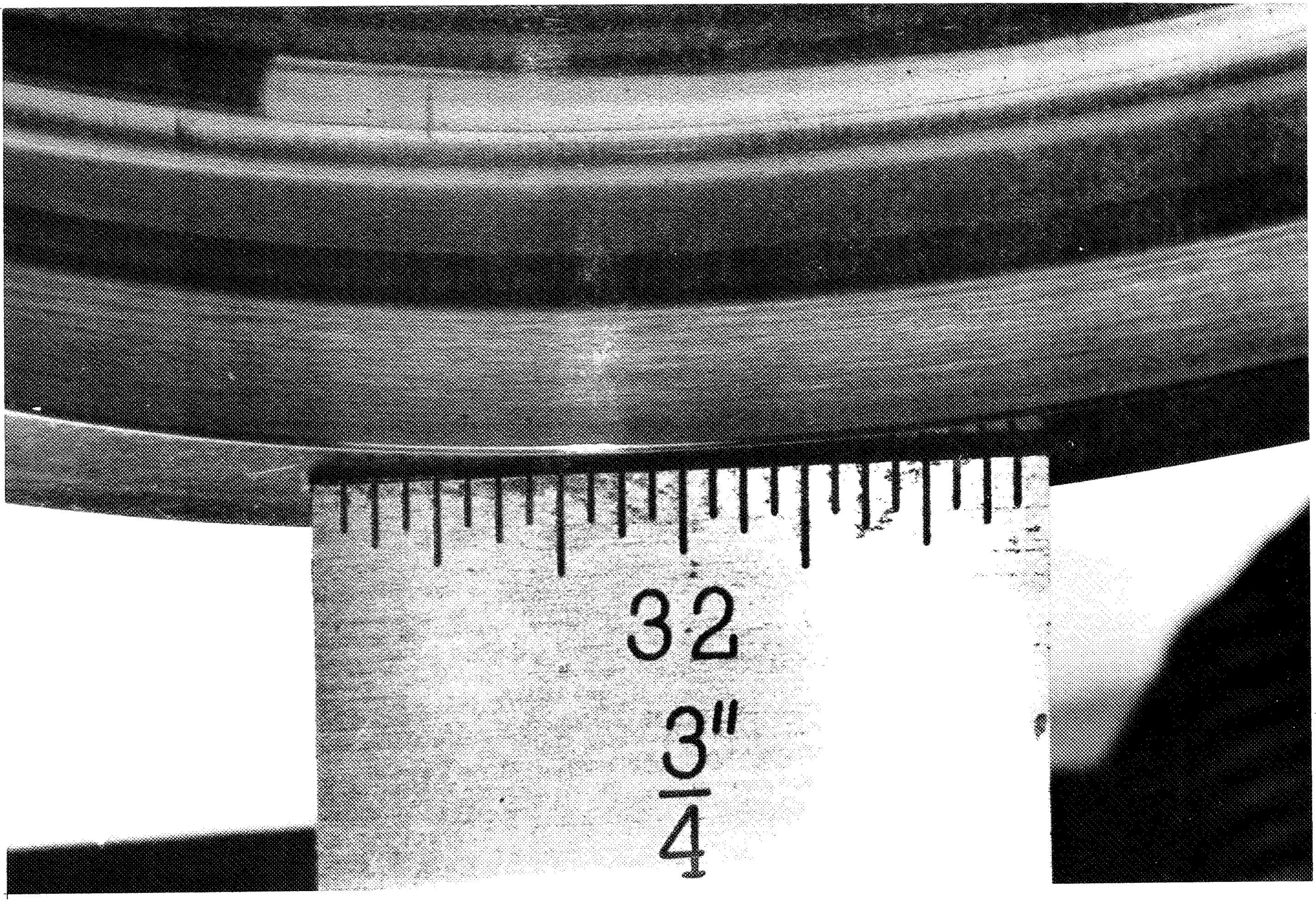
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-48 A.D.E. VIEW OF ASSEMBLED BEARING

Figure 42



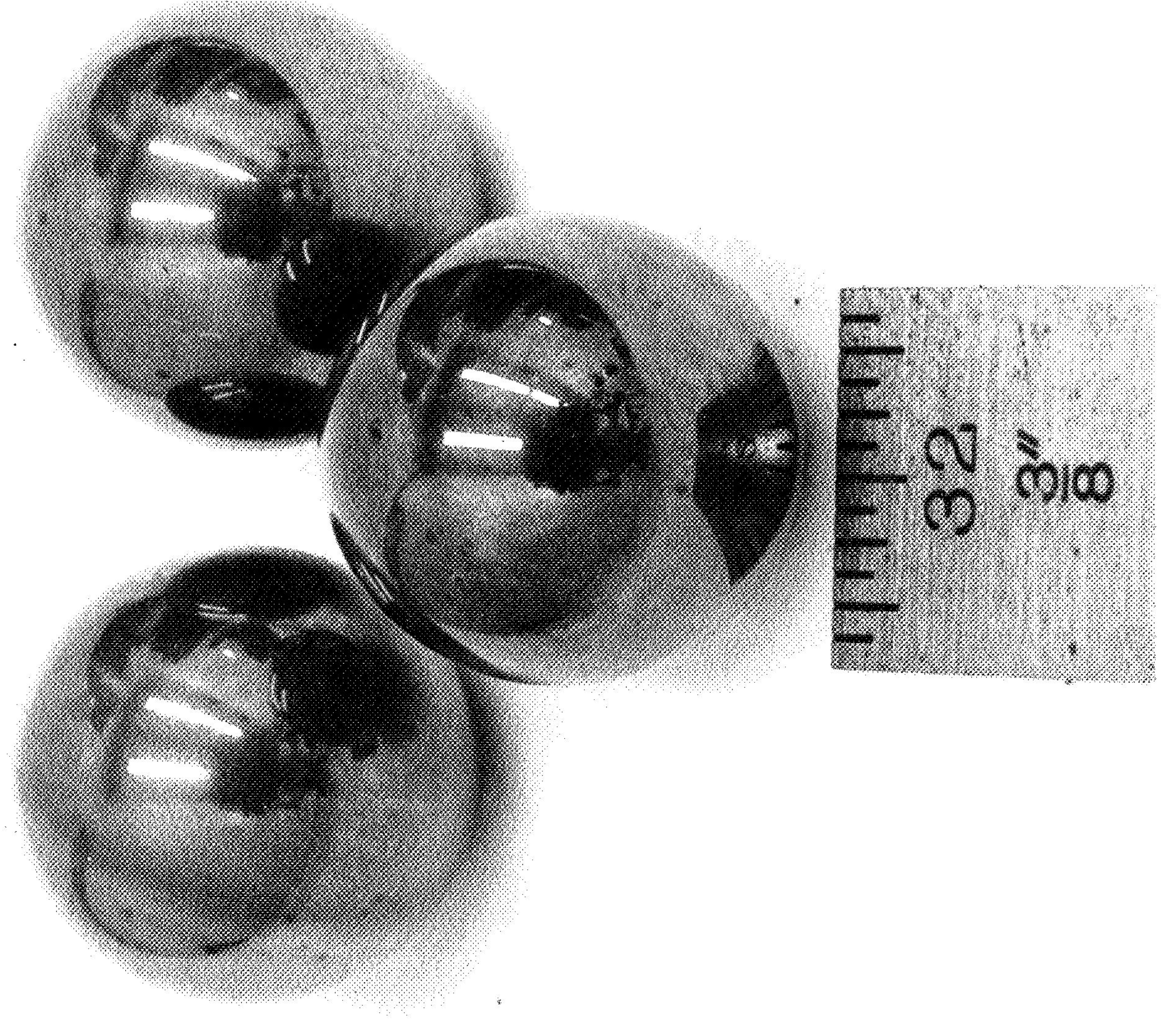
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-48 A.D.E. INNER RACE

Figure 43



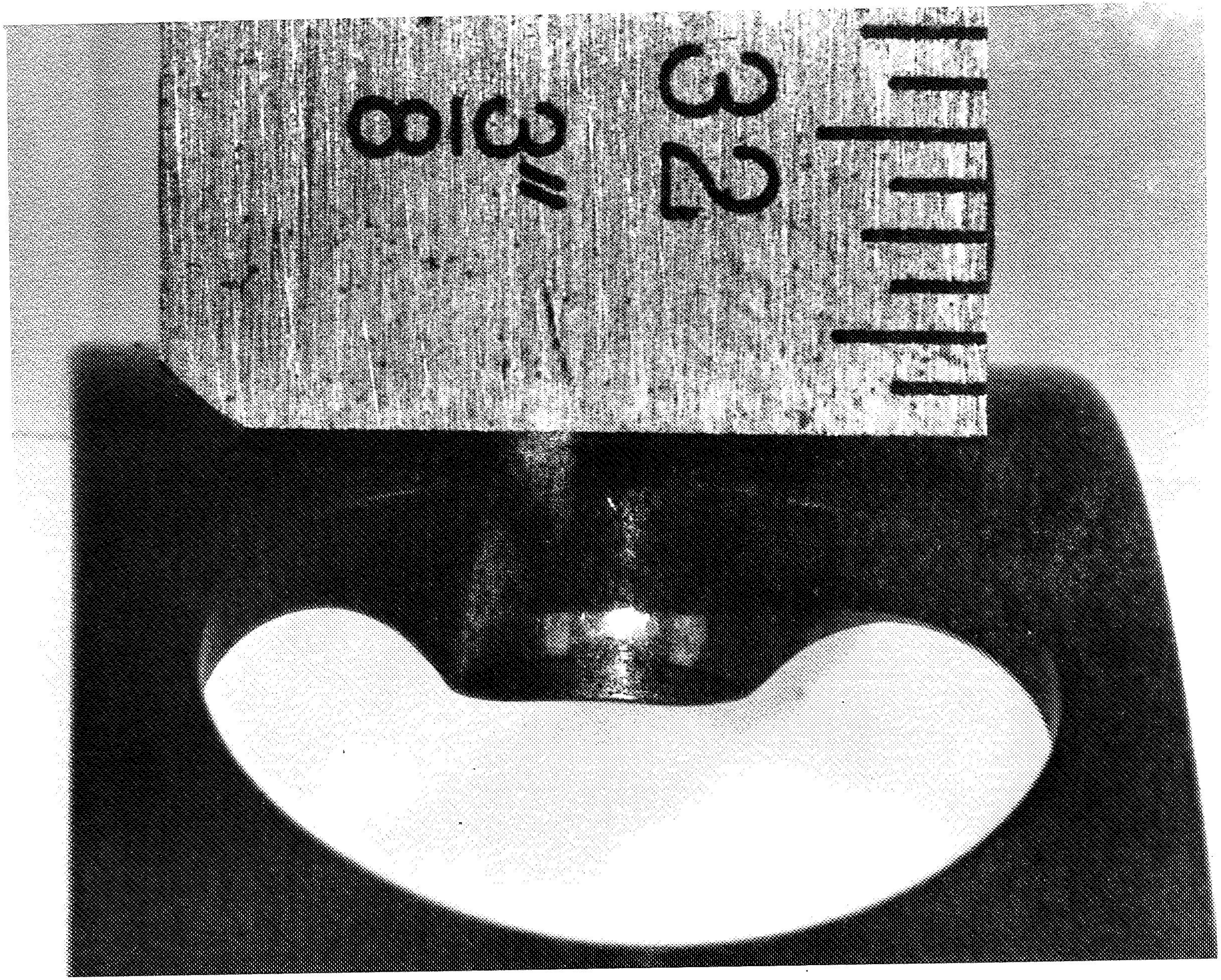
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-48 A.D.E. VIEW OF OUTER RACE

Figure 44



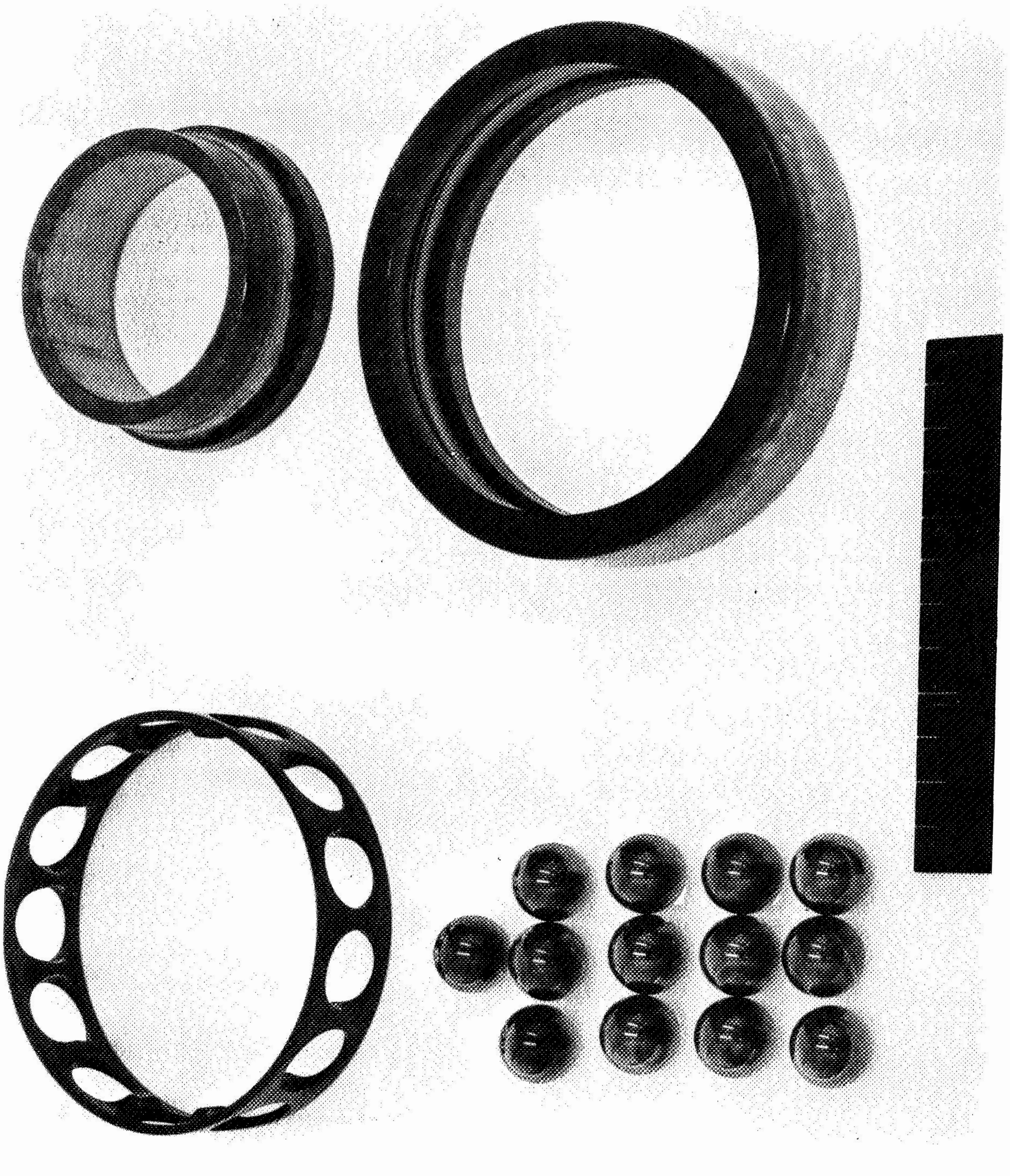
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-48 A.D.E. THREE TYPICAL BALLS

Figure 45



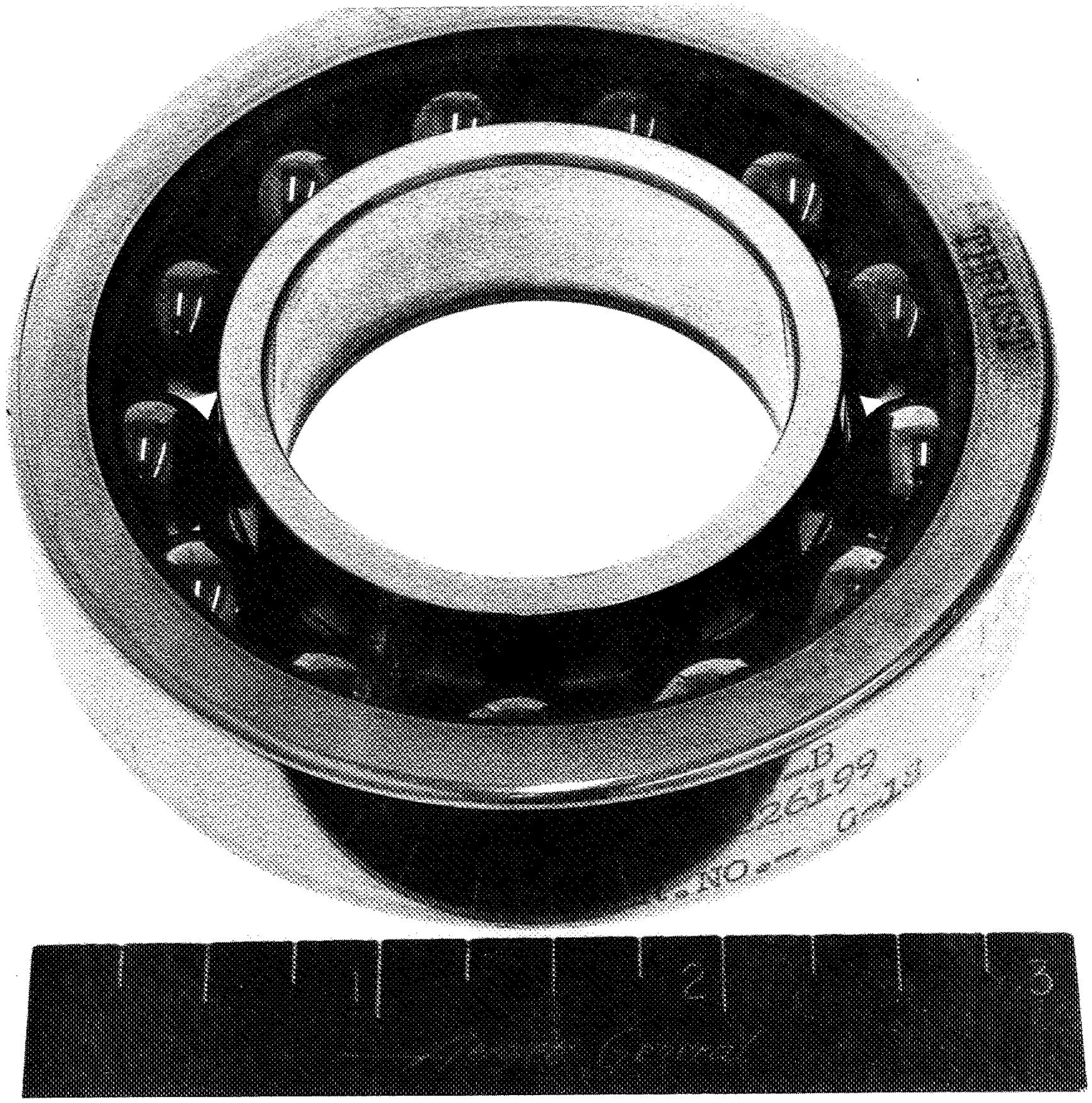
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-48 A.D.E. VIEW OF TYPICAL SEPARATOR POCKET

Figure 46



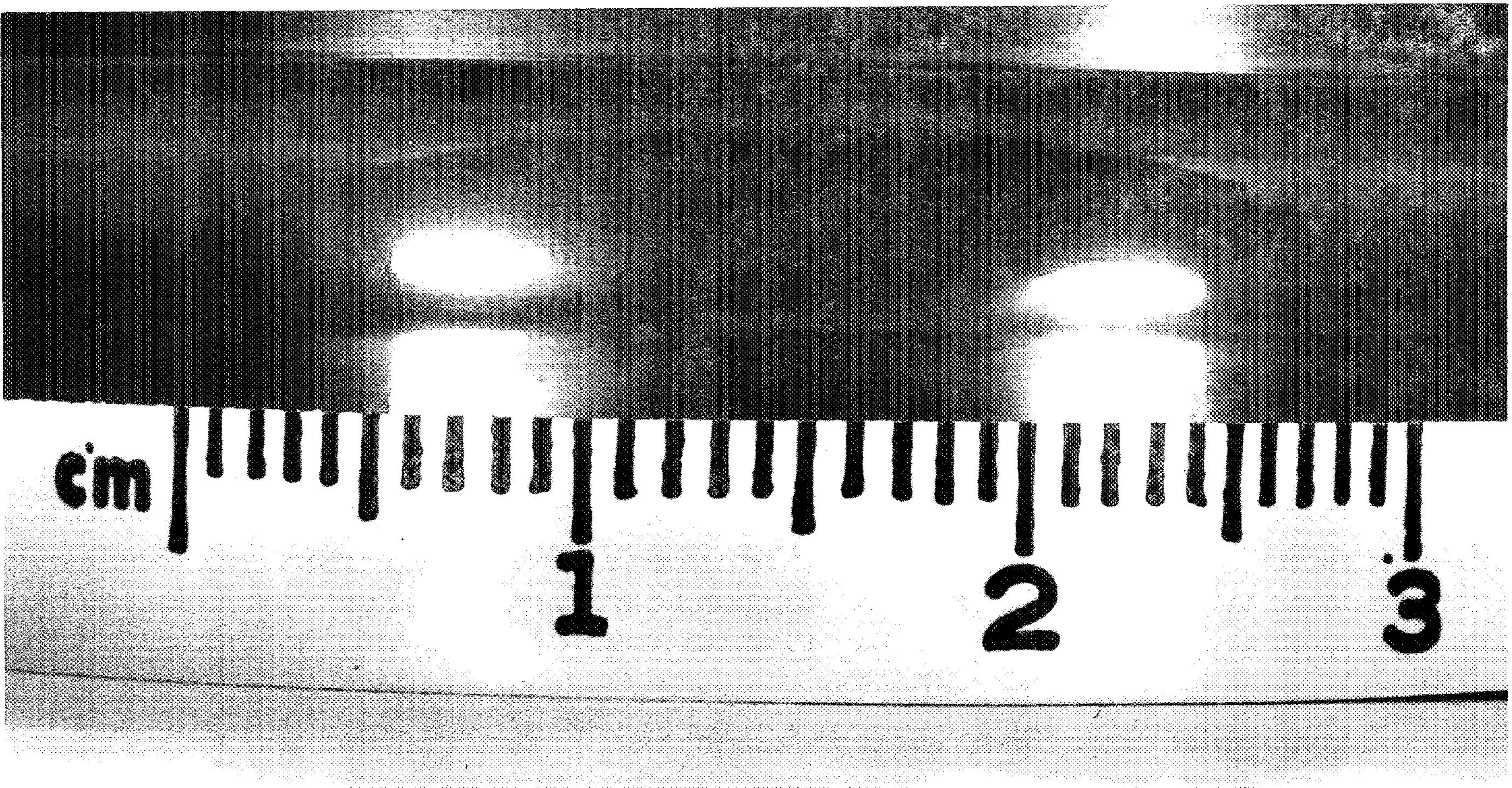
SNAP-8 ALTERNATOR P/N 094069 S/N 481490 AFTER 23130 HOURS IN ECTF
BALL BEARING P/N 095355 S/N A-48 A.D.E. VIEW OF DISASSEMBLED BEARING

Figure 47



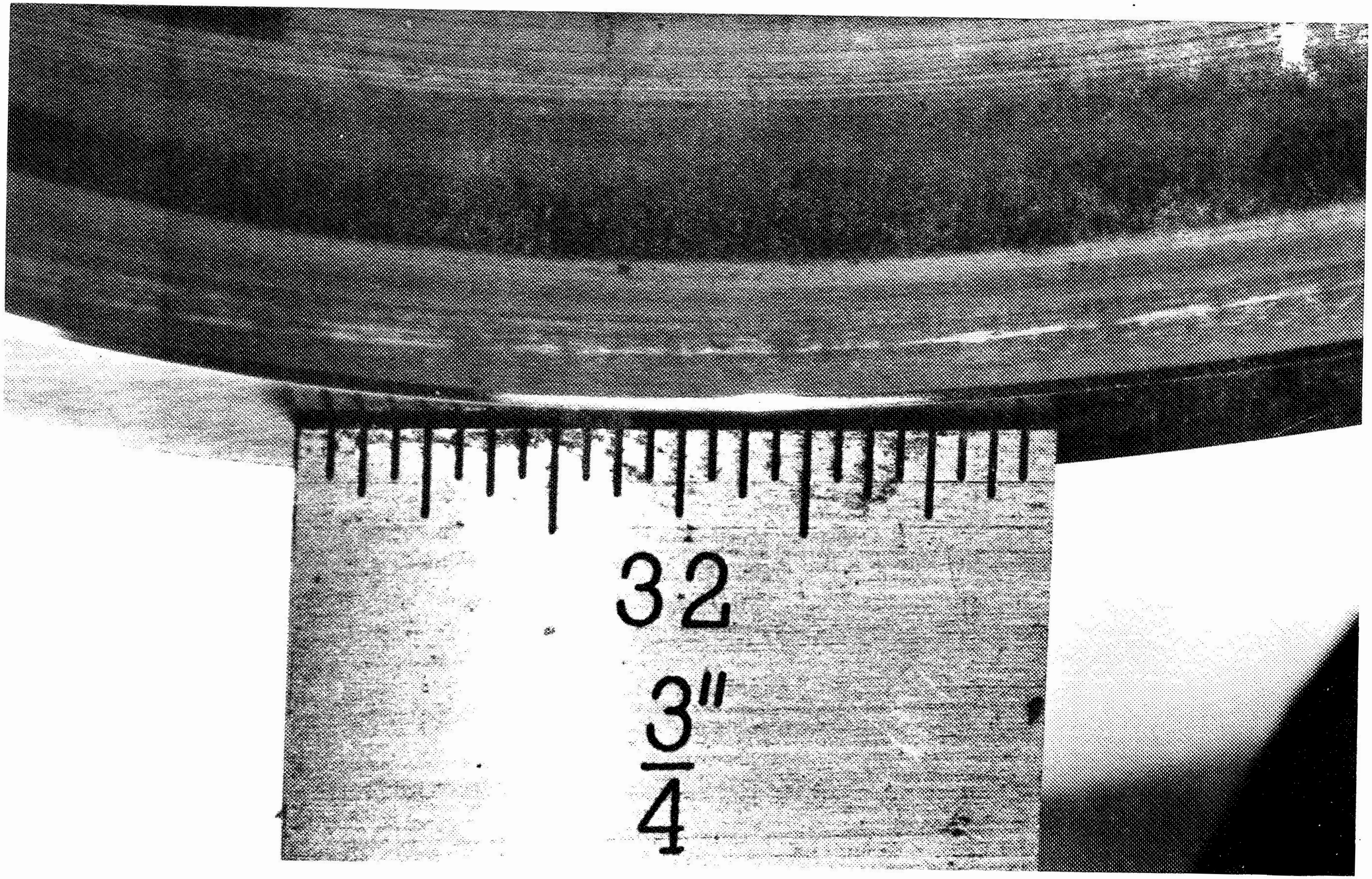
SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 36A226199 S/N G18
ALTERNATOR END (20630 HOURS SERVICE) VIEW OF ASSEMBLED BEARING

Figure 48



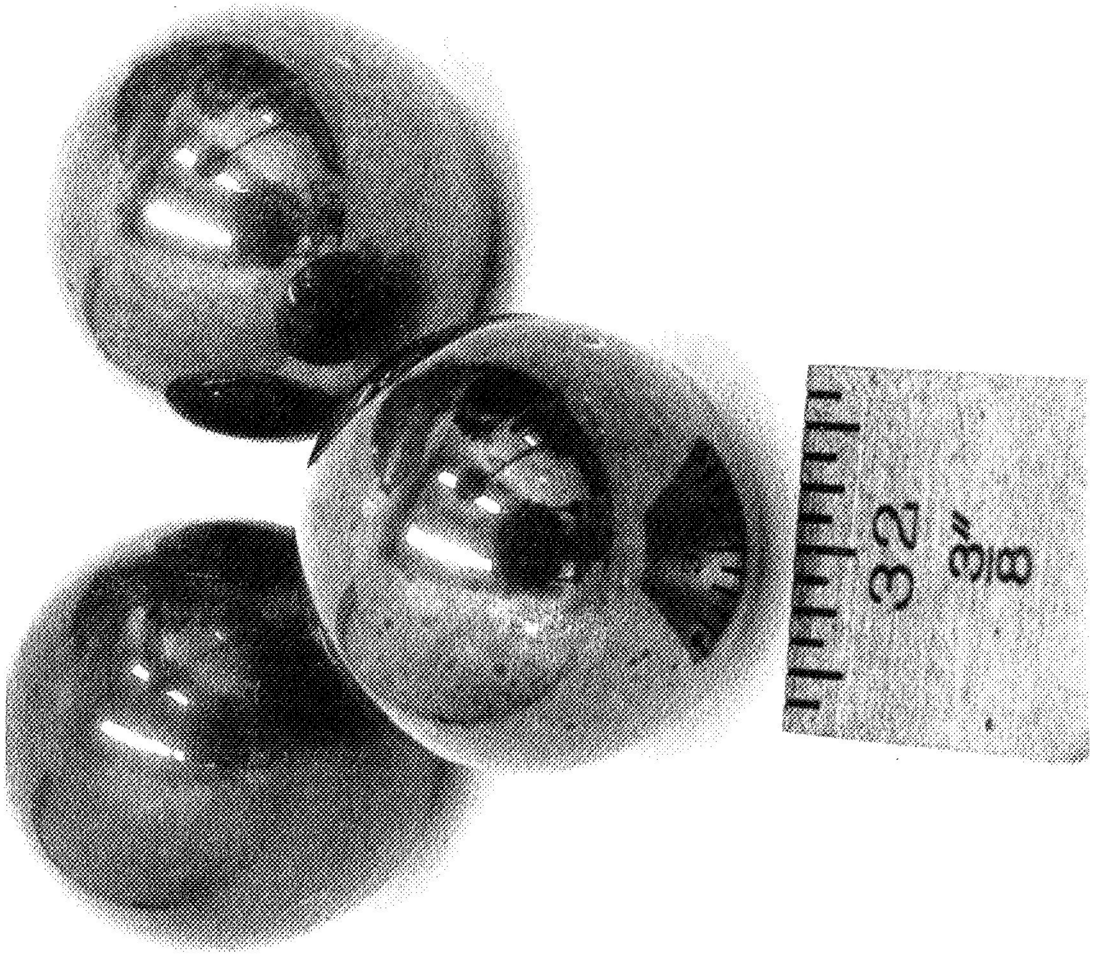
SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 36A226199 S/N G18
ALTERNATOR END (20630 HOURS SERVICE) INNER RACE

Figure 49



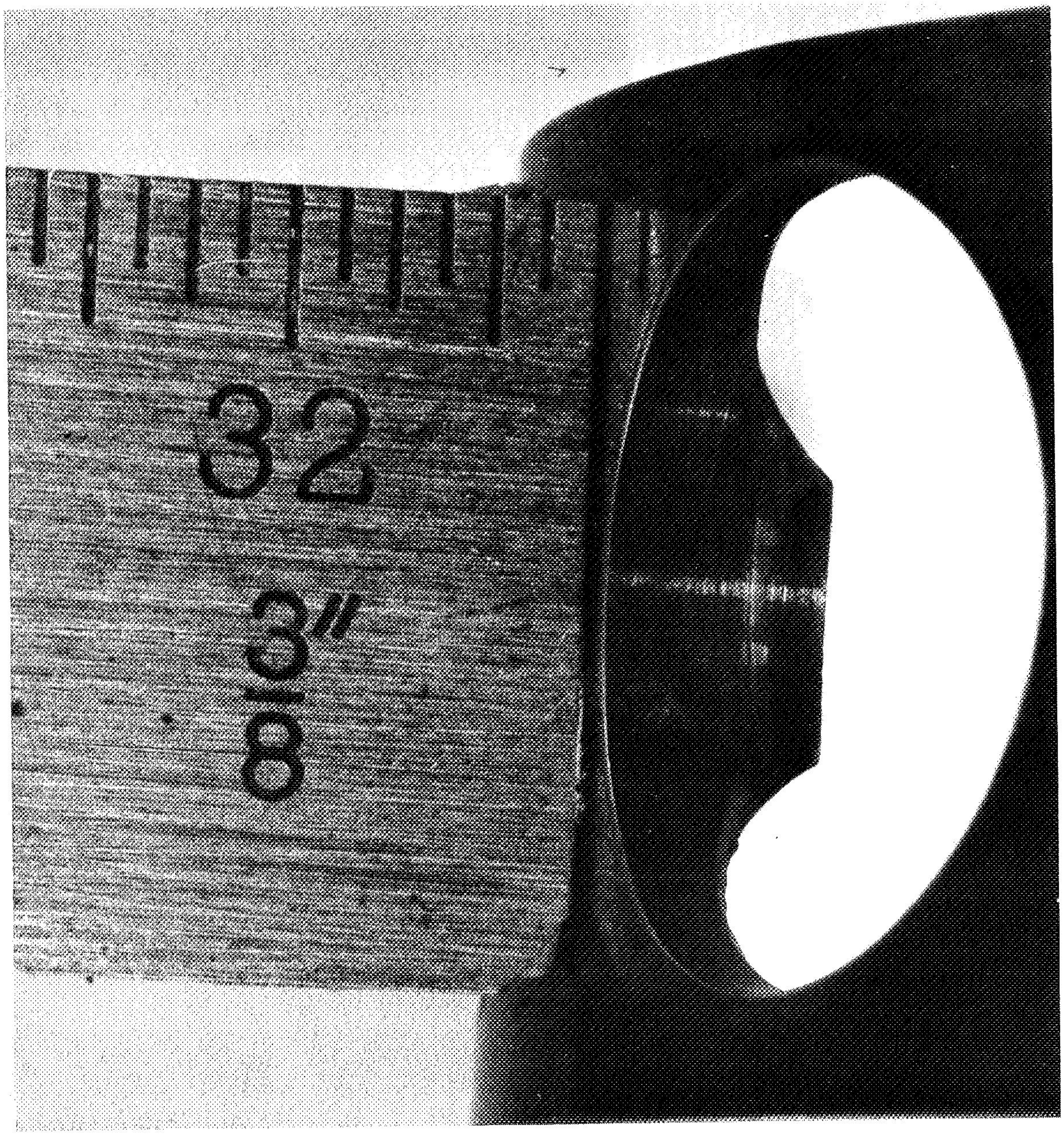
SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 36A226199 S/N G18
ALTERNATOR END (20630 HOURS SERVICE) OUTER RACE

Figure 50



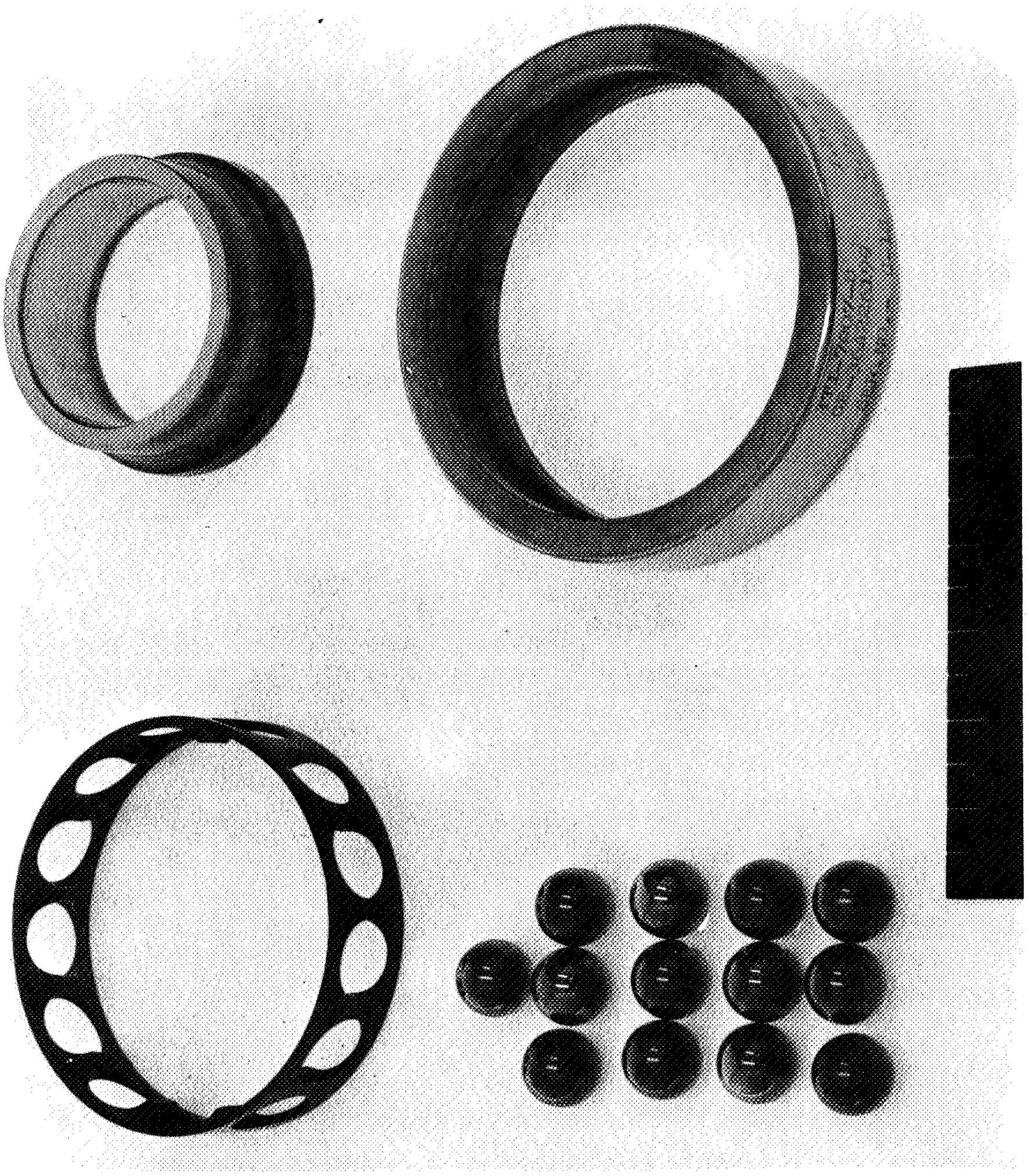
SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 36A226199 S/N G18
ALTERNATOR END (20630 HOURS SERVICE) THREE TYPICAL BALLS

Figure 51



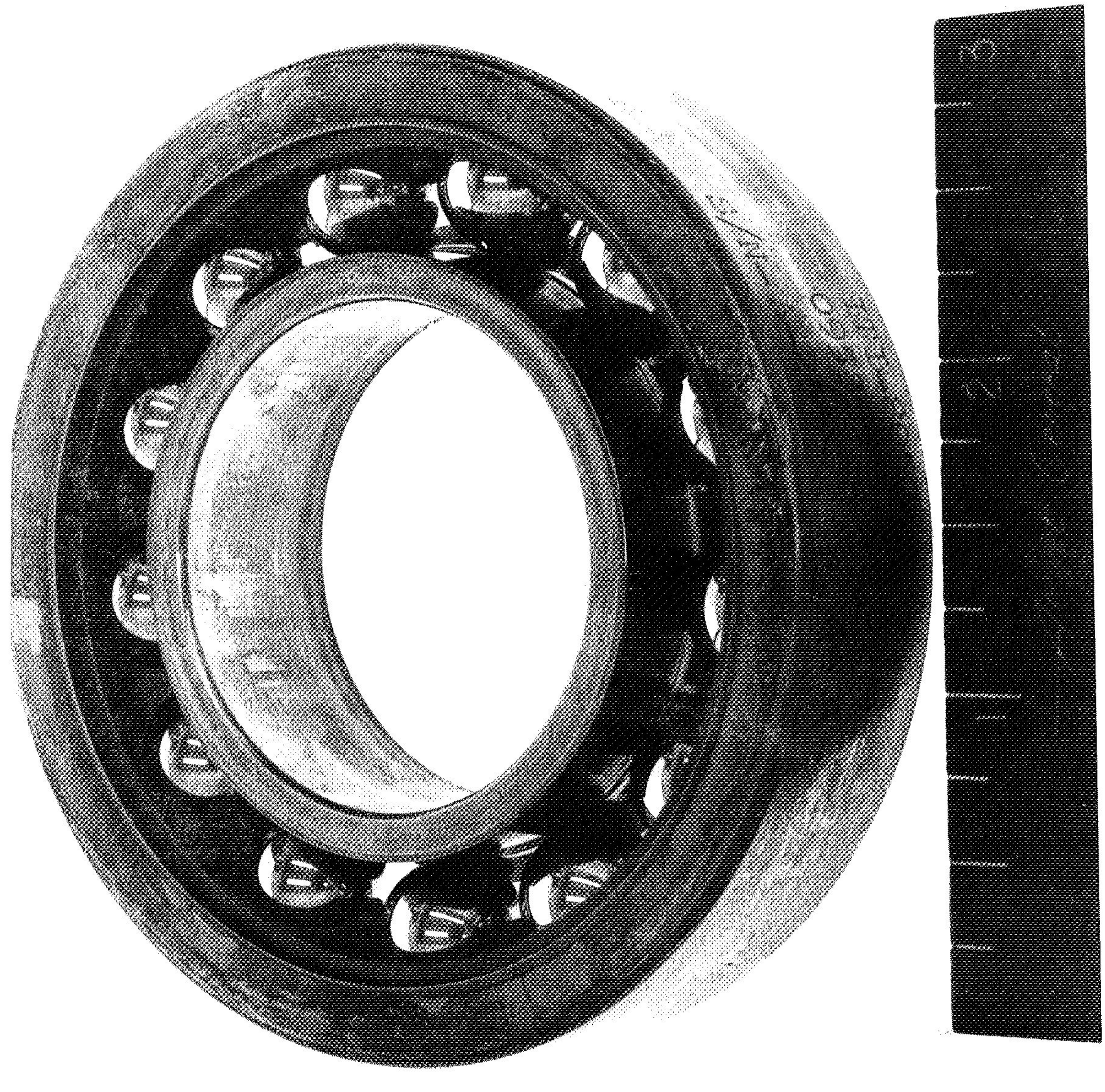
SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 36A226199 S/N G18
ALTERNATOR END (20630 HOURS SERVICE) VIEW OF TYPICAL SEPARATOR POCKET

Figure 52



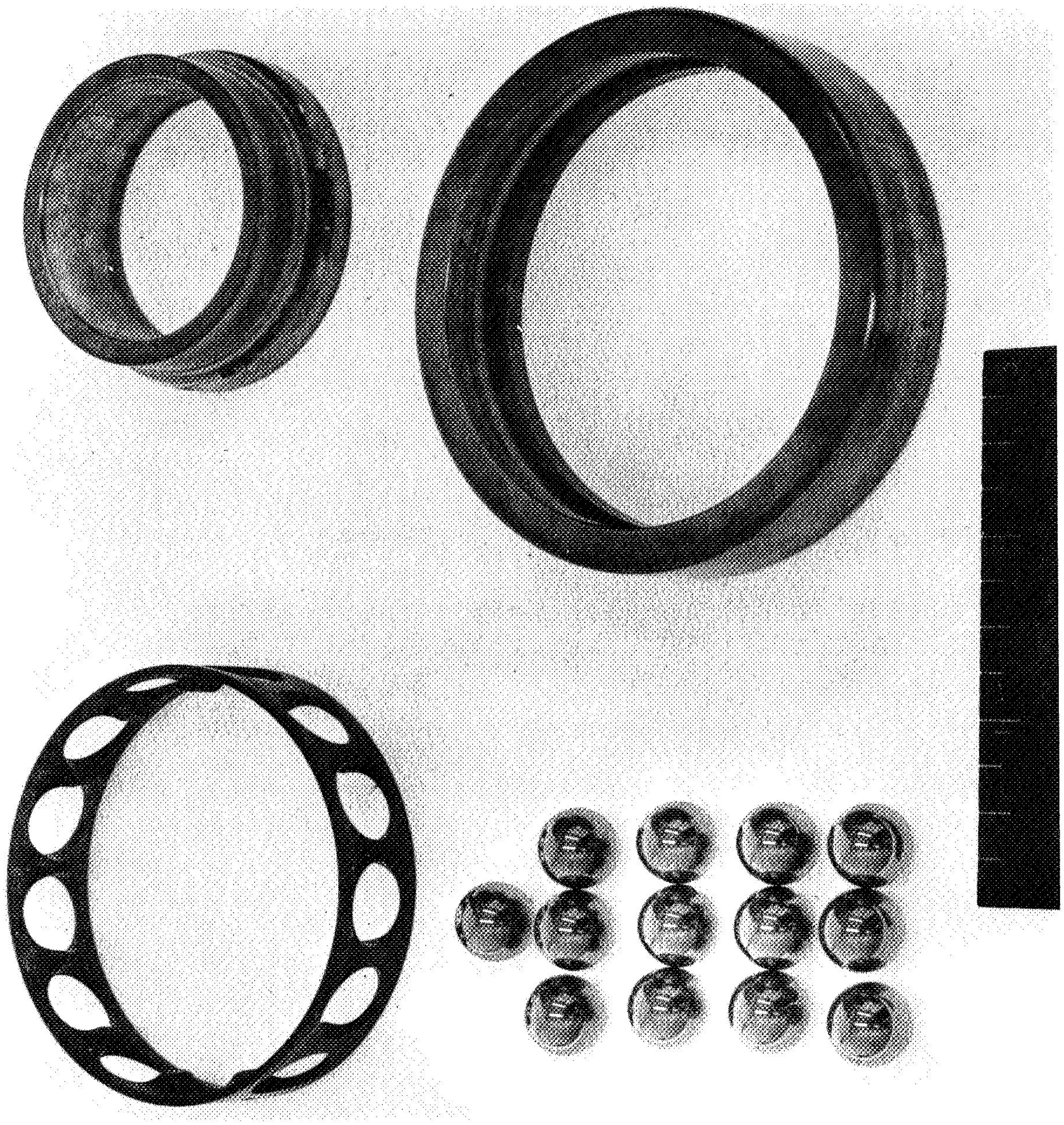
SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 36A226199 S/N G18
ALTERNATOR END (20630 HOURS SERVICE) VIEW OF DISASSEMBLED BEARING

Figure 53



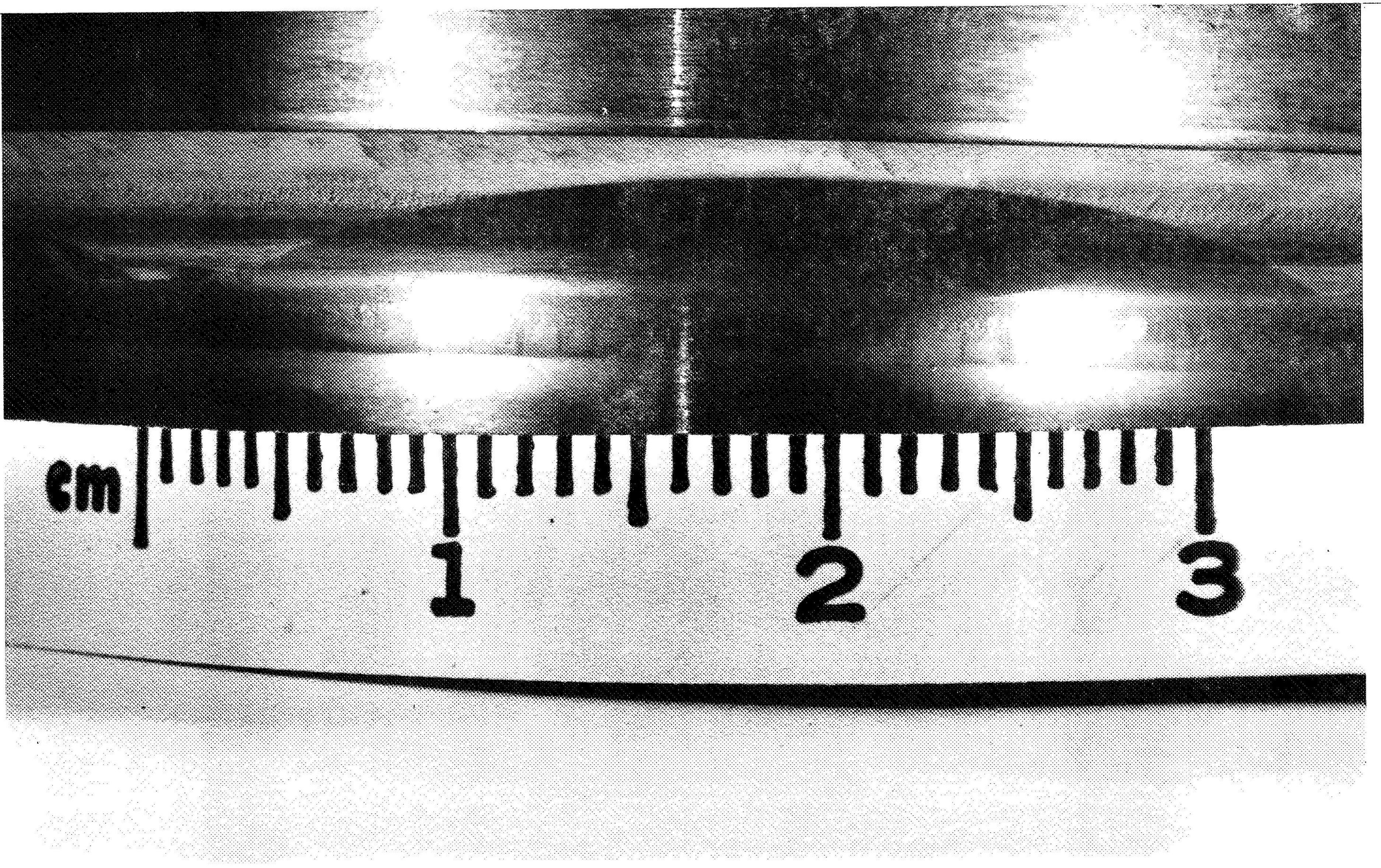
SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 095355 S/N A-25 TURBINE END (10630 HOURS SERVICE)
VIEW OF ASSEMBLED BEARING

Figure 54



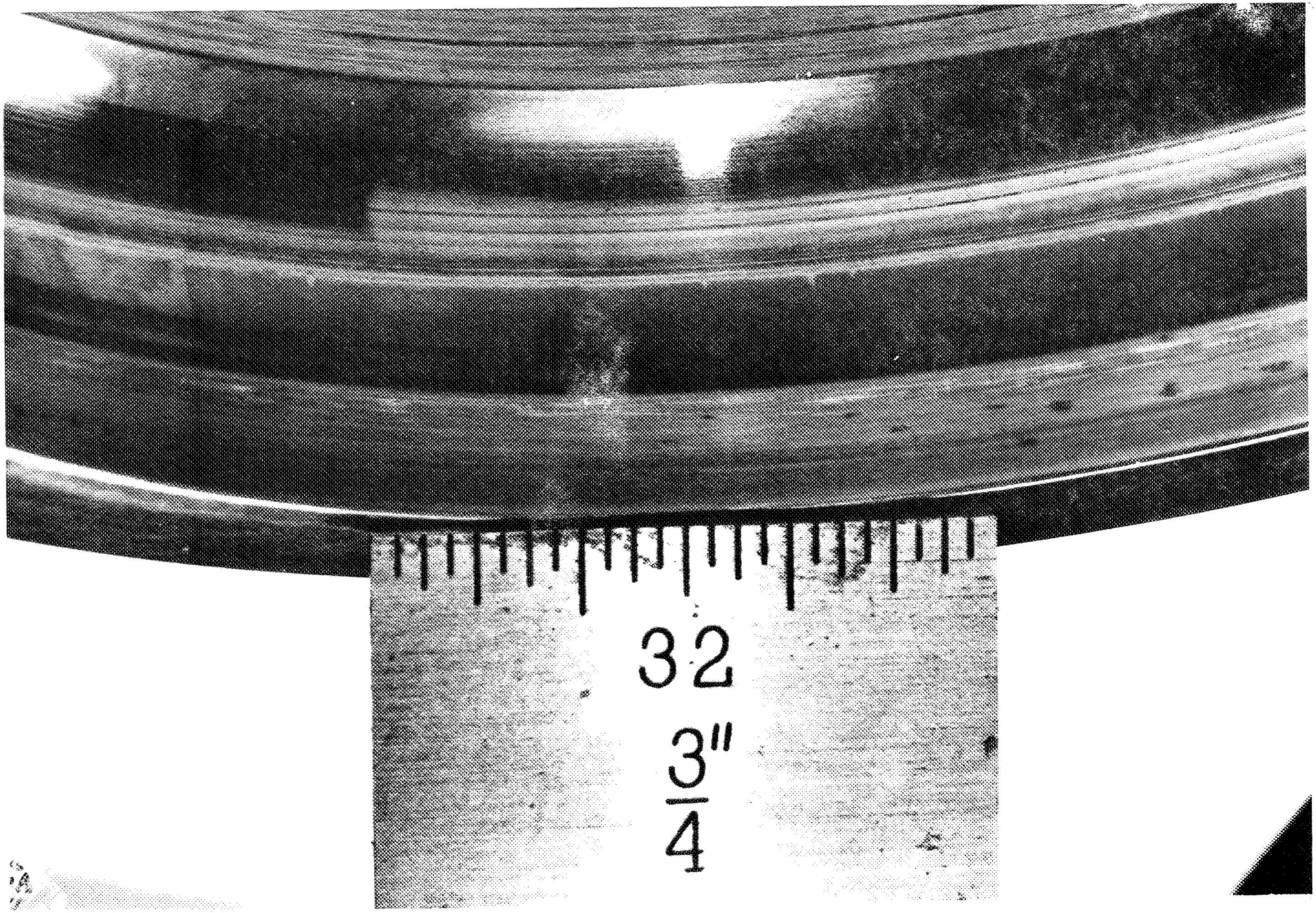
SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 095355 S/N A-25 TURBINE END (10630 HOURS SERVICE)
VIEW OF DISASSEMBLED BEARING

Figure 55



SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 095355 S/N A-25 TURBINE END (10630 HOURS SERVICE) INNER RACE

Figure 56

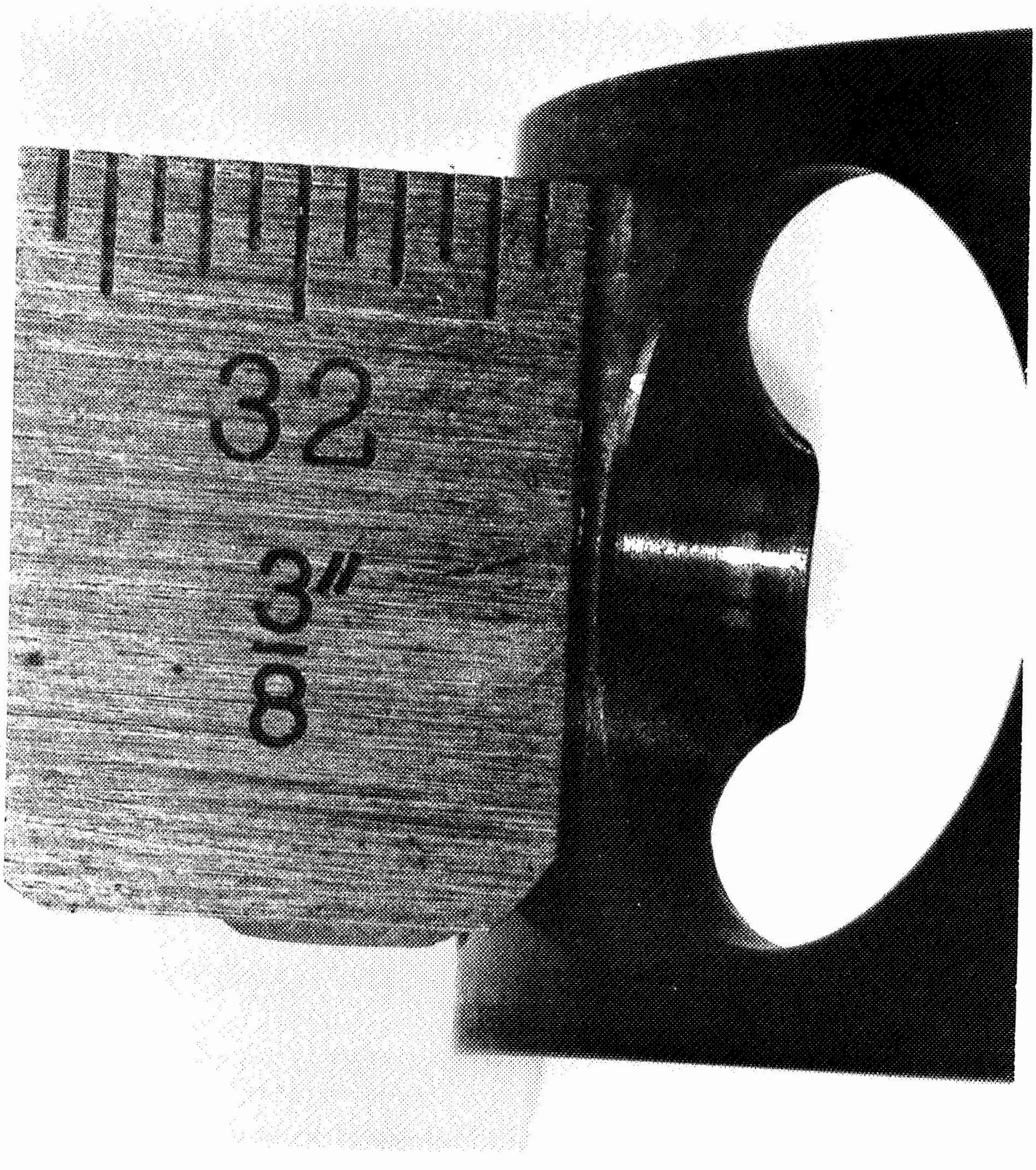


SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 095355 S/N A-25 TURBINE END (10630 HOURS SERVICE) OUTER RACE

Figure 57

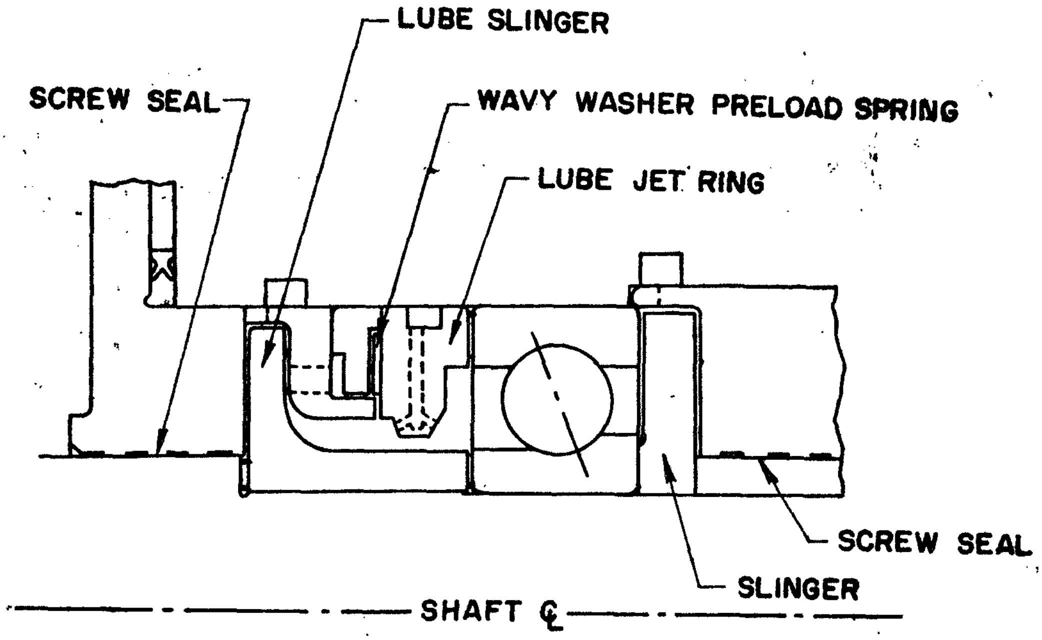
SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 095355 S/N A-25
TURBINE END (10630 HOURS SERVICE) THREE TYPICAL BALLS

Figure 58

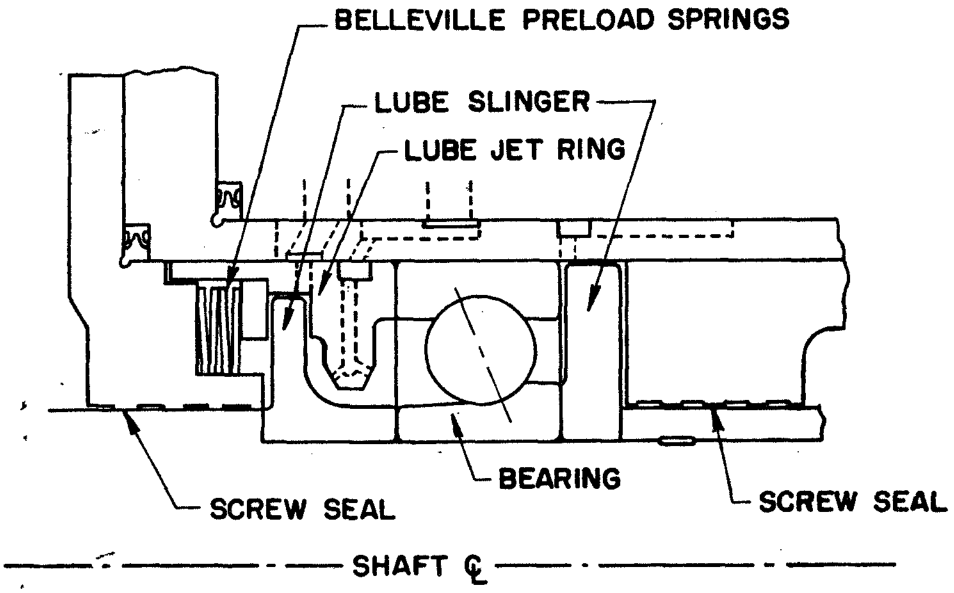


SNAP-8 DRIVE ADAPTER FOR ECTF AFTER 23130 HOURS
BALL BEARING P/N 095355 S/N A-25 TURBINE END (10630 HOURS SERVICE)
VIEW OF TYPICAL SEPARATOR POCKET

Figure 59



ALTERNATOR BEARING PRELOAD SYSTEM - CURRENT DESIGN.



ALTERNATOR BEARING PRELOAD SYSTEM - PROPOSED DESIGN.

Figure 60

# APPENDIX A

| | | |
|---|---|---|
| TO: | J. R. Pope | 4 January 1971<br>N3710-70-0887:HEB:hrt |
| FROM: | H. E. Bleil | |
| SUBJECT: | Residues and L/C Fluid from ECTF after 23,130 hours of operation. | |
| DISTRIBUTION: | S.L. Bradley, F.N. Collamore, R.S. Foley, C.E. Hawk, A.H. Kreeger | |

REFERENCE:
(a) A.J. Sellers and F.H. Cassidy "Effects of Mix-4P3E Oil Influx into the SNAP-8 Mercury Loop", Memo 4923:69:9202, 24 October 1969.
(b) F.H. Cassidy "Analysis of Mix-4P3E L/C after 2500 Hour Alternator Test, Bldg. 194". Memo 4923:67:7172, 13 October 1967.

ENCLOSURES:
(1) Table I, Location and Composition of Residues from ECTF Alternator.
Table II, Calculated Decomposition of Mix-4P3E (Ref. b)
(2) Table III, Mix-4P3E Analysis, Electrical Component Test Facility.

Residues recovered from various locations in the ECTF alternator after its disassembly were analyzed, Table I. All of the residues contained a solid, semi-plastic, organic material which exhibited an infrared spectrographic absorption pattern identical to Mix-4P3E. Since this analysis method determines the type of molecular bonding present but not the size of the molecules, it is presumed that the solid organic is a higher molecular weight polymer formed during decomposition of the Mix-4P3E during elevated temperature exposure in the ECTF. The mechanism of decomposition of Mix-4P3E has not been adequately defined, but it is known that polyphenyl ethers exposed at elevated temperatures decompose to form gaseous products and a complex mixture at higher molecular weight polyphenyl ethers which are solid, Ref. (a). In the ECTF the gaseous decomposition products are continuously removed by the vacuum maintained on the system. The solids however are deposited in the system. With the presently available information it is not possible to predict the ratio of solids to volatile decomposition products formed under various conditions. Maximum temperature, temperature profile, time at temperature, and the amount of oxygen present are among the variables which influence decomposition. Table II lists the calculated amounts of decomposition which are predicted for Mix-4P3E in 10,000 Hours at various temperatures under static, isothermal conditions.

In addition to polymerized Mix-4P3E the residues scraped from the inboard and outboard screwseals of the alternator also contained teflon. This material, however, was not detected in any of the other residues analyzed. The screw seals were teflon coated as part of their fabrication processing. The presence of the teflon in the residues from these areas indicates that it was not as tightly adherent as would be desirable, but the absence of teflon in the other residues indicates it was sufficiently adherent not to migrate during system operation.

The bulk of the residue from the outboard lube and coolant drain was polymerized Mix-4P3E. However, this residue also contained a small amount of another material which appeared most likely to be polyimid. This probably originated from the ML insulation in the alternator.

The material washed from the bearings contained in addition to polymerized Mix-4P3E, a small amount of inorganic residue. Microscopically this material consisted of fine metallic chips and light colored non-metallic particles. Emission spectrographic analysis indicated this material was primarily Na with some Fe and small amounts of Al, Cr, Si, Cu, Ag and Mo. The high sodium content may have been the result of cleaning solution residues retained in the system. The metallic particles appeared to be the result of a cutting operation.

The Mix-4P3E removed from the system, although dark in color, met the procurement specification analysis requirements, Table III, and was considered suitable for continued use. Based on the change in acid content and the fact that ten pounds of new Mix-4P3E was added to the system after 12,320 hours of operation, it is estimated that 0.008 percent decomposition of the L/C occurred in the last 10,810 hours of operation.

H. E. Bleil
SNAP-8 Project
Aerojet Nuclear Systems Company

ENCLOSURE 1
N3710-70-0887:HEB:hrt

TABLE I Location and Composition of Residues from ECTF Alternator

| | Location from which sample was taken | Composition of residue |
|---|---|---|
| 1. | Teflon coated drive end, outboard screwseal | Polymerized Mix-4P3E and Teflon |
| 2. | Anti-drive end jetring circumferential groove | Polymerized Mix-4P3E |
| 3. | Drive end, end bell oil groove | Polymerized Mix-4P3E |
| 4. | Teflon coated drive end inboard screw seal | Polymerized Mix-4P3E and Teflon |
| 5. | Electrical windings | Polymerized Mix-4P3E |
| 6. | Washed from bearing S/N A 48 DE 881490 | Polymerized Mix-4P3E<br>Na, major: Fe; Cr, Al, Si,<br>minor; Cu, Mo, Ag, Mg, Trace |
| 7. | Washed from bearing S/N A 54ADE 481490X | |
| 8. | Outboard lube and coolant drain | Polymerized Mix-4P3E and probably polyimid. |

TABLE II Calculated Decomposition of Mix-4P3E (Ref. b)

| Exposure Temperature (°F) | Decomposition of Mix-4P3E in 10,000 hours of static isothermal exposure. (percent) |
|---|---|
| 400 | 0.001 |
| 500 | 0.034 |
| 600 | 1.55 |
| 700 | 12.5 |
| 800 | 36.2 |

ENCLOSURE 2
N3710-70-0887:HEB:hrt

TABLE III Mix-4P3E Analysis, Electrical Component Test Facility

| Total Accumulated Hours of Operation | Viscosity, Centistokes, at Temperature °F | | | Density, $Gm^5/Cm^3$, at Temperature °F | | | Acid Content % | Poor Point, % | Chlorine Content, % | Water % |
|---|---|---|---|---|---|---|---|---|---|---|
| | 100 | 140 | 210 | 100 | 140 | 210 | | | | |
| 0 | 68.4 | 20.8 | 6.3 | 1.168 | - | - | .04 | 15 | 0.002 | 0.007 |
| 880 | 65.9 | 20.9 | 6.0 | 1.163 | - | - | - | 20 | - | - |
| 1615 | 65.4 | 20.4 | 6.2 | 1.164 | - | - | - | - | - | - |
| 2500 | 65.5 | 20.6 | 6.2 | 1.162 | - | - | .077 | 16 | - | 0.013 |
| 4660 | 66.2 | 20.7 | 6.2 | - | - | - | .054 | 16 | - | - |
| 6458 | - | - | 6.2 | - | - | - | .052 | - | - | - |
| 9268 | 67.6 | 20.8 | 6.2 | 1.162 | 1.145 | 1.117 | .057 | - | 0.022 | - |
| 12320* | 66.0 | 20.7 | 6.2 | 1.161 | 1.145 | 1.115 | .065 | - | - | - |
| 23130 | 67.0 | 20.9 | 6.2 | 1.163 | 1.148 | 1.116 | .067 | 20 | 0.025 | 0.014 |
| Procurement Spec. Requirement (AGC 10320) | 68 ± 5 | 20.5± 1.5 | 6.2± 0.3 | 1.17± 0.04 | No Req. | No Req. | 0.08 max. | 25° Max. | 0.03 Max. | No Req. |

* 10 pounds new Mix-4P3E added to system after 12,320 hours of operation. Amounts of previous additions made are not known.

# APPENDIX B

# MEMORANDUM

AEROJET NUCLEAR SYSTEMS COMPANY
ADVANCED PRODUCTS OPERATIONS

DATE: 11 January 1971
N3710:71-0510:FNC:hrt

TO: J. R. Pope

FROM: F. N. Collamore

SUBJECT: Review of Alternator Failure in ECTF

DISTR.: S.L. Bradley, R.S. Foley, C.E. Hawk, A.H. Kreeger

REFERENCE: (1) Identification of Vibrational Modes in TAA Shake Test, C.S. Mah to J.R. Pope, 27 October 1969, Memo 4932-69-0182

ENCLOSURES:
(1) Alternator Power at Shutdown
(2) Alternator Bearing Temperatures at Shutdown
(3) Alternator Winding Temperature at Shutdown
(4) 24 Point Recorder Reading at Shutdown
(5) 24 Point Recorder Assignment
(6) Alternator Temperature and Acceleration.
(7) Alternator Vibration Analysis
(8) Test Data Prior to Shutdown.

The operation of ECTF was reviewed to determine if there was any evidence of factors which may have contributed to the alternator failure. The available data at the time of shutdown was reviewed along with data taken prior to the shutdown. From the available data there appears to be no evidence of abnormal operation at the time of shutdown, or prior to shutdown. The recorders are operated six minutes out of each hour and were running at the time of the shutdown. All recorded temperatures and flow rates were normal just prior to shutdown.

This data is shown in the following enclosures.
(1) Alternator Power at Shutdown
(2) Alternator Bearing Temperatures at Shutdown
(3) Alternator Winding Temperature at Shutdown
(4) 24 Point Recorder Reading at Shutdown
(5) 24 Point Recorder Assignment

At the time of shutdown the alternator power (Encl. 1) decreased as a function of the output voltage which is proportional to frequency. The slight power peak at shutdown is typical as the saturable reactor power increases momentarily as the frequency drops below 380 Hz.

The alternator bearing temperatures as shown on encl. (2) are normal and steady up until shutdown at which time the drive end bearing temperature increased slightly as a result of the failure.

The alternator winding temperature shown on encl. (3) was normal up until the shutdown and then decreased as the load was removed.

Inspection of the multipoint recorder printout indicates that the failure occurred between points 15 (F-5) and 20 (F-6). The lubricant and coolant flow would stop at the moment of shutdown as the L/C pump is shut off by the protective system. All recorded parameters are normal up to the point of shutdown.

Enclosure (6) shows the alternator bearing temperatures and vibration acceleration level plotted up to the time of shutdown. In addition, data from two previous periods of operation are plotted. This indicates that these temperatures were normal prior to the failure, and not significantly different from that of previously operating periods.

The question of alternator vibration during the period prior to failure was considered. It had been observed that the general vibration level of the main alternator drive system appeared to have increased in magnitude prior to the failure. In the past this condition has existed as a result of scale forming on the water cooled eddy current coupling and causing an unbalanced condition. This has resulted in an increase in the low frequency vibration level of the drive system. However, this apparent increase in vibration level did not result in any significant change in the output of the accelerometers mounted on the alternator and turbine housing as shown on encl. (6). The recorded vibration level had been steady up to the time of failure and actually lower than at some previous periods.

Vibration frequency analysis data had been taken on the alternator and drive previously, the most recent being at 15946 hours running time. Enclosure (7) shows this data taken with a panoramic analyzer. This indicates that the highest magnitude vibration at the alternator occurs between 10,000 and 20,000 Hz and that the low frequency vibration was at a much lower magnitude. This would explain why the apparent increase in low frequency vibration did not result in an increase in the accelerometer reading. It also indicates that the lowest frequency axial vibration at the alternator was at approximately 150 Hz. and at a level of approx. 0.37 g.

Consideration was given to the possibility of an axial vibration causing the loss of preload of the alternator bearings. Reference (1) indicates an alternator rotor on bearings, axial natural frequency at approx. 88 Hz. It would appear that if the 150 Hz vibration mode was sufficient to cause an axial displacement of the bearing system that over a period of 23,000 hours there would be some evidence of this action on the bearing and bearing housing components. An inspection of these components revealed no wear or polishing of these parts which would have been indicated by continuous movement.

As a result of this investigation there appears to be no evidence indicating that the performance of the test facility was a contributing factor to the alternator failure. No abnormal operation was observed immediately before or at the time of failure. There is no evidence that the vibration of the alternator drive system caused the loss of preload of the alternator bearings.

F N Collamore

F. N. Collamore
SNAP-8 Program

10-007-102 STK. NO. J-1-001

**INTEROFFICE MEMO** AEROJET-GENERAL CORPORATION

TO: J. R. Pope

DATE 27 October 1969
4932-69-0182:CSM:djm

FROM: C. S. Mah

SUBJECT: Identification of Vibrational Modes in TAA Shake Test

COPIES TO: M. G. Cherry, R. S. Foley, R. W. Marshall, Jr., File

ENCLOSURE: (1) Natural Vibrational Frequencies to be Found in the TAA

A preliminary survey was made to determine the various modes of vibration in the frequency range of 20 to 2,000 Hz that might show up in the TAA shake test. Data was collected for the vibrational modes which had been calculated; and calculations were made for the simpler vibrational modes for which information is not available. In addition, other vibrational modes which might lie in the frequency range are identified. The results show that there will probably be over 50 modes of vibration which will be picked up by the accelerometers mounted on the TAA.

C. S. Mah

C. S. Mah
Mechanical Components Section
Power Systems Department

ENCLOSURE (1)
4932-69-0182:CSM:djm

# NATURAL VIBRATIONAL FREQUENCIES TO BE FOUND IN THE TAA

## I. INTRODUCTION

The TAA is going to be shaked on a shaker table at LeRC. The plan is to attach accelerometers to various parts of the rotor and attempt to define the extent of the vibrations. In order to do this, the vibrational frequencies of the various parts of the TAA must be known; and the interaction between the parts and the input actions must be defined.

## II. BACKGROUND

### A. Industry Experience

Experience is being gathered by the industry in this area. However, there has not been any definitive treatment of the subject in the literature. Related topics that have been studied include the theoretical analysis of one-degree-of-freedon systems with random inputs (References 1-3), the analysis of the vibrations of static structures with random inputs (Reference 4),and the scaling of the results of vibrational tests (Reference 5). In each instance, the procedures are complicated, and the results are uncertain.

### B. Aerojet Experience

The most applicable Aerojet experience is in the calculation of the critical speed of the turbine and rotors and the experimentation with the fourth-stage turbine wheel (Reference 6). The experimentation with the turbine wheel indicated that there can be vibrations which cannot be easily explained.

## III. TAA NATURAL FREQUENCIES

### A. Available Information

| | Frequency, cps |
|---|---|
| TAA Torsional [7*] | 60 |
| Turbine | |
| Rotor/housing, flexure | |
| Fundamental[8] | 300 |
| 1st Harmonic[8] | 366 |
| 2nd Harmonic[8] | 800 |
| 3rd Harmonic | 1,800 |
| Rotor on Bearings, Lateral | 530 |
| Rotor on Bearings, Axial | 152 |
| Housing, Lateral[7] | 375 |
| Housing, Axial[7] | 1,150 |
| Wheel, 2-Node[9] | 1,320 |
| Inlet Pipe | 108 |
| Space Seal Manifold | 27 |
| Alternator | |
| Rotor/Housing, Flexure[10,11] | 265 |
| Rotor on Bearings, Lateral | 300 |
| Rotor on Bearings, Axial | 88 |
| Quill Shaft, Flexure | 1,000 |

* References

### B. Vibrational Modes for Which no Information is Available

The following modes of vibration can be significant but the information is not available and the derivation is difficult:

- Turbine labyrinth seals
- Turbine bellows seals
- Individual balls in the bearings
- Bearing cages
- Nozzle diaphragms
- Wheel/curvic couplings
- Turbine exhaust housing
- L/C plumbing
- Miscellaneous thin sheeting and appendages

## IV. GENERAL COMMENTS

A simple accounting shows that there are over 20 known modes of vibration between 20 and 2,000 Hz. In addition, there are probably another 20 to 30 easily identified modes which probably lie in this range but for which calculations have not been made. Considering the multitudinous modes that probably exist, and considering the proximity of their frequencies with one another, it is likely that the identification of the vibrational modes will only be as successful as the experiement with the 4th stage turbine wheel (Reference 6). However, if a part should fail, then it is likely that the vibrational amplitude of the failed part will be more prominent, and the identification of the frequency and amplitude of the vibrations may lead to an easier redesign.

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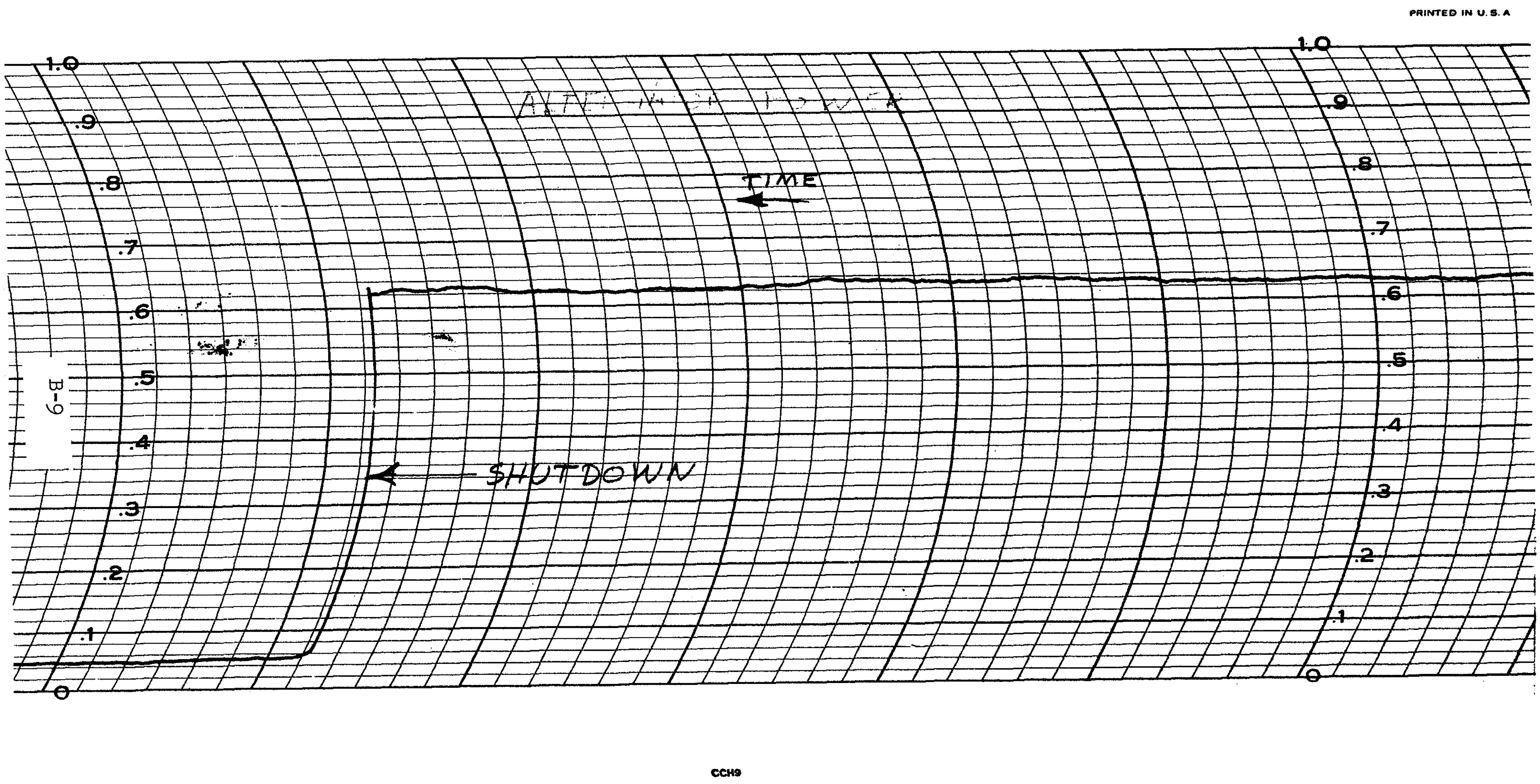
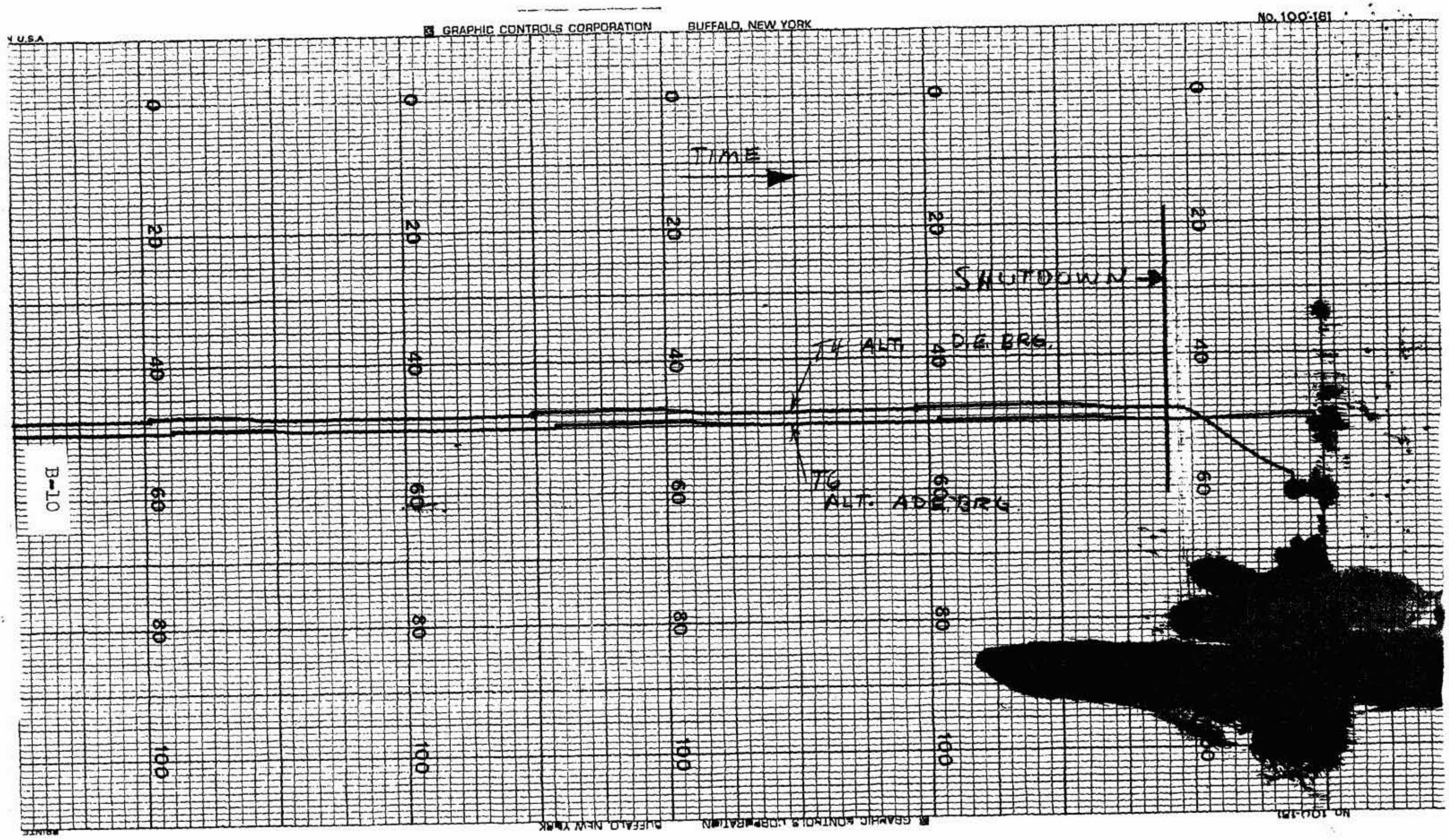


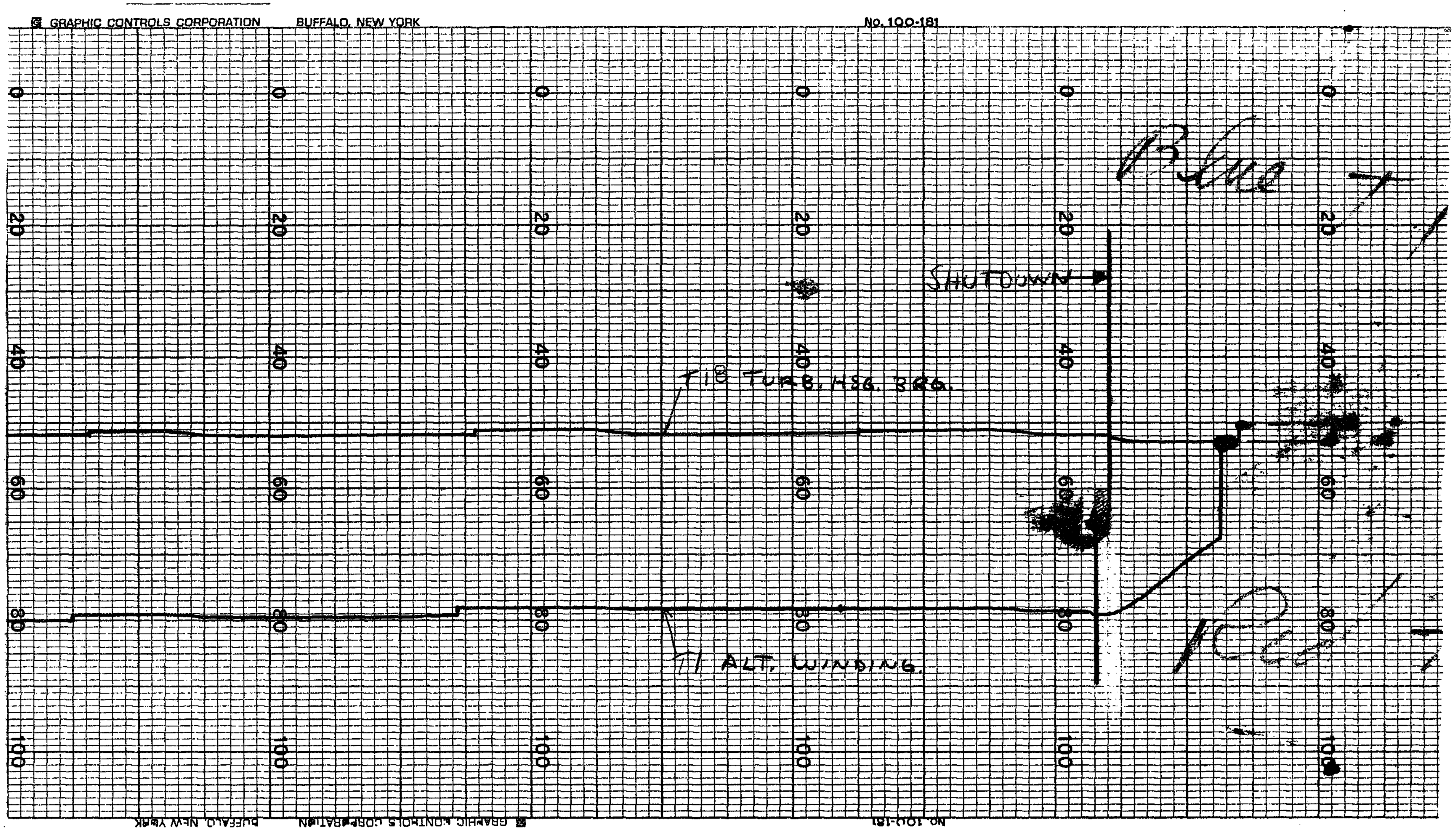
ALTERNATOR POWER AT SHUTDOWN

Enclosure 1



ALTERNATOR BEARING TEMPERATURES AT SHUTDOWN

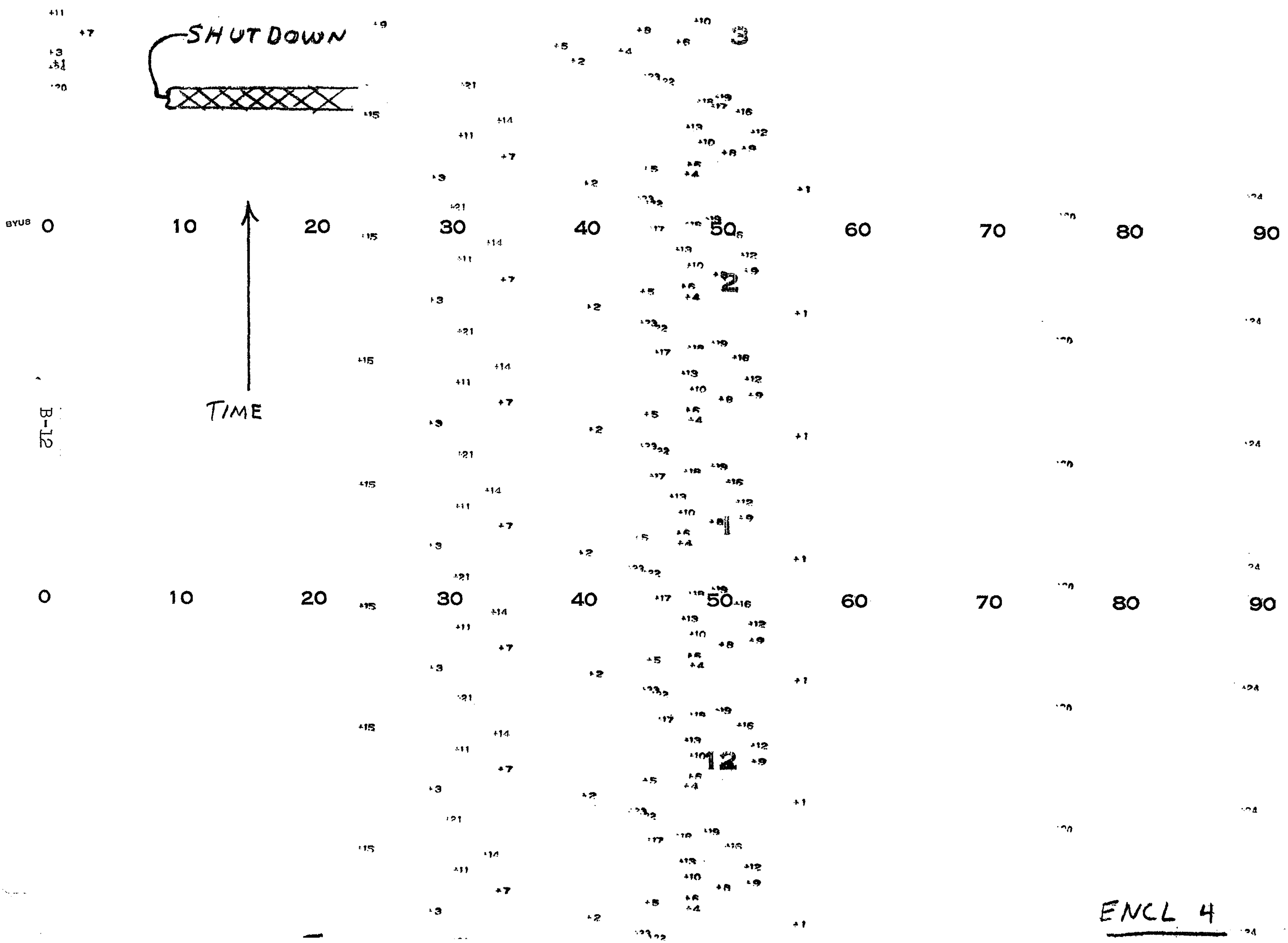
ENCLOSURE 2



ALTERNATOR WINDING TEMPERATURE AT SHUTDOWN

ENCLOSURE 3.

# 24 POINT RECORDER READING AT SHUTDOWN



ENCL 4

ENCLOSURE 5.

## 24 POINT RECORDER ASSIGNMENT

| Point No. | P & I No. | Description |
|---|---|---|
| 1 | F-1 | Alt. Coolant Inlet Flow |
| 2 | T-8 | Lube and Coolant Inlet Temperature |
| 3 | F-2 | Alt. D.E. Brg. Flow |
| 4 | T-9 | Alt. A.D.E. Brg. Lube outlet Temp. |
| 5 | T-11 | Alt. Coolant Outlet Temp. |
| 6 | T-28 | L/C Pump Discharge Temp. |
| 7 | F-3 | Alt. A.D.E. Brg. Flow |
| 8 | T-10 | Alt. D.E. Brg. Lube Outlet Temp. |
| 9 | T-12 | Alt. Power Terminal Temp. |
| 10 | T-30 | Saturable Reactor Base Temp. |
| 11 | F-4 | Housing Turbine End Bearing Flow |
| 12 | T-13 | Housing Alt. End Brg. Lube Outlet Temp. |
| 13 | T-22 | Degas Tank Fluid Temp. |
| 14 | T-31 | Voltage Regulator Base Temp. |
| 15 | F-5 | Housing Alternator End Bearing Flow |
| 16 | T-14 | Housing Turbine End Brg Lube Outlet Temp. |
| 17 | T-15 | Housing Turbine End Brg. Temp. |
| 18 | T-33 | High Temperature Heat Sink Temp. |
| 19 | T-17 | Housing Alt. End Temp. |
| 20 | F-6 | Total Flow |
| 21 | T-32 | Speed Control Base Temp. |
| 22 | T-34 | Saturating Transformer Base Temp. |
| 23 | T-35 | Speed Control Transformer Base Temp. |
| 24 | Z-1 | Alternator Frequency |

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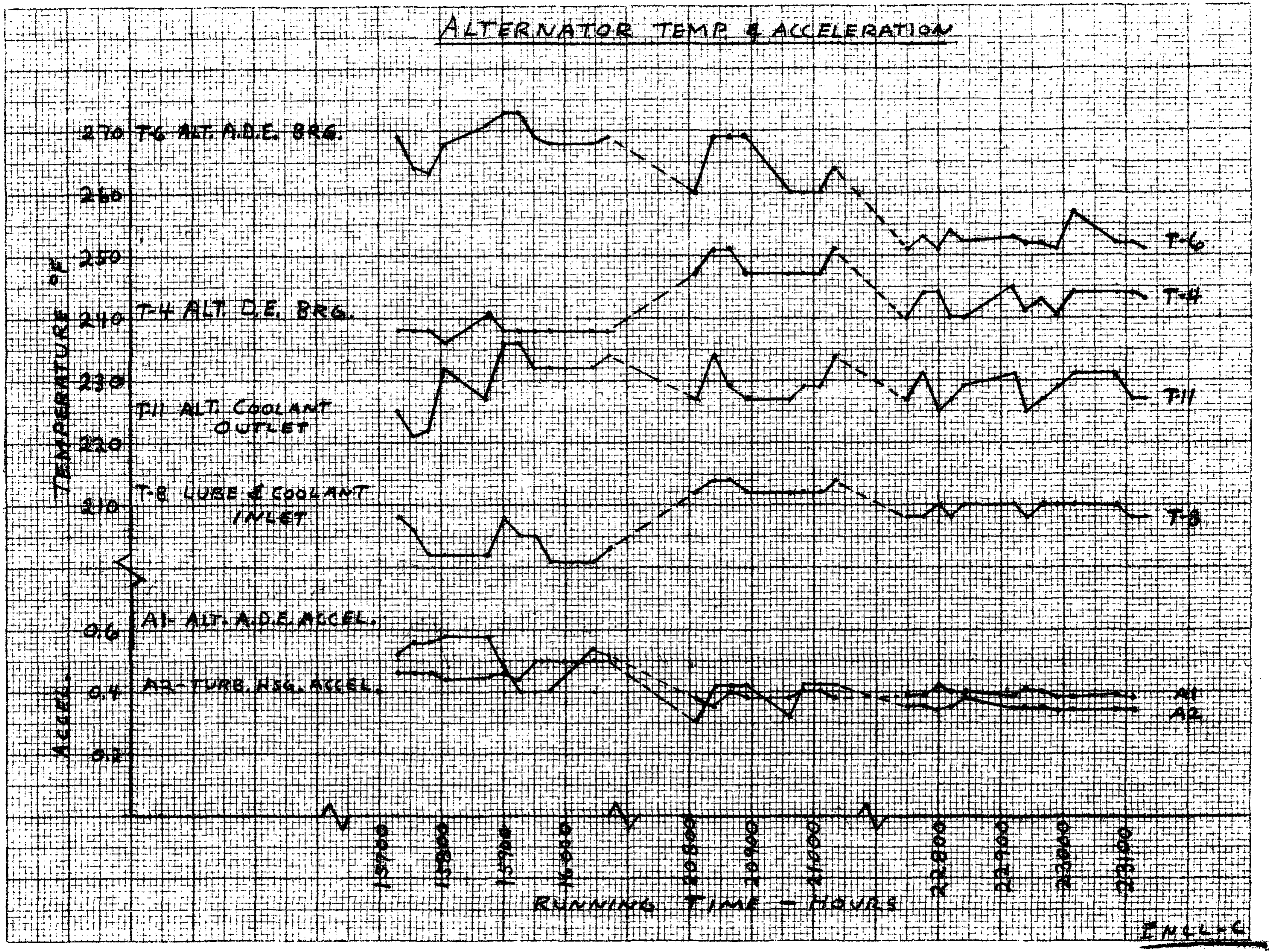
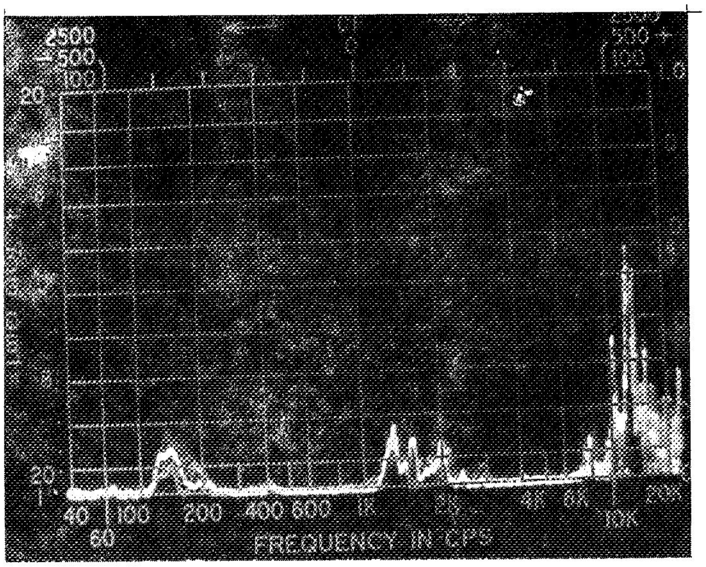


ENCL-C

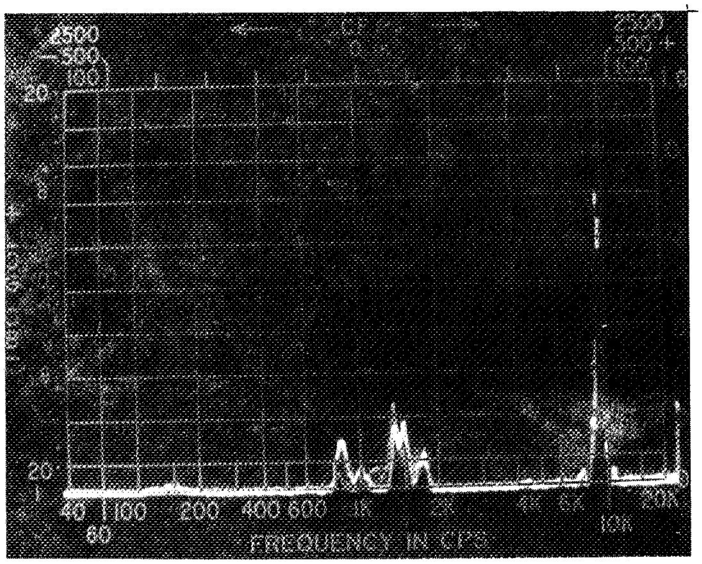


A1

Alternator ADE
Axial Acceleration

RTM 15946

1.59 g max.

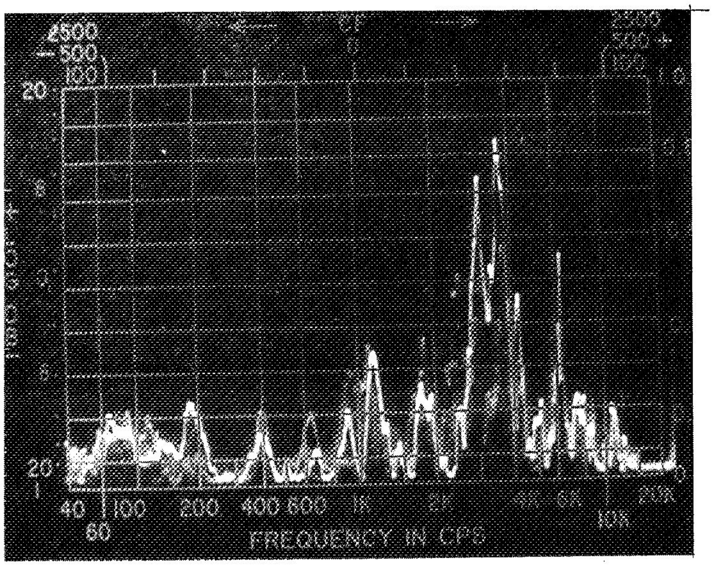


A2

Turbine Hsg Acceleration

RTM 15946

2.4 g max.



A3

Baseplate Acceleration

RTM 15946

.585 g max.

## TEST DATA RECORD
## SNAP-8 ELECTRICAL COMPONENT TEST - BLDG 194

| Data Point | | 718 | 719 | 720 | 721 | 722 | 723 | 724 | 725 | 726 | 727 | 728 | 729 | 730 * |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data | | 10-5-70 | 10/6 | 10/7 | 10/8 | 10/9 | 10/12 | 10/13 | 10/14 | 10/15 | 10/16 | 10/19 | 10/20 | 10/21 |
| Time | | 1230P | 1230P | 1230P | 1230P | 1230P | 1230P | 1230P | 1230P | 1230P | 1230P | 1230P | 1230P | 9:00A |
| RTM | R1 | 22750 | 22774 | 22798 | 22822 | 22846 | 22918 | 22942 | 22966 | 22990 | 23014 | 23086 | 23110 | 23130 |
| Alternator Ade Accel. | A1 | .39 | .39 | .42 | .4 | .4 | .39 | .41 | .4 | .38 | .38 | .39 | .38 | |
| Turbine Housing Accel. | A2 | .35 | .35 | .34 | .35 | .38 | .35 | .35 | .35 | .34 | .34 | .34 | .34 | |
| Output Volts Phase A | E2 | 121 | 121 | 121 | 121 | 121 | 121 | 121 | 121 | 121 | 121 | 121 | 121 | 121 |
| Output Volts Phase B | E3 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | |
| Output Volts Phase C | E4 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | 122 | |
| Alternator Field Volts | E5 | 35 | 35.5 | 35 | 34.5 | 35.5 | 36 | 36 | 35.5 | 36 | 36.2 | 36.2 | 35.5 | 35.5 |
| Alternator Amps Phase A | I1 | 192 | 192 | 190 | 190 | 192 | 192 | 193 | 193 | 193 | 197 | 197 | 194 | 194 |
| Alternator Amps Phase B | I2 | 193 | 193 | 191 | 191 | 193 | 193 | 194 | 194 | 194 | 198 | 198 | 195 | |
| Alternator Amps Phase C | I3 | 193 | 193 | 191 | 191 | 193 | 193 | 194 | 194 | 194 | 198 | 198 | 195 | |
| Saturable Reactor Amps Phase A | I4 | 48 | 49 | 45 | 45 | 47 | 50 | 50 | 49 | 50 | 52 | 52 | 50 | |
| Saturable Reactor Amps Phase B | I5 | 48 | 49 | 45 | 45 | 47 | 50 | 50 | 49 | 50 | 52 | 52 | 50 | |
| Saturable Reactor Amps Phase C | I6 | 48 | 49 | 45 | 45 | 47 | 50 | 50 | 49 | 50 | 52 | 52 | 50 | |
| Voltage Regulator Amps | I7 | .57 | .57 | .57 | .565 | .565 | .565 | .57 | .57 | .57 | .57 | .57 | .57 | |
| Speed Control Amps | I8 | 1.0 | 1.0 | .9 | .9 | .98 | 1.0 | 1.0 | 1.0 | 1.0 | 1.02 | 1.0 | 1.0 | |
| Alternator Field Amps | I11 | 14.8 | 14.8 | 14.5 | 14.5 | 14.8 | 15 | 15 | 14.8 | 14.8 | 15 | 15 | 14.8 | 14.8 |
| Capacitor Assy - Phase A | I12 | 123 | 124 | 122 | 122 | 123 | 123 | 124 | 124 | 124 | 124 | 124 | 123 | |
| Capacitor Assy - Phase B | I13 | 123 | 124 | 122 | 122 | 123 | 124 | 124 | 124 | 124 | 125 | 125 | 124 | |
| Capacitor Assy - Phase C | I14 | 124 | 125 | 123 | 123 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 124 | |
| Alternator P.F. - Phase A | PF1 | .92 | .92 | .92 | .92 | .92 | .92 | .92 | .92 | .92 | .915 | .915 | .92 | |
| Alternator P.F. - Phase B | PF2 | .92 | .92 | .92 | .92 | .92 | .92 | .92 | .92 | .92 | .915 | .915 | .92 | |
| Alternator P.F. - Phase C | PF3 | .92 | .92 | .92 | .92 | .92 | .92 | .92 | .92 | .92 | .915 | .915 | .92 | |
| Alternator KW | W2 | 60 | 60 | 59 | 59 | 59.8 | 60 | 60 | 60 | 60 | 61 | 60.8 | 60 | 60 |
| Saturable Reactor KW | W4 | 5 | 5 | 4.6 | 4.6 | 5 | 5.2 | 5.5 | 5. | 5.3 | 6 | 5.9 | 5 | 5 |
| Frequency | Z2 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | |

* DATA FROM RECORDERS
AT TIME OF SHUTDOWN

Rev. A

## TEST DATA RECORD
## SNAP-8 ELECTRICAL COMPONENT TEST
Bldg 194

| **Data Point** | | 718 | 719 | 720 | 721 | 722 | 723 | 724 | 725 | 726 | 727 | 728 | 729 | 730 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **L/C Flow** | ☒ | | | | | | | | | | | | | |
| **Alternator Coolant Flow** | F1 | 5.55 | 5.6 | 5.55 | 5.55 | 5.55 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.56 |
| | F1 | 1524 | 1538 | 1524 | 1524 | 1524 | 1538 | 1538 | 1538 | 1538 | 1538 | 1538 | 1538 | 1526 |
| **Alternator D.E. Bearing Flow** | F2 | 2.84 | 284 | 2.84 | 284 | 2.84 | 2.9 | 2.84 | 3.9 | 2.88 | 2.88 | 2.90 | 2.88 | 2.86 |
| | F2 | 154 | 154 | 154 | 154 | 154 | 156 | 154 | 156 | 155 | 155 | 156 | 155 | 155 |
| **Alternator A.D.E. Bearing Flow** | F3 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.38 |
| | F3 | 190 | 190 | 190 | 190 | 140 | 190 | 190 | 190 | 190 | 190 | 190 | 190 | 190 |
| **Hsg. T.E. Bearing Flow** | F4 | 3.0 | 3.05 | 3.05 | 3.05 | 3.05 | 3.05 | 3.05 | 3.05 | 3.05 | 3.05 | 3.05 | 3.05 | 3.06 |
| | F4 | 160 | 163 | 163 | 163 | 163 | 163 | 163 | 163 | 163 | 163 | 163 | 163 | 163 |
| **Hsg. A.E. Bearing Flow** | F5 | 2.7 | 2.65 | 2.65 | 2.6 | 2.65 | 2.55 | 2.55 | 2.55 | 2.5 | 2.45 | 2.4 | 2.35 | 2.35 |
| | F5 | 157 | 153 | 153 | 150 | 153 | 148 | 148 | 148 | 145 | 143 | 138 | 135 | 135 |
| **Total Flow** | F6 | 7.45 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 |
| | | 2532 | 2550 | 2550 | 2550 | 2650 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 |
| **System Pressures** | ☒ | | | | | | | | | | | | | |
| **Alternator A.D.E. Bearing Inlet** | P1 | 20 | 20.2 | 20.4 | 20.4 | 20.4 | 20.4 | 20.2 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | |
| **Alternator D.E. Bearing Inlet** | P2 | 20.5 | 20.5 | 20.4 | 20.4 | 20.4 | 20.5 | 20.5 | 20.5 | 20.4 | 20.4 | 20.5 | 20.4 | |
| **Alternator Coolant Inlet** | P3 | 21 | 20.8 | 20.8 | 20.8 | 20.8 | 20.8 | 20.8 | 20.8 | 20.7 | 20.7 | 20.6 | 20.6 | |
| **Bearing Outlet** | P4 | 5.2 | 5.2 | 5.3 | 5.3 | 5.3 | 5.3 | 5.4 | 5.3 | 5.3 | 5.3 | 5.3 | 5.3 | |
| **Rotor Cavity Pressure** | P5 | 29.5 | 29.5 | 29.5 | 29.5 | 29.5 | 29.5 | 29.5 | 29.5 | 29.5 | 29.5 | 29.5 | 29.5 | |
| **Hsg A.E. Bearing Inlet** | P6 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20.2 | 20 | |
| **Hsg. T.E. Bearing Inlet** | P7 | 19.6 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | |
| Gear Box Pressure | P8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | |
| **Degas Tank Vacuum** | P9 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | |
| Degas Tank Vacuum | P10 | .68 | .64 | .66 | .60 | .60 | .59 | .58 | .58 | .60 | .62 | .60 | .63 | |
| L/C Pump Discharge | P11 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | |
| Shaft Seal Pressure | P16 | 16.2 | 16.2 | 16.2 | 16.2 | 16.3 | 16.3 | 16.2 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | |
| | | | | | | | | | | | | | | |

TEST DATA RECORD

**SNAP-8 ELECTRICAL COMPONENT TEST**

Bldg 194

| Data Point | | 718 | 719 | 720 | 721 | 722 | 723 | 724 | 725 | 726 | 727 | 728 | 729 | 730 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| System Temperatures | ☒ | | | | | | | | | | | | | |
| Alternator A.D.E. End Turn | T1 | 7.7 | 8.18 | 7.98 | 7.87 | 7.91 | 8.11 | 8.16 | 8.22 | 8.18 | 8.27 | 802 | 8.11 | 7.9 |
| | | 392 | 394 | 385 | 380 | 382 | 391 | 393 | 396 | 394 | 398 | 387 | 391 | 382 |
| Alternator 180° Bus | T3 | 9.05 | 9.52 | 9.3 | 9.25 | 9.3 | 927 | 9.48 | 961 | 968 | 9.73 | 939 | 9.48 | |
| | | 433 | 454 | 444 | 442 | 444 | 443 | 452 | 458 | 461 | 463 | 448 | 452 | |
| Alternator D.E. Bearing | T4 | 4.75 | 4.83 | 4.83 | 4.74 | 4.74 | 4.86 | 4.77 | 4.81 | 4.74 | 4.83 | 4.83 | 4.83 | 4.8 |
| | | 240 | 244 | 244 | 240 | 240 | 245 | 241 | 243 | 240 | 244 | 244 | 244 | 243 |
| Alternator A.D.E. Bearing | T6 | 5.0 | 5.04 | 50 | 5.06 | 5.02 | 5.04 | 5.02 | 502 | 499 | 5.13 | 5.02 | 502 | 5.0 |
| | | 251 | 253 | 251 | 254 | 252 | 253 | 252 | 252 | 251 | 257 | 258 | 252 | 251 |
| Lube & Coolant Inlet | T8 | 4.0 | 4.0 | 4.05 | 4 | 4.05 | 4.05 | 4.0 | 4.05 | 4.05 | 4.05 | 4.05 | 4.0 | 4.0 |
| 2 | | 208 | 208 | 210 | 208 | 210 | 210 | 208 | 210 | 210 | 210 | 210 | 208 | 208 |
| Alternator A.D.E. Bearing Lube Out | T9 | 4.55 | 4.6 | 4.6 | 4.6 | 4.65 | 4.65 | 4.6 | 4.8 | 4.8 | 4.8 | 4.85 | 4.75 | 475 |
| 4 | | 231 | 234 | 234 | 234 | 236 | 236 | 231 | 242 | 242 | 242 | 245 | 240 | 240 |
| Alternator D.E. Bearing Lube Out | T10 | 4.95 | 5.25 | 5.0 | 5.0 | 5.0 | 5.0 | 4.45 | 5.0 | 5.0 | 5 | 5.05 | 5. | 501 |
| 8 | | 249 | 262 | 251 | 251 | 251 | 251 | 229 | 251 | 251 | 251 | 253 | 251 | 251 |
| Alternator Coolant | T11 | 4.45 | 4.55 | 4.4 | 4.45 | 4.5 | 4.55 | 4.4 | 4.45 | 4.5 | 4.55 | 4.55 | 4.45 | 4.45 |
| 5 | | 227 | 231 | 225 | 227 | 229 | 231 | 225 | 227 | 229 | 231 | 231 | 227 | 217 |
| Alternator Power Terminal | T12 | 2.6 | 2.85 | 2.6 | 255 | 255 | 2.55 | 240 | 5.20 | 5.25 | 5.25 | 5.25 | 5.1 | 5.15 |
| 9 | | 147 | 158 | 147 | 145 | 145 | 145 | 139 | 260 | 262 | 262 | 262 | 256 | 258 |
| Hsg. A.E. Bearing Lube Out | T13 | 5.15 | 5.25 | 5.2 | 5.2 | 5.25 | 525 | 5.2 | 5.2 | 5.25 | 525 | 5.3 | 5.2 | 5.22 |
| 12 | | 258 | 262 | 260 | 260 | 262 | 262 | 260 | 260 | 262 | 262 | 264 | 260 | 261 |
| Hsg T. E. Bearing Lube Out | T14 | 5.05 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 51 | 5.1 | 5.1 | 5.2 | 5.05 | 5.1 |
| 16 | | 253 | 255 | 255 | 255 | 255 | 255 | 255 | 255 | 255 | 255 | 260 | 253 | 255 |
| Hsg. T.E. Bearing | T15 | 4.45 | 4.5 | 4.5 | 4.5 | 4.55 | 453 | 4.5 | 4.5 | 4.5 | 4.55 | 4.55 | 4.5 | 448 |
| 17 | | 227 | 229 | 229 | 229 | 231 | 231 | 229 | 229 | 229 | 231 | 231 | 229 | 228 |

TEST DATA RECORD
SNAP-8 ELECTRICAL COMPONENT TEST - BLDG 194

SPS-010, Section I
Sheet 4

| Data Point | | 718 | 919 | 720 | 921 | 722 | 723 | 724 | 925 | 726 | 727 | 728 | 729 | 730 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hsg. T.E. Bearing | T16 | 257 | 257 | 256 | 256 | 256 | 258 | 258 | 258 | 258 | 258 | 258 | 258 | |
| Hsg. Alternator End | T17 | 4.9 | 4.95 | 4.9 | 4.95 | 4.95 | 4.95 | 4.95 | 4.95 | 4.95 | 4.95 | 5.0 | 4.9 | 4.9 |
| 19 | | 247 | 249 | 247 | 249 | 249 | 249 | 249 | 249 | 249 | 249 | 251 | 247 | 247 |
| Hsg. Alternator End Bearing | T18 | 5.1 | 5.2 | 5.17 | 5.11 | 5.13 | 5.22 | 5.11 | 5.17 | 4.99 | 5.2 | 5.2 | 5.17 | 5.2 |
| | | 256 | 260 | 259 | 256 | 257 | 261 | 256 | 259 | 257 | 260 | 260 | 259 | 260 |
| Gear Box Inlet Temp. | T21 | 134 | 134 | 133 | 133 | 132 | 134 | 134 | 133 | 133 | 133 | 134 | 133 | |
| Degas Tank Fluid | T22 | 4.65 | 4.7 | 4.7 | 4.7 | 4.7 | 4.75 | 4.7 | 4.7 | 4.75 | 4.75 | 4.8 | 4.7 | 4.7 |
| 13 | | 236 | 238 | 238 | 238 | 238 | 240 | 238 | 238 | 240 | 240 | 242 | 238 | 238 |
| Heat Exchange Oil Outlet | T23 | 174 | 175 | 173 | 173 | 174 | 176 | 175 | 175 | 175 | 175 | 177 | 175 | |
| Heat Exchange Coolant In | T26 | 78 | 78 | 78 | 76 | 76 | 78 | 78 | 77 | 77 | 78 | 78 | 76 | |
| Heat Exchange Coolant Out | T27 | 96 | 98 | 97 | 96 | 97 | 100 | 98 | 98 | 97 | 98 | 98 | 97 | |
| L/C Pump Discharge | T28 | 4.7 | 4.75 | 4.75 | 4.75 | 4.8 | 4.8 | 4.75 | 4.75 | 4.8 | 4.8 | 4.85 | 4.75 | 4.75 |
| 6 | | 238 | 240 | 240 | 240 | 242 | 242 | 240 | 240 | 242 | 242 | 245 | 240 | 240 |
| L/C Pump Discharge | T29 | 238 | 238 | 236 | 236 | 236 | 240 | 239 | 239 | 239 | 239 | 240 | 238 | |
| Saturable Reactor Base | T30 | 4.75 | 4.8 | 4.8 | 4.85 | 4.85 | 4.75 | 4.75 | 4.8 | 4.8 | 4.8 | 4.85 | 4.75 | 4.75 |
| 10 | | 240 | 242 | 242 | 245 | 245 | 240 | 240 | 242 | 242 | 242 | 245 | 240 | 240 |
| Voltage Regulator Base | T31 | 3.25 | 3.3 | 3.3 | 3.35 | 3.35 | 3.3 | 3.25 | 3.3 | 3.3 | 3.3 | 3.35 | 3.3 | 3.3 |
| 14 | | 175 | 177 | 177 | 180 | 180 | 177 | 175 | 177 | 177 | 177 | 180 | 177 | 180 |
| Speed Control Base | T32 | 3.0 | 3.05 | 3.05 | 3.05 | 3.05 | 3.0 | 3.05 | 3.0 | 3.05 | 3.0 | 3.05 | 3.0 | 3.0 |
| 21 | | 165 | 167 | 167 | 167 | 167 | 165 | 167 | 165 | 167 | 165 | 167 | 165 | 165 |
| High Temp. Heat Sink | T33 | 4.75 | 4.8 | 4.75 | 4.8 | 4.8 | 4.7 | 4.8 | 4.75 | 4.75 | 4.80 | 4.8 | 4.7 | 4.75 |
| 18 | | 240 | 242 | 240 | 242 | 242 | 238 | 242 | 240 | 240 | 242 | 242 | 238 | 240 |
| Saturating Transformer Base | T34 | 4.45 | 4.5 | 4.45 | 4.5 | 4.5 | 4.45 | 4.5 | 4.45 | 4.45 | 4.45 | 4.5 | 4.45 | 4.45 |
| 22 | | 227 | 229 | 227 | 229 | 229 | 227 | 229 | 227 | 227 | 227 | 229 | 227 | 227 |
| S.C. Transformer Base | T35 | 4.4 | 4.45 | 4.4 | 4.35 | 4.4 | 4.45 | 4.4 | 4.35 | 4.4 | 4.4 | 4.45 | 4.3 | 4.4 |
| 23 | | 225 | 227 | 225 | 223 | 225 | 225 | 225 | 223 | 225 | 225 | 227 | 223 | 225 |
| Low Temp. Heat Sink | T36 | 168 | 169 | 169 | 168 | 168 | 169 | 169 | 169 | 169 | 168 | 169 | 170 | |
| Capacitor Assembly Base | T37 | 174 | 173 | 172 | 174 | 175 | 174 | 173 | 174 | 174 | 174 | 174 | 174 | |
| | T38 | 210 | 211 | 210 | 210 | 211 | 213 | 212 | 213 | 212 | 213 | 213 | 212 | |

# APPENDIX C

THOMAS BARISH
CONSULTING ENGINEER

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Aerojet Nuclear Systems Co.
1100 W. Hollyvale St.
Azusa, Calif. 91702

Jan. 19, 1971

Attn: John R. Pope, Program Manager -- Snap 8
and Robert S. Foley, Project Engineer

Subject:

## Snap-8

## Alternator Bearings
## Final Examination

## and Seal Problem

1. This report follows 23,125 hrs. of operation. Last preceeding report, Oct. 17, 1969, was after 10,800 hrs.

This report includes the result of a very thorough preliminary examination and measurement of the bearings made by Mr. Foley, two conferences at this office with Mr. Foley and Andrew Stromquist of NASA on Jan. 11th and Jan. 13th, and the additional analysis and careful checkup completed by the author.

Ball Bearings

2. General Conclusion: The bearings have amply proved that they can be quite satisfactory for 40,000 hrs. life.

3. The minor deterioration which showed up on previous checkups has continued very slowly: a wear of the balls to an out-of-round condition, and the wear in the cage pockets at the ball contact with a "dog bone" pattern. The measurements recorded on page C-1 indicate that the balls are all banded with a maximum out-of-round on balls C and E of 40 M" and 28 M". Apparently, this was not enough to interfere with the continued operation of the bearings as long as the balls were kept preloaded so that the axis did not change. This does not mean that the bearing could operate with this much out-of-round though it might be able to, but it means that during the last period of operation the ball axis did not change. In use for the long run, there should be no reason for the axis to change and the bearing could operate considerably longer.

4. However, the bearing did show up favorably because the balls were out-of-round at the last checkup, (12,679 hrs.). We do not know how much, except that the ball size had gone down 130 M" at that time. We do know that the balls change in axis at that time because four of the eight balls I checked showed two bands, at angles from 60° to 90°. This means that the balls changed axis when the bearing was examined, and from then on operated in the

out-of-round condition in the direction of the contact. It is evident that the extent of this did not interfere with operation.

5. One other detail that gives us information is the fact that three of the balls C, E, and M, had a clear polar cap where there had been no rubbing at all at one point at right angles to the bands, with no cap on the other side. This means that the cage itself was pushed axially with a very light force, probably the force of the oil jets, and therefore left the opposite side with no rubbing at all.

6. This was further confirmed by an examination of the cages. The cage pockets showed on one side, that there was no contact with the ball because the fine varnish coating was not disturbed. On the other side of the pocket there was a small chamfer about .010-.020, where the varnish had been rubbed off and there was a sharp 45° corner.

7. This minor effect was further conformed by bearing A-54 where the cage had never been disturbed, and it had always been pushed in the one direction. The "dog-bone" contact had only 1/2 of the usual pattern on the cage tongues.

8. It is still recommended that this effect could be sharply reduced if the cage were designed so that the contact between the ball and the tongues of the cage would not be off center and against the edge of the area. This means designing the cage so that it does not have axial play. This was recommended before by the use of elongated pockets broached from a round. In addition, it is suggested (per R.S. Foley) that the cage could be made with the cross bars at the pitch diameter instead of at the O.D.

9. One other minor effect was observed: both of the alternator bearings were fairly completely covered with a very thin varnish. This was not evident where the surfaces were covered as on the O.D. or the bore of the bearing, but existed on all of the exposed surfaces and was a little bit darker and thicker on the O.D. of the inner. In the case of the drive end bearing A54, the varnish coat was considerably darker and heavier, approaching a bluish tinge that would occur with higher temperatures. This is to be expected as the bearing is close to the rotor.

10. It is thought that this varnish is a very slow temperature effect on the lubricant. It is easily removed by the fingernail or an eraser. It did not exist in the two drive shaft bearings. It is very slow because there is only a small increase compared to the last checkup at 12,679 hrs.

11. This varnish has not interfered with the performance of the bearings except that the ball wear and the cage wear is probably slightly higher because of its presence. Nevertheless, some

checking is indicated for the lubricant because a minor change in the lubricant, or quantity, or temperature pattern, might make this condition worse.

12. The O.D. of the outer race in every case showed a slight amount of working. In one case there was no impression at all for 90°, indicating that the outer race did not rotate in that case. In the first bearing, #A48, this had reached the point where there was a small chafing condition: enough to possibly interfere with axial float under the preload, but not likely. If there is such a hang-up, it would come from the fact that some of the varnish penetrated into the O.D. fit. This indicates that the fit was near the maximum looseness of .0009.

13. Recommendations: These bearings, as now made and mounted, can be approved for 40,000 hrs. operation.

14. Nevertheless, if there is time before they are reactivated and installed in an operating unit, it is desirable to make a cage with the modifications suggested and to make minor modifications in the lubricant or lubricant quantity, and to operate for a short time in order to make sure that these revisions would not introduce some unexpected minor variation.

15. In each case, the hardness of the inner race dropped 1-2 points Rockwell. It is suggested that the heat treatment of the bearing be specified that it can handle 400° F without a drop in hardness.

16. At the last checkup, some of these bearings showed specific rusting condition. This apparently has not interfered with their use. The only evidence of possible trouble is a spot (brg. G18 ball) which seems to be a fairly deep rust pit that operated enough to show a depression of 45 M", but this has not interfered with its use. The absence of trouble from rusting is a further indication of the design being adequate from a bearing viewpoint, including some margin for "forgiveness".

17. Both of the alternator bearings showed a relatively wide contact leaning toward the low angle side, though not actually reaching the bottom of the groove. This indicates temporary conditions which caused the balls to ride at a lower angle for a short time. The resulting widening of the contact makes it impossible to determine actual loads by the contact area.

## Seal Problem

18. The imprint on the rotating member of the seal which siezed clearly shows
(a) Circumferential scratches initially, that went all the way around the piece, and

(b) A positive seizure with no rotation and much later heating, causing a partial weld of each groove and an imprint of the spiral groove on the rotating collar.

<u>Conclusion</u>: the clearance at the seal closed down enough to cause positive rubbing and the resulting severe heating and siezure.

19. A careful study of the seal clearance is presented, (next page). The indications are that the bearings themselves could not have produced enough motion to close down the clearance in the molecular seal. The maximum motion which the bearing would permit if the balls actually rolled into the bottom of the groove would be .0008 radial motion at the bearing, and this is not enough to close the seal clearance.

The only two things that could have approached such displacement in the bearing would be
(a) a sticking of the outer race that removed the preload. This would require a very considerable amount of end motion, approximately .013, and therefore was very unlikely to have occurred because the unit will not permit that much end motion without the outer race bottoming on the spring control.
(b) large unbalanced loads. This would require a load of several hundred pounds (see page C-3 for deflection). Such unbalance is very unlikely to occur, as it would require a radial displacement of .0015 (TIR = .003). The only approach to this would be the effect of the creep in the rotor. This could be unequal for the two opposing ears. But, it would have had to be much larger not indicated by the unbalance existing.

20. The major source for closing the seal clearance would then be the <u>temperature differential</u> between the outer member of the seal and the rotating member. With the rotor itself reaching temperatures above 600°F and very little heat transfer, and with the stationary member of the seal being cooled by the outgoing oil, it is quite possible that the temperature differential can reach and exceed 200°F. This would take out 1/3 of the seal clearance. When combined with the much smaller additional effects listed in the tabulation, this temporary greater thermal difference, would produce a rub.

21. Apparently, the original calculations needed .003 radial clearance for effective operation of the molecular seal. However, in actual use, the thermal effect apparently would always cut this to .002.

22. <u>Recommendation</u>: The seal clearance be increased by .002 on the diameter. Previous tests may indicate if this would reduce the effectiveness of the molecular seal appreciably. If no such data exists, it may be necessary to use some short operating test to see if this would be harmful on the overall unit performance.

Thomas Barish

TB/jsl

Thomas Barish

## Seal Clearance

| | | Per Side: |
|---|---|---|
| Initial | .004 - .008 (Drawing) | |
| | Actual ~~.0064~~ .0054 RLF | ~~.0032~~ .0027 RL Foley 1-21-71 |

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Losses

| | | |
|---|---|---|
| A) Brg. Fitting | | |
| | Inner Ring 0 | |
| | Outer Ring .0001 - .0008 | .0004<br>Max. Possible Unlikely |
| B) Brg. Looseness 0 | | 0 |
| | If no preload .0016 | .0008<br>(hardly possible) |
| C) Brg. Deflection (See curve Page C-3) | | |
| | at 120 lb. unbalance per brg. | .00015<br>(rotating unlikely) |
| D) Eccentricities | | |
| | Inner and Outer | .00015 (max.) |
| | Housing and Shaft | .0002<br>(both unlikely) |
| E) Thermal | | |
| | 200° Temp. Differential | .00105 |
| | = 200 x 1.75 x 6 M" = .0021 | (likely) |

## SNAP-8 ALTERNATOR BEARINGS AND SEAL

BALL EXAMINATION 1/19/71 T. Barrish

| Bearing A 48 | Ball | Out-of-Round $\mu$ in. | | Diameter Under .47500 $\mu$ in. | Bands | Angle | Polar Cap |
|---|---|---|---|---|---|---|---|
| 23130 hours<br>alternator<br>anti-drive end | A | 20 | 15 | 10 | 2 (1 faint) | 60° | Smeared over |
| | B | 18 | 17 | 20 | | | |
| | C | 40 | 18 | 0 | 1 Clear | | Clear |
| | D | 20 | 14 | 10 | | | |
| | E | 28 | 8 | 0 | 1 Clear | | Clear |
| | F | 20 | 10 | 30 | | | |
| | G | 6 | 2 | 50 | 2 | 80° | Smeared |
| | H | 14 | 11 | 60 | 2 Faint | 60° | Just visible |
| | I | 20 | 9 | 50 | | | |
| | J | 13 | 10 | 40 | 2 | 90° | Smeared |
| | K | 18 | 8 | 60 | None | | None |
| | L | 10 | 10 | 40 | 2 Very faint | | |
| | M | 18 | 18 | 20 | 1 Clear | | Clear |
| A 54<br>20630 hours<br>drive end | 1 | 16 | 15 | 50 | 3 bright scratches near equator | | |
| | 2 | 12 | 10 | 50 | | | |
| | 3 | 20 | 15 | 40 | | | |
| A 25<br>10,630 hours<br>drive outb'd | 1 | 10 | 10 | .46873 | none | | |
| | 2 | 12 | 8 | " | " | | |
| | 3 | 7 | 6 | .46876 | " | | |
| G 18<br>20,630 hours<br>drive inb'd | 1 | 8 | 16 | .47217 | none | | |
| | 2 | 14 | 6 | .47218 | " | | |
| | 3 | 19 | 8 | " | " | 1 pit - 45 $\mu$ in. deep- many smaller | |

## Measurement of Bearings

| Brg. No. | Altrntr. Time Hrs. | Radial Play | Ball Diam. | Flushness | Contact Angle | Hardness Outer | Hardness Inner | O.D. Nom. 3.1496 | I.D. Nom. 1.5748 |
|---|---|---|---|---|---|---|---|---|---|
| A-48 Altrntr. Anti-Dr. End | New | .00165 | .47068 | .0005 | 15°53' | 63.6 | 64 | -150 M" | -100 M" |
| | 2553 | | -130 M" | | | | | | |
| | 12,679 | | | | | | | | |
| | 23,130 | .0015 | -220 M" | .00015 | 15°30' | 62.3 | 61.7 | -100/-100 | -100 |
| A-54 Altrntr. Drive End | New | | | | | | | | |
| | 2553 | .00165 | .46068 | -.0001 | 15°53' | 64 | 63.6 | -90 | -100 |
| | 12,679 | | | | | | | | |
| | 23,130 | .0017 | -210 M" | -.0004 | 15°50' | 62.7 | 62.4 | -30/-100 | -60 |
| A-25 Drive Shaft Outboard End | New | | | | | | | | |
| | 12,679 | .00165 | .46877 | .0002 | 14°43' | 64 | 63.6 | -140 | -140 |
| | 23,130 | .0016 | -50 M" | -.0001 | 14° 7' | 63.7 | 61.9 | -100/-160 | -200 |
| G-18 Drive Shaft Inboard End | New | | | | | | | | |
| | 2553 | .0016<br>.004 | .472 | ±.0002 | 14°18' | | | | -50/-100 |
| | 12,679 | .0016 | .0 | -.0011 | 14°34.5' | | | -0/-75 | -40/-70 |
| | 23,130 | .0016 | +150 M" | -.00005 | 14°45' | 63.7 | 61.9 | -30/-70 | -20 |

SNAP-8 Alternator Brgs.

RADIAL DEFLECTION

7208 J Brg.
13 - 15/32 Balls
52 & 53% Curvatures
15° Initial Angle
with 60 lb. Axial Preload