NASA TECHNICAL MEMORANDUM

NASA TM X-71806

NASA TM X-71806

(NASA-TM-X-71806) DEVELOPMENT OF CIRCUMFERENTIAL SEAL FOR HELICOPTER TRANSMISSIONS: RESULTS OF BENCH AND FLIGHT TESTS (NASA) 20 p HC $3.25 CSCL 11A

N75-33055

Unclas

G3/07 42330

DEVELOPMENT OF CIRCUMFERENTIAL SEAL FOR HELICOPTER TRANSMISSIONS - RESULTS OF BENCH AND FLIGHT TESTS

by Thomas N. Strom and Lawrence P. Ludwig
Lewis Research Center
Cleveland, Ohio
September 1975

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-71806		

4. Title and Subtitle	5. Report Date
DEVELOPMENT OF CIRCUMFERENTIAL SEAL FOR HELICOPTER TRANSMISSIONS - RESULTS OF BENCH AND FLIGHT TESTS	
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Thomas N. Strom and Lawrence P. Ludwig	E-8496
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A modified circumferential segmented ring seal was designed for direct replacement of a helicopter transmission elastomeric lip seal operating on a shaft diameter of 13.91 centimeters (5.481 in.) at sliding velocities to 52.48 m/sec (10 330 ft/min). The modifications involved the garter spring tension, shaft roundness, seal housing flatness, and pumping grooves to inhibit leakage. Operation of the seals in bench tests under simulated helicopter transmission conditions revealed that the seal leakage rate was within acceptable limits and that the wear rate was negilible. The low leakage and wear rates were confirmed in flight tests of 600 and 175 hours (sliding speed, 48.11 m/sec (9470 ft/min)). An additional 200 hours of air worthiness qualification testing (aircraft tie down) demonstrated that the seal can operate at the advanced sliding conditions of 52.48 m/sec (10 330 ft/min).

17. Key Words (Suggested by Author(s))	18. Distribution Statement
	Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22151

E-8496

DEVELOPMENT OF CIRCUMFERENTIAL SEAL FOR HELICOPTER TRANSMISSIONS - RESULTS OF BENCH AND FLIGHT TESTS

by Thomas N. Strom and Lawrence P. Ludwig

Lewis Research Center

SUMMARY

A segmented carbon circumferential seal was modified to reduce leakage when operating under the ample lubrication conditions found in helicopter transmissions. These modifications consisted of (a) increased garter spring force, (b) improved shaft roundness, (c) improved housing sealing face flatness, (d) closer control of the seal housing to transmission housing interference fit, and (e) additions of pumping bevels and grooves to the carbon segments to inhibit leakage. The seals were designed to replace an elastomeric lip seal, in a helicopter transmission, operating on a shaft diameter of 13.91 centimeters (5.481 in.) at sliding velocities of 48.11 to 52.48 meters per second (9470 to 10 330 ft/min). Operation of the seals in bench tests, one with a beveled sealing ring and another with a beveled ring plus helical grooves in the cover ring bore, revealed that the leakage rate was within the acceptable limit of 2 cc per hour and the wear was negligible. Flight tests, 600 hours on the seal with the beveled sealing ring and 175 hours on the seal with the beveled seal ring and helical grooves in the cover ring, demonstrated that the leakage was within acceptable limits. The low wear rate indicated that the seal will operate for the full time between overhauls. An additional 200 hours of air worthiness qualification testing for an advanced helicopter transmission demonstrated that the seal with the helical grooves can operate at sliding conditions of 52.48 meters per second (10 330 ft/min).

INTRODUCTION

Many types of helicopter transmissions have elastomeric type lip seals to prevent lubricant leakage (the seal also acts to exclude dirt, water, and debris from entering the transmission). Elastromeric seals are attractive because of low cost, but in some cases their use has led to excessive seal replacement in service because of the inherent inability of the lip seal to operate at high sliding speeds. Lip seal failure is thought to be precipitated by lubricant film temperatures (between the lip and the shaft) reaching the boiling point because of high shear rates. This high temperature, which is local, gradually causes a hardening and degradation of the elastomer. Other factors that may contribute to the seal failures are the inability of the lip to follow the shaft runout motions and local loss of the lubrication film because of film boiling.

Carbon ring seals are able to operate at much higher sliding speeds than elastomeric seals (ref. 1). Carbon can withstand the high temperatures generated in shearing a lubricating fluid film, and can even run dry. Conventional face seals with carbon rings have been operated to sliding speeds of 101.7 meters per second (20 000 ft/min); this is about 3 times the speed capability of lip seals. However, in some existing transmissions the carbon face seal is not suited for direct replacement of lip seals because of extra space and assembly requirements. On the other hand, the segmented carbon ring (circumferential) seal is compact and has space and assembly requirements equivalent to that of a lip seal. But a problem with the segmented seal has been its tendency to leak, and for this reason it has been applied only to mist lubricated and gas sealing (dry) applications. (ref. 2).

Except for this leakage tendency, the circumferential seal is attractive for high sliding speed applications since the carbon ring materials have good wear resistance and can withstand the expected high temperature developed in shearing the lubricant film. Also, the circumferential seal materials are compatible with liquid lubricants (elastomeric lip seals and elastomeric secondary seals in face seals sometimes present compatibility problems). Furthermore, the circumferential seal is easy to assemble and is compact. Thus, if the inherent leakage problem can be overcome, the circumferential seal will become very attractive for wide use in aircraft transmissions.

The objectives of this study were to (1) determine which modifications of the circumferential seal are needed so that it can operate under the ample lubrications conditions found in helicopter transmissions, and (2) obtain operating experience on circumferential seals in helicopter transmissions (flight or tie down tests).

This study was on the three-ring segmented type (fig. 1) having a seal ring, a top cover ring, and a side cover ring. It was designed to replace an existing lip seal on a high speed input shaft of a helicopter transmission. The shaft diameter was 13.91 centimeter (5.481 in.) diameter and the sliding speed was 48.11 to 52.48 meters per second (9470 to 10 330 ft/min). The sealed pressure was estimated to be less than 0.69 N per square centimeter (1 psi) in the helicopter transmission.

APPARATUS AND PROCEDURE

The circumferential (segmented ring) seal evaluated in this study is shown in figure 1. The seal consists of three rings (each having three segments as shown in fig. 2). The top cover ring and the side cover ring lay over the gaps in the seal ring. Garter springs (11 N (2.5 lbf) tension) load the segmented rings against the wear sleeve. A wave spring (26.7 N (6 lbf)) loads the carbon rings against the seal housing. Leakage rates were measured for a circumferential seal having a sealing ring with beveled ends, and for a circumferential seal with a beveled ring plus helical grooves in the cover ring bore (see figs. 3 and 4). The orientation (see fig. 4) of the beveled edges and of the helical grooves is such that they pump against leakage tendency. Each segment contained 30 helical grooves approximately 1.52 millimeters (0.06 in.) wide, 0.51 millimeter (0.02 in.) deep, and orientated at about a 30° helical angle (see fig. 4).

The test head (bench test) schematic is shown in figure 5. It consists of a housing that holds the seal, and a shaft that is mounted on grinding spindle. Speed control was through a hydraulic drive pump and motor. The lubricant (MIL-L-7808) is introduced by a jet, and the lubricant flows under a centrifugal head along the inside diameter of the shaft. The lubricant temperature in and out of the housing cavity was monitored.

In the flight tests and the air worthiness qualification tests the seals were evaluated on the input shaft quill (see fig. 6 (from ref. 3)) of the transmission. The maximum seal sliding speed was 52.48 meters per second (10 330 ft/min).

RESULTS AND DISCUSSION

Wear and leakage rates of circumferential seals were measured in bench tests that simulated helicopter transmission operation. Additional seals were evaluated in helicopter flight and tie down tests.

OPERATION IN BENCH TYPE TESTS

Effect of Spring Force

Evaluation of the seals in bench tests revealed that lubricant leakage was a strong function of the radial load imposed by the garter springs. Figure 7 shows the leakage for the two different spring tension loads, 6.7 and 11.12 N (1.5 and 2.5 lbf). (The 4.45 N (1 lbf) tension load, which was the original recommendation by the manufacturer, permitted excess leakage even at pressures less than 0.35 N per square centimeter (0.5 psi)). Increasing the spring tension force to 11.12 N (2.25 lbf) (see fig. 7) resulted in a leakage rate that was within the acceptable limits (ref. 1) of 2 cc/hr. over a wide pressure range. With this spring tension of 11.12 N (2.5 lbf) the carbon wear rate over a 100 hour period of operation was negligible. The shaft spacer showed only slight polishing due to sliding contact with the carbon rings. (also see ref.4).

Effect of Shaft Spacer Roundness

Figure 8 shows a typical shaft spacer roundness check. The inner circle indicates that the shaft surface over which the spacer is press fitted, was round within 3.175 micrometers (0.000125 in.). The outer circle is the roundness measurement after the spacer is pressed onto the shaft. Excessive variation in roundness is evident. Four prominent lobes due to spacer wall variations are evident with a maximum amplitude of 25.4 micrometers (0.001000 in.). (This shaft spacer is the typical of the original equipment furnished for the lip seal; and it can be visualized that the elastomeric lip would not be able to follow to the roundness variation at high shaft speeds). Since the carbon segments are rigid they tend to span the lobes and form leakage paths. Improved spacers were manufactured by pressing an over sized spacer on a mandrel which had the same diameter as the transmission shaft, and then grinding to size. Thus variations in spacer wall thickness were minimized. In this manner final assembled spacer roundness of less than 12.7 micrometers (0.000500 in.) can be obtained. In regard to seal assembly, the shaft spacer should be chamfered on the oil side edge in order to facilitate assembly of the carbon rings and to preclude carbon breakage.

Effect of Housing Sealing Face Flatness

Operation of seals in bench tests which simulated helicopter transmission operation revealed that housing face flatness was critical from a leakage standpoint. Typically a housing face (as manufactured) reveals, after lapping, surface waves which may be due to chucking deformation in the machining operation. (see fig. 9) In addition to waves, the lapping pattern usually widens toward the inside diameter, and this indicates a coning out-of-flatness. Bench tests show that the carbons conform to the housing face waviness but the coning is a potential source of leakage.

In addition, calculations revealed that the seat housing to transmission housing interference fit tends to cause a coning deformation of the housing sealing face. The present tolerance spread on the transmission and seal housings results in an interference fit of 0.089 to 0.179 millimeters (0.0035 to 0.0070 in.), and this tends to cause the type of coning deformation indicated in figure 10. Since coning is critical from a leakage standpoint, close control should be established on both the coning produced in manufacture and the coning caused by the interference fit.

Effect of Carbon Ring Bore Grooves

Two different types of bore grooving modifications were made to the conventional seal. The first modification consisted if adding a 60 degree bevel to one end of each segment of the seal ring (see figs. 4 and 11). Note that shaft rotation is such that this bevel acts to pump any leakage back to the oil side. The effectiveness of this bevel was demonstrated in bench tests in which reverse rotation resulted in excessive leakage, while proper rotation direction resulted in an acceptable leakage rate (ref. 4). This idea of pumping grooves to inhibit leakage was carried on even further by adding helical grooves to the side cover ring in the second modification. Figures 3 and 4 show the location of these grooves. Reference 2 contains a detailed result of the operating effectiveness of these grooves. Results indicate that in applications where the transmission pressure is 0.34 N per square centimeter (0.5 psi) or less, this second modification (helical grooves in the cover ring) may be an unnecessary expense.

Operation in Helicopter Transmissions

Seals with the two different types of bore grooving were evaluated in helicopter transmissions. These seals were furnished by NASA Lewis Research Center to Bell Helicopter Company. Both seal types were evaluated in transmissions (bench tests) according to the verification run cycle shown in table 1, which was taken from reference 3. The seal with the beveled edge on the seal ring (no helical grooves) was installed in a helicopter at Fort Rucker under the control of the U.S. Army Aviation Test Board. To date this seal has accumulated a total of 600 hours of flight operation with no reports of leakage.

The seal with the beveled edge and helical grooves was installed in a helicopter at Bell and accumulated a total of 175 hours of testing (flight testing ref. 3). Of this total time 11.1 hours was ground run time in a cold-weather test cell located at Elgin AFB. Also included was 10.5 hours of high-altitude tests at Alamosa, Colorado (ref. 3). After the 175 hours of flight tests the seal was inspected by NASA Lewis Research Center personnel and found to be in excellent condition and the insignificant wear indicates that the seals will operate for the full time between overhauls.

A second seal with beveled edges on the seal ring segments and helical grooves in the cover ring was furnished by Lewis Research Center to the Bell Company for advanced helicopter transmissions. This seal has successfully completed the 200 hour air worthiness qualification test (tie down).

SUMMARY OF RESULTS

Segmented carbon circumferential seals were modified to reduce leakage when operating under the ample lubrication conditions found in helicopter transmissions. The seal design, which had the same space and assembly requirements as that of a lip seal, was designed for a shaft diameter of 13.91 centimeters (5.481 in.). Analysis, bench testing and flight testing revealed the following:

1. The seal leakage rate is a strong function of the garter spring tension, and a tension force of 1.72 N (2.5 lbf) kept leakage rates within acceptable limits without excessive wear.

2. The shaft out-of-roundness affects leakage, and to reduce the leakage tendency between the carbon rings and the shaft, the shaft roundness should be held within 12.7 micrometers (500 μin.).

3. Coning deformation of the housing sealing face is critical from a leakage standpoint. This deformation, which is a result of manufacturing and interference fit up, should be controlled within close limits.

4. The bevel ends on the seal ring segments act to pump back any leakage; the helical grooves in the cover ring act in the same manner.

5. Seal operation in a helicopter transmission (600 hours of flight tests on the seal with the beveled seal ring ends, and 175 hours of flight tests plus 200 hours of air worthiness tests on the seal with beveled edges and the helical grooves) demonstrated that the seals have low leakage and wear rates under actual operation conditions.

REFERENCES

1. Hayden, T. S.; and Keller, C. H., Jr.: Design Guide for Helicopter Transmission Seals. (SER-50791, United Aircraft Corp.; NAS-15684.) NASA CR-120997, 1974.
2. Ludwig, Lawrence P.; and Strom, Thomas N.: Improved Circumferential Shaft Seal for Aircraft Gear Transmissions. NASA TN D-7130, 1973.
3. Turner, Charles A.: Results of Helicopter Flight Tests of a Circumferential Carbon Oil Seal. Rep. No. 299-099-740; USAAMRDL-TR-75-23, Bell Helicopter Company, 1975.
4. Hayden, T. S.; and Keller, C. H., Jr.: Development of Helicopter Transmission Seals, Task 2. (SER-50776, United Aircraft Corp.; NASA CR-120983, 1973.

Table I.- Verification Run Cycle in Helicopter Transmission

(from ref. 3)

Time (hr)	Accum. Time (hr)	Speed (rpm)	Torque (ft - lb)	Approx. Horsepower
0.1	0.1	4000	Min	Min
0.1	0.2	4800	1,860	141
0.1	0.3	5800	1,860	171
0.1	0.4	6400	4,335	440
0.1	0.5	7040	7,600	827
0.1	0.6	6600	7,400	775
0.1	0.7	6400	8,275	840
0.1	0.8	6400	9,750	990
0.1	0.9	6400	10,601	1077
0.2	1.1	6600	10,781	1129
0.2	1.3	6600	10,924	1144

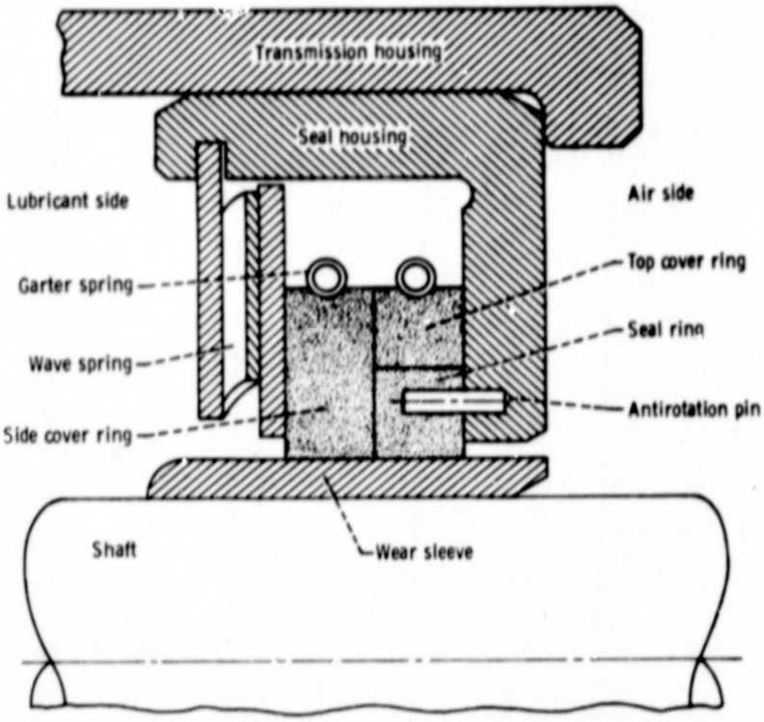

Figure 1. - Conventional circumferential seal; three-ring type (each ring segmented).

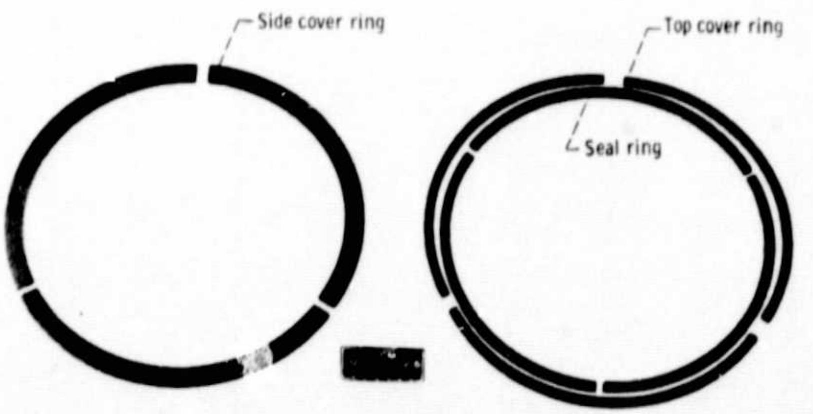

Figure 2. - Carbon rings for conventional circumferential seal.

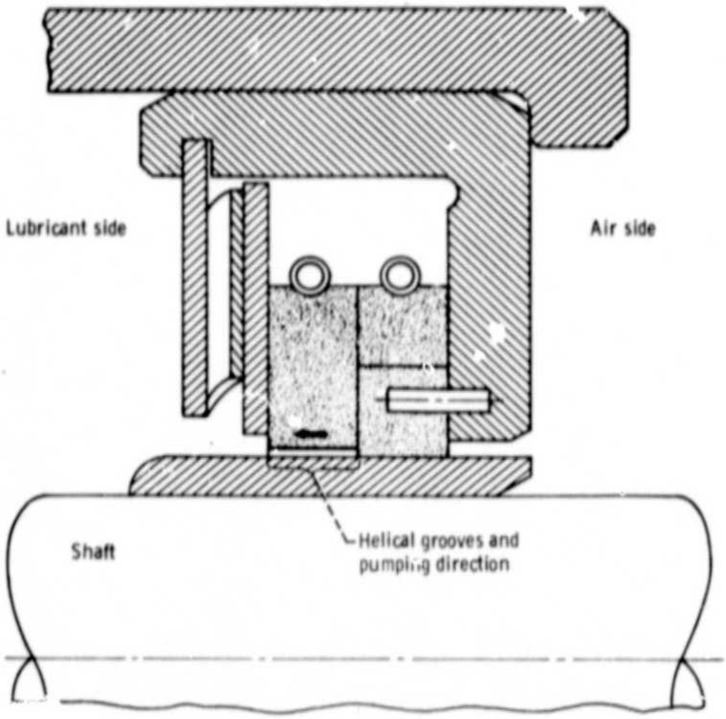

Figure 3. - Circumferential seal modified to have helical grooves in side cover ring.

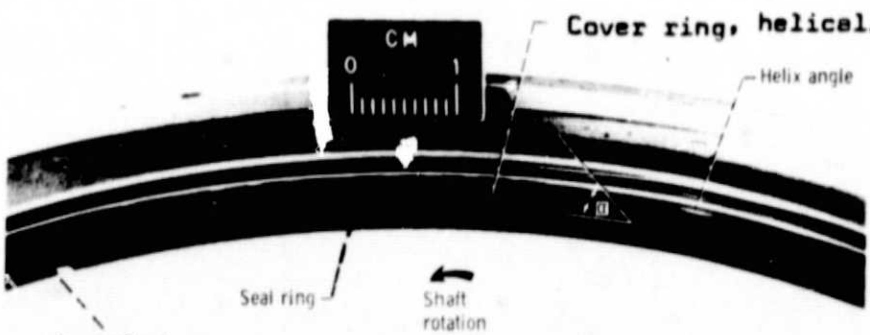

Fig 4.- Modified circumferential seal

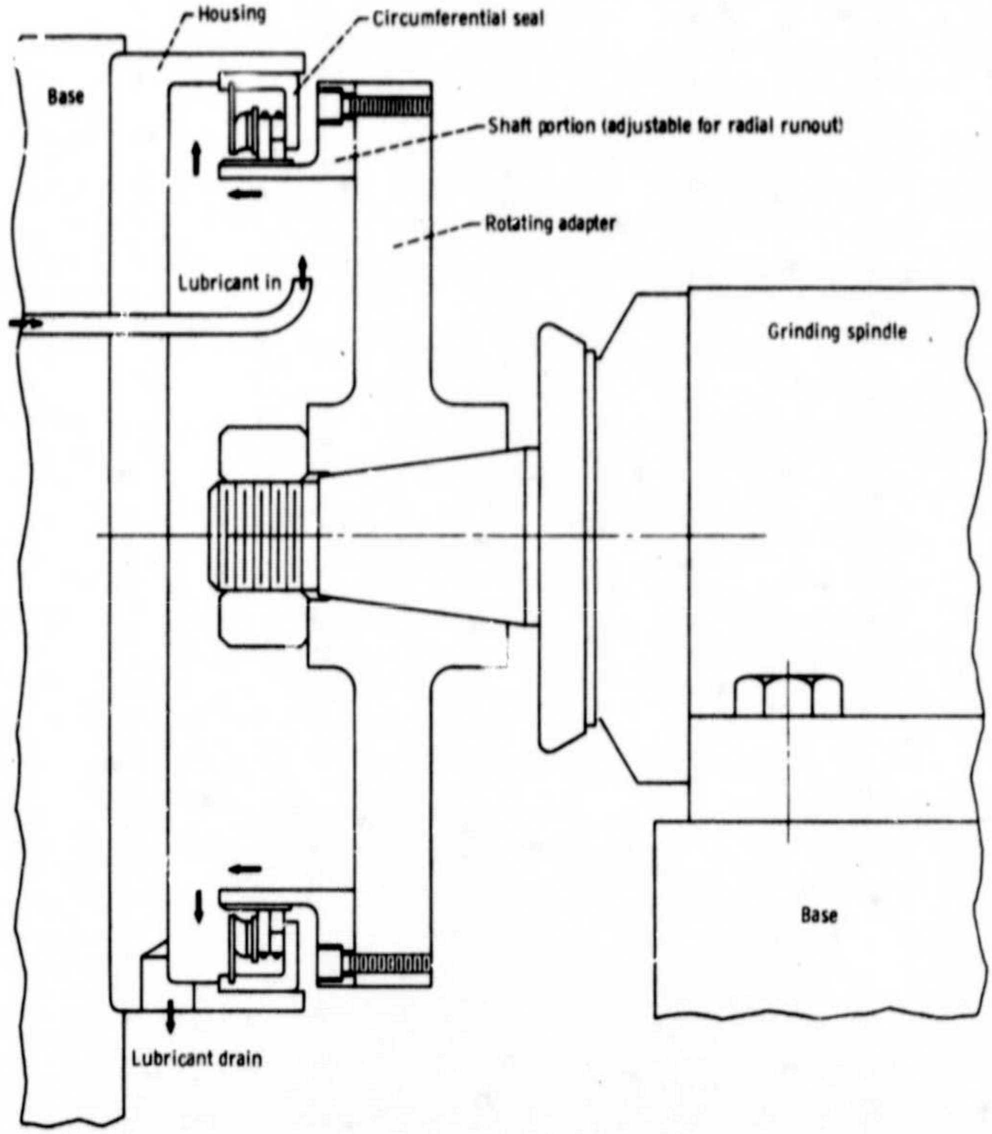

Figure 5. - Test head schematic.

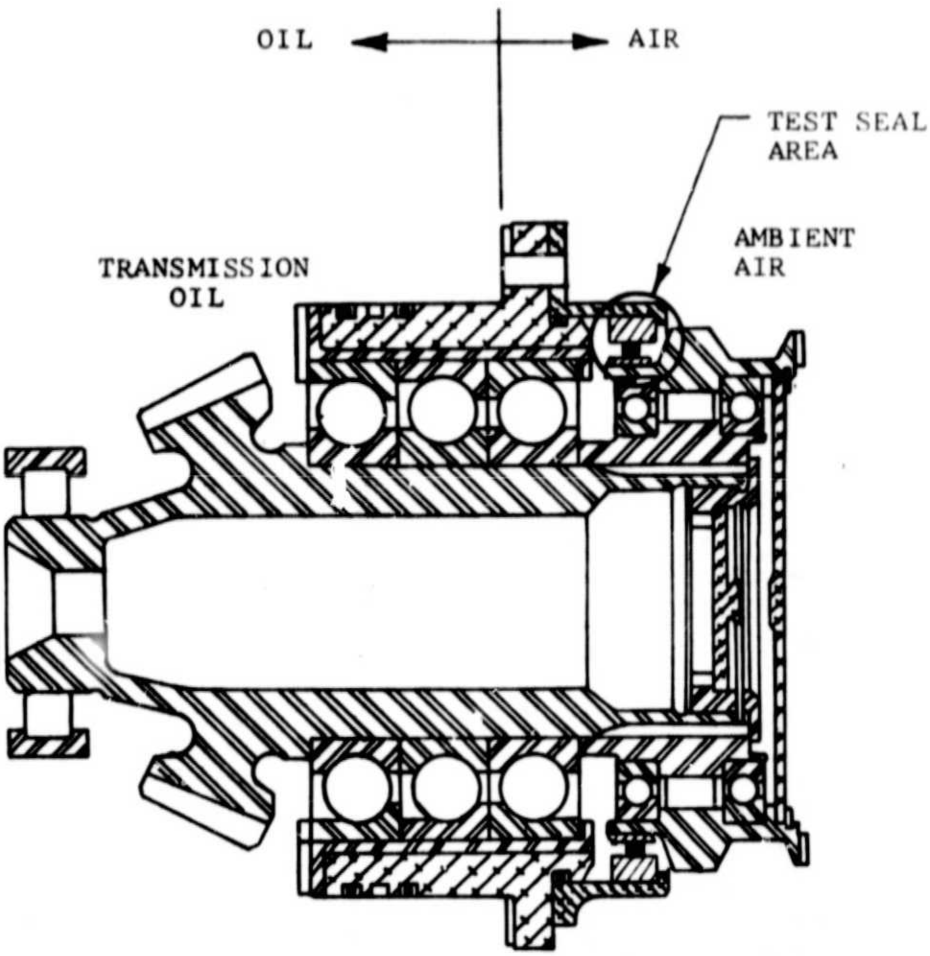

Figure 6.- Helicopter Transmission Input Shaft Assembly
(from ref. 3)

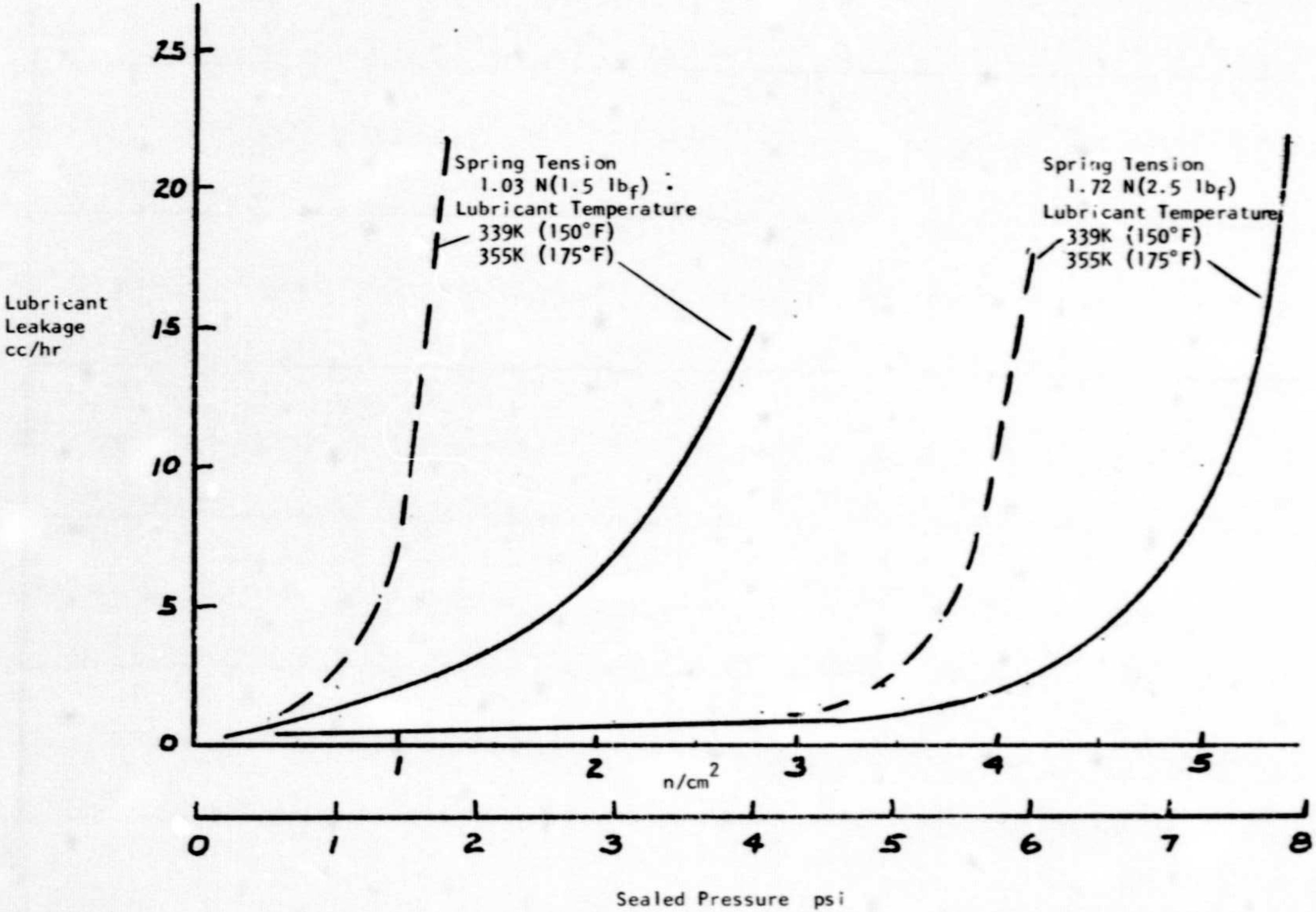

Figure 7. Effect of Garter Spring Tension on Circumferential Seal Leakage; Sliding Speed, 9,350 ft./min.

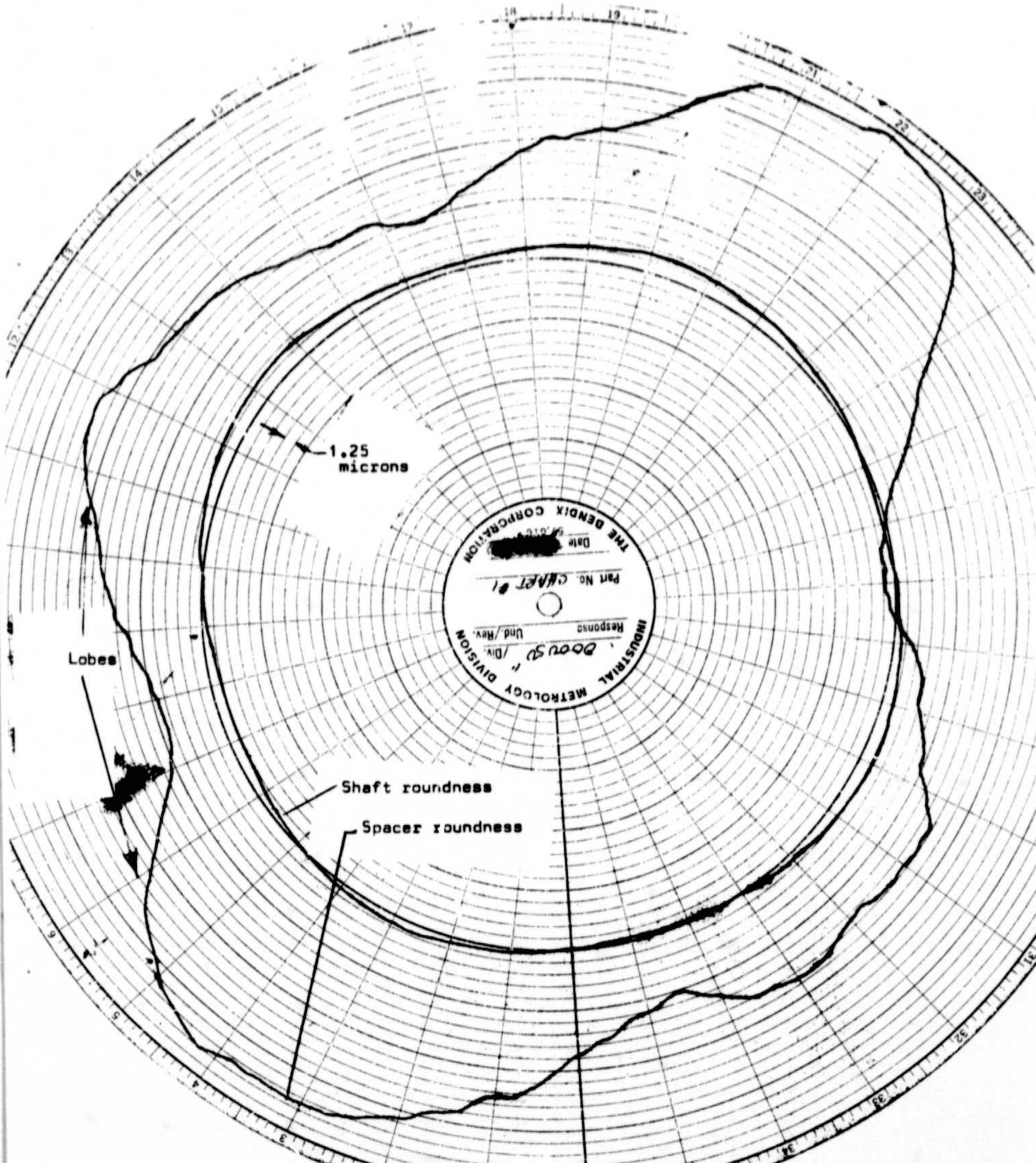

Figure 8.- Traces Showing Roundness of Shaft and Spacer

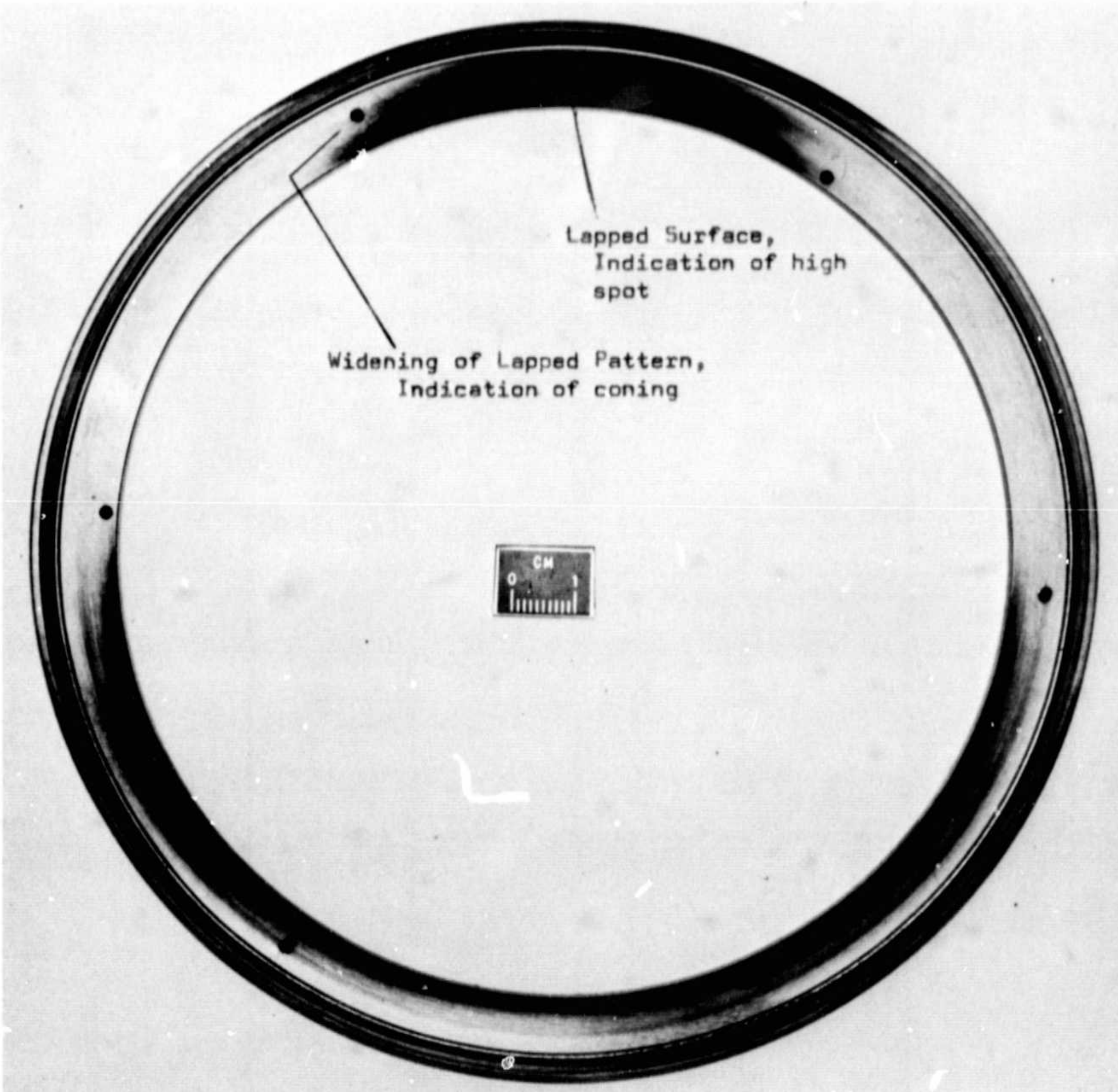

Figure 9.- Lapping Pattern on Housing Sealing Face Indicating Waviness and Coning Flatness Variations

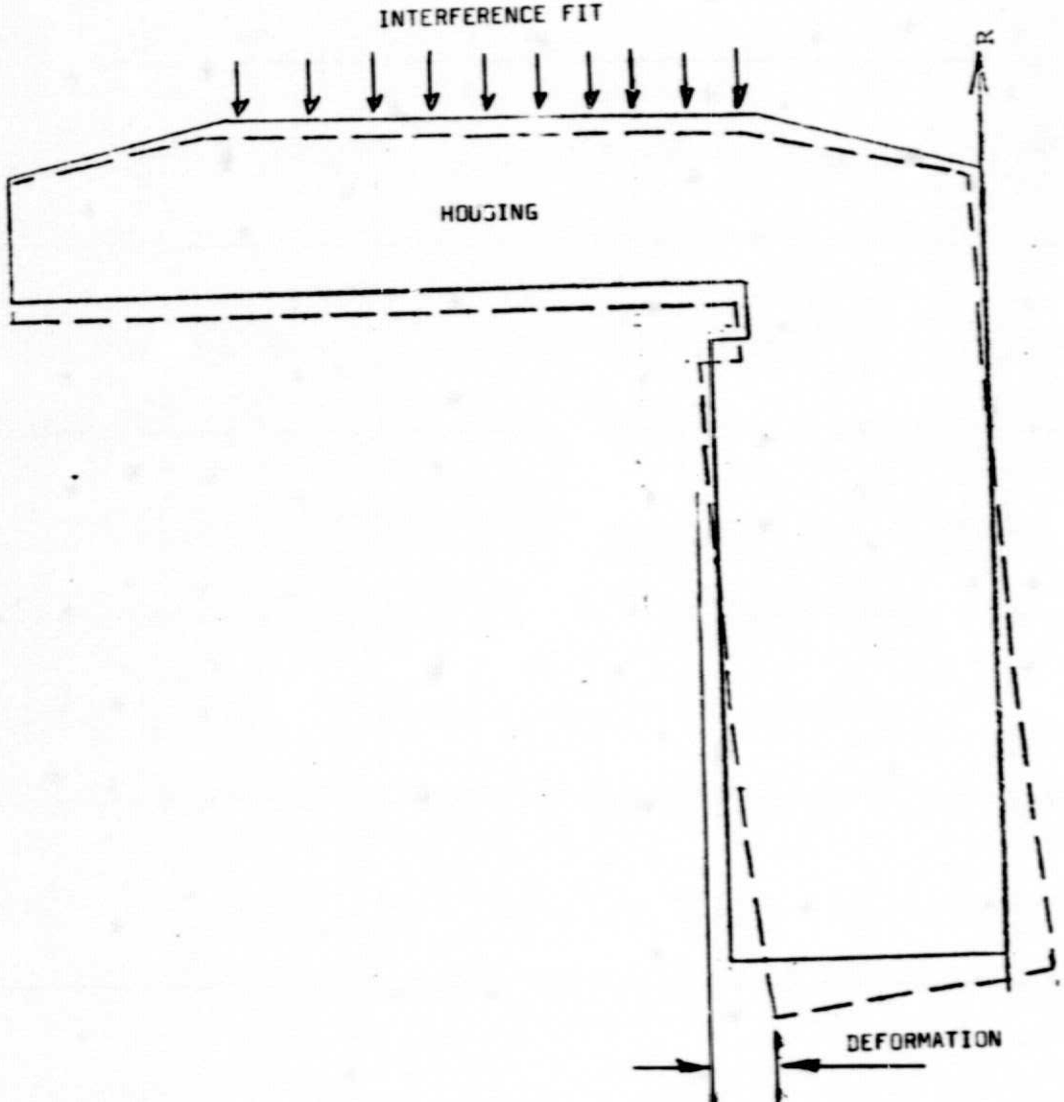

Figure 10.- Coning Deformation of Housing Sealing Face Due to Interference Fit

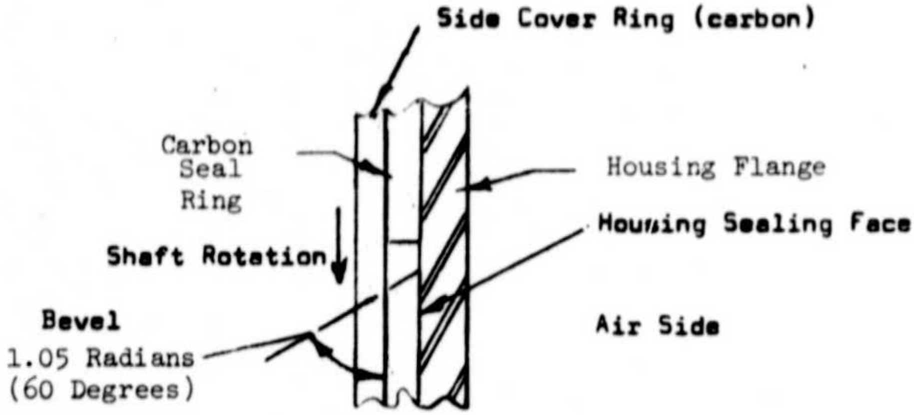

Figure 11.- Bevel at End of Seal Ring Segment