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16. Abstract

Operation under simulated aircraft transmission conditions of speeds to 2850 m/min (9350 ft/min), lubricant temperatures to 394 K (250° F), shaft radial runouts to 0.254 mm (0.010 in.) F.I.R. (full indicator reading), and pressure differentials to 1.03 N/cm^2 (1.5 psi) revealed that conventional circumferential seals leaked excessively. Modifying the conventional seal by adding helical grooves to the seal bore reduced leakage rates to within the acceptable level of 10 cm^3/hr. The leakage rate of this modified seal was not significantly affected by lubricant flooding or by shaft radial runout.

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SUMMARY

Circumferential (segmented ring) seals were evaluated in simulated aircraft transmission operation at speeds to 2850 meters per minute (9350 ft/min), lubricant temperatures to 394 K (250° F), shaft radial runouts to 0.254 millimeter (0.010 in.) F.I.R. (full indicator reading), and pressure differentials to 1.03 newtons per square centimeter (1.5 psi). The results revealed that lower leakage rates are obtained by adding helical pumping grooves to the conventional seal. This modified seal has leakage rates well within the accepted limits (10 cm^3/hr) for many aircraft transmission applications; the conventional seal leaks excessively except at near zero pressure differential. The results revealed that the modified seal leakage rate is, for practical purposes, insensitive to the effects of radial runout and lubricant flooding, whereas the conventional seal leaked excessively when flooded or when the runout was 0.254 millimeter (0.010 in.) F.I.R. . The torque of the circumferential seals (conventional and modified) was comparable to that of a conventional lip seal.

INTRODUCTION

Shaft seals in aircraft transmissions operate at sliding speeds from less than 305 to near 4572 meters per minute (1000 to 15 000 ft/min). The pressure differential across these seals is low; for example, in helicopter main power transmissions the pressure differential is less than 0.69 newton per square centimeter (1 psi). However, for some engine accessory transmissions the pressure differential may reach 5.5 newtons per square centimeter (8 psi) if the transmission case is vented to the engine lubricant scavange system. The study reported herein covers pressure differentials to 1.03 newtons per square centimeter (1.5 psi), which is a high enough pressure differential to cover many aircraft transmission applications.

The functions of these seals are to prevent lubricant leakage and to keep dirt, water, and debris from getting into the transmission. Although seal failure is not usually catastrophic, it can be a significant cost if failure is frequent since the cost involves not only replacement but aircraft downtime. Also, exposure of the system to the environment during disassembly and assembly for seal replacement can allow the introduction of debris or dirt. Furthermore, the probability of misassembly is present. Therefore, it is highly desirable to have the seals operate without excessive leakage, at least for the time between transmission overhauls. An acceptable lubricant leakage rate through a seal is specified by some transmission manufacturers and users to be 10 cubic centimeters per hour or less; others use a limit of 2 cubic centimeters per hour.

The types of seals most frequently used in aircraft transmissions are radial face seals and elastomeric lip seals. The conventional (segmented ring) seal has limited usefulness because of the inherent tendency of the ring segments to hydroplane (i.e., in the presence of a liquid lubricant, a thick lubricating film readily forms under the segments and the seal leaks even at low pressures).

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 the shearing of the lubricant film. Also, the circumferential seal materials are compatible with liquid lubricants (elastomeric lip seals and secondary seals in face seals sometimes present compatibility problems). Furthermore, the circumferential seal is easy to assemble and is compact (same space requirement as a lip seal). 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 if adding helical grooves to the circumferential seal would decrease leakage tendency, (2) investigate seal capability to operate under shaft runout conditions, and (3) measure seal torque and related heat generation. This study was on the three-ring segmented seal type (fig. 1) having a seal ring, a top cover ring, and a side cover ring. It was designed for a shaft with a 13.91-centimeter (5.481-in.) diameter and was operated at a sliding speed of 2850 meters per minute (9350 ft/min). Seal operation under shaft radial runouts to 0.254-millimeter (0.010-in.) F.I.R. (full indicator reading) was evaluated, and pressures to 1.03 newtons per square centimeter (1.5 psi) were used.

APPARATUS AND PROCEDURE

The conventional 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 cover the gaps in the seal ring. Garter springs (8.9 N (2 lbf) tension) load the segmented rings against the wear sleeve with a radial load of 5 newtons per square centimeter (7.3 psi). A wave spring (26.7 N (6 lbf)) loads the carbon rings against the seal housing. Leakage rates were measured for the conventional circumferential seal and for a modified circumferential seal. This modification consisted of adding helical grooves to the bore of the side cover ring as shown in figures 3 and 4. The orientation (see fig. 4) of the helical grooves is such that the grooves pump against leakage tendency. Each segment contained 30 grooves (filed by hand) approximately 1.52 millimeters (0.06 in.) wide, 0.51 millimeter (0.02 in.) deep, and orientated at about a 35° helix angle (see fig. 4).

The test head schematic is shown in figure 5. It consists of a housing that holds the seal, and a shaft that is mounted on a grinding spindle. Speed control was through a hydraulic drive pump and motor. Desired shaft runout was obtained by offsetting the shaft portion attached to the rotating adapter. The lubricant 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.

The amount of lubricant in the housing was controlled such that the seal was either fully or partially flooded. The fully flooded condition is shown in figure 6. The shaft rotation causes the lubricant to swirl, and the location of the lubricant interface was determined with a scanning pitot tube (see fig. 6) type pressure probe (P_2). (Another pressure tap (P_1) located at the shaft centerline measured the pressure that simulated the transmission housing pressure.) In this fully flooded condition, a swirling mass (rotating annulus) of lubricant existed with an interface diameter of 12.90 centimeters (5.080 in.); this diameter is less than the seal bore diameter (see fig. 6). A partially flooded condition was defined as the case when oil interface did not exist because the lubricant was being drained out too rapidly for the lubricant to collect and form into a swirling mass.

The lubricant used in the evaluation conformed to MIL-L-7808.

RESULTS AND DISCUSSION

The leakage rates of two circumferential seals were measured while running under conditions that simulated aircraft transmission operation. One of the seals was a conventional circumferential (segmented ring, 3 ring) design; the other was modified to have helical grooves in the bore of the side cover ring (see fig. 4).

Effects of Lubricant Flooding and Pressure

Figure 7 shows the leakage rate of conventional and modified (helical grooved) circumferential seals. Leakage rates were determined at shaft radial runouts of 0.025 millimeter (0.001 in.) F.I.R. (full indicator reading) with two modes of lubrication, full flooding of the seal and partial flooding. The pressures are simulated transmission case pressure. Therefore, in the case of full flooding, the seal is subjected to a hydraulic pressure (due to centrifugal force of the rotating fluid) in addition to the case pressure. This hydraulic pressure was measured to be 0.69 newtons per square centimeter (1 psi) at the carbon ring outside diameter. Figure 7 reveals that the conventional seal is very sensitive to flooding but that the modified seal actually has less leakage under fully flooded lubrication.

Referring to figure 7(a) reveals that the conventional seal leakage rate increases rapidly as the transmission case pressure differential increases. For example, under partial flooding (which is the more likely lubricating mode rather than full flooding) the leakage rate is 2.5 cubic centimeters per hour at 0.34 newton per square centimeter (0.5 psi) and 12 cubic centimeters per hour at 0.69 newton per square centimeter (1.0 psi). This is above the accepted limit of 10 cubic centimeters per hour. In contrast, the modified seal leakage is relatively insensitive to case pressures. For example, at a case pressure differential of 0.69 newton per square centimeter (1.0 psi) the leakage rate (1.9 cm^3/hr) is well within the accepted leakage rate (10 cm^3/hr), and at 1.03 newtons per square centimeter (1.5 psi) the leakage rate is 2.9 cubic centimeters per hour. Thus, the preceding results indicate that the helical groove pumping action prevents hydroplaning (onset of thick film lubrication) that is an inherent problem with conventional circumferential seals.

Effect of Shaft Radial Runout

The carbon ring segments of the seal ride on a lubricating film, and these segments have a radial motion that is induced by the radial runout of the shaft. The amount of shaft radial runout is different for different seal locations and for different applications. However, it is anticipated that radial runouts in most applications are not less than 0.025 millimeter (0.001 in.) or greater than 0.254 millimeter (0.010 in.); therefore, these two values were selected for the test points.

With conventional circumferential seals the effect of runout is strong. For example, as shown in figure 7(b) when the radial runout (for partially flooded case at 0.69 N/cm^2 (1 psi)) is changed from 0.025 to 0.254 millimeter (0.001 to 0.010 in.) F.I.R., the leakage rate increases from 12 to 100 cubic centimeters per hour. However, for the modified seal for the same pressure differential (0.69 N/cm^2 (1 psi)), the leakage increased from 1.9 cubic centimeters per hour (at 0.025 mm (0.001 in.) F.I.R.) to 2.8 cubic centimeters per hour (at 0.254 mm (0.010 in.) F.I.R.). Thus, the modified seal is very insensitive to changes in radial runout as compared to the conventional seal and again the helical groove pumping action is responsible for forestalling the onset of segment hydroplaning (development of a thick lubricating film).

Torque

Figure 8 shows the effect of temperature on the torque of the conventional and modified seals. Operation is partially flooded. (The evaluation was not carried out beyond temperatures of 394 K (250° F) because most aircraft transmissions operate at lower temperatures.) The test results (fig. 8) revealed that the modified seal has a slightly lower torque than the conventional seal. But the important point is that the torque shows a slight decrease (for both seals) with increasing temperature of the bulk lubricant. This torque decrease was attributed to lubricant viscosity decrease with temperature. (It should be noted that the seal lubricating film becomes thinner as the viscosity decreases, which tends to offset the viscosity effect. But the net result was a torque decrease.)

Figure 9 shows how the seal torque varies with sealed pressure for both the fully flooded and partially flooded cases. The torque rises principally from the shearing stress in the thin lubricating film between the carbon rings and the shaft. In general, the sealed pressure has little influence on the seal torque.

Results show that the fully flooded case has about 25 percent more torque than the partially flooded case. This is not an unexpected result because of the additional bulk fluid in shear when the seal operates full flooded. Also of interest is the magnitude of the seal torque as compared to a conventional elastomeric lip seal. Measurements of lip seals made under partially flooded conditions revealed a torque in the range of 266 centimeter-newtons (20 in.-lbf); this is slightly higher than that of the circumferential seals.

SUMMARY OF RESULTS

Two types of circumferential (segmented ring) seals were evaluated. These were a conventional three-ring type and a conventional three-ring type modified to have helical grooves in the carbon ring bore. Garter springs load the ring segments against the shaft with a radial load of 5 newtons per square centimeter (7.3 psi). These circumferential seals were operated under conditions that simulated aircraft transmission pressure, radial shaft runout, and MIL-L-7808 lubricant temperatures (to 394 K (250° F)). Lubricant leakage rates were determined for shaft raidal runouts of 0.025 and 0.254 millimeter (0.001 and 0.010 in.) F.I.R. (full indicator reading) and for pressure differentials from 0 to 1.03 newtons per square centimeter (0 to 1.5 psi). Also, leakage rates were determined for the seal operating fully and partially flooded with lubricant. The shaft diameter of 13.91 centimeters (5.481 in.) provided a seal sliding speed of 2850 meters per minute (9350 ft/min). The simulated aircraft transmission operation revealed the following:

1. The modified (helical grooved) circumferential seal has lower lubricant leakage than the conventional seal. This lower leakage rate was attributed to the pumping action of the helical grooves which forestalled the onset of ring segment hydroplaning (development of thick lubricating film).

2. The modified seal leakage rate is well within the accepted limit of 10 cubic centimeters per hour at pressure differentials to 1.03 newtons per square centimeter (1.5 psi).

3. The leakage rate of the modified seal is nearly insensitive to radial runout (at least to 0.254 mm (0.010 in.) F.I.R.).

4. The leakage rate of the modified seal is insensitive to flooding by the lubricant. (Leakage actually decreased under flooded conditions.)

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 24, 1972,
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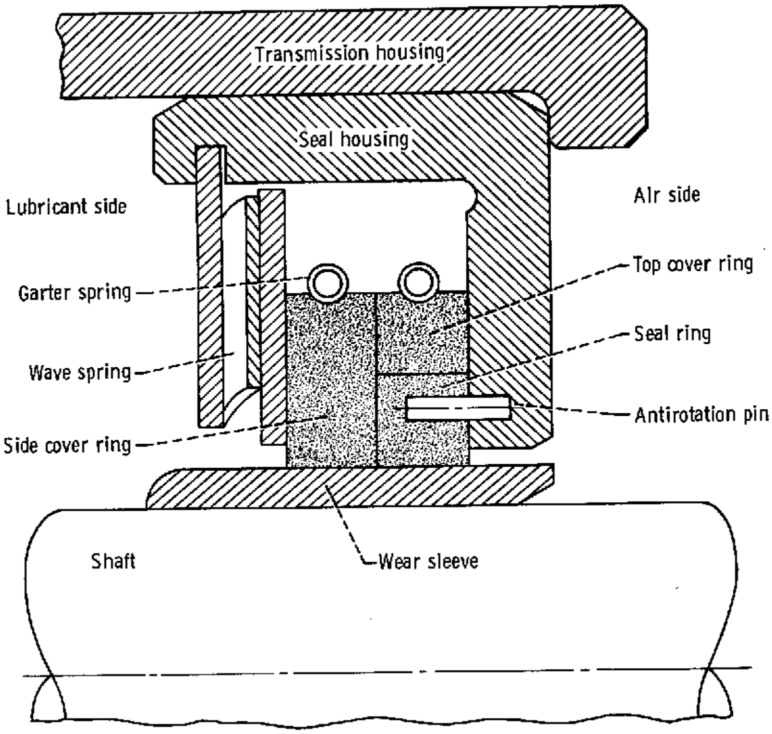

Figure 1. - Conventional circumferential seal; three-ring type (each ring segmented).

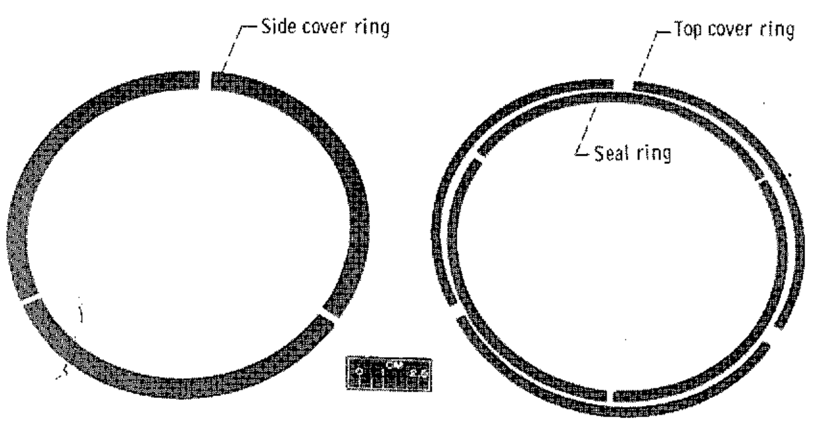

Figure 2. - Carbon rings for conventional circumferential seal.

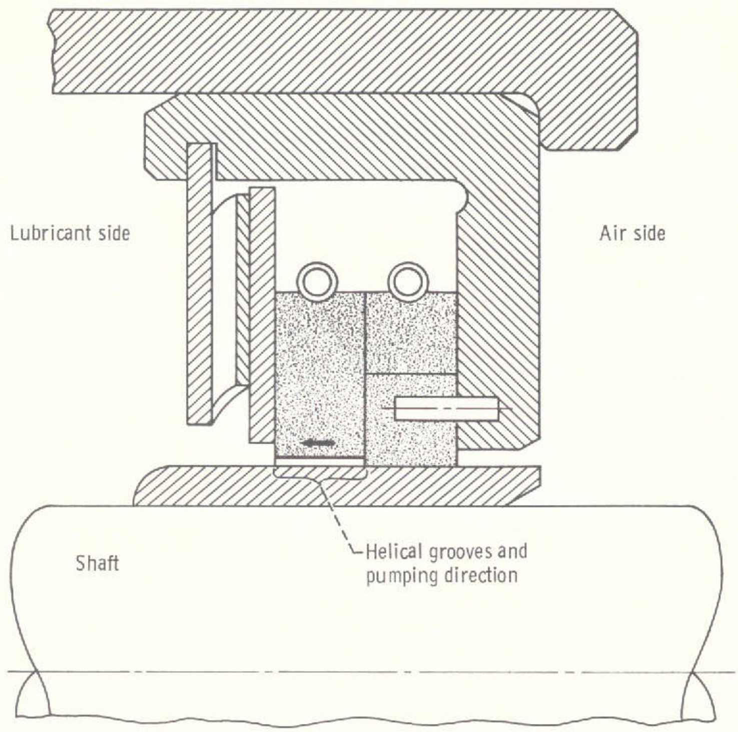

Figure 3. - Circumferential seal modified to have helical grooves in side cover ring.

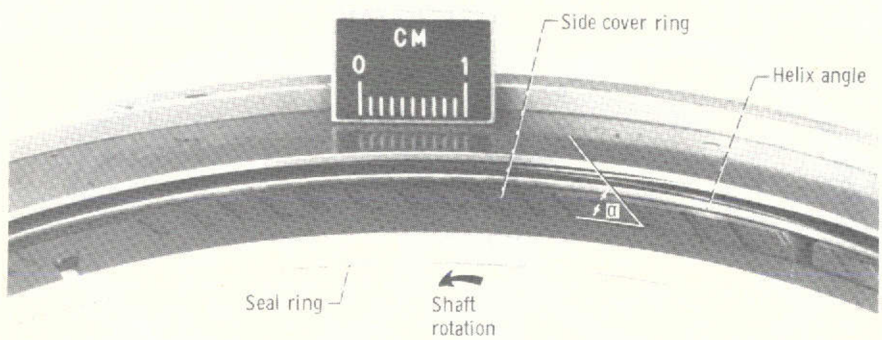

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Figure 4. - Modified (helical grooved) circumferential seal.

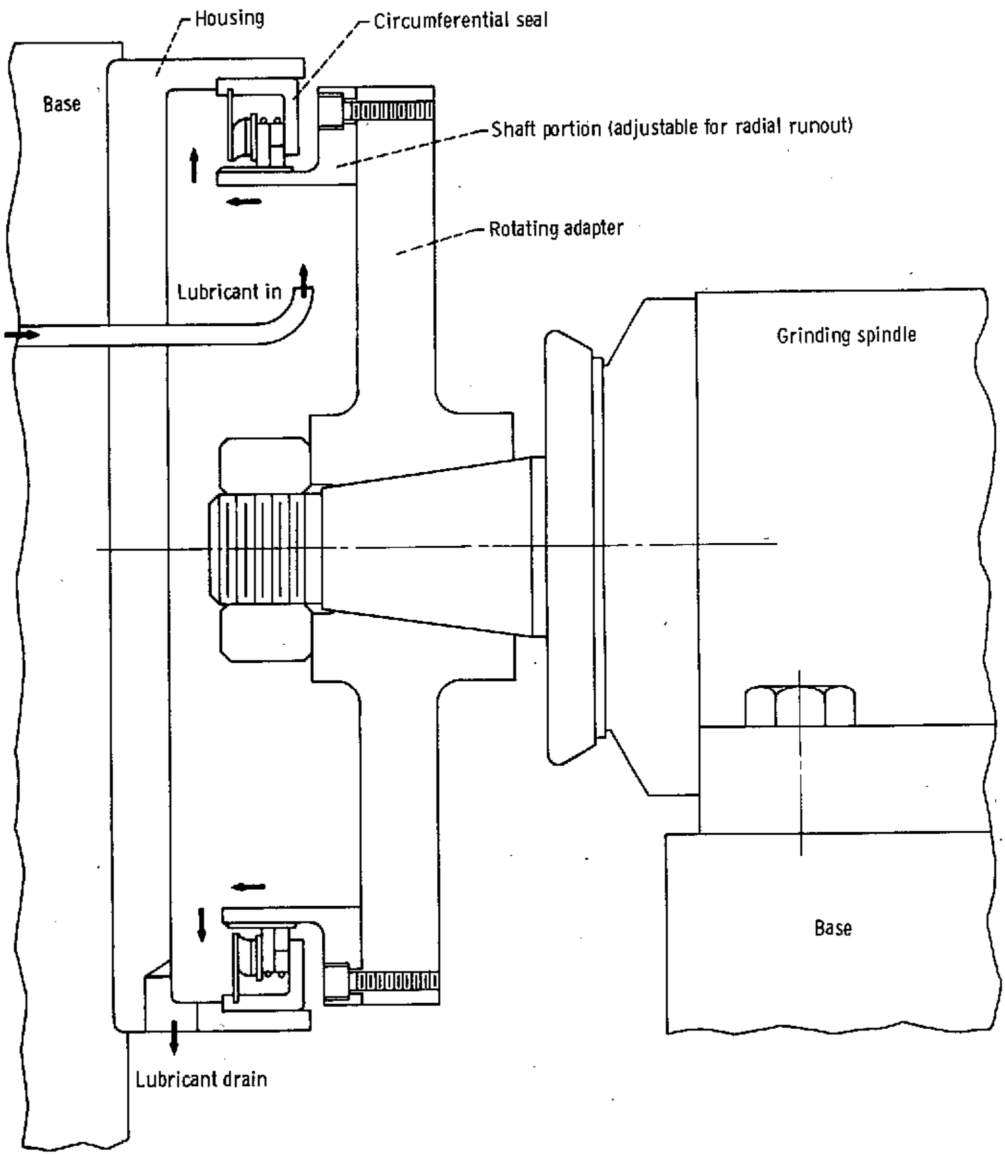


Figure 5. - Test head schematic.

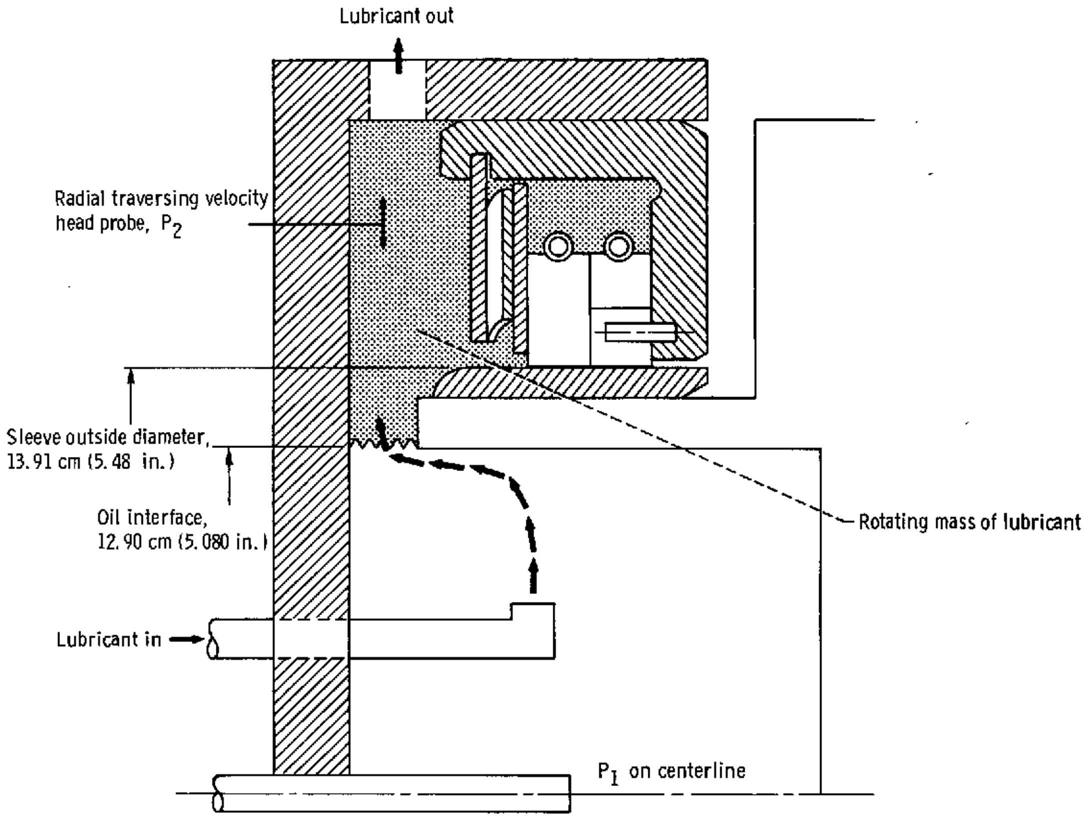
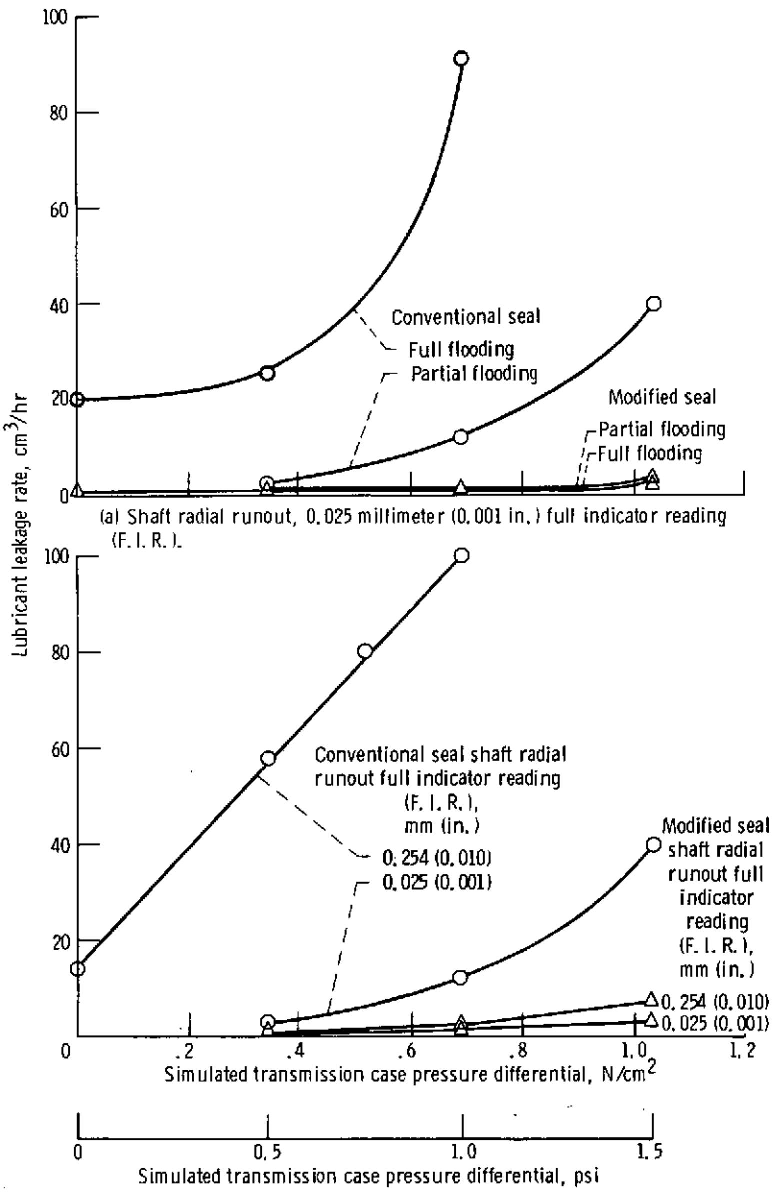


Figure 6. - Test head showing seal operating under fully flooded conditions as well as pressure tap locations.



(b) Lubrication, partial flooding.

Figure 7. - Seal leakage rates for conventional and modified (helically grooved) circumferential seal. Seal sliding speed, 2850 meters per minute (9350 ft/min); lubricant bulk temperature, 394 K (250° F); garter spring radial load, 5 newtons per square centimeter (7.3 psi); lubricant, MIL-L-7808.

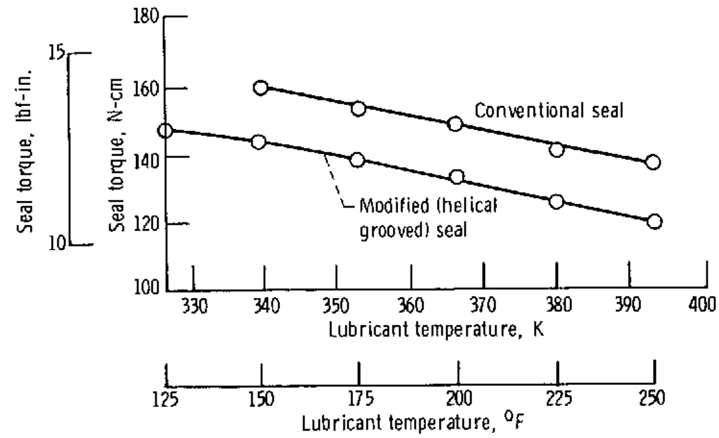


Figure 8. - Effect of lubricant temperature on torque of conventional circumferential seal and of modified (helical grooved) circumferential seal. Speed, 2850 meters per minute (9350 ft/min); lubrication, partially flooded; shaft radial runout, 0.025 millimeter (0.001 in.); garter spring radial load, 5 newtons per square centimeter (7.3 psi); lubricant, MIL-L-7808.

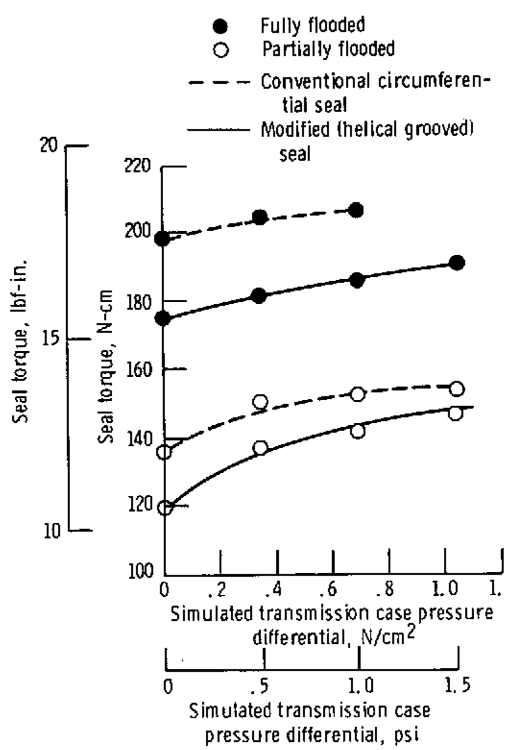


Figure 9. - Seal torque as function of transmission case pressure. Speed, 2850 meters per minute (9350 ft/min); lubricant temperature, 394 K (250° F); shaft radial runout, 0.025 millimeter (0.001 in.) full indicator reading (F.I.R.); garter spring radial load, 5 newtons per square centimeter (7.3 psi); lubricant, MIL-L-7808.

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