FRICTION AND WEAR OF
PAPER TYPE WET FRICTION ELEMENTS

SCIENTIFIC RESEARCH STAFF

PUBLICATION PREPRINT

Ford

8002 1900

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ABSTRACT

A simple model of the engagement process has been conceived for paper friction materials, consisting of squeeze film, squash film, and adhesive contact phases. In support of the model, laboratory test results are presented of paper clutch squeeze and squash film behavior in a new laboratory test fixture. Also SEM photographs, profilometer data, and clutch inertia dynamometer friction and wear results are discussed in the context of the new engagement model..

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INTRODUCTION Paper-type friction materials have been used in automatic transmissions for over 10 years and presently are specified for all OEM passenger car and light truck automatic transmission plates. However a plausible mechanism of the friction and wear process for these materials has not been reported. Most published research appears to have been directed towards measuring the effects of different fluids and test conditions on the frictional behavior of wet clutches. In these studies, complete automatic transmissions, constant velocity test machines, and clutch inertia dynamometers have been employed.

Complete transmissions are used extensively in development and durability testing since the behavior of clutch elements and transmission fluids in actual service is the final determinant of acceptability. But automatic transmissions are ill-suited for clutch research investigations. For this reason investigators generally use production and experimental clutch elements and fluids in special laboratory test fixtures. For example, studies of single clutch plates and full clutch packs have been performed at steady-state sliding conditions over a wide range of rubbing speeds with the SAE No. 1 Friction Test Fixture(1). To obtain conditions more closely resembling actual clutch engagements, later versions of this machine and the SAE No. 2 Friction Text Fixture operate as inertia dynamometers for the transient testing of clutches(2,3). Static and low-speed dynamic friction of small specimens of clutch materials and fluids has been studied at quasi-equilibrium conditions by several investigators using the Low Velocity Friction Apparatus (LVFA)[4] and modified 4-ball testers[5].

While each of these test machines has undoubtedly provided valuable test results, there has been rather poor agreement of friction data among the different test machines, even for the same material combinations, the same test fluid, and nominally the same test conditions[2]. Despite this, each test machine has yielded results which were reported to correlate with actual transmission operation.

This apparent inconsistency may be resolved through examination of the wet clutch friction and wear processes. The purpose of this paper is to present a simple model of the engagement process for wet friction materials in general, and for clutches with porous paper-type facings in particular.

ENGAGEMENT MODEL A simple concept of wet clutch engagement was developed to aid in research and diagnostic investigations. This model employs three phases:

1. Squeeze Film Phase - where oil flows over and through the porous paper material, preventing physical contact of the friction surfaces, and providing torque through viscous shear of the fluid film;
2. Squash Film Phase - where intermittent rubbing contact of the clutch asperities produces some adhesive and hysteresis friction and "squashes" oil from within the porous paper material;
3. Adhesive Contact Phase - where hydrodynamic and elasto-hydrodynamic effects are minimal and adhesive effects are dominant.

SQUEEZE FILM PHASE - In this phase the hydrodynamic forces predominate such that the friction elements are separated by a continuous film of oil. In the development of this model an analytical investigation of the squeeze film phase was conducted. This work has been published separately [6,7,8]. Portions of the analysis describe squeeze films with porous annular plates[6] and porous rectangular plates[7]. The annular plate model applies directly to an ungrooved clutch plate. A grooved clutch plate may be viewed as an array of rectangular plates in those instances where the pressure in the grooves is negligible.

The effect of sliding velocity on the squeeze film is only partially known. If an ungrooved porous flat plate is pressed against a similar non-porous plate, the effect of rotation is to reduce the oil film thickness[8]. But actual paper plates are usually grooved and their surfaces may be non-parallel. No analytical solution of this case has been found as yet, but these factors can be expected to provide positive hydrodynamic action.

Extensions of the squeeze film analysis for flat ungrooved porous plates has led to the simulation of a complete clutch application, including the calculation of clutch torque, oil film thickness, and film temperature rise[9]. From this analysis it was found that only near the end of the squeeze film phase does the calculated friction reach levels normally associated with paper plates. The early portion provides an apparent time lag between pressure application and torque generation. In this early portion of the squeeze film, the oil between the plates flows predominantly over the clutch surfaces, rapidly closing the initial gap to about 600 microinches. As the plate separation diminishes, this flow rapidly decreases and the resultant flow becomes largely into the porous clutch material. The oil within the paper plates probably is slowly exchanged by this means.

While the power density and energy absorbed by viscous shear in the squeeze film phase is relatively small for paper plates, this time-dependent phase is important to:

1. supply "fresh" oil into the porous paper facings;
2. assure uniform convergence of the clutch plates, thereby preventing cocking and uneven plate loading;
3. provide a smooth torque buildup for the initial engagement.

SQUASH FILM PHASE - With a porous friction element, the squeeze film thickness does not asymptotically approach zero. Instead there is a finite closing velocity, since oil can flow into and through the porous material. The squash film phase begins and the squeeze film phase ends when mechanical contact is made. Initial contact is to the highest surface asperities of the resilient paper plate, producing elastic deflections which release oil from within the surrounding porous material. The oil flow provides localized cooling for the contact zone and helps generate hydrodynamic support around the asperity. This unique self-protection of asperity contacts appears to be essential for durability of paper-type clutches. With the passage of time the proportion of hydrodynamic support generally will decrease and the extent of mechanical action will increase. This mechanical action results in adhesive and hysteresis friction which complements the friction due to viscous shear.

The phenomena of the squash film phase are both time and speed dependent and are not readily amenable either to mathematical analysis or controlled experimental investigations. This is unfortunate, since the bulk of the engagement energy absorption appears to occur in this phase. If this phenomenon were fully understood it would be possible to optimize paper density, permeability, and resilience. However, it is probable that present paper materials are nearly at their optimal form, as the result of years of intensive evolutionary development.

ADHESIVE FRICTION PHASE - When the sliding velocity is low and sufficient time has elapsed for the hydrodynamic squeeze and squash films to vanish, the adhesive friction predominates. According to the theory of adhesion this friction is sensitive to the paper compliance, flow pressure, surface geometries, and surface energy of adhesion. With an ATF present, the physical and chemical properties of the adsorbed and chemical reaction surface films must also be considered. These are both temperature and prior-history sensitive. With typical friction elements and transmission fluids, the unknown factors become so overwhelming that experimental studies must be used almost exclusively.

Investigations of wet clutch friction using the LVFA and modified four-ball testers have revealed phenomenological effects of changing fluids, additives and temperatures. These steady-state studies can help provide understanding of wet clutch engagement phenomena for the final phase of clutch engagement where adhesive effects predominate. Tests of this type show that when physical adsorption governs, the adhesive friction will decrease with increased sliding velocity. This is the characteristic of Type F transmission fluids. Dexron[R] transmission fluids appear to depend on chemical action to provide a positive friction slope with sliding velocity.

PAPER FRICTION MATERIALS This class of materials is made from cellulosic and often chrysotile asbestos fibers, using a liquid phenolic-type resin as a binder. Filler materials may be used, the most apparent of which is graphite. The two prime vendors of these materials appear to differ primarily in the finishing of the paper surface. One vendor obtains the final finish directly from a hot-pressing operation in which the paper material is bonded to the steel core plates. This results in a relatively smooth and flat surface, but with some density and permeability variations over the plate. These variations presumably result from small irregularities in the paper stock. Furthermore, with this process the paper surface may have a lower permeability than the interior material.

The second vendor grinds the surface of the paper after bonding to provide a more uniform structure, but with substantially greater surface roughness and waviness. With this process the paper surface may retain substantial amounts of the grinding debris. Both types of paper materials have performed well in automotive service. Typical profilometer* traces for new samples of these materials are shown in Figure 1.

The differences between pressed and ground surfaces should be readily apparent from the SEM (Scanning Electron Microscope) photographs of Figures 2 and 3. A partially opened asbestos fiber bundle and some manufacturing debris can be seen in Figure 2b. The smoother sections of

* All profile and roughness measurements were made using a Brush-Clevite 150 system. Surface damage and attendant profile error during measurement was avoided by limiting the profilometer stylus pressure to 200 mg.

the corresponding profilometer trace result from local flat areas such as appear in this photograph. The corresponding photograph of the ground sample (Fig. 3b) reveals the effects of grinding; obscured fiber structure, irregular plastic flow zones and substantially greater surface debris. These plastic flow zones provide some of the smooth-curved portions of the corresponding profilometer trace.

SQUEEZE FILM TESTS The complete clutch pack was judged impractical for direct squeeze film measurements. For this reason a small, constant force fixture was designed which could accept most passenger car clutch plates and permit precise transient measurements of the oil film thickness for constant force, non-rotating applications (Fig. 4). The apply force is set by adjusting air pressure to the Bellofram actuator with a precision regulator. A single clutch plate, located in a pool of oil, is supported by low rate springs (not shown) to provide a known initial oil film thickness. Individual clutch faces also may be tested by bonding clutch plates directly to the base. When the release lever is tripped, the voltage signal from the displacement sensor triggers a storage oscilloscope which records the variation of displacement with time.

The squeeze film fixture was tested with precision ground steel plates to compare experimental oil film thickness-time test results with analytical values. The test and analytical thickness-time curves were coincident down to 70 microinches. Below 70 microinches the results were somewhat erratic, presumably due to a randomly occurring, very slight cocking of the plate. Above this film thickness the test results were repeatable within an indicated 10 microinches.

New paper plates were found to require up to 100 applications to achieve repeatable behavior. This was believed to be the result of air removal from the interior of the paper structure. When new plates were vacuum impregnated with the test oil, the oscilloscope traces were immediately repeatable, within 15 microinches, over the entire trace. Test results then matched well with calculations from the squeeze film analysis for porous facings when the transient vibrations were filtered (Fig. 5). The initial contact occurred at roughly 200 microinches, apparently due to a slight cocking of the plate.

This squeeze film apparatus has served as a means to measure conveniently and rapidly the average permeability of complete clutch facings and the elastic response of the paper. As might be suspected, both the squeeze film and elastic deflections differ between hot-pressed and ground paper plates of similar paper structure (Figs. 6,7). These differences nearly vanished after both plates were ground in an identical manner, cleaned, vacuum impregnated and retested (Figs. 8,9). The horizontal lines on the right of the traces denote the equilibrium deflection for each load.

FLUID EFFECTS - Continued squeeze film cycling on this fixture with an ATF using a high molecular weight Viscosity Index (VI) improver resulted in an apparent loss of paper permeability after about 1000 cycles. No such effect was noted when a similar fluid with a low molecular weight VI improver was used. Furthermore, the squeeze film behavior could be restored by pentane extraction of the fluid within the paper plate and reimpregnating with fresh oil. Some used plates which exhibited abnormally low friction levels in service similarly were found to provide near-normal friction after a solvent extraction and reimpregnation. The squeeze film behavior of these plates also recovered normal properties by this process. The extract from these used plates was analyzed and found to be high in oxidized oil and acrylates, compared with fresh factory-fill oil. This suggests that one possible cause of clutch failure is the selective accumulation of thickened oil onto and into the paper plates, causing a thicker oil film, lower friction, and an extended, higher energy shift. Presumably, this added energy and resultant higher temperatures would precipitate the thermal degradation of the cellulosic fibers and their binder resin.

PARTICLE EFFECTS - Independent of fluid effects, production samples of paper plates sometimes exhibited small variations of squeeze-squash behavior with cycle time. Small particles were found in the oil after cycling which looked like the debris pictured in the SEM photographs. Microscopic examination of these cycled plates revealed the paper pore structure to be substantially cleared of debris, apparently from the alternating oil flow of the squeeze and squash film action. A lesser quantity of these particles were found upon cycling pressed paper plates than with ground plates.

The possibility that the debris from ground paper clutch plates might influence clutch engagement behavior was then investigated. For this study a production paper clutch plate was tested which was known to exhibit a drop in dynamic friction after the first few engagements, then slowly recover over the next few hundred engagements. This paper was graphited, so lamellar wear particles from the graphite possibly could foliate on the paper surface during the squeeze film phase. From the model it was hypothesized that during breakin the combination of surface debris and the graphite wear particles might "clog" the pores of the paper surface, effectively reducing its permeability and thereby providing a thicker oil film and a lower dynamic friction. With repeated use, the flakes of graphite and other debris could slowly erode away, restoring the normal frictional characteristics.

A clutch plate of this type was tested on the SAE No. 2 clutch test fixture and found to have low friction after 18 application cycles. This plate was then tested on the squeeze film fixture, cleaned, reimpregnated with fresh ATF, and retested. An apparent increase in permeability was noted after cleaning. Substantial amounts of debris, high in graphite flake content, were released during the initial squeeze film tests, although little was visible following subsequent squeeze film tests which were performed after cleaning. Further clutch machine tests initially showed normal friction, but a small dip in friction occurred with added application cycles. This minor drop was presumed to have resulted from the generation of additional wear debris with the added testing.

SAE NO. 2 CLUTCH FIXTURE TESTS Tests of single plates and complete clutch packs were performed on the SAE No. 2 machine to further evaluate the engagement model. From tests on the squeeze film apparatus, it appeared that the wear of the paper material should be insignificant for a few tenths of a second, since most of the engagement energy in this period would be dissipated in viscous shear. To test this notion, ungrooved single plates were carefully measured, then tested with an apply time of 0.2 seconds. Measurements were taken periodically until equilibrium conditions were reached. This required about 400 applications. The samples wore rapidly for the first several applications, then gradually tapered off such that no additional wear was detectable after 200 applications. When the apply time was increased to 0.4 seconds, apparently the samples both wore and swelled.

After additional testing, surface examination of some samples showed greater contact areas, but with an increased average paper thickness.

Indirect measurements of the wear then had to be employed, such as profile mapping several areas of the clutch plate and noting changes in the peak-to-valley height distributions with added testing. These calculations showed an equilibrium wear rate for the 0.4 second apply time of 0.1×10^{-9} cu.in/ft.lb. The apply time was extended further in increments until a complete engagement was made at 2.2 seconds. The volume of paper material worn, per unit of work, was found generally to increase and at an increasing rate as the engagement time increased. The specific wear rate was 1.6×10^{-9} cu.in./ft.lb. for the full engagement. However, the wear sometimes was confined to one area of one side of a plate. The cause of this had not been determined, but it appears that the paper material wears in a manner such as to produce a constant contact pressure. With some localized swelling, the paper wear presumably also becomes highly localized until the paper material becomes stabilized dimensionally. Despite the non-uniformity of wear, the wear rate per unit of work done was found to increase dramatically as the engagement time increased and the sliding velocity decreased.

After this wear testing, paper clutch plates of both the pressed type and the ground type may be quite similar in visual appearance, profilometer traces, and squeeze film behavior. SEM photographs of a ground paper plate after 4000 clutch applications are shown in Figure 10. Note the similarity of this used, ground paper sample with the new, pressed paper sample of Figure 2. The relative absence of particulates within the paper structure should be apparent in Figure 10b.

Representative profilometer traces of this and other clutch surfaces are shown in Figure 11. Note the change of scale from Figure 1, particularly the horizontal scale. This was done to provide a better visualization of surface flatness. The sample with 8000 cycles was tested under more severe conditions, resulting in a slightly wavy surface. This seems to cause a slightly lower dynamic friction at the higher sliding velocities, presumably due to the more favorable hydrodynamic action of a wavy surface. Two glazed appearing plates were included in Figure 11 to illustrate the fact that "glazing" does not necessarily produce substantial friction changes. The sample with the low friction was found to have near-normal friction after a solvent extraction of the retained oil and reimpregnation with fresh oil. Both samples exhibited a smeared, almost scaled surface appearance under the SEM, with periodic pores of a few thousandths diameter. These surface scales could be expected to greatly reduce the permeability of the surface layer and possibly produce a lower friction level in the squeeze and squash film phases. However, when examined under an optical microscope, it was found that the "scales" open readily as the paper surface is loaded in compression by a flat glass plate. Apparently the "scales" are relatively free to move, making them influence friction only in the relatively short squeeze film period.

WEAR OF A CLUTCH PACK A pack of four new paper plates was measured at several locations on each face and tested for 2000 cycles on the SAE No. 2 clutch machine. Plates were periodically removed during the test for wear measurements and squeeze film testing, then reinstalled in the same order and orientation. The wear of the paper plates was uneven at first, being greatest toward the plate OD and at circumferential locations where the total pack thickness was greatest. Thus, in some plates the wear was not a maximum at the point of maximum plate thickness. These findings were expected, since the largest mechanical contact pressure should occur at the thickest section of the pack and be biased toward the OD due to mechanical deflections of the end plate. After about 500 cycles the OD bias diminished rapidly. The paper wear from 1000 to 2000 cycles was essentially uniform from OD to ID, but was not yet uniform circumferentially. The wear of the facing closest to the apply piston was greatest, with wear generally decreasing for more remote positions (Fig. 12). This may be attributed to the effect of spline friction, since displacement of the clutch and separator plates is required to maintain torque in the squeeze and squash film phases. The plates nearest the piston then have a larger average apply pressure and a slightly longer apply time. Since the wear occurs primarily at the end of the engagement, these relatively small differences of load and time can produce significant differences of paper wear rate.

The steel separator plates exhibited a similar trend (Figure 13). Steel plate wear was variant with angular position, also tending to reduce the total separator pack thickness variations. The greatest wear on each plate occurred at the same angular location. Some minor scoring was observed in these tests which appeared to have resulted from abrasive inclusions in the asbestos.

EFFECT OF FATTY ACIDS In an attempt to determine experimentally the extent of mechanical contact, a clutch plate was cycled under closely controlled conditions on the SAE No. 2 machine until steady state frictional behavior was reached. Several successive torque-velocity traces were recorded using a Type F fluid. At the end of one of these engagements a syringe was used to inject 0.1% oleic acid into the fluid chamber of the test machine. While this concentration does little to alter the fluid flow and viscous shear behavior, it is more than adequate to lower the adhesive forces greatly. The change of torque was immediately apparent on the next clutch application and was repeatable thereafter. The shaded area of Figure 14 should be indicative of the relative amount of mechanical contact during the clutch application, since this is the result of a change primarily to the adhesive component of friction.

SUMMARY AND CONCLUSIONS A simple model of the engagement process has been conceived for wet friction materials, especially those with porous paper surfaces. The model consists of three phases: a time-dependent hydrodynamic squeeze film phase where no mechanical contact is made and torque is generated through viscous shear alone; a time and velocity dependent squash film phase where intermittent rubbing of asperities generates some adhesive friction, produces additional hydrodynamic action, and provides local cooling; an adhesive contact phase where hydrodynamic effects are minimal and where physical and chemical reaction surface films largely control the friction.

In support of the model, laboratory test results were presented of paper clutch squeeze/squash film behavior in a new laboratory test fixture. Also SEM photographs, profilometer data, and clutch inertia dynamometer friction and wear results were discussed in the context of the new engagement model.

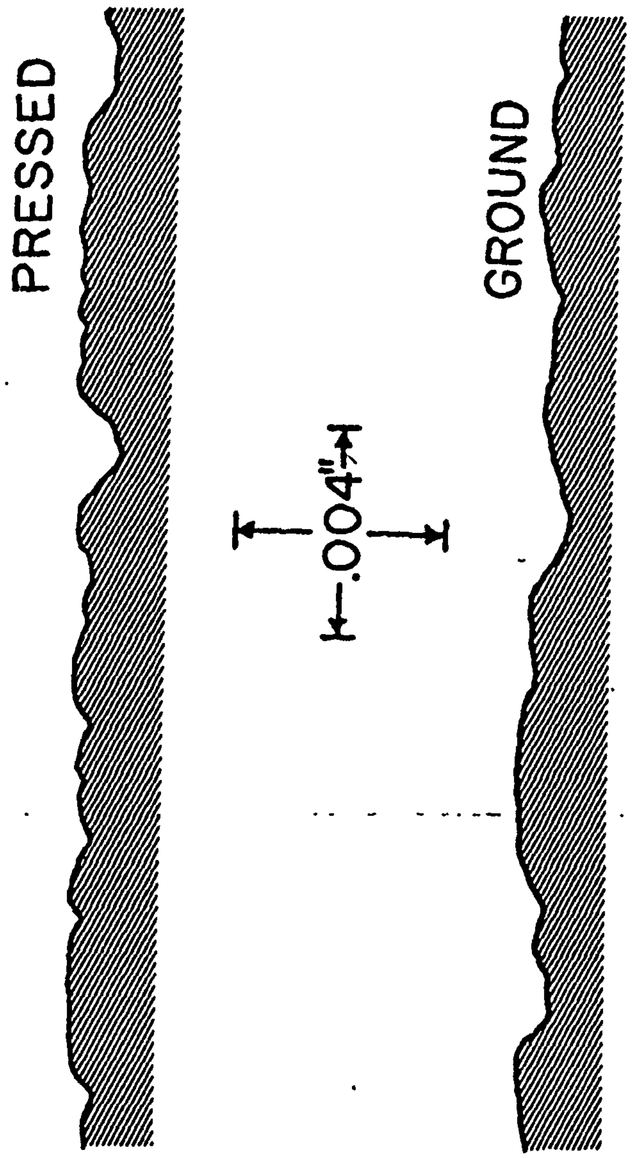
While no incontrovertible conclusions may be reached at this time about the validity of the model, it has proven to be useful in understanding inconsistencies of test results from different test machines. Both the model and the squeeze film fixture have aided in diagnostic investigations.

References:

1. G. R. Smith, V. J. Jandasek, S. R. Sprague, R. B. Springer, "A New Concept of Measuring Frictional Characteristics", Preprint 363A SAE Midyear Meeting, June 1961.
2. G. R. Smith, W. D. Ross, P. L. Silbert, W. B. Herndon, "Putting Automatic Transmission Clutch Friction Researchers on Speaking Terms", Preprint 670051, SAE Annual Meeting, January 1967.
3. E. D. Davidson, "A New Bench Test for Evaluating Clutch Plate Lubrication", Preprint 642A, SAE Annual Meeting, January 1963.
4. J. J. Rodgers and M. L. Haviland, "Friction of Transmission Clutch Materials as Affected by Fluids, Additives and Oxidation", Preprint 194A, SAE Midyear Meeting, June 1960.
5. S. R. Sprague and R. G. Cunningham, "Chemical Additives Control Friction Characteristics of Lubricants", Industrial and Engineering Chemistry, Vol. 51, No. 9, September 1959, pages 1047-1050.
6. Hai Wu, "Squeeze Film Behavior for Porous Annular Disks", Jour. of Lubrication Technology, October 1970.
7. Hai Wu, "An Analysis of the Squeeze Film Between Porous Rectangular Plates", ASME Paper No. 71 Lub-2, presented at ASLE-ASME Joint Lubrication Conference, Pittsburgh, Pa., October 1971.
8. Hai Wu, "The Squeeze Film Between Rotating Porous Annular Disks" Wear, Vol. 18 (1971) pages 461-470.
9. Hai Wu, "An Analysis of the Engagement of Un-Grooved Wet Clutch Plates", Private Communication, May 26, 1971.
10. C. E. Albertson and H. S. Okubo, "Influence of Lubricant Breakdown on Frictional Performance" Preprint 642C, SAE Annual Meeting, January 1963.

Figure Captions:

Figure 1	Profilometer traces of typical unused paper materials.
Figure 2 (a and b)	SEM photographs of a typical pressed paper material.
Figure 3 (a and b)	SEM photographs of a typical ground paper material.
Figure 4	Schematic of squeeze film fixture.
Figure 5	Comparison of squeeze film results.
Figure 6	Squeeze film traces for a new pressed paper plate.
Figure 7	Squeeze film traces for a new ground paper plate.
Figure 8	Squeeze film traces for a ground pressed plate.
Figure 9	Squeeze film traces for a reground paper plate.
Figure 10 (a and b)	SEM photographs of a typical ground paper plate after 4000 applications.
Figure 11	Comparison of new and used paper surface profiles.
Figure 12	Paper plate wear as a function of pack position.
Figure 13	Separator plate wear as a function of pack position.
Figure 14	Effect of a fatty acid on clutch torque.



PRESSED
GROUND
.004"

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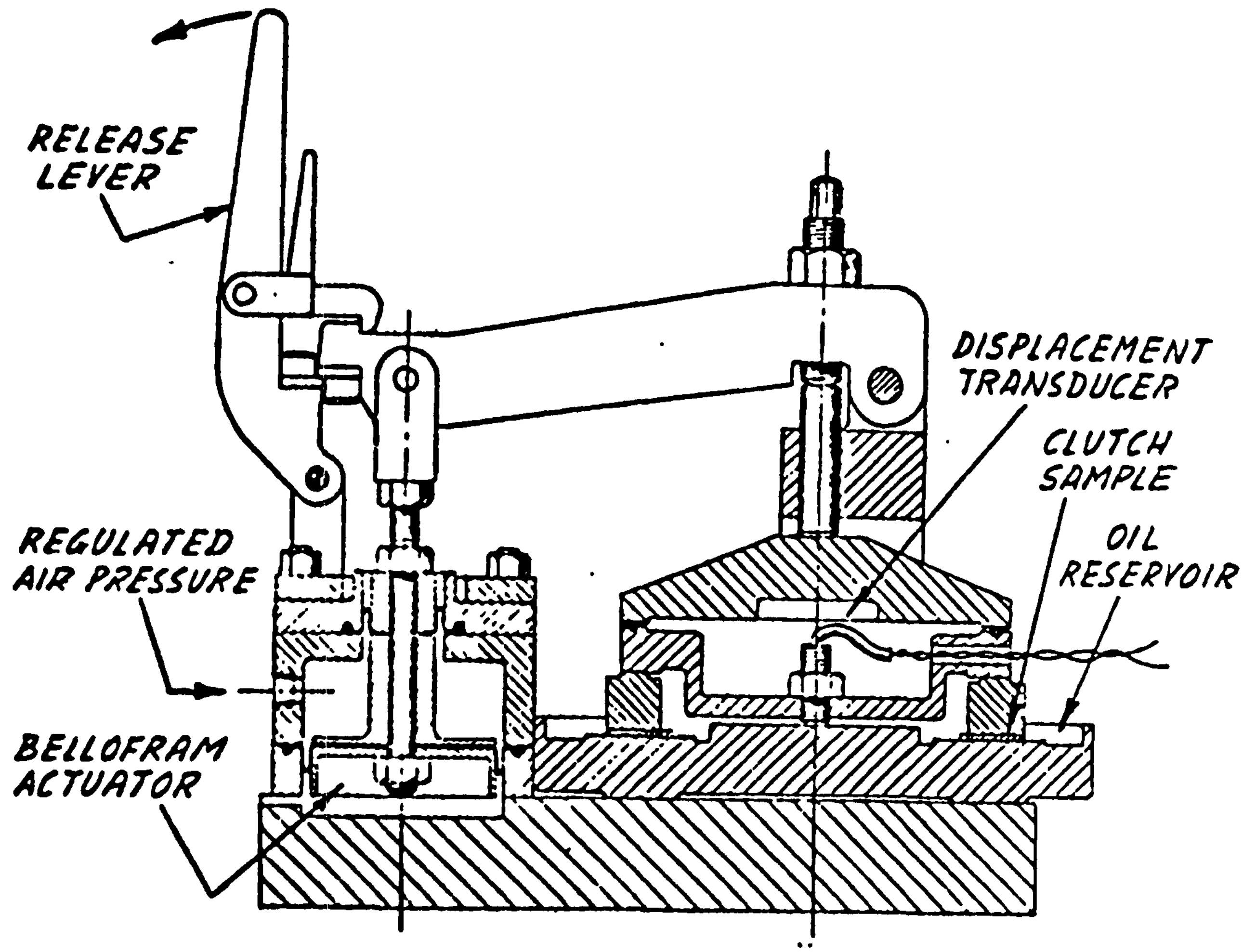
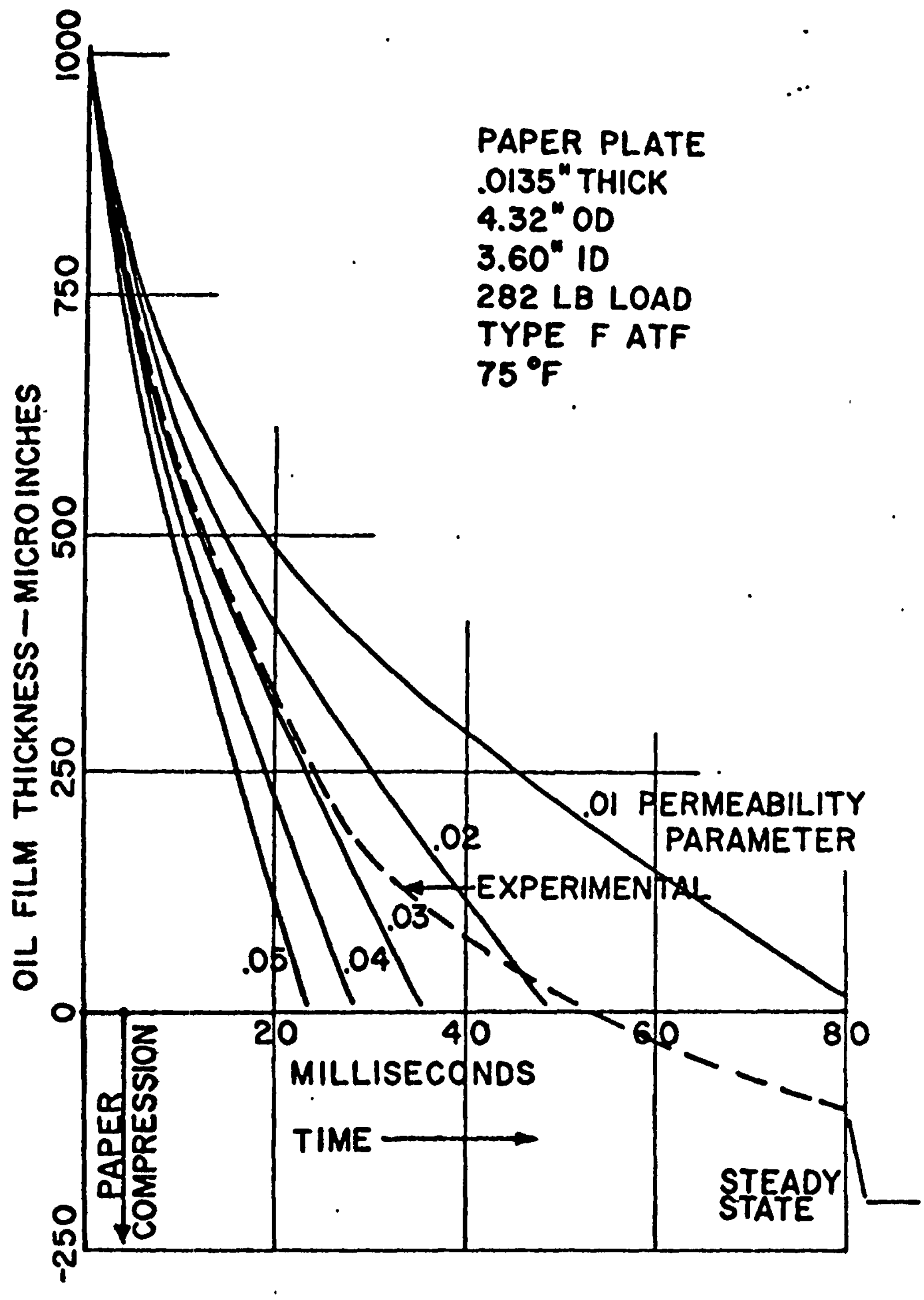
8002 1922 **PQ**

PRODUCED BY FORD

8002 1923

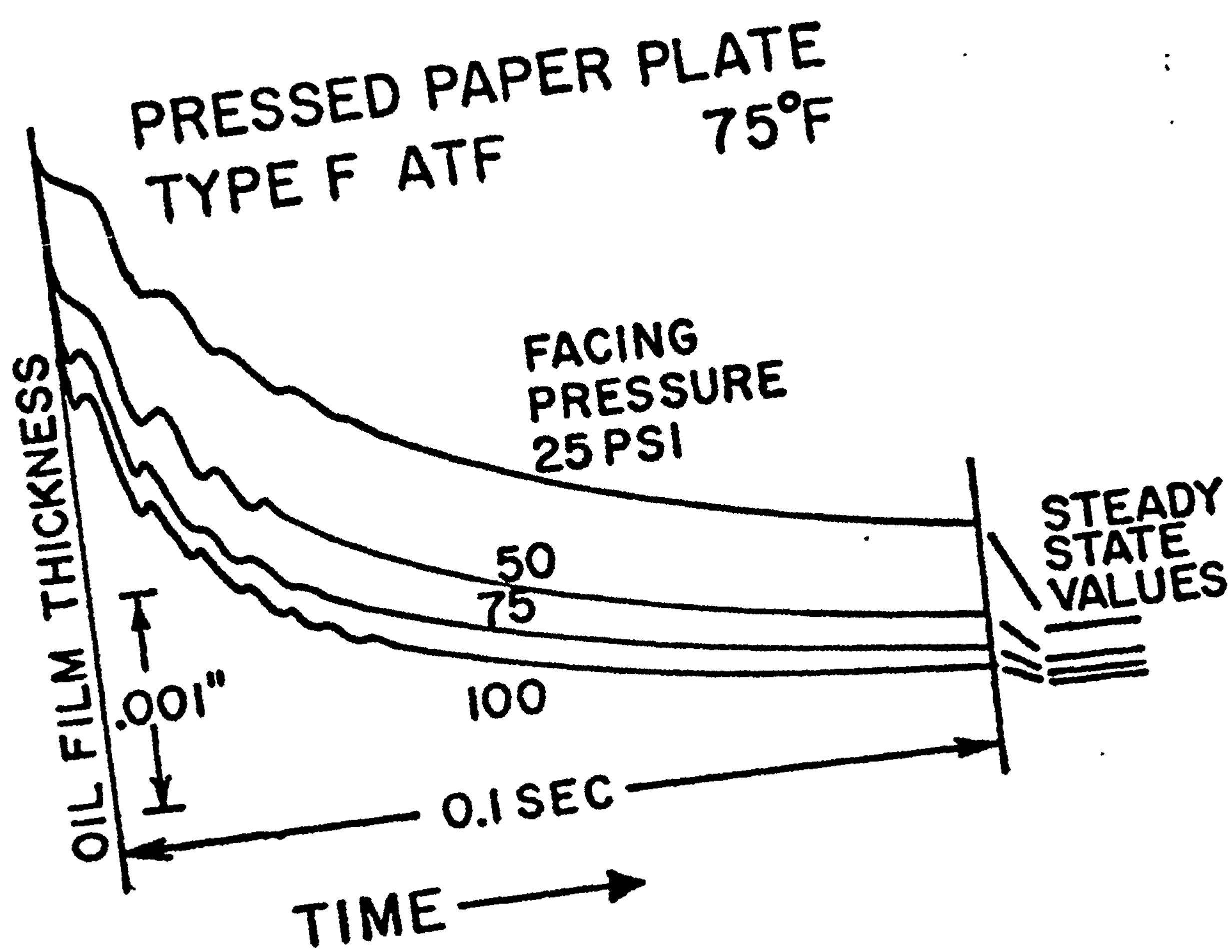

RELEASE LEVER
DISPLACEMENT TRANSDUCER
CLUTCH SAMPLE
REGULATED AIR PRESSURE
OIL RESERVOIR
BELLOFRAM ACTUATOR

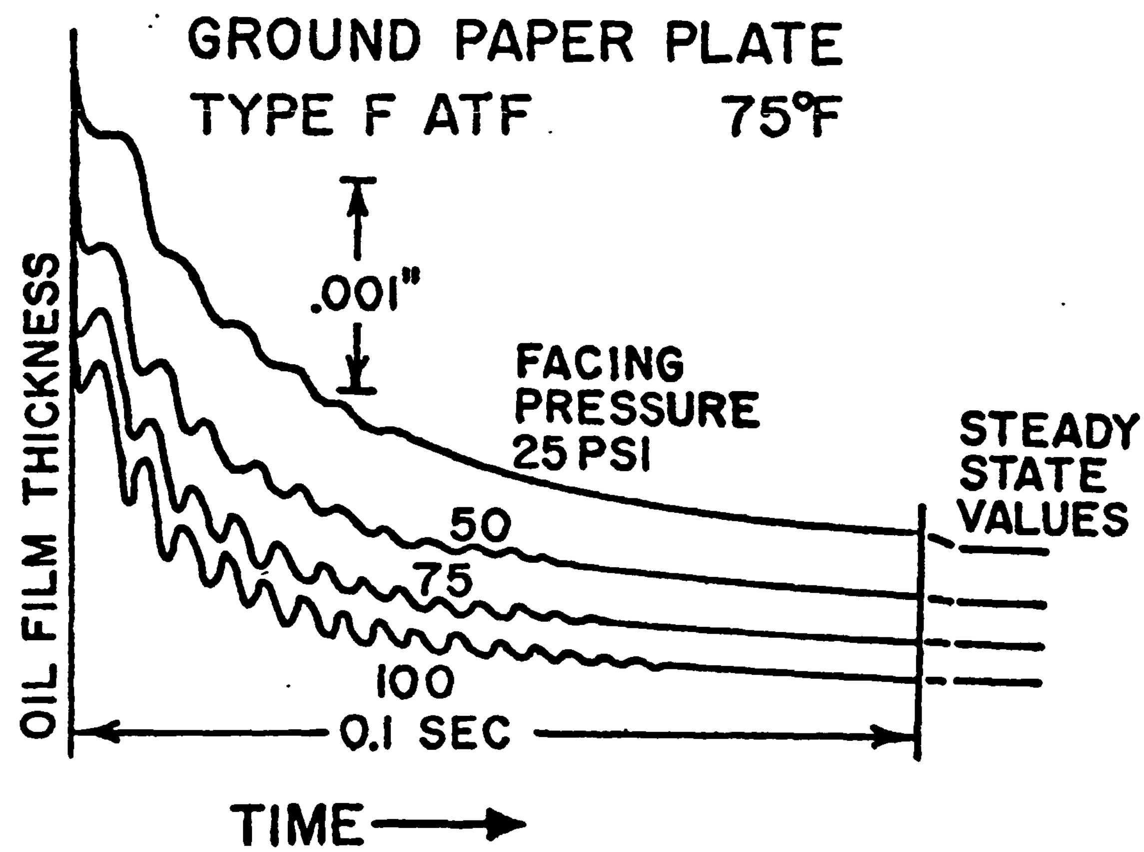
8002 2924



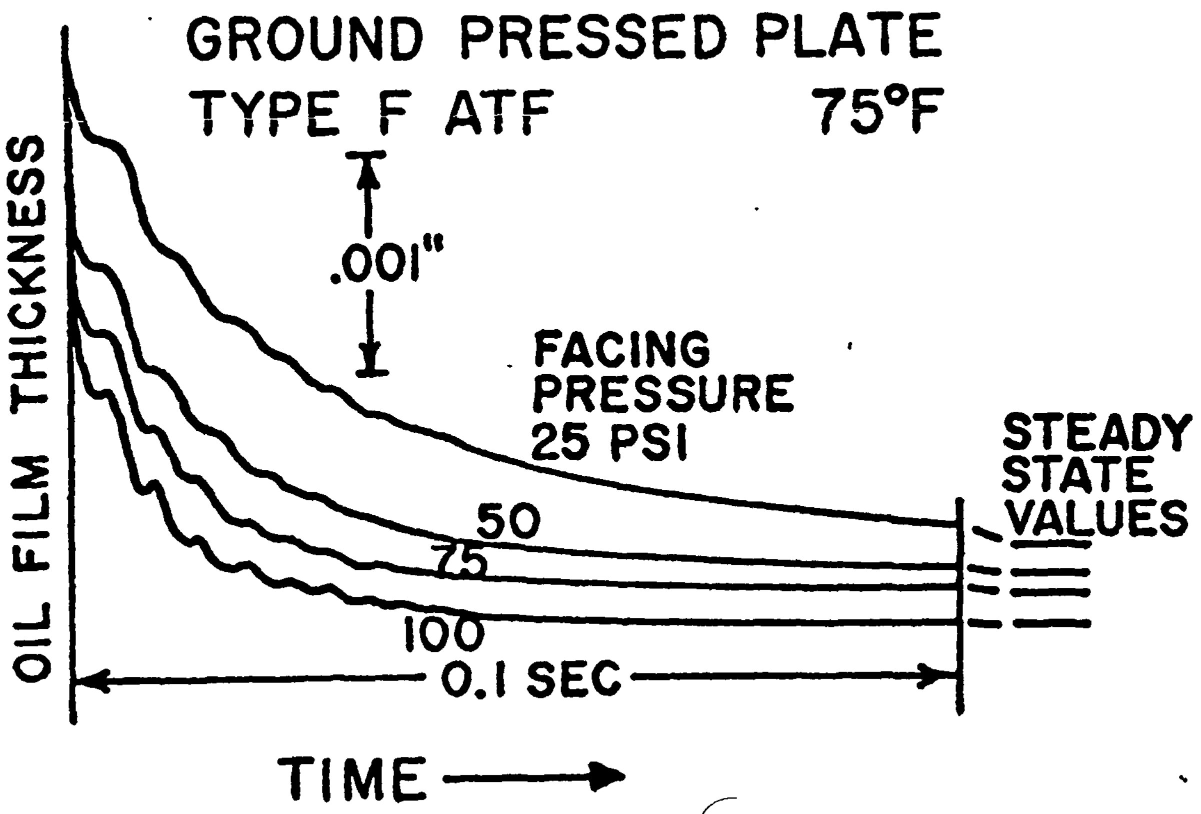
PAPER PLATE
.0135" THICK
4.32" OD
3.60" ID
282 LB LOAD
TYPE F ATF
75 °F
OIL FILM THICKNESS—MICROINCHES
1000
750
500
250
0
-250
.01 PERMEABILITY PARAMETER
.02
.03
.04
.05
EXPERIMENTAL
20
40
60
80
MILLISECONDS
TIME
PAPER COMPRESSION
STEADY STATE

8082 1925


PRESSED PAPER PLATE
TYPE F ATF
75°F
FACING
PRESSURE
25 PSI
50
75
100
STEADY
STATE
VALUES
OIL FILM THICKNESS
.001"
0.1 SEC
TIME


GROUND PAPER PLATE
TYPE F ATF 75°F
.001"
FACING
PRESSURE
25 PSI
50
75
100
STEADY
STATE
VALUES
OIL FILM THICKNESS
0.1 SEC
TIME

8002 1927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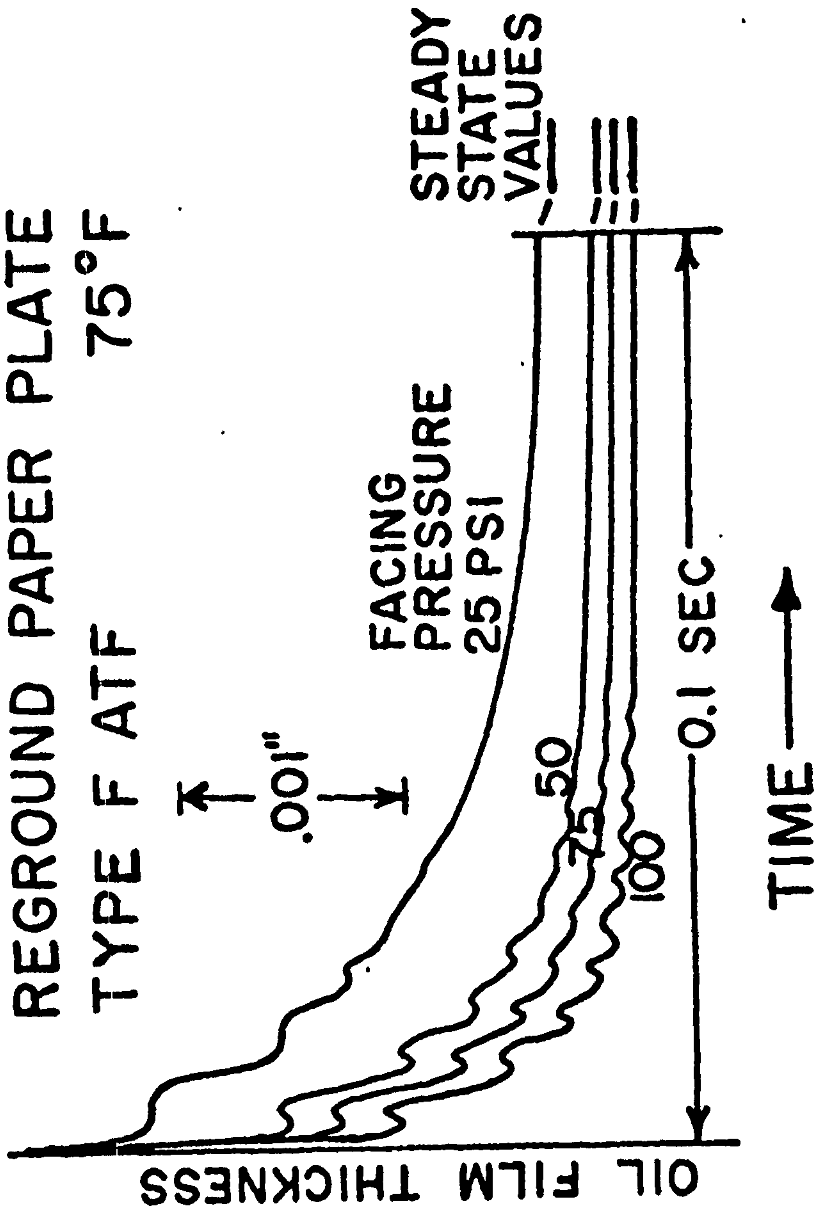
TYPE F ATF
75°F
.001"
FACING
PRESSURE
25 PSI
50
75
100
STEADY
STATE
VALUES
OIL FILM THICKNESS
0.1 SEC
TIME



REGROUND PAPER PLATE
TYPE F ATF 75°F
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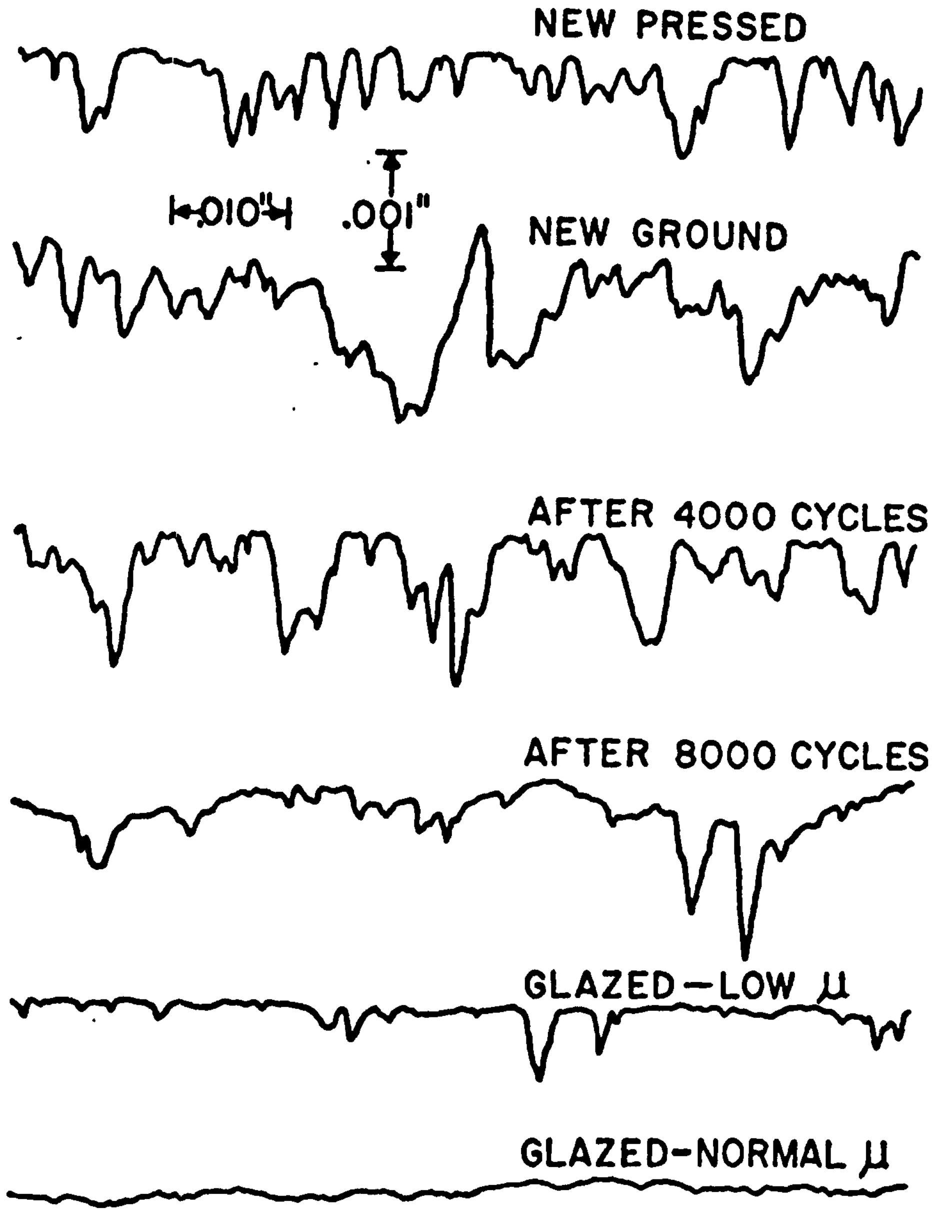
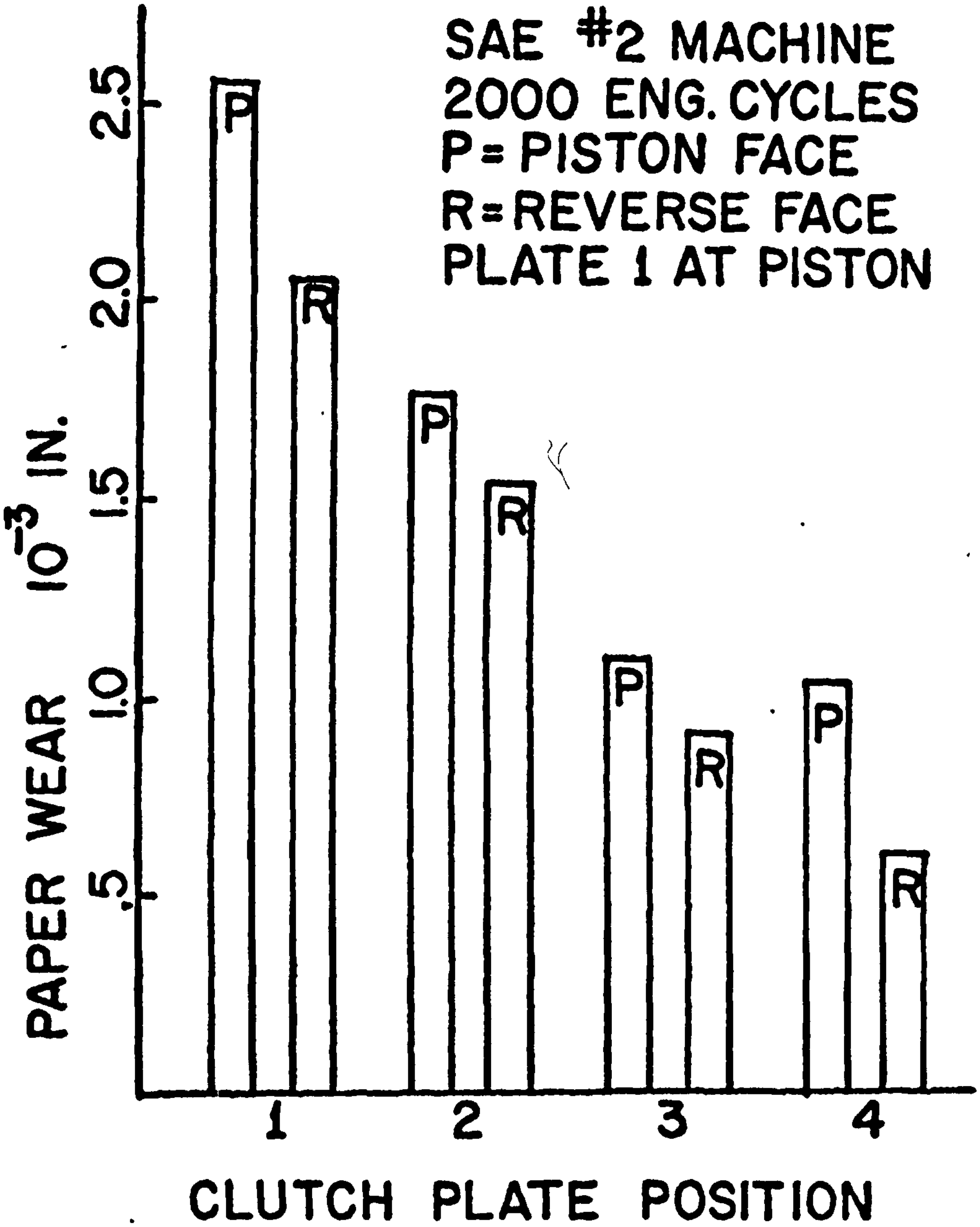
FACING PRESSURE 25 PSI
50
75
100
STEADY STATE VALUES
0.1 SEC
TIME
OIL FILM THICKNESS

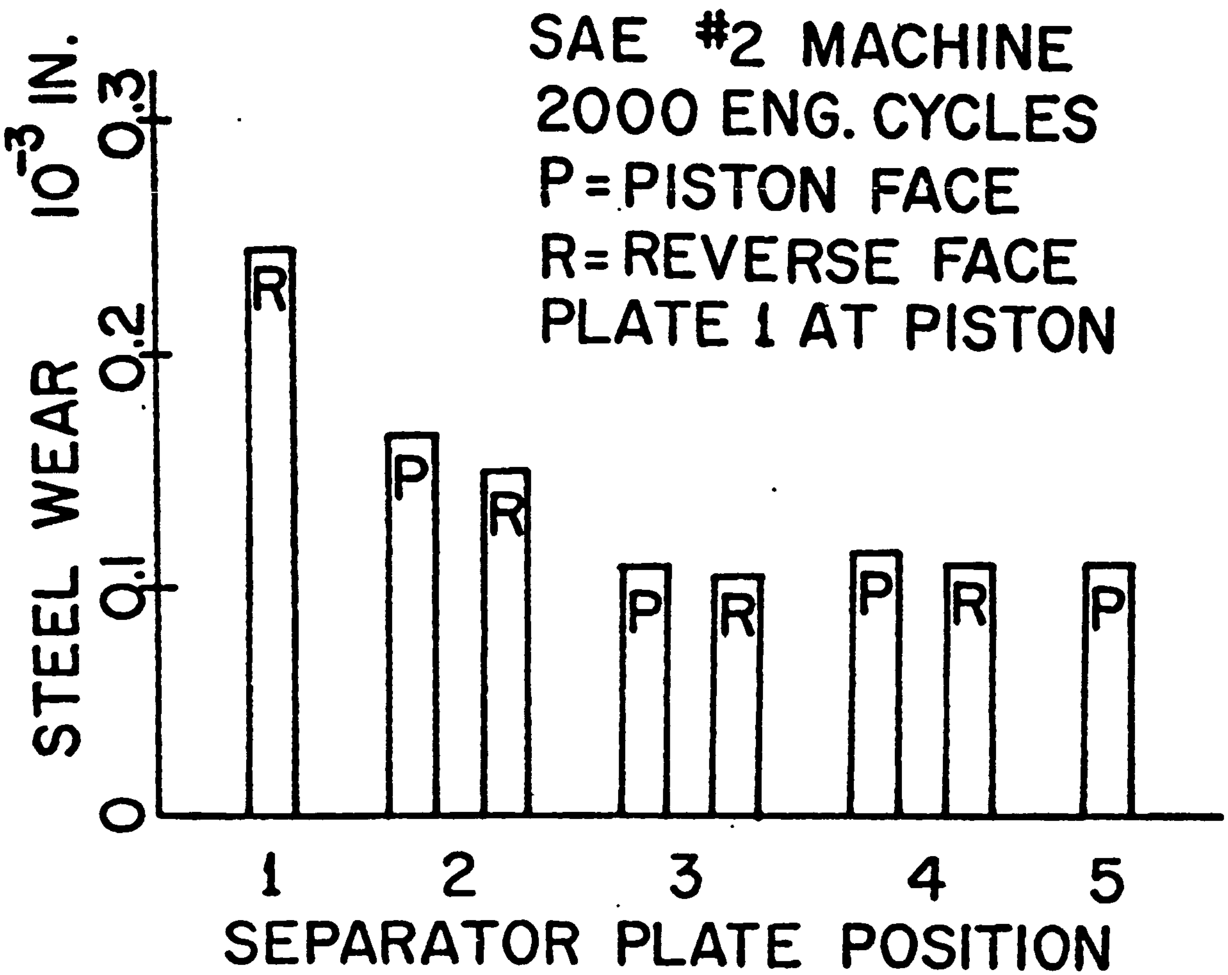
8002 1929


NEW PRESSED
|←.010"→|
.001"
NEW GROUND
AFTER 4000 CYCLES
AFTER 8000 CYCLES
GLAZED—LOW μ
GLAZED—NORMAL μ

8002 2930

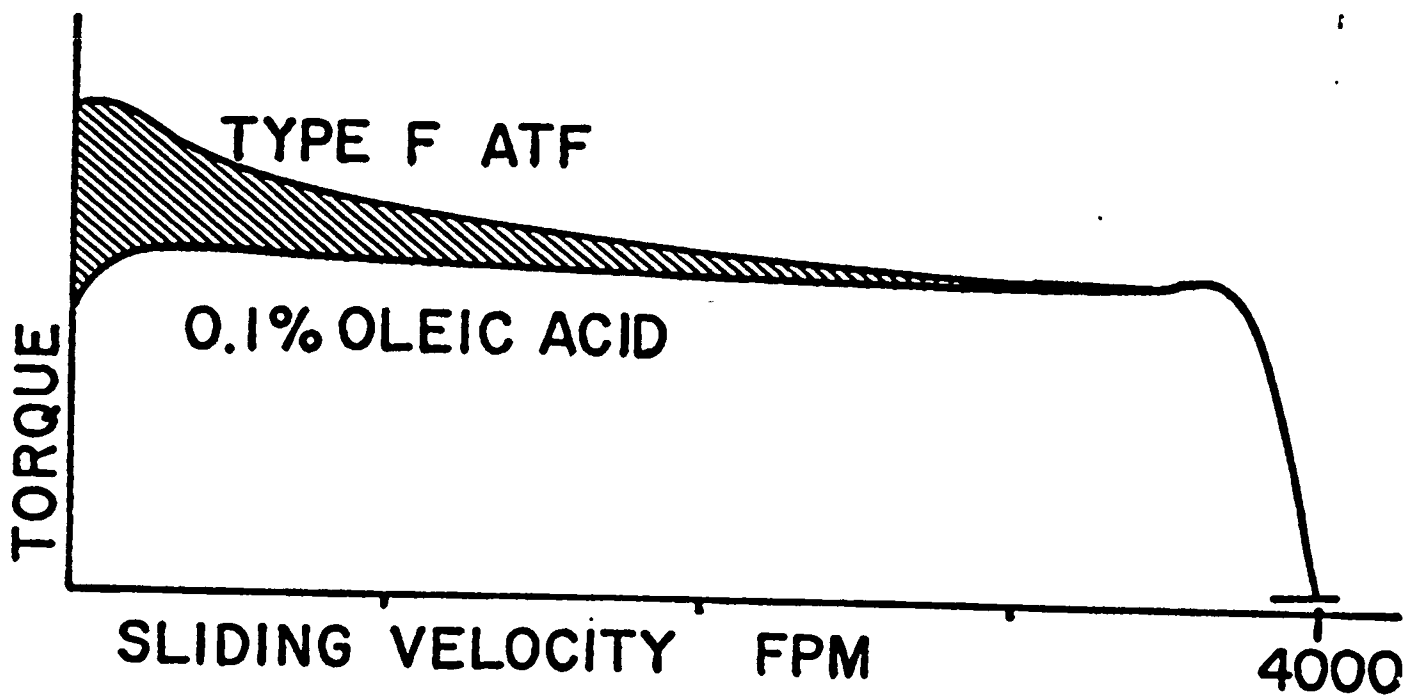

SAE #2 MACHINE
2000 ENG. CYCLES
P = PISTON FACE
R = REVERSE FACE
PLATE 1 AT PISTON
PAPER WEAR 10^{-3} IN.
2.5
2.0
1.5
1.0
.5
P
R
1
2
3
4
CLUTCH PLATE POSITION

8002 1931


SAE #2 MACHINE
2000 ENG. CYCLES
P=PISTON FACE
R=REVERSE FACE
PLATE 1 AT PISTON
STEEL WEAR 10^{-3} IN.
0.3
0.2
0.1
0
R
P
R
P
R
P
R
P
1
2
3
4
5
SEPARATOR PLATE POSITION

8002 1982

SAE #2 MACHINE



Comments and Questions

(1) Since the objective (one and only) of the study was to assess the capabilities of the testing procedures, the specific observations from individual tests are of interest, not the general conclusions on material character and expected performance. Since we have no idea of the application, I think we would be taking quite a chance ~~max~~ if we were to go so far into making predictions, and there is no reason that we should.

(2) For the reasons in point (1), the material in Appendix B and some of the material in Appendixes A and C are really the important parts, and therefore they must be in the text, rather than in the Appendix.

(3) If point (2) is followed, then it would be easier to retain the figure order selected by combining Exptl. Proc. and Exptl. Results. Hence I tried to do this; I may not like it when I look it over a few days hence.

(4) The perspective in Fig. 1 does not seem very good to me; in particular, some lines for Dark Samples which I believe should be radial do not look radial as drawn. must be my eyes,

(5) Bands on Fast tests: how obtained? not clear to me. actual mean ±.05 or .1% which is great

(6) In Fig. 40 -- Graphite area -- How obtained? Not clear to me. estimated by microscope examination of used samples

(7) The Bibliography references are so incomplete that I cannot locate most of them; I am particularly puzzled by reference 7, which apparently is addressed to me but, to the best of my knowledge I have never received, and reference 10, in which only the authors are given. Some of the other reference descriptions are also incomplete, but not as bad.

arbitrary units approximate area percentage of graphite

Appendix I. ARL Test Procedures

Appendix II. Illustrations of Correlation Between Results of Chemical & Fact ARL Test Procedure.

Feb. 15

8002 1934 PQ

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