NASA/TM—1999-208833 ARL–TR–1912

U.S. ARMY
RESEARCH LABORATORY

A Preliminary Study on the Vapor/Mist Phase Lubrication of a Spur Gearbox

Wilfredo Morales
Lewis Research Center, Cleveland, Ohio

Robert F. Handschuh
U.S. Army Research Laboratory, Lewis Research Center, Cleveland, Ohio

February 1999

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized data bases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at (301) 621-0134

- Telephone the NASA Access Help Desk at (301) 621-0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076

This report contains preliminary
findings, subject to revision as
analysis proceeds.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076
Price Code: A03

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100
Price Code: A03

A PRELIMINARY STUDY ON THE VAPOR/MIST PHASE LUBRICATION OF A SPUR GEARBOX

Wilfredo Morales
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

and

Robert F. Handschuh
U.S. Army Research Laboratory
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

Organophosphates have been the primary compounds used in vapor/mist phase lubrication studies involving ferrous bearing material. Experimental results have indicated that the initial formation of an iron phosphate film on a rubbing ferrous surface, followed by the growth (by cationic diffusion) of a lubricious pyrophosphate-type coating over the iron phosphate, is the reason organophosphates work well as vapor/mist phase lubricants. Recent work, however, has shown that this mechanism leads to the depletion of surface iron atoms and to eventual lubrication failure. A new organophosphate formulation was developed which circumvents surface iron depletion. This formulation was tested by generating an iron phosphate coating on an aluminum surface. The new formulation was then used to vapor/mist phase lubricate a spur gearbox in a preliminary study.

INTRODUCTION

Klaus, Lai, and Graham (refs. 1 and 2), laid the foundation for high temperature vapor phase lubrication studies when they used tributyl phosphate (TBP) and tricresyl phosphate (TCP) vapors, delivered in a carrier gas, to form deposit films on metal surfaces and to lubricate a four-ball wear tester. Since then, a number of vapor phase lubrication studies, using organophosphates, have been reported. Vapor phase lubrication research can be divided into deposition studies and dynamic friction and wear studies.

In deposition studies, organophosphate molecules are impinged at hot metal or ceramic surfaces and subsequent surface reactions are analyzed. The results from these deposition studies indicated that lubricating films formed only on metal surfaces containing certain active metal sites such as iron or copper (ref. 3). Lubricating films did not form on SiC (ref. 4), nickel (ref. 3) or aluminum (ref. 5) surfaces.

Dynamic friction and wear studies have been conducted using a four ball wear tester (ref. 2), a pure sliding reciprocating tester (ref. 6), a ball-on-rod tester (ref. 7) and a gas turbine engine (ref. 8). In general, successful results were reported for vapor phase lubrication of ferrous material such as cast iron, M50 steel, and 1018 steel specimens. Vapor phase lubrication of ceramics and a Ni-based superalloy were unsuccessful. The work conducted by Forster et al. (ref. 8) also revealed that lubricant delivery as a mist to rubbing surfaces worked as well as vapor delivery, prompting the phrase "vapor/mist phase lubrication."

The experimental results indicate organophosphates work well with certain ferrous materials due to an initial, rapid formation of a predominant iron phosphate film. This is followed by the formation and growth of a pyrophosphate-type film over the iron phosphate via cationic diffusion. As long as iron is present at a wearing surface the vapor phase lubrication method using organophosphates works well. Evidence, however, has been reported (ref. 9) that continued organophosphate interaction with ferrous bearing materials can lead to depletion of surface iron and to eventual lubrication failure.

If vapor/mist phase lubrication is to work for prolonged periods of time then the depletion of surface iron must be circumvented. A deposition study was undertaken to test the capability of a new organophosphate solution, containing an iron additive, to form iron phosphate on the surface of aluminum reasoning that if an iron phosphate film can be formed on an aluminum surface then it may be formed on most other surfaces. A preliminary dynamic test was then undertaken testing the new organophosphate solution, as a vapor/mist phase lubricant, in a spur gearbox.

EXPERIMENTAL

Deposition Studies

An alcohol solution was prepared by dissolving 1 g of an aryl phosphate ester into 100 ml of ethanol. A second solution was prepared by dissolving 1 g of the same phosphate ester, and 1 gram of ferric acetylacetonate into 100 ml of ethanol (ref. 10). Aluminum foil samples (1×1 cm) were ultrasonically cleaned in an acetone bath for 10 min and dried in air. One foil sample was dipped into the phosphate/ethanol solution for 1 min, withdrawn from the solution and the ethanol allowed to evaporate from the foil surface. The foil was then inserted into a preheated oven (300 °C) for 2 min. This procedure was repeated for a second foil sample dipped into the phosphate/ferric acetylacetonate/ethanol solution. The foil samples were analyzed using X-ray photoelectron spectroscopy (XPS). The XPS spectra were acquired on a commercial spectrometer operated at 100 eV pass energy. The sample surface was perpendicular to the spectrometer axis, the spectrometer acceptance angle was ±12 degrees, and the area of analysis was 2×5 mm. Non-monochromatized, Al K-alpha x-rays were used. The areas of peaks in the spectra were calculated by subtracting a Shirley background, and the composition of the specimen surface was calculated from the areas by applying sensitivity factors supplied by the instrument manufacturer. Depth profiling of surface films was not attempted in this study.

Spur Gear Test Facility

The facility (ref. 11) used to conduct the vapor/mist phase lubrication tests is shown in figure 1. It operates in a closed-loop arrangement where the drive motor only needs to supply the power to overcome the frictional losses of the system. The system loop is loaded through a torque actuator contained internal to one of the slave gears. High pressure oil, the same oil used to lubricate the gears under normal operation, is supplied to the rotating shaft via a seal assembly. The level of pressure applied to the torque actuator is related to the level of contact stress attained.

The test gears are aligned such that only one half of the face width is loaded. Using the test hardware in this manner can permit four fatigue tests to be run on one pair of gears provided tooth breakage does not occur. The facility can operate with the gears transmitting 75 kW (100 hp) at rotational speeds equal to 10 000 rpm. These maximum test rig conditions will induce a Hertzian contact stress maximum of 1.7 GPa. The test gears were made from AISI 9310 gear steel. Test gear dimensional information is contained in table I.

The existing spur gearbox was modified to accommodate a misting unit (fig. 2a). A photograph of the test arrangement is shown in figure 2(b). The mister was filled with the aryl phosphate ester and compressed air was used to deliver the ester to the spur gearbox as a fine mist or fog. The spur gears were then rotated initially at 2400 rpm and 0.5 GPa contact stress for 5 min. The gearbox was then disassembled and the gears removed and cleaned for visual inspection. After inspection, the gears were assembled back in the gearbox and rotated at a higher speed and load for another five minutes before stopping the test run for another visual inspection. This procedure was repeated several more times until a final run was made at 7000 rpm at 1.1 GPa contact stress.

A 1 percent (by weight) solution of ferric acetylacetonate in the phosphate ester was prepared and loaded into the mister unit. Subsequent lubrication tests were performed using different sets of gears, again gradually increasing the gear speed and load capacity. The gearbox was modified to allow insertion of a thermocouple to monitor the turbulent air temperature next to one of the gears (fig. 3).

RESULTS AND DISCUSSION

Deposition Studies

Figure 4 is the XPS spectrum of the heat-treated Al surface which was dipped into the pure phosphate solution. Oxygen, carbon, and aluminum peaks were identified but not phosphorous. The calculated aluminum-to-oxygen ratio, from the XPS spectrum, is 0.60 and the stoichiometric aluminum-to-oxygen ratio for aluminum oxide, Al_2O_3, is 0.66. Comparison of these two ratios, along with the XPS spectrum, indicates an aluminum oxide surface with carbonaceous material over it.

Figure 5 is the XPS spectrum for the heat treated Al surface which was dipped into the ferric/phosphate solution. Oxygen, carbon, iron and phosphorus peaks were detected but not aluminum. This indicates the presence of a film thick enough to cover the strongly absorbing aluminum on the foil surface. If only iron phosphate is present then the phosphorous-to-iron and the phosphorous-to-oxygen ratios, from the XPS spectrum, should be about 1 and 0.25 respectively. The ratios, however, are 0.55 and 0.19 which indicates excess iron and oxygen. This excess iron and oxygen could be present as iron oxide but further surface analysis is needed to discern the calculated ratios. Nevertheless, the XPS spectrum indicates a phosphate film, with carbonaceous material, covering the aluminum surface.

This deposition study revealed the inability of a phosphate film to form on an aluminum surface using only the pure organophosphate. Either the organophosphate simply evaporated from the surface or it decomposed with subsequent evaporation of the decomposition products. This result is not surprising considering a review of phosphate conversion coatings in the literature (ref. 12). In general, cast irons and low carbon steels are easily phosphated whereas stainless steels cannot be successfully phosphate coated. The only phosphate easily deposited on aluminum surfaces is zinc phosphate and only via a process where fluoride ions are present in a phosphating bath. This study, however, has shown that the presence of ferric acetylacetonate, in the organophosphate, led to the formation of an iron phosphate film on the aluminum foil. The iron phosphate film on any metal or ceramic surface is crucial for successful high temperature, vapor/mist phase lubrication.

Spur Gear Studies

The results of the first test, using only pure phosphate ester, are summarized in table II. This run was conducted in 5 min intervals where, at the end of each interval, the gears were disassembled and visibly examined. No tooth wear or scratches were observed at the end of the first interval. The speed and load were increased for the second interval. This time slight scratches on some of the teeth were observed. The speed and load were increased for the third and fourth intervals with no visible changes to the gear teeth. At the end of the fifth interval, surface scratches on the gear teeth were more pronounced. No changes were noticed for the sixth interval. For the seventh interval, a 1.1 GPa contact stress was applied to the gears rotating at 7000 rpm. Two minutes elapsed before a sudden increase in noise was heard and the test stopped. The test chamber was very cloudy as seen through the plexiglass window covering the test gears. Visual inspection revealed 3 teeth on the driver gear and 9 teeth on the driven gear had severely overheated as noted by the bluish discoloration of the teeth (ref. 13).

The driver gear was continuously sprayed with ethanol for several minutes to remove residual oil. One gear tooth, randomly selected, was removed and its contact surface analyzed using XPS. Its XPS spectrum, shown in figure 6, revealed a surface film consisting essentially of carbon and oxygen. A small iron peak was detected along with a few minor contaminants. No phosphorous was detected.

Because only three sets of spur gears were available for experimentation, it was decided to mist phase lubricate a new set with the 1 percent ferric/phosphate solution. A thermocouple recorded the fling-off air lubricant temperature near the driven gear. The results of this second test are summarized in table III. The run started with a gear rotation of 2800 rpm, no load on the gears, and an initial temperature of 20 °C. Gear speed or load was increased every 5 min; however, this time the gearbox was stopped for gear inspection only at the end of the sixth interval. The thermocouple measured 38 °C at the end of the first interval. The gear load pressure was increased to apply a contact stress equal to 0.8 GPa for the second interval and a 50 °C temperature reading was recorded. During the next three intervals, the speed and load were increased to 7300 rpm and 1.1 GPa contact stress. The temperature increased to 84 °C.

Inspection of the gear teeth at the end of the sixth interval revealed only slight wear scars on the teeth. After reassembly, the gearbox was started at 7730 rpm and a 1.3 GPa contact stress was applied. This seventh interval ran for 10 min and the thermocouple held steady at 92 °C. The load was increased to 1.5 GPa contact stress for the eighth interval where the gearbox ran for 1.5 min until a sudden increase in gear noise and vibration resulted in test termination. The temperature increased rapidly to 119 °C. Inspection of the gears showed worn teeth but no fatal damage and the gear teeth were not discolored.

Table IV summarizes the results of the third test, again using the 1 percent ferric/organophosphate solution, where the position of one of the air/mist jets was changed (fig. 7) to lubricate the gear teeth just before they entered the contact zone. This run started with a gear speed of 3000 rpm and 0.8 GPa contact stress. The thermocouple measured 32 °C after the first (5 min) interval. The speed was increased to 7000 rpm for the second interval and the temperature reached 57 °C. The load was increased to 1.1 GPa contact stress for the third interval where the temperature rose to 72 °C. The load was increased to 1.3 GPa for the fourth interval where the temperature rose to 85 °C. The gear speed was increased to 10 000 rpm for the fifth interval where the temperature gradually rose to 149 °C and then started to decrease. During the next 7 min, the sixth interval, the temperature dropped and stabilized at 141 °C. The load was increased to 1.4 GPa for the seventh interval. The temperature increased steadily to 164 °C when the test was terminated. Gear teeth examination revealed some visible wear but very little surface metal removal, and no discoloration of the teeth was observed.

After ethanol cleaning, a tooth from the driver gear was removed and its contact surface analyzed using XPS. The XPS spectrum (fig. 8) revealed a surface film consisting primarily of carbon and oxygen along with amounts of iron and phosphorus. Minor contaminants were also present.

Unfortunately only three gear runs could be performed at this time. It was deemed, however, that these favorable results justified a preliminary report. Keeping in mind that we were lubricating the spur gears with about 0.1 percent of the oil capacity used during normal operation, no catastrophic wear of the gear teeth occurred. The major differences between the runs were: (1) the blue discoloration of several gear teeth, which occurred only for the pure organophosphate run, indicating very high gear temperatures, and (2) the presence of iron and phosphorous on the gear tooth surface, from the last run, using the iron additive.

Although much work remains to be done—for instance, optimizing the concentration of the iron additive in the organophosphate, adjusting the flow rates, selecting the best locations for the mist jets—this method can be used immediately as an emergency back-up system for helicopter transmission gearboxes in the event of oil loss. One or two liters of the ferric/organophosphate solution can be used as a vapor/mist phase lubricant allowing the pilot ample time to safely land his craft.

CONCLUSIONS

Deposition studies, using a pure aryl organophosphate on aluminum foil, revealed that a phosphate film did not form on the foil surface. An iron phosphate film, however, did form on the foil surface using a ferric acetylacetonate/organophosphate solution. This unique liquid solution provides the means to circumvent iron depletion on ferrous surfaces vapor/mist phase lubricated with organophospates. It also ensures successful vapor/mist phase lubrication on nonferrous surfaces. A minute amount of this formulation was used to successfully lubricate a spur gearbox at high speed and load.

REFERENCES

1. Klaus, E.E. and Lai, C.W.: “Vapor-Deposited Lubricants for Extreme Conditions,” ASLE Special Publication SP-15, pp. 75–79.
2. Graham, E.E. and Klaus, E.E.: “Lubrication from the Vapor Phase at High Temperatures,” ASLE Trans., 29, 2, pp. 229–234 (1986).
3. Klaus, E.E., Jeng, G.S. and Duda, J.L.: “A Study of Tricresyl Phosphate as a Vapor Delivered Lubricant,” Lubr. Eng., 45, 11, pp. 717–723 (1989).
4. Klaus, E.E., Phillips, J., Lin, S.C., Wu, N.L. and Duda, J.L.: “Structure of Films Formed During the Deposition of Lubrication Molecules on Iron and Silicon Carbide,” Tribology Trans., Vol. 33, 1, pp. 25–32 (1990).
5. Hanyaloglu, B., Fedor, D.C. and Graham, E.E.: “Vapor Phase Lubrication of a Ni-Based Superalloy,” Lubr. Eng., 51, 3, pp. 252–258 (1995).
6. Makki, J.F. and Graham, E.E.: “Formation of Solid Films from the Vapor Phase on High Temperature Surfaces,” Lubr. Eng., 47, 3, pp. 199–206 (1991).
7. Graham, E.E., Nesarikar, A., Forster, N. and Givan, G.: “Vapor Phase Lubrication of High Temperature Bearings,” Lubr. Eng., 49, 9, pp. 713–718 (1993).
8. Van Treuren, K.W., Barlow, D.N., Helser, W.H., Wagner, M.J. and Forster, N.H.: “Investigation of Vapor-Phase Lubrication in a Gas Turbine Engine,” J. of Engineering for Gas Turbines and Power, Vol. 120, pp. 257–262 (1998).

9. Forster, N.H., “Rolling Contact Testing of Vapor Phase Lubricants—Part IV: Diffusion Mechanisms,” STLE Preprint No. 98-AM-2A-1.
10. U.S. Patent No. 5,738,913; “Method of Providing Ceramic Article with Wear Resistant Coating,” Apr. 14, 1998.
11. Townsend, D.: “Improvement in Surface Fatigue Life of Hardened Gears by High Intensity Shot Penning”, NASA TM–105678, AVSCOM TR-91-C-042.
12. ASM Handbook, Vol. 5, Surface Engineering, pp. 378–404 (1994).
13. Alban, L.E.: “Systematic Analysis of Gear Failures,” p. 34, published by ASM (1985).

TABLE I.—SPUR GEAR DATA

[Gear tolerance per AGMA class 12.]

Number of teeth	28
Diametral pitch	8
Circular pitch, cm (in.)	0.9975 (0.3927)
Whole depth, cm (in.)	0.762 (0.300)
Addendum, cm (in.)	0.318 (0.125)
Chordal tooth thickness (reference), cm (in.)	0.485 (0.191)
Pressure angle, deg	20
Pitch diameter, cm (in.)	8.890 (3.500)
Outside diameter, cm (in.)	9.525 (3.750)

TABLE II.—SPUR GEARBOX TEST USING PURE ORGANOPHOSPHARE

Interval	Elapsed test time, min during interval	RPM	Gear contact stress, GPa	Observation
1	0 to 5	2400	0.5	No visible wear
2	5 to 10	2700	0.8	Slight scratches on teeth
3	10 to 15	2830	0.8	No change
4	15 to 20	4900	0.8	No change
5	20 to 25	4900	0.9	Surface scratches on teeth
6	25 to 30	7000	0.9	No change
7	30 to 32	7000	1.1	Shut down

TABLE III.—SPUR GEARBOX TEST USING 1 PERCENT FERRIC/PHOSPHATE FORMULATION

Interval	Elapsed test time, min during interval	RPM	Gear contact stress, GPa	Temperature, °C
1	0 to 5	2800	0	38
2	5 to 10	2800	0.8	50
3	10 to 15	4200	0.8	59
4	15 to 20	4200	1.1	67
5	20 to 25	7300	1.1	84
6	25 to 30	7300	1.3	91
7	30 to 40	7730	1.3	92
8	40 to 41.5	7730	1.5	119

TABLE IV.—SPUR GEARBOX TEST USING 1 PERCENT FERRIC/PHOSPHATE FORMULATION WITH DIFFERENT JET PLACEMENT

Interval	Elapsed test time, min during interval	RPM	Gear contact stress, GPa	Temperature, °C
1	0 to 5	3000	0.8	32
2	5 to 10	7000	0.8	57
3	10 to 15	7000	1.1	72
4	15 to 20	7000	1.3	85
5	20 to 25	10 000	1.3	149
6	25 to 32	10 000	1.3	141
7	32 to 37	10 000	1.4	164

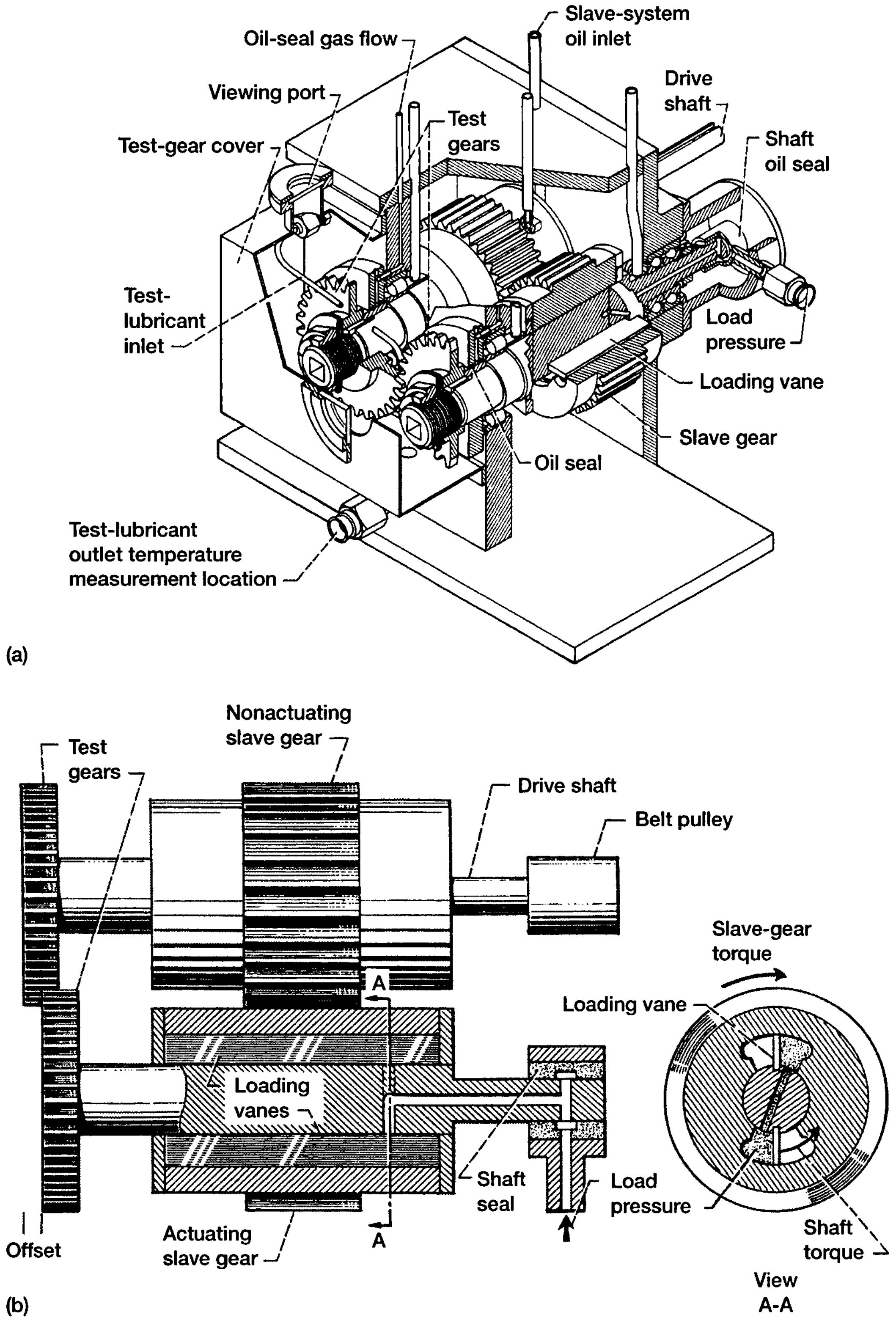

Figure 1.—NASA Lewis Research Center's gear fatigue test apparatus. (a) Cutaway view. (b) Schematic diagram.

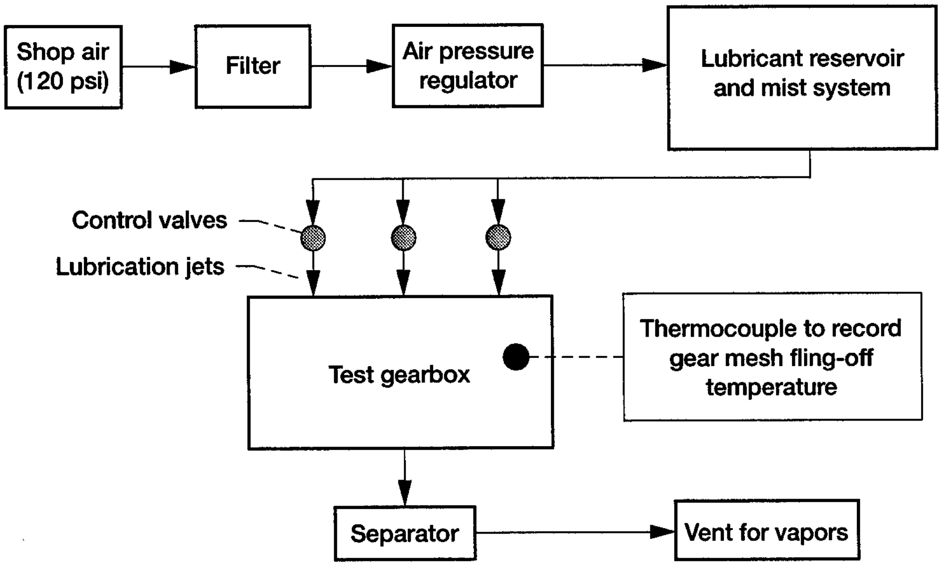

Figure 2a.—Vapor/mist phase lubrication system.

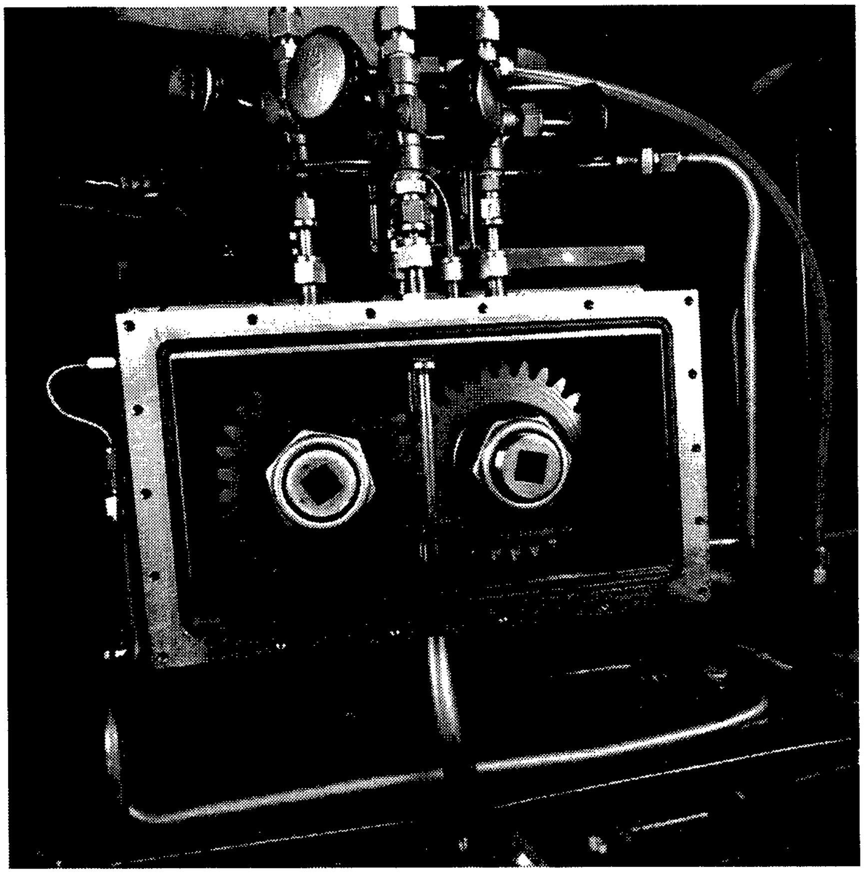

Figure 2b.—Photograph of experimental test arrangement.

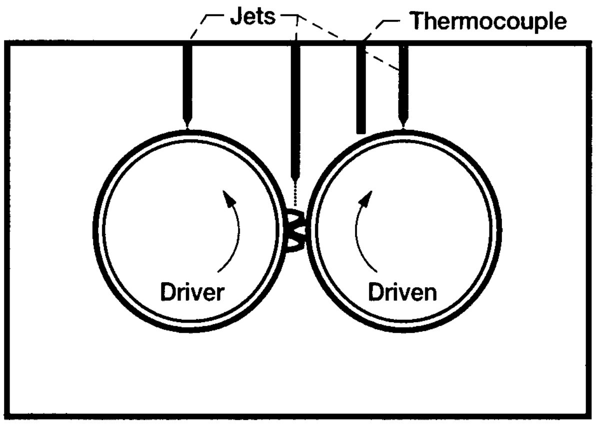

Figure 3.—Spur gearbox showing jet and thermocouple placement. Each gear has twenty eight teeth, only a select few shown here.

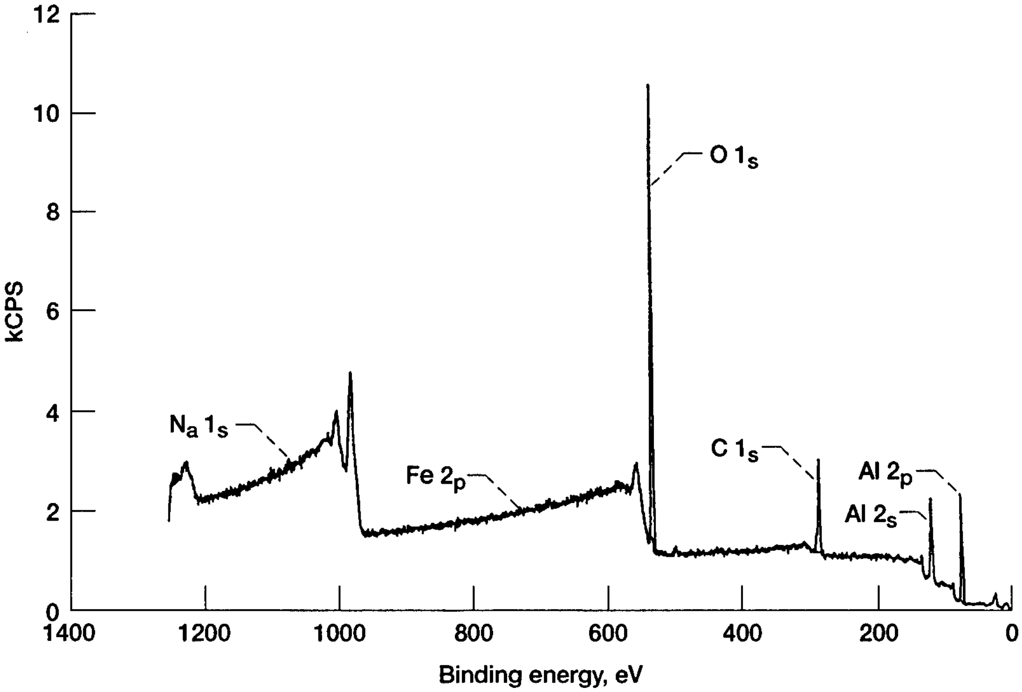

Figure 4.—XPS spectrum of heat-treated Al surface dipped into pure phosphate solution.

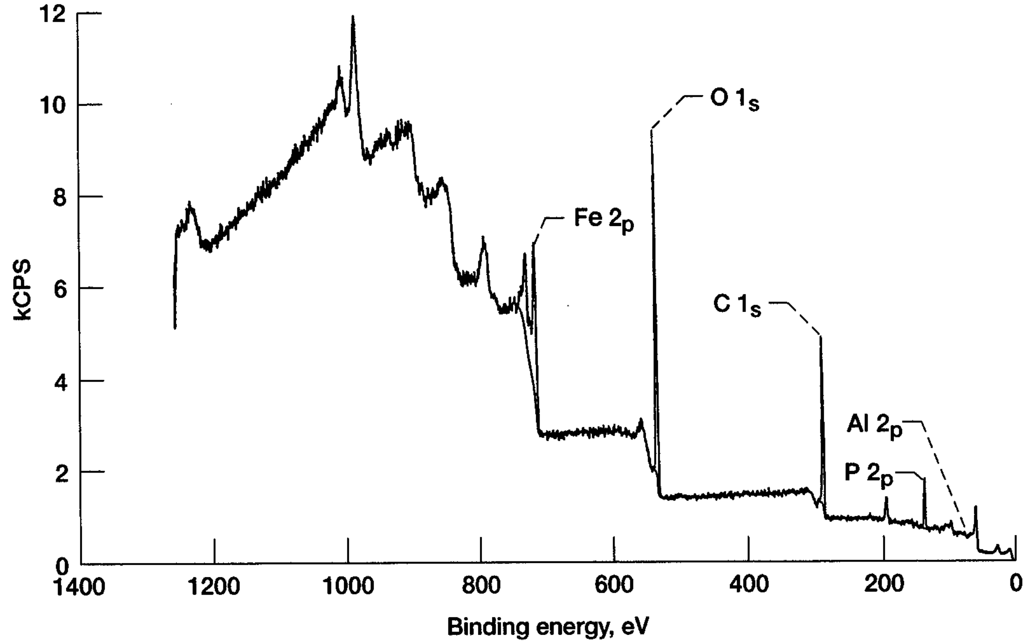

Figure 5.—XPS spectrum of heat-treated Al surface dipped into ferric/phosphate solution.

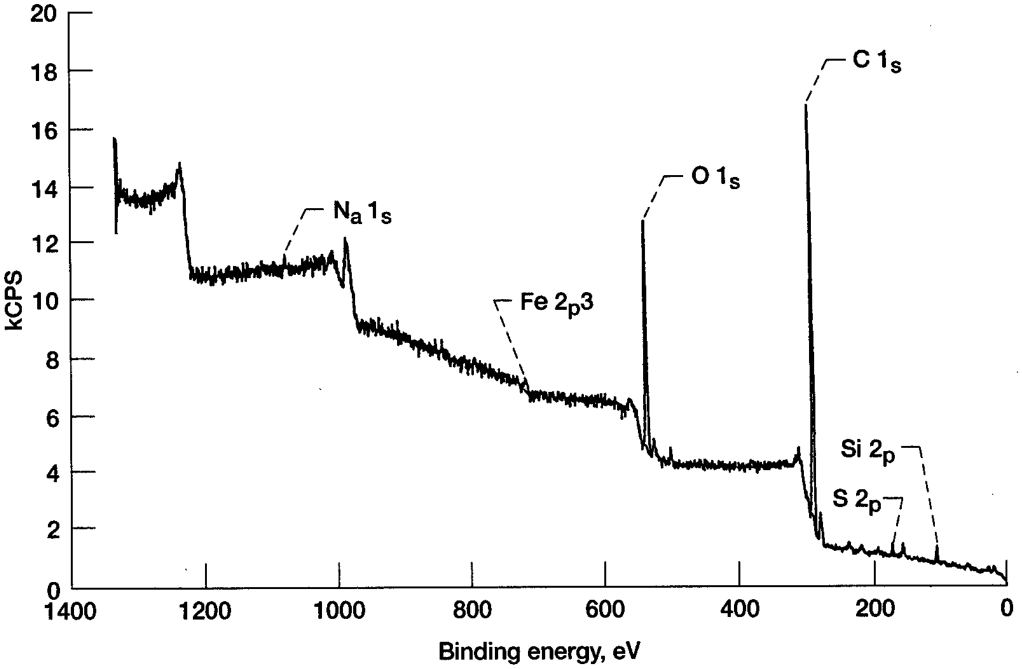

Figure 6.—XPS spectrum of gear tooth from test conducted using pure phosphate.

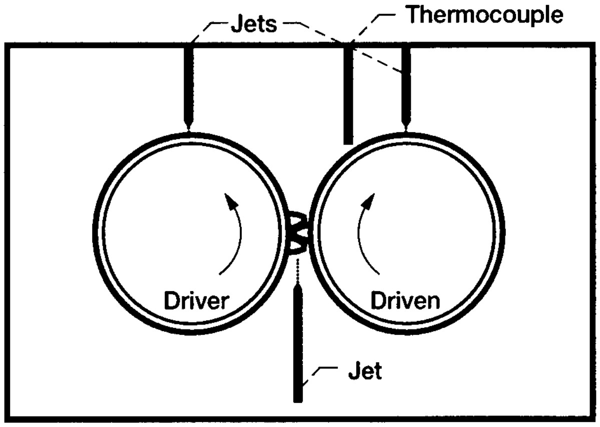

Figure 7.—Spur gearbox showing different jet placement.

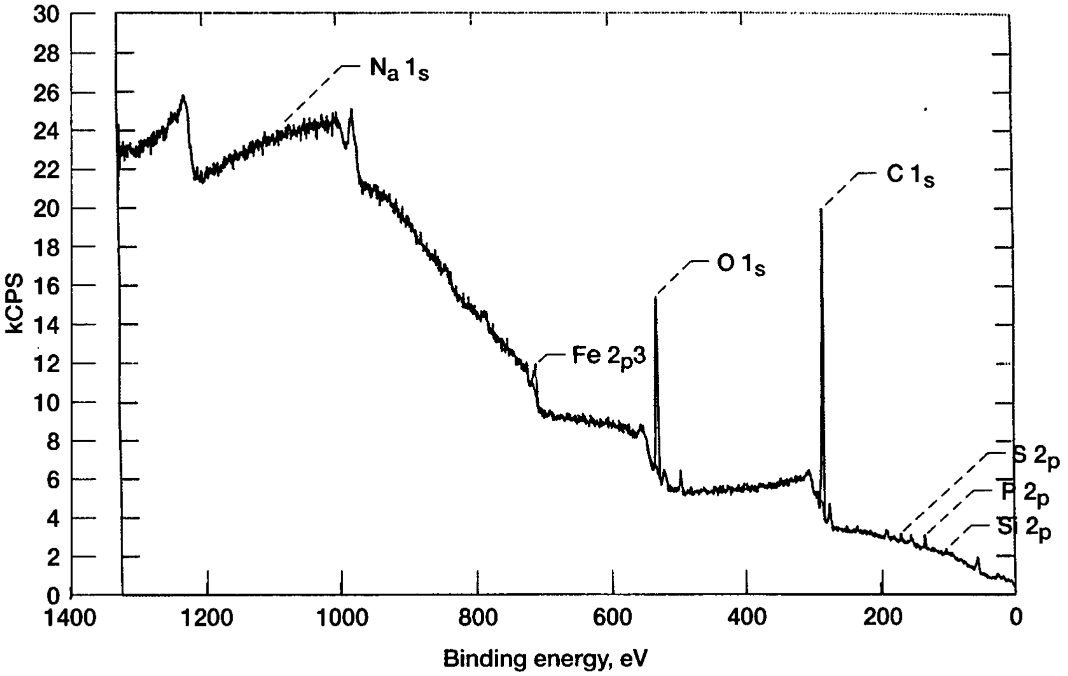

Figure 8.—XPS spectrum of gear tooth from test conducted using the ferric/phosphate formulation.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
February 1999

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
A Preliminary Study on the Vapor/Mist Phase Lubrication of a Spur Gearbox

5. FUNDING NUMBERS
WU–523–22–13–00
1L162211A47A

6. AUTHOR(S)
Wilfredo Morales and Robert F. Handschuh

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Lewis Research Center
Cleveland, Ohio 44135–3191
and
U.S. Army Research Laboratory
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E–11444

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NASA Lewis Research Center
Cleveland, Ohio 44135–3191
and
U.S. Army Research Laboratory
Cleveland, Ohio 44135–3191

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM—1999-208833
ARL–TR–1912

11. SUPPLEMENTARY NOTES

Wilfredo Morales, NASA Lewis Research Center; and Robert F. Handschuh, U.S. Army Research Laboratory, NASA Lewis Research Center. Responsible person, Wilfredo Morales, organization code 5140, (216) 433–6052.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Categories: 23 and 27 Distribution: Nonstandard

This publication is available from the NASA Center for AeroSpace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Organophosphates have been the primary compounds used in vapor/mist phase lubrication studies involving ferrous bearing material. Experimental results have indicated that the initial formation of an iron phosphate film on a rubbing ferrous surface, followed by the growth (by cationic diffusion) of a lubricious pyrophosphate-type coating over the iron phosphate, is the reason organophosphates work well as vapor/mist phase lubricants. Recent work, however, has shown that this mechanism leads to the depletion of surface iron atoms and to eventual lubrication failure. A new organophosphate formulation was developed which circumvents surface iron depletion. This formulation was tested by generating an iron phosphate coating on an aluminum surface. The new formulation was then used to vapor/mist phase lubricate a spur gearbox in a preliminary study.

14. SUBJECT TERMS
Chemistry; Lubrication; Catalyst

15. NUMBER OF PAGES
16

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102