PAP-630

ENVIRONMENTALLY SAFE OR "GREEN" LUBRICANTS FOR WICKET GATE BUSHING APPLICATIONS

March 1994

by

Leslie J. Blum

Presented at the Northwest Power Pool's
Hydro Maintenance Conference
Great Falls, Montana

ENVIRONMENTALLY SAFE OR "GREEN" LUBRICANTS FOR WICKET GATE BUSHING APPLICATIONS

by

Leslie J. Blum

U.S. Bureau of Reclamation
Denver Office
Hydraulic Branch

March 1994

DISCLAIMER

The information contained in this report regarding commercial products or firms may not be used for advertising or promotional purposes and is not to be construed as endorsement of any product or firm by the Bureau of Reclamation. The test apparatus was designed to simulate conditions encountered in Reclamation's applications. The lubricants may perform differently under different conditions.

Background

The Bureau of Reclamation recognizes the need for a biodegradable, food grade, waterproof grease to be used in hydroelectric facilities due to increased environmental emphasis. The greases presently used within these facilities in generator wicket gate bushings could contain lead, phosphorous, lithium, and benzene compounds which may be introduced to waterways and affect water quality, including effects on biological food chains. However, replacement of these lithium based greases will require not only that a grease meet water quality standards but must also duplicate mechanical properties that maximize service life, allowing the bushings to last at least forty years. In order to assure these standards are met, laboratory and field tests will be required. The Hydraulics Branch, Denver Office, is conducting a study to determine the mechanical performance of several environmentally safe or "green" lubricants, and is entering into a memorandum of understanding with Powertech Labs Inc. (a subsidiary of BC Hydro in British Columbia) who will determine various other properties including the lubricant's toxicity and biodegradability characteristics.

Mechanical Test Setup and Procedure

A test apparatus was developed by the Hydraulics Branch , Denver Office, specifically to test the mechanical performance of environmentally safe greases for wicket gate bushing applications. The test apparatus (Figure 1) was modeled on a 1:4 scale after a prototype wicket gate at the Mt Elbert Powerplant near Leadville Colorado. The gate is enclosed in a rectangular conduit with flow through the gate scaled to represent flow through one wicket gate. A motor driven operator is attached to the shear lever arm as shown in Figure 1. The operator cycles the gate continuously on a 20 second, 4 degree stroke - with a 7 second pause between each cycle. In addition, a full 22 degree stroke is executed three times per equivalent prototype day. Total test time for each test case is 20 hours. Model operation simulates a prototype gate operated on automatic generation control which represents the most severe duty cycle experienced by a wicket gate. Gate torque which will be used to indicate the lubricant's performance is measured with strain gages mounted on the wicket gate shaft as shown in figure 1.

Preliminary Test Results

A lithium based grease (Lubricant A) was tested initially to be used as the baseline for performance. In addition, a test case using no grease was used to validate the test apparatus. Three "green" lubricants have been tested thus far. Gate torque was measured at one hour intervals during full gate swing. The maximum torque values during full swing were recorded and plotted over time for each test case (figures 2 and 3). The top curve on each graph in figures 2 and 3 represents the maximum torque values recorded during gate opening. The bottom curve on each graph represents the maximum values recorded during gate closing. To interpret the meaning of these graphs, a free body diagram of the test apparatus was used. An analysis of the forces acting on the gate (See Appendix A) demonstrates that the difference in the values between the two curves on each graph actually represents twice the value of the torque due to the friction force which is inherent in the system. Whereas the friction force is a function of the lubricating ability of the grease. Therefore, this gives us a quantitative analysis to compare the performance of one grease to another. Using this analysis, torque due to friction for each completed test case is given below in Table 1:

Table 1. Friction Torque due to Lubricating Performance.

TEST CASE	TORQUE (IN-LB)
Lubricant A (lithium based grease)	401
Lubricant B	629
Lubricant C	437
Lubricant D	590
No Lubricant	905

This gives us a relative comparison of how these "green" lubricants will perform in the field.

Powertech Labs Tests

A brief description of the tests that will be performed Powertech Labs Inc. are listed in Table 2. A discussion of several of these tests follows:

1. LC_{50} for toxicity - This test is the standard currently required in Canada. (the microtox test will be used first as a screening device since it shows high correlation with the LC_{50} and is much less expensive). In the United States, the Environmental Protection Agency (EPA) issued a standard in 1986 called "Quality Criteria for Water", which includes the LC_{50} test as part of their criteria for oil and grease. It is up to the individual states to determine their own regulations, but most states do adopt this criteria.

2. Biodegradability (CEC L-33-T-82) - The Acronym CEC stands for Coordinating European Council. The test was developed to determine the biodegradability of lubricants in water. Vegetable oils and a number of synthetic esters easily meet ready biodegradability criteria. However there are serious performance concerns for vegetable oils especially at low temperatures. Ester based lubricants can be designed to be readily biodegradable and non-toxic, and possess lubricant performance advantages over vegetable oils, however they are higher in cost.

3. Copper strip corrosion test - This test is important to determine if the lubricant is

Table 2. Tests to be performed by Powertech Labs

TEST NAME	TEST DESCRIPTION	TEST METHOD
Biodegradability	Developed to determine the biodegradability of lubricants in water	CEC L-33-T-82
Toxicity	Rainbow Trout will be exposed to lubricant-water dispersion	LC_{50}
Toxicity of degraded products	Same as above except degradation products of lubricants will be used	LC_{50}
Element Scan	Determines elemental concentrations	ASTM D4951
Copper Strip Corrosion	Determines lubricant's corrosiveness to copper	ASTM D4048
Rust preventive characteristics	Indicates the ability to prevent rust	ASTM D665
Resistance to water spray	Evaluates the ability of the lubricant to stick to a metal surface when subjected to direct water spray	ASTM D4049
Hydrolytic stability	Differentiates the stability of the lubricant in water	ASTM D2619
Compatibility with mineral oil	Determines the compatibility of the replaced mineral oil with the new lubricants	FTM 791C Method 3470.1
Water Solubility	Determines water absorption of lubricant	In house test
Storage stability	Determines breakdown of lubricant during storage	FTM 791C Method 3467.1
Categorize grease	Determines if composition agrees with specification sheet	Infrared scan
Compatibility with elastomers	Determines lubricants affect on elastomers	ASTM D4289
Swelling of Synthetic rubbers	Determines lubricants affect on synthetic rubbers	FTM 791C Method 3603.5
EP Properties - Timken	Determines EP characteristics	ASTM D2266
Wear characteristics	Determines relative wear preventive properties	ASTM D2266
Worked penetration	Determines consistency within NLGI grades	ASTM D217

causing a reaction to occur with the bronze bushing, since this can lead to excessive and unnecessary wear. The copper corrosion test became of particular interest after field testing one of the "green" lubricants designated as Lubricant B. On inspection of the unit which had used this product for about six months, we saw what appeared to be a copper coating on the wicket gate shaft. This was not seen on the units that had not used the Lubricant B product. A chemical analysis of a sample scraped from the shaft did show the sample to contain a significant amount of copper. Additionally, a sample of the Lubricant B product that was used in the model tests showed significantly more copper than an unused sample of the same grease (3640 mg/kg as opposed to 3mg/kg in the unused sample). Galvanic and resistivity tests conducted by the Materials Engineering Branch, Denver Office, on Lubricant B showed that the grease had high resistivity to current flow and therefore eliminated this as the cause of the copper transfer. This may indicate that the grease is chemically reacting with the bronze. Each grease will be tested for increased copper content after model tests to determine if the copper transfer is a common characteristic of the other lubricants as well.

4. Elemental scan - This will distinguish which of the lubricants contains metal components which can be harmful if they seek their way into the biological food chain.

5. Resistant to water spray - This will serve as a good indicator of how quickly the lubricant will be washed out of the bushings during field operations where it is subjected to high pressure water conditions. This may help determine a revised grease schedule for wicket gate applications. One of the best ways to protect the environment is to simply put less grease into the waterways. If funding becomes available for further tests, we plan to run a series of tests with the model test apparatus to determine how often the bushings really need to be greased. The requirements may be less than what is currently being followed.

6. Rust Preventive Characteristics - Some of the "green" lubricants may not have adequate rust preventive additives that are needed for long term performance. This test will determine this characteristic.

7. Compatibility with Mineral Oil - This is important since the "green" lubricants will, in most cases, be replacing mineral oil lubricants. Incompatibility of the new lubricants with the traces of mineral oil that will be left behind may cause formations of gums, varnishes or other insoluble contaminants.

8. Water Solubility - This test will determine if the lubricant is absorbing water which comes into contact with it. If this tendency occurs, the lubricant may eventually become diluted with water which will change its lubricating properties and may cause rust or premature breakdown of the lubricant.

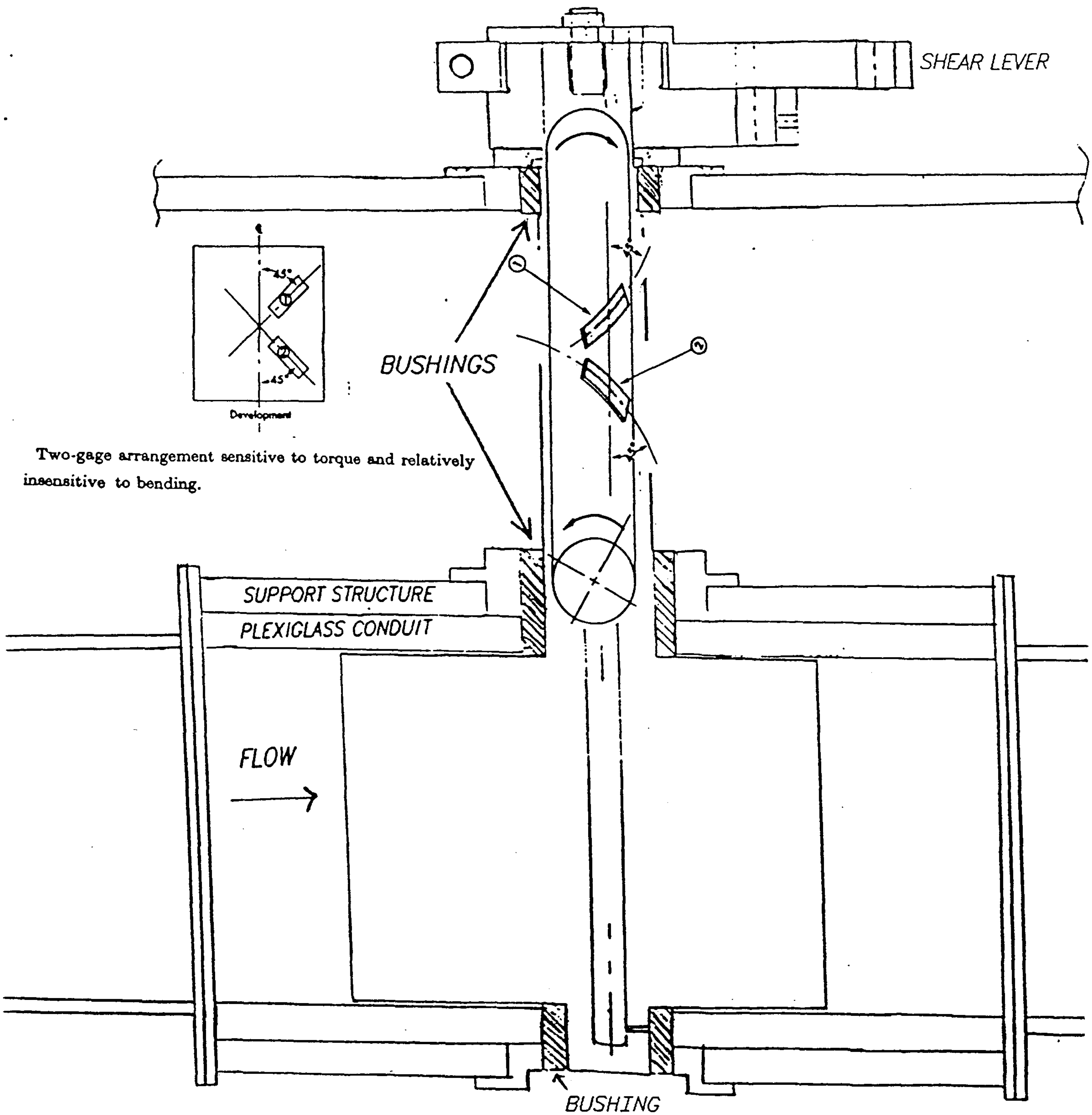
9. Storage stability - Biodegradable products may have a tendency to biodegrade on the shelf before they are put into service. This will test the tendency of the lubricant to do this.

10. EP Properties or Timken - This test will determine the extreme pressure (EP) characteristics of the grease which is classified with a timken load rating. One question that

has arisen in selecting lubricants is whether a high timken rating is required for wicket gate bushing applications. The extreme pressure (EP) additives that are used in these greases work by reacting with the metal to form a compound which acts as a protective layer on the metal's surface; preventing metal to metal contact which can lead to scoring or failure. Under extreme pressure conditions this layer wears away, protecting the metal. As this layer is removed, the EP additive acts to form another layer. EP additives control wear rather than prevent it. To prevent excessive corrosion most EP additives are activated by excessive heat created during extreme pressure conditions, but do not react at room temperature. There is a question as to whether point pressure within the wicket gate bushings is ever great enough to activate the EP additives. Field tests are currently being conducted to determine whether the magnitude of prototype bearing loads warrants high timken load requirements. The timken ratings of greases currently being used in Reclamation facilities range from about 40 lb to 45 lb.

The tests performed by the Bureau of Reclamation as well as those performed by Powertech Labs will be used as a basis to determine criteria for selection of environmentally safe lubricants. As result of these tests we should be able to identify several environmentally safe lubricants which meet both water quality standards and mechanical performance requirements.

WICKET GATE MODEL



Two-gage arrangement sensitive to torque and relatively insensitive to bending.

FIGURE 1

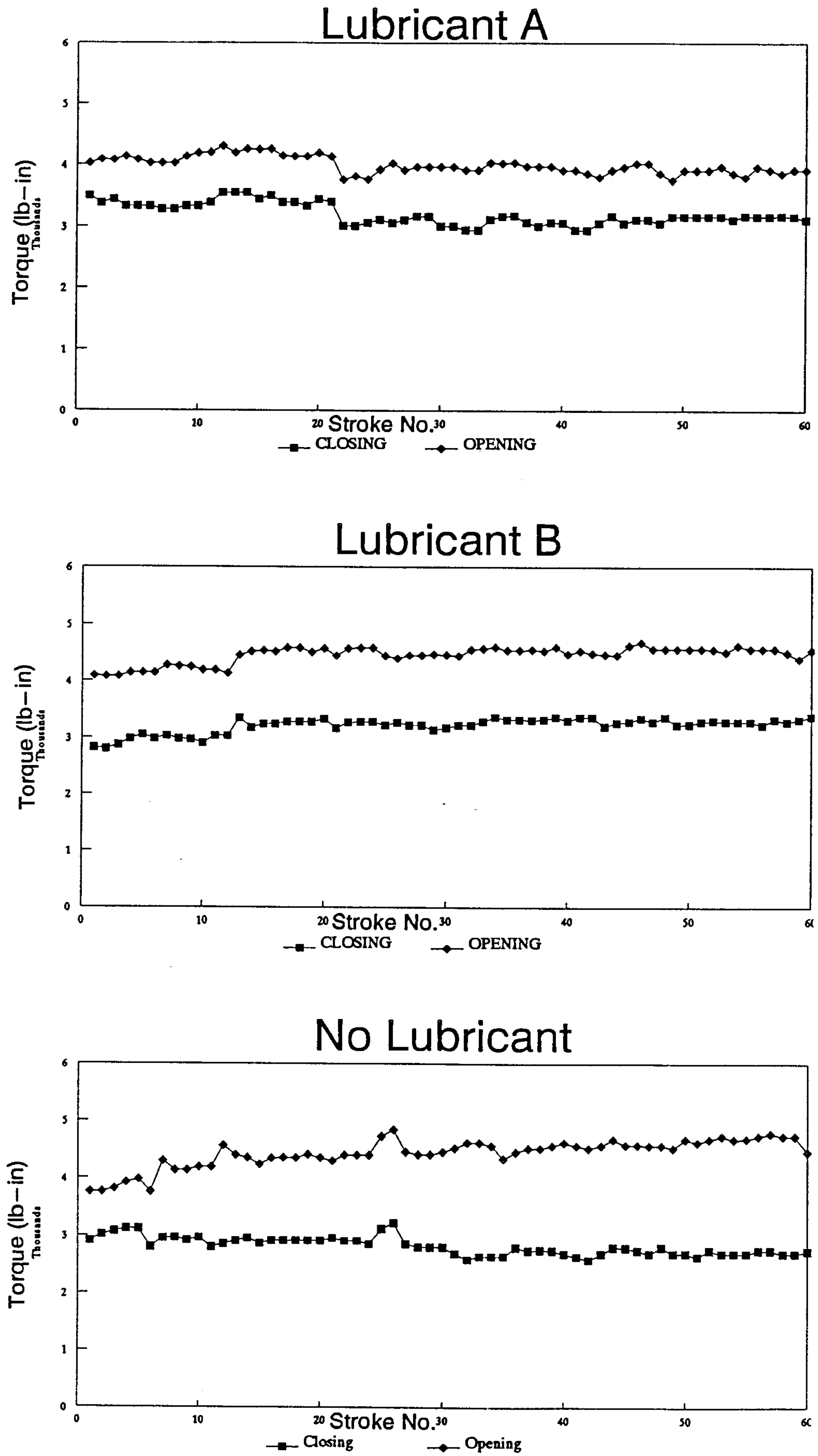
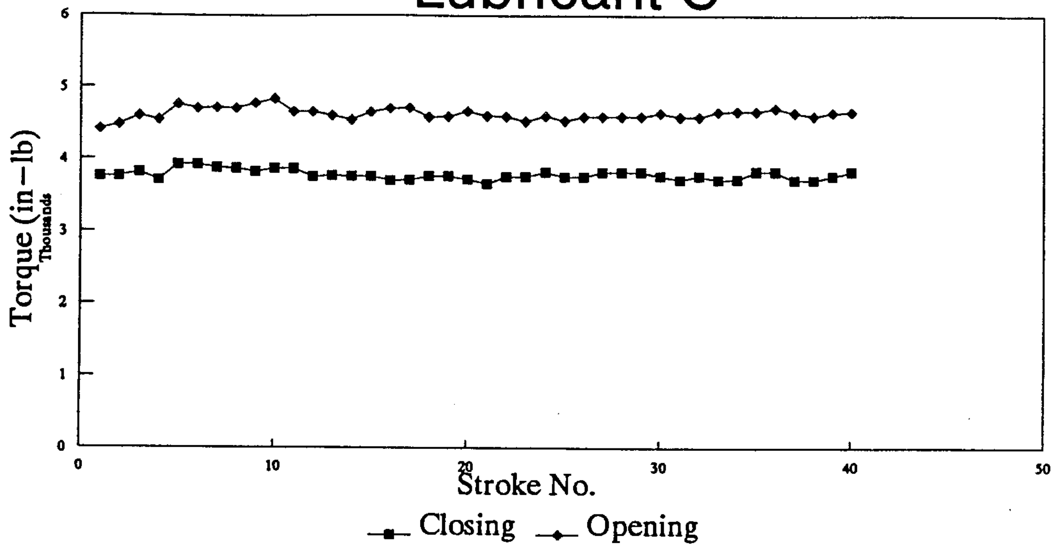

Lubricant A
Torque (lb-in) Thousands
0 1 2 3 4 5 6
0 10 20 Stroke No. 30 40 50 60
CLOSING
OPENING
Lubricant B
Torque (lb-in) Thousands
0 1 2 3 4 5 6
0 10 20 Stroke No. 30 40 50 60
CLOSING
OPENING
No Lubricant
Torque (lb-in) Thousands
0 1 2 3 4 5 6
0 10 20 Stroke No. 30 40 50 60
Closing
Opening

FIGURE 2

Lubricant C



Lubricant D

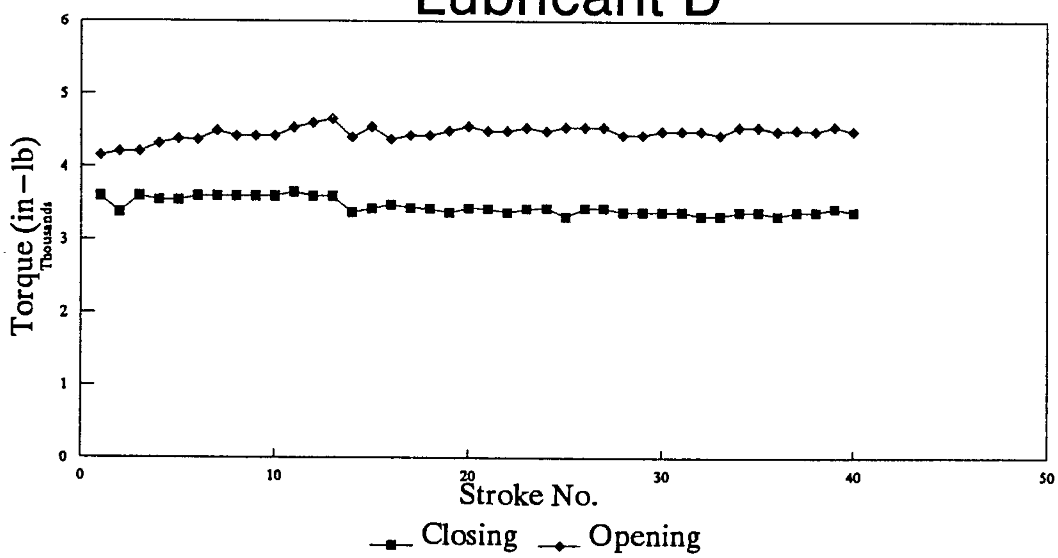
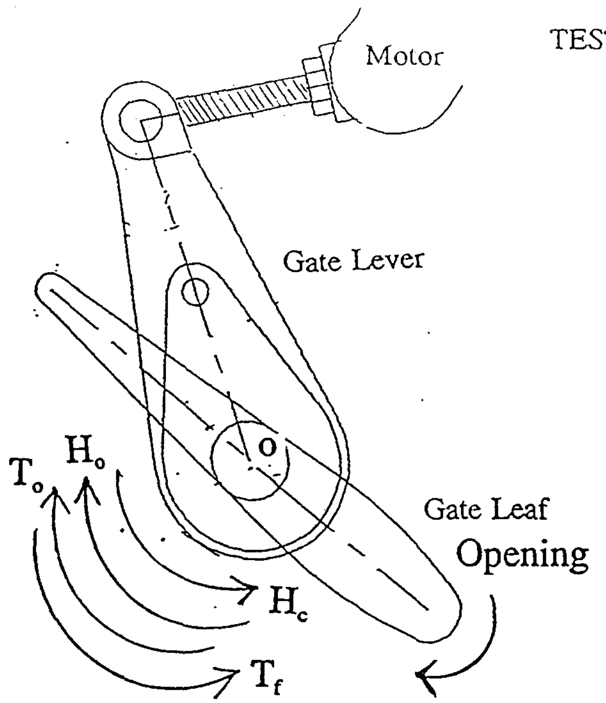
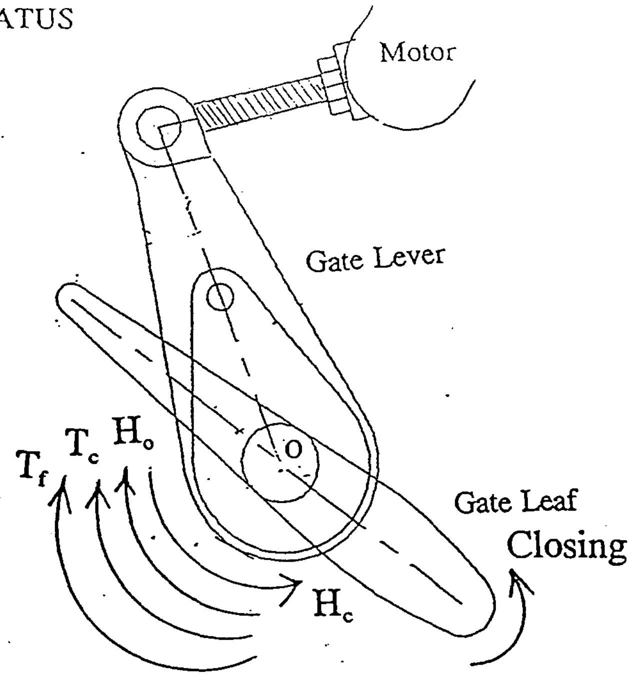


FIGURE 3

TEST APPARATUS





Summing the moments about the center of the gate shaft for gate closure gives:

$$\Sigma M_o = 0$$

$$1)\quad -T_c - T_f + H_c - H_o = 0$$

Summing the moments about the center of the gate shaft for gate opening gives:

$$2)\quad -T_o + T_f + H_c - H_o = 0$$

where: T_f = Torque due to the friction force in the bearings trying to resist the gate movement
T_c = Torque due to the motor resisting the hydraulic forces as the gate is closed
T_o = Torque due to the motor pushing the gate open
H_c = Torque due to hydraulic forces trying to close the gate
H_o = Torque due to hydraulic forces trying to open the gate

Subtracting equation 1) from equation 2) gives:

$$T_o - T_c = 2T_f$$

or

$$T_f = (T_o - T_c)/2$$