Introduction

Since the mid-1980's many customers, particularly in Europe, have recognized mineral-based hydraulic oils were potentially harmful in environmentally-sensitive applications. Applications in areas where an oil spill could contaminate a water supply have been of great concern. Biodegradable hydraulic fluids were developed to lessen the environmental impact in the event of an accidental spill. Low-toxicity additives were also incorporated to minimize detrimental effects in these applications.

Seeing the growing trend for biodegradable hydraulic fluids, Caterpillar soon incorporated guidelines for these fluids into its machine lubricant recommendations. Most fluids available at that time were based on vegetable oils and provided adequate performance in many applications.

Caterpillar machines are under continuous change to meet customer needs. Increased demands on the hydraulic system has necessitated the development of high-performance biodegradable hydraulic fluids. These fluids include synthetic-based fluids, synthetic blends, and improved formulations of vegetable-based fluids. Because of the wide performance range of biodegradable fluids now in the industry, it became necessary to identify those fluids which offer maximum life and performance over a broad temperature range.

Caterpillar has introduced a new biodegradable hydraulic fluid specification, "BF-1". This document contains all of the performance requirements that a finished lubricant must meet before it can legitimately be marketed as meeting the Caterpillar BF-1 requirements.

Caterpillar will not monitor or approve any fluid marketed under the BF-1 designation. Each supplier is responsible for the performance of their own product and the associated liabilities.

Fluids Engineering
Caterpillar Inc.
501 S.W. Jefferson Street
Peoria, IL 61630-2172

Objective:

These requirements are intended to communicate the minimum performance requirements for a lubricant that is intended for use in Caterpillar equipment, wherever BF-1 fluids are recommended. The primary use of these fluids will be in hydraulic systems.

General Description:

The Caterpillar BF-1 requirements are divided into seven principal areas: Chemical and Physical Properties, Elastomer Compatibility, Oxidation Stability, Viscometric Properties, Wear Properties, Environmental Compliance and Friction Properties.

Summary and Table of Contents:

The following information is a summary of the performance requirements that define a fluid that meets the Caterpillar BF-1 fluid requirements. Information regarding the appropriate test methods and the applicable limits for each can be found in the referenced section.

Fluid Cleanliness

1.0 Scope:

This method will be used to evaluate the level of particle contamination within the oil.

2.0 Test Method:

ISO 4406

3.0 Test Procedure:

The ISO 4406 standard test method should be followed as given.

4.0 Acceptance Limits:

A maximum measured value of 18/15 is allowed for the hydraulic system.

Homogeneity

1.0 Scope:

This method will be used to evaluate the compatibility of additives with the biodegradable oil base stock.

2.0 Test Method:

The test fluid is held at –32°C for 24 hours, then warmed to room temperature, and centrifuged. The absence of sedimentation or separation of insoluble material indicates that the oil and the additive are homogeneous.

3.0 Test Equipment:

100 mL centrifuge tubes

High speed centrifuge capable of producing 6000g

4.0 Test Procedure:

A 100 mL sample of the test fluid is put into a 100 mL centrifuge tube. The sample is stoppered and held at –32°C for a minimum of 24 hours. Allow the sample to reach room temperature and then centrifuge for 30 minutes at 6000 g. The tube containing the test sample shall be examined for sedimentation or separation of insoluble material.

5.0 Acceptance Limits:

A maximum of 0.01 volume percent sedimentation or precipitation is allowed.

Fluid Compatibility

1.0 Scope:

This test method will be used to evaluate the compatibility of different hydraulic fluid additive formulations with one another.

2.0 Test Method:

The test oil is mixed with Caterpillar Inc. 1E493 (HYDO), MTO, 1E1829 TDTO) and 1E2750 (Biodegradable) reference oils. The mixture then is heated, cooled, and centrifuged to determine if any residue is present.

3.0 Test Equipment:

100 mL centrifuge tubes

High speed centrifuge capable of producing 6000 g

4.0 Test Procedure:

A 50 mL sample of the test fluid and 50 mL of one of the three reference fluids are poured into a 100 mL centrifuge tube. Shake well and heat to 204°C. Cool to room temperature. Centrifuge for 30 minutes at 6000 g. The tube containing the test sample and the selected fluids shall be examined for precipitation of insoluble residue and separated components. Repeat the procedure for the remaining three reference fluids.

5.0 Acceptance Limits:

No sedimentation or precipitation is allowed.

Foaming Characteristics

1.0 Scope:

This test method will be used to determine the foaming characteristics of hydraulic fluids at specified temperatures. The method of empirically rating the foaming tendency and the stability of the foam are described.

2.0 Test Method:

ASTM D892 modified as described in the test procedure outlined below

3.0 Test Procedure:

ASTM D892 standard test method will be used to evaluate the foaming characteristics of hydraulic fluids with the following modifications. The test will be divided into two parts. The first part uses the standard ASTM D892 and the second part uses ASTM D892 with 0.1 volume percent of water added to simulate water accumulating in hydraulic applications.

Part I. of this test is the standard ASTM D892 test method without water added.

PART II. of this test determines the foaming of hydraulic fluids having 0.1 volume percent added water. This procedure measures the effect of a small amount of water on the foaming of hydraulic fluids. Water is mixed with the test fluid and the foaming characteristics are measured following the ASTM D892 standard test method.

Procedure: Mix 500 mL of the fluid to be tested with 0.5 mL of distilled water in a blender for 5 minutes at low speed (1000 RPM) and then for 1 minute at high speed (1300 RPM). Allow any foam to dissipate before determining the foam by all three sequences of the ASTM D892 test method.

4.0 Acceptance Limits:

Part I:	Without Added Water	With 0.1% Water
Sequence I	25/0	25/0
Sequence II	50/0	50/0
Sequence III	25/0	25/0

Humidity Corrosion

1.0 Scope:

This test method will be used to determine the corrosion protection offered by hydraulic fluids to a finished ferrous surface under dynamic humidity conditions.

2.0 Test Method:

Cleaned ferrous rods are exposed to dynamic humidity conditions and the rod is monitored for the appearance of corrosion spots over time.

3.0 Test Equipment:

500 mL Erlenmeyer flask, wide mouth
25 mL Erlenmeyer flask
Modified no. 10 rubber stopper
Bath capable of maintaining a temperature of 32 ± 1°C
Water jacket
Drill or lathe rated at 2500 revolutions per minute
Bath, controlled at 27 ± 1°C with pump capable of circulating solution through water jacket

4.0 Test Materials:

Test specimen: The test specimen is made from a 14 mm (9/16 inch) outside diameter cold drawn bar of C1018 steel and finished to a maximum of 0.279 micron (11 microinch) arithmetical average. Finished part from vendor must be free from scratches and rust and must be protected for storage by coating with MIL-C-1507b fluid. Supplier for test specimen is Centerless Grinding Co., 2330 17th Street, Franklin Park, IL 60131

Toluene - ACS Reagent purity
Isopropanol - ACS Reagent purity
Metal Polishing Cloth - Grade A-320 (25 mm [1”] side), Carborundum 320 Grit, Kim-Wipe tissue or equivalent absorbant wiper

5.0 Test Procedure:

Use three separate rods for each hydraulic fluid. The rod specimens shall be given a preliminary cleaning by immersing in a hot 50% mixture of toluene and isopropanol to remove the rustproof coating.

Chuck the test specimen in a lathe or drill (fixed position) and run at 2500 revolutions per minute. Use a 356 x 25 mm (14 x 1 inch) strip of the abrasive cloth and pass slowly from the chuck end to the specimen tip. Pull the abrasive cloth slowly from one end to the other in opposition to the rod rotation to provide a fresh surface on the paper while progressing down the specimen. The pass should take approximately 20 seconds. Make three passes using a new strip of abrasive cloth each time. The final overall specimen finish shall range from 0.278 to 0.356 micron (9 to 14 microinches) arithmetical average, except for the chucking area. Caution: Do not use chucking area as the tested portion of the rod.

Rinse rods with with toluene and wipe clean with toluene-soaked Kim-Wipe tissue. Rinse again with toluene followed by dipping six times in clean toluene at 57°C (135°F) for 15 seconds each. Remove any adhering drop at the bottom of rod with a clean piece of Kim-Wipe after each dipping. Dip the rod six times into a 500 mL flask containing clean isopropanol at 49°C (120°F).

Allow the rod to air dry and immediately immerse the 152 mm (6 inch) test section of the specimen 6 times per minute for 1 minute in a 250 mL graduated cylinder containing 200 mL of the fluid to be tested.

After the last dip, place the test section of the rod in a beaker (on a nonskid surface) containing approximately 25 mm (1 inch) of the test fluid. Push the pre-drilled rubber stopper down the rod until a 76 mm (3 inch) section protrudes. Hang the rod vertically by the exposed 76 mm (3 inch) section and allow the test fluid to drain for 30 minutes. Next, place the rod vertically in a 500 mL Erlenmeyer flask containing 100 mL of distilled water and a 25 mL Erlenmeyer flask containing 15 mL of distilled water. Place the 25 mL flask so that the test fluid from the rod cannot enter the smaller flask.

Immerse the assembly to the bottom of the stopper in a constant temperature bath maintained at 32 $\pm$ 1°C (90°F). Place the water jacket over the exposed 76 mm (3 inches) of rod and circulate water controlled at 27 $\pm$ 1°C (80°F). This will maintain a 5°C (10°F) differential over the length of the rod.

Caution: Care should be taken throughout the test that the test rod is not touched with bare hands. Plastic gloves should be worn at all times when handling the rod.

6.0 Acceptance Limits:

Minimum time is 200 hours to failure. The specimen shall be examined for appearance of corrosion spots every 24 hours. Failure is defined as six or more spots per any linear inch (as viewed without magnification). The first 9.5 mm (3/8 inch) below the contact line between the stopper and the rod shall be disregarded. Two specimen failures in less than 200 hours shall be considered a failure.

Copper Strip Corrosion

1.0 SCOPE:

This test method will be used to evaluate the corrosiveness of hydraulic fluids to copper.

2.0 Test Method:

ASTM D130

3.0 Test Procedure:

The ASTM D130 standard test method will be used to evaluate the copper strip corrosion characteristics of hydraulic fluids under the following conditions:

Oil Temperature: 150°C
Time of Immersion: 3 hours

4.0 Acceptance Limits:

1a slight tarnish is allowed.

1b or worse is considered to be a failure.

Low Temperature Storage

1.0 Scope:

This test method will be used to evaluate the low temperature storage stability of biodegradable hydraulic fluids.

2.0 Test Method:

Following preliminary heating, the fluid sample is placed in a freezer preset to -25°C. The sample is checked every 24 hours for the formation of precipitates, particles, and for fluidity.

3.0 Test Equipment:

Test jar made of clear cylindrical glass with a flat bottom, 30 to 33.5 mm inside diameter and 115 to 125 mm in height. To indicate the height of the sample, the jar should be marked with a line 54 $\pm$ 3 mm above the inside bottom.

Cork to fit the mouth of the test jar

Tray to hold the sample jars in an upright position while in the freezer

Freezer capable of maintaining the test temperature

4.0 Test Procedure:

Pour the fluid sample into the test jar to the level marked on the outside.

Heat the fluid sample to 50°C for 30 minutes.

Remove the sample from the oven and stopper the test jar with the cork. Allow the sample to cool to room temperature.

Place the sample in a freezer preset at –25°C.

Check the sample following each 24 hour period for fluidity and for the appearance of any type of precipitate and particles.

End the test at the first appearance of precipitates forming anywhere in the sample or when the sample shows no movement within 5 seconds when the sample jar is tilted to the horizontal. Report this time as the test duration and cite the reason for failure.

If failure has not occurred within 168 hours, end the test.

5.0 Acceptance Limits:

Those samples that show no precipitates and remain fluid for 168 consecutive hours are considered passing.

DEMULSIBILITY

1.0 Scope:

This test method will be used to evaluate the ability of biodegradable hydraulic fluids to separate from water.

2.0 Test Method:

ASTM D1401

3.0 Test Procedure:

The ASTM D1401 standard test method should be followed as given.

4.0 Acceptance Limits:

The test sample must have separated sufficiently that a water layer having a volume of at least 37 mL is observed before 20 min has elapsed.

Iodine Number

1.0 Scope:

This test method will be used to evaluate the degree of unsaturation of the fatty acids in the biodegradable hydraulic fluid.

2.0 Test Method:

AOCS Da 15-48 (WIJS Method)

3.0 Test Procedure:

The AOCS Da 15-48 standard test method should be followed as given.

4.0 Acceptance Limits:

Report the values obtained.

Flash and Fire Points

1.0 Scope:

This test method will be used to evaluate the flash point of biodegradable hydraulic fluids by the Cleveland Open Cup method.

2.0 Test Method:

ASTM D92

3.0 Test Procedure:

The ASTM D92 standard test method should be followed as given.

4.0 Acceptance Limit:

Flash point	220°C or legal limit, whichever is greater.
Fire point	220°C or legal limit, whichever is greater.

Pour Point

1.0 Scope:

This test method will be used to determine the minimum temperature for which biodegradable hydraulic fluids remain fluid.

2.0 Test Method:

ASTM D97

3.0 Test Procedure:

The ASTM D97 standard test method should be followed as given.

4.0 Acceptance Limit:

Viscosity Grade	Pour Point (°C)
ISO 32 and 46	Below or equal to –35
ISO 68	Below or equal to –25

Water Content

1.0 Scope:

The Karl Fischer test method will be used to determine the amount of water in a candidate biodegradable hydraulic fluid.

2.0 Test Method:

ASTM D6304

3.0 Test Procedure:

The ASTM D6304 standard test method should be followed as given.

4.0 ACCEPTANCE LIMIT:

The maximum water content as measured by ASTM D6304 should not exceed 0.05 volume percent.

Elastomer Compatibility

1.0 Scope:

The ASTM D471 and D2240 test methods will be used to evaluate the compatibility of lubricating oils with selected elastomeric materials.

2.0 Method:

ASTM test method D471 “Rubber Property - Effect of Liquids” and D2240 “Rubber Property-Durometer Hardness” will be used to evaluate the compatibility of lubricants with a series of specific elastomers. Specimens of the elastomer materials are aged in the candidate oil for 1000 hr at 100°C. A comparison of change in volume and hardness is made to determine the elastomer/oil compatibility.

3.0 Test Procedure:

Initial properties of the elastomers, including the sample volume and hardness, must be evaluated and recorded before aging. Aging the test specimens in the candidate oil must be performed at 100°C for 100 hours by following the procedure outlined in ASTM D471. Determine the change in volume and Shore A hardness by following ASTM D471. Report all data.

4.0 Acceptance Limits:

The allowed changes in volume and hardness for the selected elastomeric materials are given in the table below. Only one elastomer from each category need be tested.

GM/Cat ID	Part No.	Lot	Material	Supplier/Compound	Property	Min. % Chg.	Max. % Chg.
GM P1	GMDX3007	A	PA (Poly)	Acadia A-6-0160-85-ETI	Volume	0	10
GM P2	GMDX3009	A	PA (Poly)	Parker GR-A2256	Hardness	-5	0
GM P3	GMDX3011	A	PA (Poly)	Lutz 6830			
GM F1	GMDX3013	A	FKM (Viton)	Parker 7V2127	Volume	0	5
GM F2	GMDX3015	A	FKM (Viton)	Lutz V150B	Hardness	-5	5
GM N1	GMDX3017	A	Nitrile	Parker GR-N1386	Volume	-5	5
GM N2	GMDX3019	A	Nitrile	Lutz B-46	Hardness	-5	5
Cat 1E676	-	-	Silicone	NA (Caterpillar will supply)	Volume	+20	+30
					Hardness	-20	-15

Oxidation Stability

1.0 Scope:

This test method will be used to evaluate the thermal oxidation stability of biodegradable hydraulic fluids.

2.0 Test Method:

ASTM D943 modified as described below.

3.0 Test Procedure:

Follow the procedure outlined in ASTM D943 except for the addition of water. Do not initially add water to the hydraulic fluid or replenish water during the testing.

4.0 Acceptance Limit:

A lifetime of 2000 hr is considered passing.

Viscosity

1.0 Scope:

This test method will be used to evaluate the ability of biodegradable fluids to provide acceptable viscometric properties in cold and hot ambient conditions when used in hydraulic systems.

2.0 Test Methods:

ASTM D445

3.0 Test Procedure:

The ASTM D445 standard test method should be followed as given.

4.0 Acceptance Limits:

Viscosity Grade	Temperature	Kinematic Viscosity (cSt)
ISO 32	0°C	420 Maximum
	100°C	5.4 Minimum
32/46*	0°C	580 Max.
	100°C	6.7 Min.
ISO 46	0 °C	780 Max.
	100°C	7.5 Min.
46/68*	0°C	1050 Max.
	100°C	8.7 Min.
ISO 68	0°C	1400 Max.
	100°C	10.0 Min.

Pumps

1.0 Scope:

This test method will be used to evaluate the ability of a hydraulic fluid to provide acceptable pump antiwear characteristics.

2.0 Test Method:

Vickers® "Pump Test Procedure for Evaluation of Antiwear Fluids for Mobile Systems". Form M-2952-S (Rev. 8/88)

3.0 Test Procedure:

Vickers® test method and procedure in the Vickers® publication Form M-2952-S (Rev. 8/88) will be used to evaluate the performance of hydraulic fluids when used in conjunction with fluid pump applications in Caterpillar Inc. hydraulic systems. The test should be run with an inlet temperature of 93°C and an outlet pressure of 20.7 MPa.

4.0 Acceptance Limits:

Total weight loss of all vanes from individual cartridges tested should be less than 15 mg (not including intravanes).

Weight loss of ring from individual cartridge tested should be less than 75 mg.

Regardless of weight loss measurements, the pump parts, especially the rings, should not have evidence of unusual wear or stress in contact areas. Examples of acceptable and unacceptable rings are shown in the Vickers® publication Form M-2952-S (Rev. 8/88). There might be instances when unsatisfactory performance is indicated even though the weight loss is low. For example, galling or excessive burning might not show excessive weight loss, but would be unacceptable.

FZG Rating

1.0 Scope:

This test method will be used to evaluate the scuffing load capacity of hydraulic fluids.

2.0 Test Method:

ASTM D5182

3.0 Test Procedure:

ASTM D5182 standard test method will be used to evaluate the scuffing load capacity of hydraulic fluids when used in hydraulic applications in Caterpillar Inc. products.

4.0 Acceptance Limits:

The test must achieve a passing rating through a minimum of ten load stages. Failure criteria is reached when the total sum of the width of scuffing, scoring, and adhesive wear damage from each of the 16 gear teeth is equal to or exceeds one gear tooth width (20 mm).

Four-Ball Wear Test

1.0 Scope:

This test method will be used to evaluate the relative wear preventative properties of hydraulic fluids in sliding contact.

2.0 Test Method:

ASTM D4172

3.0 Test Procedure:

ASTM D4172 standard test method will be used to evaluate the wear preventative properties of fluids when used in hydraulic applications in Caterpillar Inc. products. The required test conditions are as follows: 40 kg load, 93°C, 600 RPM, and 30 minutes test duration.

4.0 Acceptance Limits:

The measured wear scar diameter must not exceed 0.40 mm.

Biodegradability

1.0 Scope:

This test method will be used to evaluate the amount of ultimate degradation for biodegradable hydraulic fluids to carbon dioxide.

2.0 Test Methods:

ASTM D5864 - Standard test method for determining the aerobic aquatic biodegradation of lubricants and their components

ASTM D6139 - Gledhill Shake Flask test.

3.0 Test Procedure:

Follow the procedure outlined in ASTM D5864 or ASTM D6139.

4.0 Acceptance Criteria:

Acceptable fluids will attain a minimum of 60 weight percent biodegraded to carbon dioxide in 28 days.

Toxicity, Water Hazard

1.0 Scope:

This classification system will be used to assign chemicals or mixtures of chemicals a specific water-endangering class.

2.0 Test Procedure:

Calculate the WGK rating by following the procedure outlined in “Bewertung Wassergefahrdender Stoffe (1979)”.

3.0 Acceptance Criteria:

Acceptable fluids will attain a maximum rating of WGK 0.

Toxicity, Fish

1.0 Scope:

This test method will be used to evaluate the acute toxicity of any material to fish.

2.0 Test Method:

OECD 203

3.0 Test Procedure:

Follow the procedure outlined in OECD 203

4.0 Acceptance Criteria:

Acceptable fluids will have acute fish toxicity levels (LC_{50}) of greater than 1000 PPM for amounts measured at 48 hours.

Friction Properties

Introduction:

This test method will be used to evaluate the ability of a biodegradable lubricant to provide acceptable friction performance characteristics when used in conjunction with various oil-cooled friction mechanisms in Caterpillar brakes or wherever BF-1 is specified for service fill.

Any question pertinent to the test method shall be directed to:

BF-1 Oil/Friction Test
Caterpillar Inc., Component Development Division
Technical Center

(For First Class Mail:)
P. O. Box 1875
Peoria, IL 61656-1875
Phone (309) 578-8309 or 578-9229

Standard Test Method for Lubrication and Friction
Characteristics of Biodegradable Oils in Caterpillar Hydraulic Compartments

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   - 7.1 Drain and Refill
   - 7.2 Filtration
   - 7.3 Disc and Plate Installation

1.0 Scope:

1.1 This procedure defines the test method for evaluation of the lubrication and frictional performance characteristics of a biodegradable hydraulic oil used in Caterpillar hydraulic friction mechanisms.

1.2 This procedure defines the acceptance criteria related to the lubrication and frictional requirements which must be met by an oil for it to be given an BF-1 rating.

1.3 This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.4 These requirements are subject to revision at any time by Caterpillar Inc.

2.0 Terminology:

2.1 Average Dynamic Coefficient of Friction, μ_d -- The coefficient value calculated from initial speed, stop time and unit load. This calculation is made as though the coefficient were constant throughout the engagement.

2.2 Static Coefficient of Friction, μ_s -- The coefficient value calculated from unit load and the torque measured at the instant that sliding velocity reaches zero.

2.3 Initial Speed -- The surface speed of the friction disc at the mean radius at the start of an engagement.

2.4 Energy Limit -- The highest speed at which the friction material/oil/reaction plate will operate in the specified sequences and produce uniform results consistent with the results produced at lower speeds. In most instances the limit can be determined visually from the torque trace, but for oil certification with this specification, the limit will always be determined by the computer.

2.4.1 Visual Determination: The shape of the torque curve is indicative of the conditions at the lubricated interface of the friction disc and reaction plate. In normal operation, the torque makes a smooth, repeatable transition from the initial engagement through lockup. When the energy limit is reached there will usually be a hump or irregular shape in the torque curve revealing that there are unstable or destructive changes occurring at the friction interface. This condition is indicated by a significant change in the coefficient of friction. Figures 1 and 2 show typical torque curves both in normal operation and above the energy limit.

2.4.2 Computerized Determination: The computer will check for changes in μ_d (average dynamic coefficient of friction) during the phases after phase 20. The μ_d of each cycle will be compared with the mean μ_d of the previous phase. A change of 12% or more will be taken as an indication that the energy limit has been reached. The dynamic coefficient was chosen

because minor inaccuracies in the speed or pressure settings will not influence its value, and, by using a baseline from the previous phase, the check can be applied to all cycles.

2.5 Phase -- A specified number of engagements at a given unit pressure and initial speed.

2.6 Sequence -- A specific series of phases.

2.7 Run -- The operation of the M1158 machine through a sequence.

2.7.1 Each run will be identified using the following numbering system: first character - letter assigned to the specific M1158 machine; next four digits - month and year of last machine qualification; last three digits - number of runs since last qualification

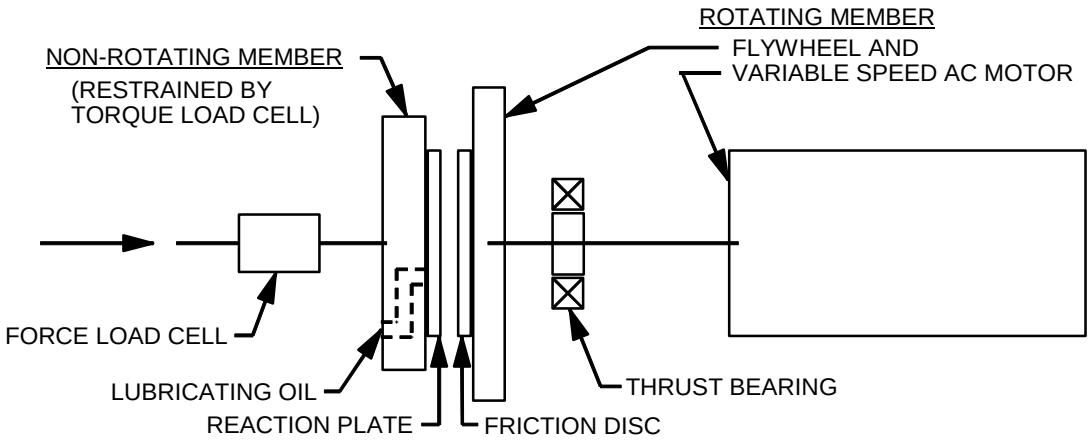
EXAMPLE: B0589023

- 23rd RUN SINCE QUALIFICATION
- MACHINE LAST QUALIFIED IN MAY '89
- MACHINE B

2.8 Test -- The two runs required for oil certification.

3.0 Summary of Test Method:

3.1 This procedure utilizes the Link Model 1158 Oil/Friction Test Machine, which is an inertia dynamometer in which the kinetic energy of a freely rotating mass is absorbed by the reaction of a rotating friction disc and an opposing stationary steel plate. A flywheel is accelerated to predetermined speeds and brought to a stop by bringing the disc and plate together at various engagement pressures.



SCHEMATIC OF THE LINK M1158 OIL/FRICTION

3.2 This apparatus will be used to measure the characteristics itemized below on one friction material, as these characteristics are influenced by the lubricating oil.

Average Dynamic Coefficient of Friction

Static Coefficient of Friction

Energy Capability

Wear Resistance

3.3 A complete oil test consists of one or more runs using the friction discs and reaction plates from a single 137-1271 clutch group - (oil test kit).

3.3.1 Because of the restrictions on the material in each kit, all performance comparisons for evaluating a test oil will be made using discs from the same manufacturing lot and reaction plates with the same range of surface finish variation.

4.0 Significance and Use:

4.1 This test method is used to determine comparative values for static coefficients of friction, energy capability and wear properties of a friction disc and opposing plate when tested under prescribed conditions. The lubricating oil used can influence the results. The procedure and values established are for evaluating the suitability of these oils.

4.2 The results of a test on the M1158 machine, if they are within the allowable ranges of variation from the reference test made from the same 137-1271 kit, may be used to designate the test oil as an BF-1 oil.

5.0 Interferences:

5.1 Each M1158 machine is made with identical components to eliminate functional differences between the machines.

5.1.1 Replacement of the air valves or air lines with components of different size will change the response of the machine.

5.1.2 Changes in bearing drag or windage losses will change the effective inertia of the machine.

5.2 An air leak from the tank, lines, valves or rotochamber will change the response and loading of the machine.

5.3 An oil leak of more than one liter in any run will significantly reduce the volume of oil being tested.

5.4 Items which are stated as constants must be true, viz.:

Cooling oil temp and flow
Filtration - 8J1600 Filter
Oil Capacity - total system volume
Friction disc size - mean radius
Reaction plate surface finish
Calibration of instrumentation - torque, load, flow, temperature, time, speed
Cycle time
Retraction clearance

6.0 Apparatus:

6.1 This procedure utilizes the Model 1158 Oil/Friction Test Machine available from Link Engineering Company, Detroit, Michigan. This specific model and manufacturer must be used for reproducibility. The factors which are critical are: effective inertia, coast-down time, rate of pressure rise at the beginning of engagement, cooling flow distribution, response of the transducers and signal conditioners, the mass elastic system of the machine and its components and the method of heating the lube oil.

6.2 The friction discs are supplied by Wellman friction products, and the reaction plates by Raybestos Products Company. They are assembled into a kit and packaged by Caterpillar Inc. As 137-1271 Clutch Group (Oil Test Kit). The kits are available through the Caterpillar parts distribution system.

6.2.1 Each 137-1271 Kit contains enough material for a reference test and nineteen oil tests (if no runs have to be repeated). These friction materials are identified by manufacturing lot. The reaction plates are closely controlled for surface finish, and the clutch groups are certified for performance by Caterpillar Inc.

6.2.2 The following combinations of friction disc and reaction plate, which are to be used only in these pairings, make up a 137-1271 kit:

137-1274 Clutch Group: 118-7181 Disc (Brake Paper) and 1Y0726 Plate

6.3 The surface roughness (roughness average; refer to 1E2122) of each plate will be measured circumferentially by the supplier in four places. The average roughness will be within the roughness range specified on the drawing. The side of the plate which is to be in contact with the friction disc will be marked with the average of the roughness measurements (microns) from that surface; the other side of the plate will be marked with the part number and the words: “Do Not Use This Side”. The markings on the plates will be of smear-resistant ink.

6.4 Thickness measurements of the disc and plate are to be taken with a micrometer which has a spindle and anvil with contact faces approximately 19.0 mm diameter.

7.0 Preparation of Apparatus:

7.1 The system is drained and refilled with new oil for each test. If the oil is different than that used in the previous test, the drain and refill is done a second time after the new oil has been circulated through the system at a temperature of at least 60°C for at least 5 minutes. The machine is to be operating, disengaged, at about 15 m/s while the oil is circulating.

7.2 Filtration - A new filter element (Caterpillar 8J1600) is to be installed whenever oil is added for a new test. if the oil is different than that used in the previous test, install a new filter only with the second refill.

7.3 Disc and Plate Installation

7.3.1 Friction Disc - Friction material bonded to both sides of a steel core, to be mounted on the flywheel with the test surface toward the steel plate.

7.3.2 Plate - Steel plate, to be mounted on the stationary member with the test surface toward the friction disc.

7.3.3 Clearance between disc and plate: 0.76±0.05 mm when retracted.

7.4 Selection and Definition of Sequences

7.4.1 Sequence no. SEQ1274 (To be used with 137-1274 group)

Twenty second cycle time: engaged 4.0 seconds, disengaged 16.0 seconds.

Phase No.	Phase Repetitions	Speed, m/s	Initial Unit Pressure, kPa	Plot Coefficient Averages and Save Torque Curves at These Cycles:
Initial Measurement for Wear Determination				
1	5	15	350	
2	5	15	1050	
3	100	15	1750	
Second Measurement for Wear Determination				
4	10	15	350	
5	10	15	700	
6	500	15	1050	Each 50th Cycle
Final Measurement for Wear Determination				
7	10	15	350	
8	10	15	700	
9	50	15	1050	
10	15	5	350	15
11	15	5	700	15
12	15	5	1050	15
13	15	5	1400	15
14	15	5	1750	15

15	15	15	350	15
16	15	15	700	15
17	15	15	1050	15
18	15	15	1400	15
19	15	15	1750	15
20	15	15	1050	15
21	15	17.5	1050	15
22	15	20	1050	15
23	15	21	1050	15
24	15	22	1050	15
25	15	23	1050	15
26	15	24	1050	15
27	15	25	1050	15
28	15	26	1050	15
29	15	27	1050	15
30	15	28	1050	15
31	15	29	1050	15
32	15	30	1050	15
33	15	31	1050	15
34	15	32	1050	15
35	15	33	1050	15
36	15	34	1050	15
37	15	35	1050	15
38	15	36	1050	15
39	15	37	1050	15
40	15	38	1050	15
41	15	39	1050	15
42	15	40	1050	15

Energy limit detection is based on a percentage change in μ_d compared to the average μ_d of the previous phase. In SEQ1274, a 12% change denotes failure.

If the energy limit is exceeded before the schedule is completed, the data from the final cycle will be saved and the run will be ended.

7.5 General Instructions

7.5.1 Each sequence is to proceed without delay between cycles except to measure disc thickness. That pause is part of the program. If any of the test or safety conditions are not met (such as: test oil flow too low, bearing temperature too high, desired speed or pressure not reached, etc.), the sequence will be stopped automatically. Except for the following two conditions, the sequence can be continued after the fault is corrected: any interruption of the cycle after the start of Phase 21 in SEQ 1274 will invalidate the run; any interruption of the cycle for more than ten minutes, or more than ten interruptions during a run, will invalidate the run.

7.5.2 Thickness measurements are to be made at six equally spaced locations at both ID and OD of the friction material. Mark position 1 on two teeth, count clockwise around the disc 10 teeth to position 2, then another 11 teeth to each of the remaining positions. The starting position can be at any location. The measurements to determine wear must be taken at the same locations on the disc. The disc is to be installed in the machine with position 1 at the marked drive pin.

7.6 Cooling Oil - Fill Requirement: 18.9±0.5 L
Flow rate: 3.78±0.06 L/min. (As indicated on the M1158 machine instrumentation)

7.6.1 Operating Temperature Range - Set point +3/ -10°C

7.6.1.1 The temperature setting for SEQ 1274 will be based on the viscosity of the test oil at 82°C.

8.0 Procedure

8.1 Perform the signal conditioner calibration check.

8.2 Perform the force output calibration.

8.3 Edit and select the test directory. Define new one if needed.

8.4 Select and edit the run subdirectory. Define new one if needed.

8.5 Select the sequence to be used.

8.6 Select the disc and plate to be used (specified when the sequence is selected).

8.7 Initiate the test sequence. The machine will control the initial speed, unit pressure and the number of repetitions of each phase.

8.8 Remove the disc and plate for inspection and measurement as required. Check the parts for warpage, measure the disc and reinstall it in the same location and with the same orientation.

8.9 Resume the test sequence. The machine will shut down at the end of the sequence, or earlier if the energy limit is exceeded.

8.10 Produce the printed reports and curves.

8.11 Transfer the test directory to floppy discs when all the runs in it have been completed.

9.0 Calculation and Interpretation of Results:

9.1 Equations and Constants

9.1.1 The average dynamic coefficient of friction is calculated by the M1158 machine from stop time, load and initial speed.

$$\mu_d = 2.44037S/Lt \quad (1)$$

Where: μ_d = Average dynamic coefficient of friction
S = Surface speed at mean radius - m/s
L = Unit axial load on friction material - kPa
t = Stop time - s

9.1.2 The static coefficient of friction is calculated by the M1158 machine from torque measured at the instant that sliding velocity reaches zero.

$$\mu_s = 0.3121T/L \quad (2)$$

Where: μ_s = Static coefficient of friction
L = Unit load on friction material - kPa
T = Lockup torque - N·m

9.1.3 In equations 1 and 2 the constants are based on:
Inertia = 1.003 $N \cdot m \cdot s^2$
Friction material area = 0.02499 m^2
Mean radius of friction material = 0.1283 m

9.1.4 Average thickness and wear values are calculated by the M1158 machine from disc measurements entered by the operator. The average thickness is the numerical average of the 12 thickness measurements; the wear is the change in average thickness.

9.2 Oil Requirements - Oils will be evaluated by comparing their performance under controlled conditions with the performance of a reference oil under nearly identical conditions. The controlled conditions include the test machine, test procedure, friction disc and reaction plate.

9.2.1 The friction discs and reaction plates will be supplied in 137-1271 oil test kits. Each kit will contain matched parts so that the performance of the candidate oil on a given machine can be compared directly with the performance of the reference oil (Caterpillar Multipurpose Tractor Oil, part no. 105-3334 in 55-gal. drums) on the same machine. The test sponsor will provide (at nominal cost) the reference fluid which will produce minimum acceptable performance. When the clutch groups in a given test kit have been depleted and a new kit is obtained, a

new performance baseline with the new kit and the reference oil must be established.

9.2.2 A Link 1158 Oil/Friction Test Machine which has been qualified can be used for a reference test to establish a performance baseline for oil certification work with a set of friction discs and reaction plates from an oil test kit. The results of the reference test will determine the performance limits for oil certification within that test kit. The M1158 software will read data from the reference test, calculate the values for the limit lines and save them as the limit files to be used with that specific oil test kit.

9.2.2.1 If any one of the baseline runs with the reference oil reaches its energy limit at a speed equal to or lower than that given in 9.2.4, that reference run is invalid and must be repeated.

9.2.2.2 Instructions for generating the limit files to be used with a specific kit are:

Before a 137-1271 Kit is used for certification testing of candidate oils, a reference test must be done using parts from the kit and a reference oil supplied by Caterpillar Inc. A SEQ1274 run will be made. At the completion of the run, the limit files are to be generated or updated as follows:

Go to the print report menu.

Select the reference test.

Select the limit file for the friction material.

Select the report format for that friction material.

Press F7 and “Enter”. The limit file will be automatically updated using the factors defined in Figure 3. (These factors are stored as part of the software in limit generation reference files.) The update of the limit file will also put the run number of the reference run into the description of the limit file.

9.2.2.3 A lab can repeat any of the reference runs on another disc and plate from the kit if they desire, realizing that fewer complete sets will remain for testing of candidate oils. The final reference runs made will be used to establish the baseline.

9.2.3 An oil to be certified as a BF-1 oil must have performance characteristics relative to those of the reference oil, as defined in 9.3.

Run Sequence SEQ1274 with 137-1274 Clutch Group (118-7181 Disc and 1Y0726 Plate).

9.2.4 The energy limit must not occur at (during an engagement from) a speed lower than 28 m/s.

9.2.5 Total wear of the friction disc must not exceed 0.07 mm.

9.2.6 Successful completion means that for each sequence the coefficients stay above the specified minimum, the energy limit is at a speed at or above the minimum, and the total wear is less than or equal to the maximum allowable. If the first attempt in any run is unsuccessful, two succeeding successful completions of that run will meet the requirement.

9.2.7 Except as described in 9.3 (multiple run averaging), any one of the following conditions constitutes failure of a candidate oil:

-Any of the plotted points of static coefficient of friction fall below the low-limit lines on the coefficient plots.

-The "Wring-in Ratio" (defined as the ratio of the static coefficient of friction to the dynamic coefficient of friction, or μ_s/μ_d) exceeds 1.50 at a unit axial load of 1050 kPa.

-The energy limit, as determined by the limit detection option of the software, is reached and the sequence is stopped at a speed lower than that indicated by the vertical limit line on the coefficient vs speed plot.

-The disc wear is greater than the allowable maximum.

-The disc or plate becomes dished or warped at a speed less than the minimum acceptable energy limit even if the energy limit is not detected.

-The friction material is structurally damaged by erosion or chemical or mechanical forces during the test.

9.3 Multiple run averaging is allowed as follows for the values of friction coefficient:

9.3.1 If the static friction coefficient for any of the runs with a candidate oil are slightly below the low limit, or if the wring-in ratio is greater than 1.50, a second run with that material may be made and the average coefficient values of the two runs (calculated by the M1158 machine) may be plotted against the two-run limit -- which represents the same performance level as does the single run limit with a single run. The friction level of the oil with that material is considered passing if the plotted points are above the low limit and the wring-in ratio is 1.50 or lower.

9.3.2 If the averaged friction data of two runs of a given material with a candidate oil are slightly below the two-run limit, a third run with that material may be made and the average coefficient values of the three runs (calculated by the M1158 machine) may be plotted against the three-run limit -- which represents the same performance level as does the single run limit with a single run. The friction level of the oil with that material is considered passing if the plotted points are above the low limit and the wring-in ratio is 1.50 or lower.

9.3.3 Neither the values of energy limit, nor the speed at which warpage might occur, nor total wear are subject to multiple-run averaging.

9.3.4 The limit files and report format files identified in the following table are to be used in printing the respective test reports. The limit files are generated on command by the M1158 machine based on the performance of the reference runs.

		Limit Files			Report Formats	
Clutch Group	Sequence	1-Run	2-Run	3-Run	1-Run	Multiple
137-1274	SEQ1274	LIM1274	2LIM1274	3LIM1274	REP1274	MULT1274

9.3.5 The acceptability requirements (low limits) for the static coefficient of friction relative to the friction coefficients measured in the reference test are:

Single Run – 93.0% Two-Run Average – 93.0% Three-Run Average – 93.0%

9.4 Test Discontinuation

Any one of the following conditions, if the results are otherwise satisfactory and neither the friction disc nor the reaction plate show damage or warping, would constitute sufficient reason to abort a run without classifying it as a failure of the oil:

The machine is shut down because of low oil level. (The M1158 calls this a spurious fault, stops the run and turns off the circulating pump.)

The energy limit of the friction material is exceeded because a feedback or instrumentation problem causes the input force or input speed to be far greater than the desired amount.

The air supply fails, making it impossible to achieve the required pressures.

The drive motor does not achieve the required speeds.

10.0 Report:

10.1 All reference reports shall be submitted to the address given in the introduction.

10.2 Data presentation

10.2.1 Verification of calibration and setup will be included with each report (Plot type: 6, example in Figure 3).

10.2.2 Coefficient of friction will be plotted against no. of cycles, unit pressure and speed (Plot types 3, 1 and 2, examples in Figures 4, 5 and 6, respectively).

10.2.3 Torque vs time from each of the last 6 recorded cycles of the run will be plotted to show the changes which occurred at the energy limit. (Plot type 5, example in Figure 7).

10.2.4 Disc thickness measurements and average wear will be reported in tabular form (Example in Figure 4).

10.2.5 A print-out of the M1158·VAL file will be included with all reference reports. This can be done with the following command entered at the “c:” prompt:

Type “M1158.VAL>PRN”.

10.2.6 The summary data file and the cycles recorded in full in all test sequences are to be retained on diskette by the testing lab for at least seven years for future reference.

11.0 Precision and Bias:

11.1 No statement is made about either the precision or bias of this method for measuring the frictional characteristics of a hydraulic oil, since the result merely states whether there is conformance to the criteria for success specified in the procedure.

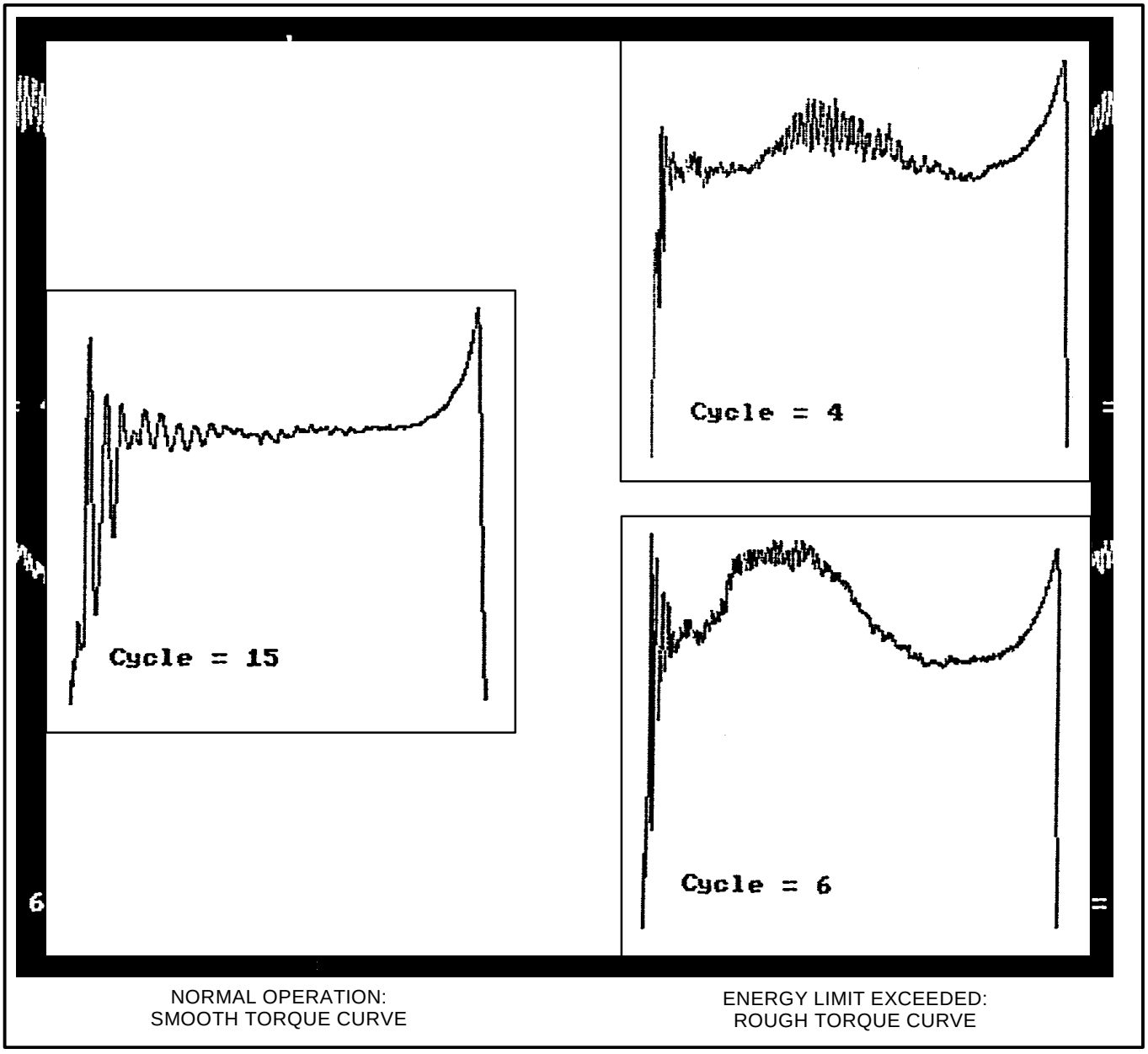


Figure 1 – Typical Torque Traces From the Link 1158 Oil/Friction Test Machine

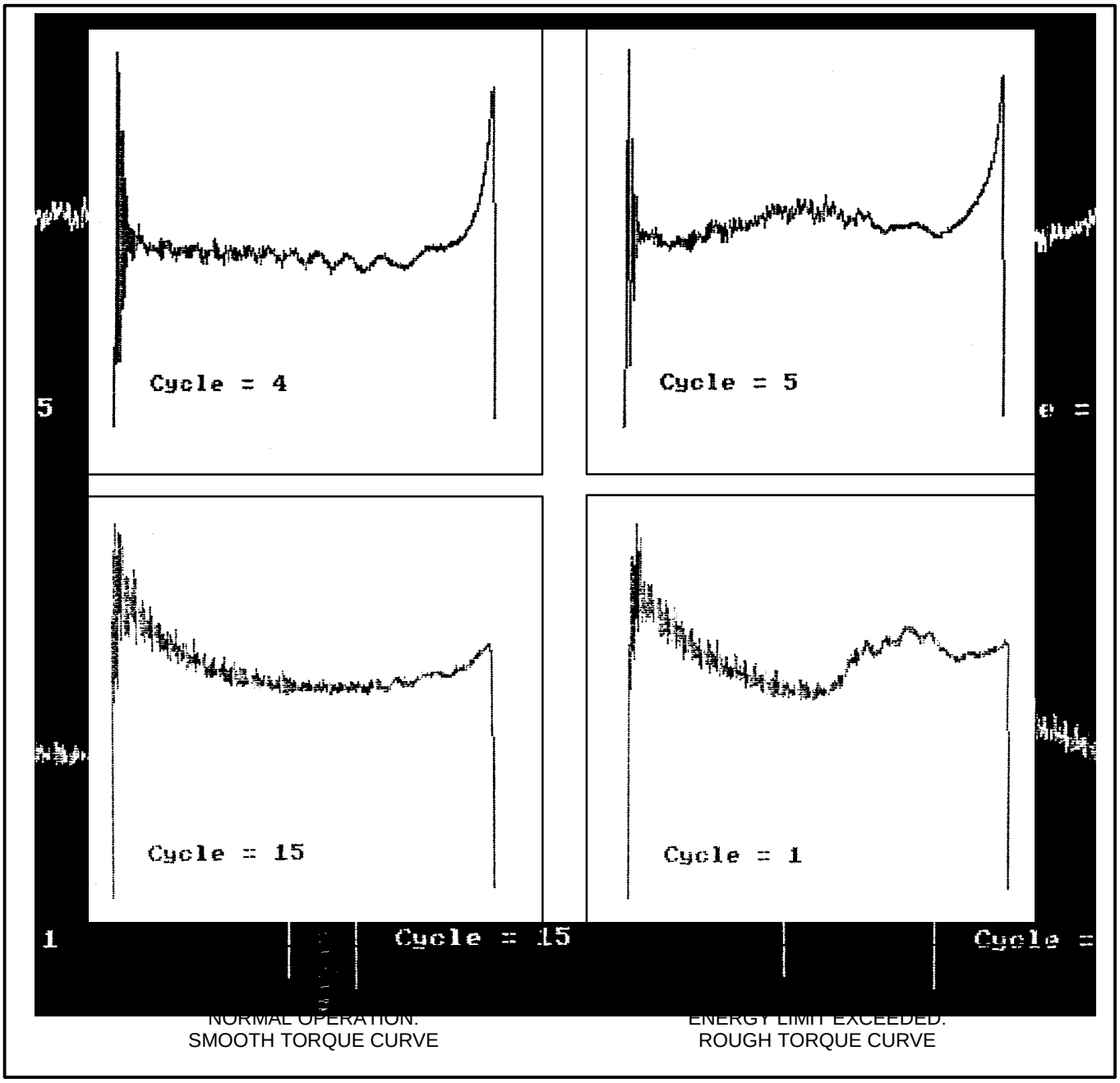
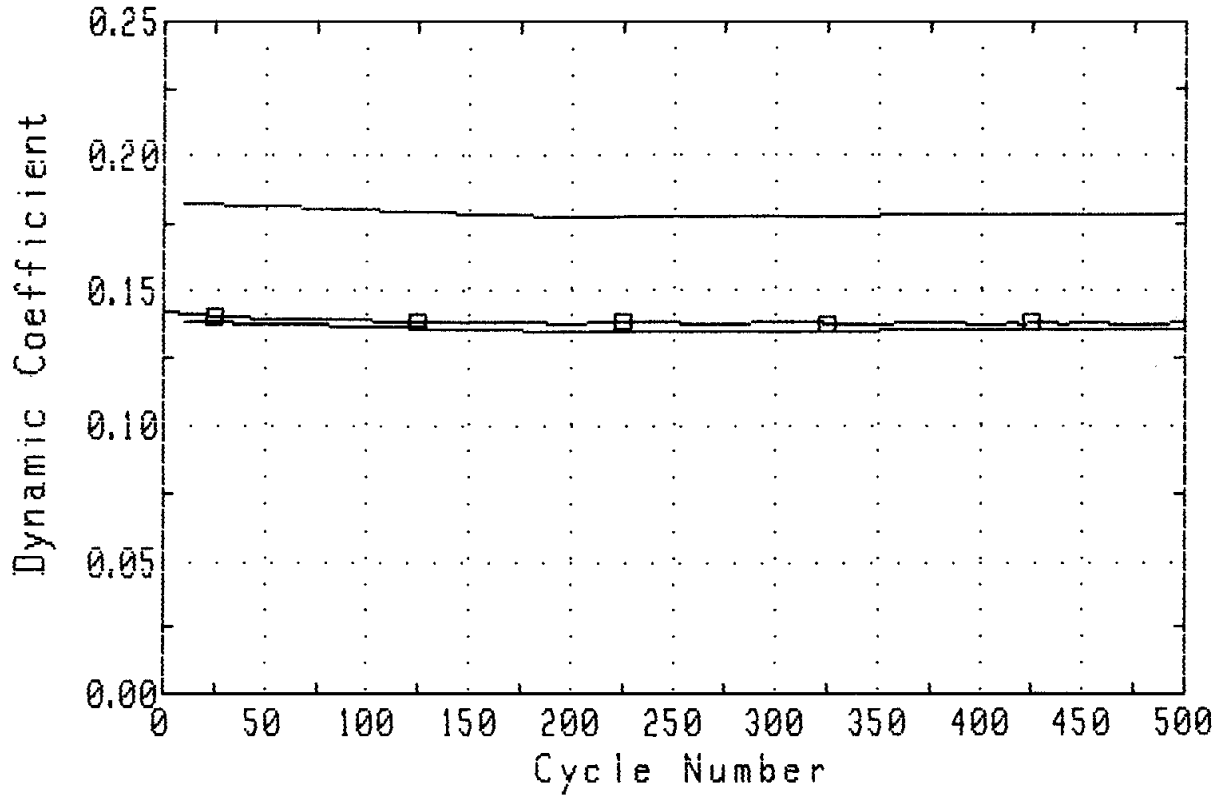


Figure 2 – Typical Torque Traces from the Link 1158 Oil/Friction Test Machine

XYZ Laboratories
BF-1 Certification of Oil Sample # 12345-C

Test Name:	12345C01
Test Date:	08/27/03
Test Description:	First Certification Test of 12345-C
Oil Type:	Hometown Oil Co.
Viscosity:	ISO VG 46
Miscellaneous:	----
Software Version:	1.2
Run Name & Desc:	N0690032 – 137-1274 Clutch Group
Run Date:	08/27/03
Oil Temperature:	82° C
Oil Flow Rate:	3.78 liter/minute
Operator:	SJones
Remarks:	----
Sequence Name:	SEQ1274
Remarks:	Use 118-7181 disc and 1Y0726 plate
Number Of Cycles Run:	1126
Machine:	N
Coast Down Check Run:	08/20/03
Result:	79.88 seconds
Inertia Check Run:	08/20/96
Result:	1.0239 N-m-s^2
Disc Name & Desc:	Brake Paper
Material:	Wellman Friction Products 266-4
Groove Pattern:	2-37 Multiple - Parallel
Miscellaneous:	Use with 1Y0726 steel plate
Outer Diameter (mm):	285.80
Inner Diameter (mm):	223.20
Mean Radius (mm):	128.21
Batch Number:	C592
Remarks:	----
Plate Name & Desc:	1Y0726 - steel plate
Surface:	0.70 To 1.00 micron roughness
Miscellaneous:	----
Batch Number:	----
Remarks:	0.76 micron measured roughness
Report Limit Name:	LIM1274 - Reference Run: N0690018
Limit File Generated:	08/06/03
Report Format Name:	REP1274 – Wheel Brake Paper

Figure 3. Report Title Page - Example



118-7181
Disc Thickness

	Outer Diameter			Inner Diameter		
Location	M1	M2	M3	M1	M2	M3
1	4.90	4.87	4.87	4.90	4.88	4.87
2	4.90	4.87	4.86	4.91	4.87	4.86
3	4.91	4.88	4.87	4.91	4.88	4.87
4	4.90	4.87	4.87	4.90	4.87	4.87
5	4.89	4.87	4.86	4.90	4.87	4.87
6	4.90	4.87	4.87	4.91	4.87	4.87
Avg	4.90	4.87	4.87	4.91	4.87	4.87

Compression Set Average Wear: 0.030
M2-M3 Average Wear: 0.006
Total Wear (All measurements in mm): 0.036

Figure 4 -- Dynamic Coefficient vs Number of Cycles

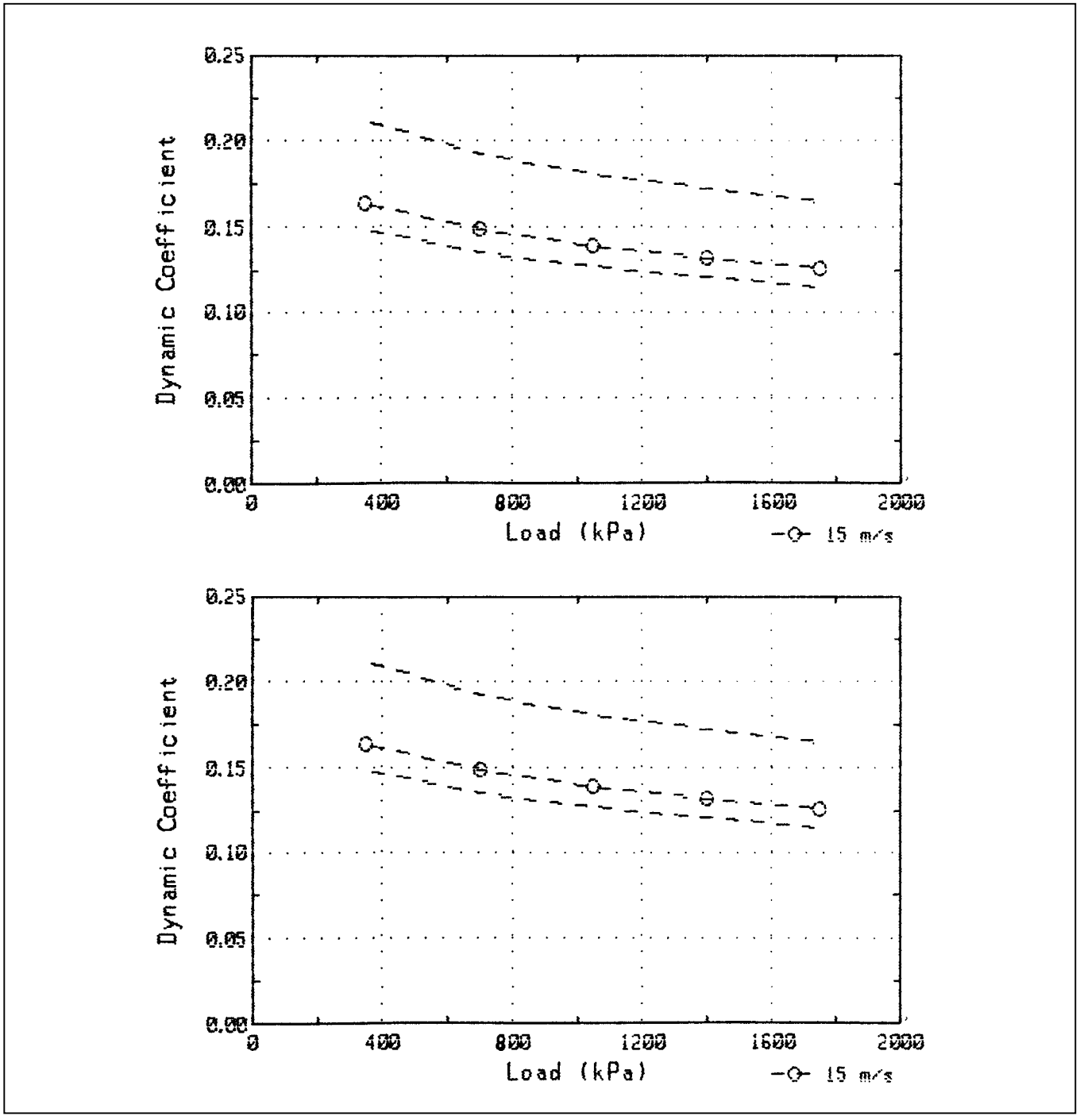


Figure 5 - Dynamic and Static Coefficients vs Unit Pressure

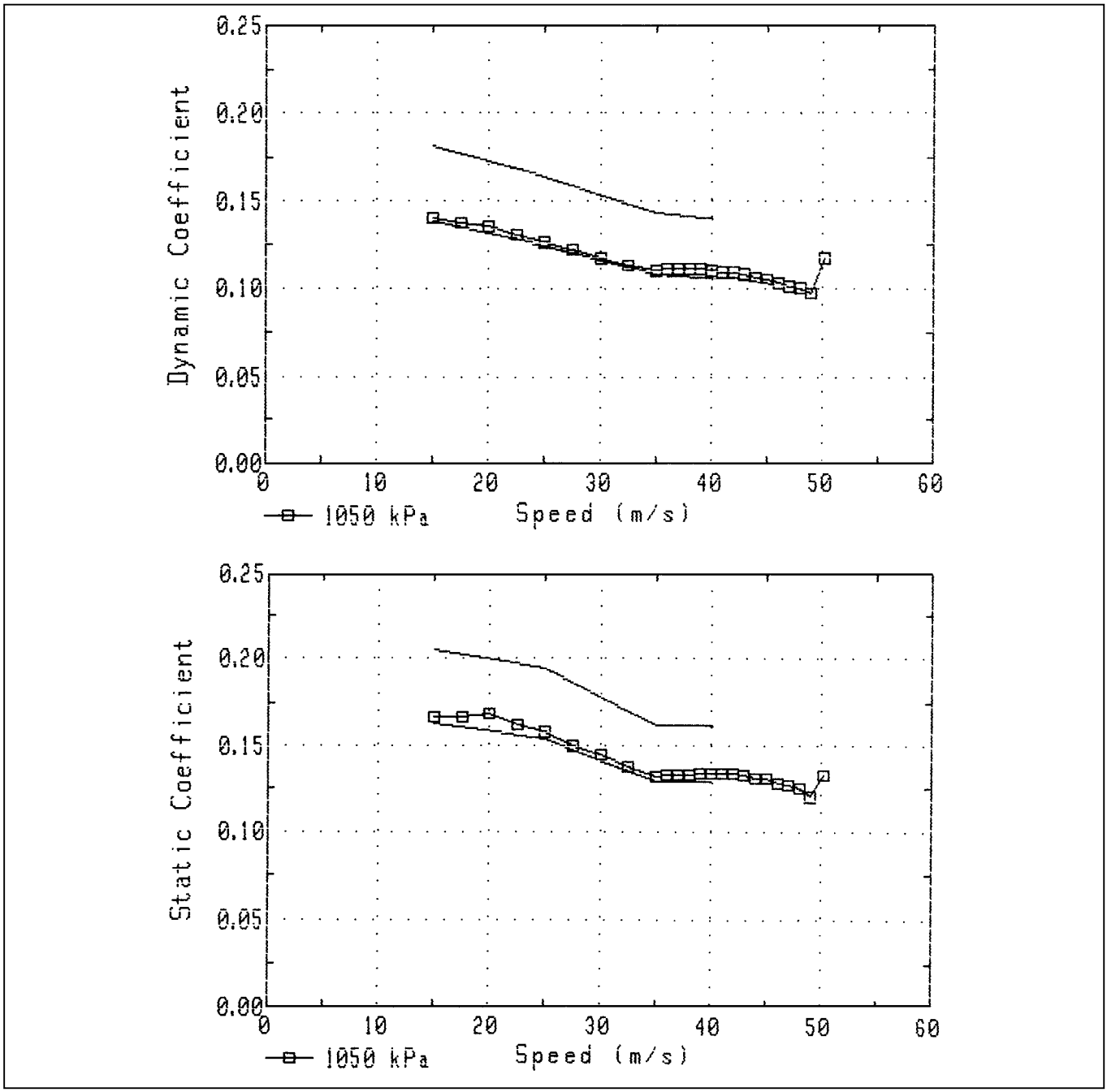


Figure 6 - Dynamic and Static Coefficients vs initial Speed

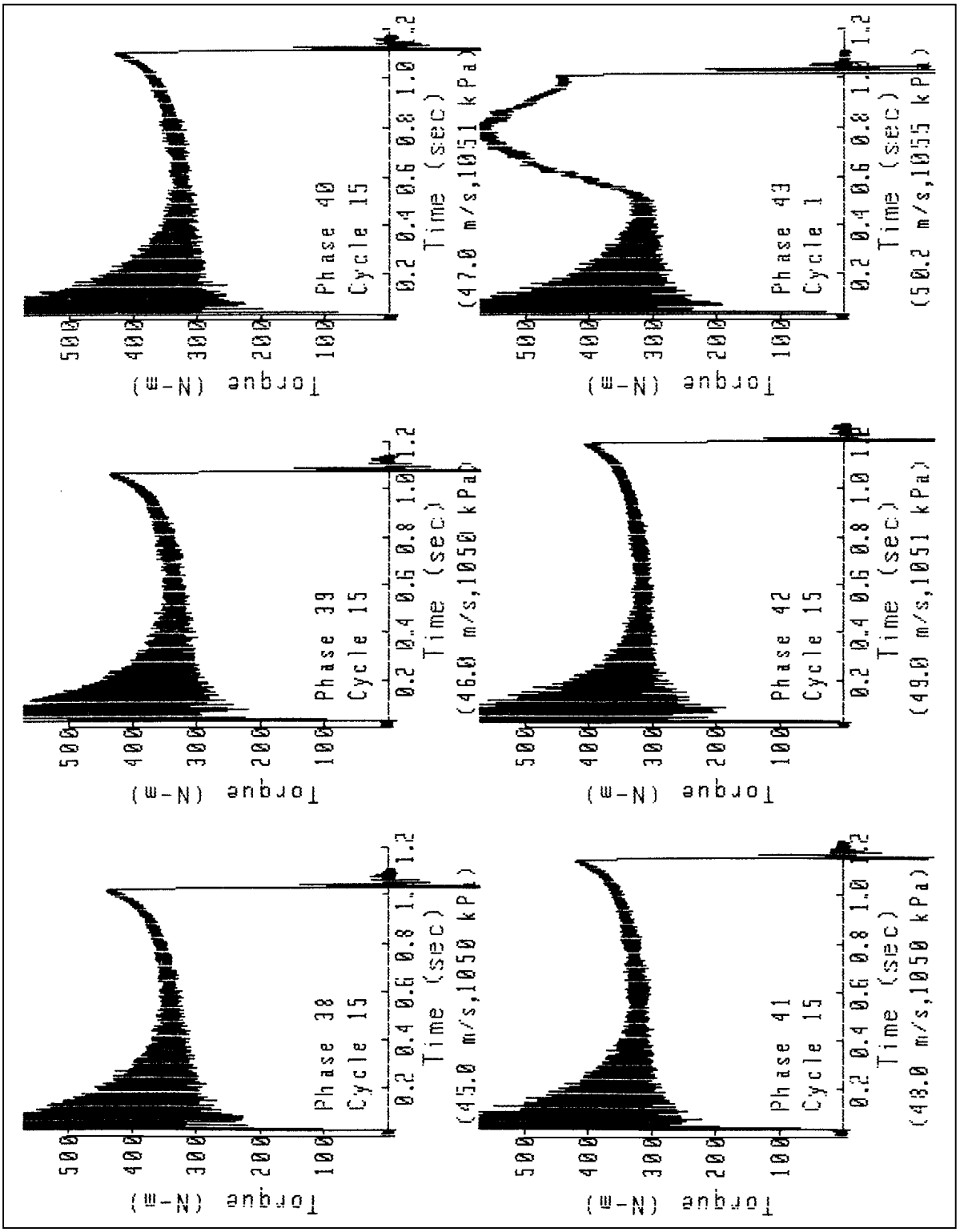


FIGURE 7 – TORQUE VS TIME

Annex I. Sequence Definitions

Sequence: SEQ1274 Desc: 137-1274 Group
Remarks: Use 118-7181 Disc and 1Y0726 Plate
Constant Factors:

Acceleration Time - 8.00 s Torque Threshold - 50 N·m
Soak Time - 4.00 s Sample Rate - 5000/s
Cycle Time - 20.00 s Cycle Type - Normal

No.	Phase Name	Apply Speed	Cool. Speed	Load	No. of Cycles	Store Intv.	Det. Type	Pause	Allow. Var.
1	1WU05A15	15.00	4.00	350	5	0	0	N	0
2	1WU05C15	15.00	4.00	1050	5	0	0	N	0
3	1WU1CE15	15.00	4.00	1750	100	0	0	Y	0
4	2WU1XA15	15.00	4.00	350	10	0	0	N	0
5	2WU1XB15	15.00	4.00	700	10	0	0	N	0
6	WER5CC15	15.00	4.00	1050	500	50	0	Y	0
7	3WU1XA15	15.00	4.00	350	10	0	0	N	0
8	3WU1XB15	15.00	4.00	700	10	0	0	N	0
9	3WU5XC15	15.00	4.00	1050	50	0	0	N	0
10	PRT15A05	5.00	4.00	350	15	15	0	N	0
11	PRT15B05	5.00	4.00	700	15	15	3	N	12
12	PRT15C05	5.00	4.00	1050	15	15	3	N	12
13	PRT15D05	5.00	4.00	1400	15	15	3	N	12
14	PRT15E05	5.00	4.00	1750	15	15	3	N	12
15	PRT15A15	15.00	4.00	350	15	15	0	N	0
16	PRT15B15	15.00	4.00	700	15	15	3	N	12
17	PRT15C15	15.00	4.00	1050	15	15	3	N	12
18	PRT15D15	15.00	4.00	1400	15	15	3	N	12
19	PRT15E15	15.00	4.00	1750	15	15	3	N	12
20	ST15C150	15.00	4.00	1050	15	15	0	N	0
21	SS15C175	17.50	4.00	1050	15	15	3	N	12
22	SS15C200	20.00	4.00	1050	15	15	4	N	12
23	SS15C210	21.00	4.00	1050	15	15	4	N	12
24	SS15C220	22.00	4.00	1050	15	15	4	N	12
25	SS15C230	23.00	4.00	1050	15	15	4	N	12
26	SS15C240	24.00	4.00	1050	15	15	4	N	12
27	SS15C250	25.00	4.00	1050	15	15	4	N	12
28	SS15C260	26.00	4.00	1050	15	15	4	N	12
29	SS15C270	27.00	4.00	1050	15	15	4	N	12
30	SS15C280	28.00	4.00	1050	15	15	4	N	12
31	SS15C290	29.00	4.00	1050	15	15	4	N	12
32	SS15C300	30.00	4.00	1050	15	15	4	N	12
33	SS15C310	31.00	4.00	1050	15	15	4	N	12
34	SS15C320	32.00	4.00	1050	15	15	4	N	12
35	SS15C330	33.00	4.00	1050	15	15	4	N	12
36	SS15C340	34.00	4.00	1050	15	15	4	N	12
37	SS15C350	35.00	4.00	1050	15	15	4	N	12
38	SS15C360	36.00	4.00	1050	15	15	4	N	12
39	SS15C370	37.00	4.00	1050	15	15	4	N	12
40	SS15C380	38.00	4.00	1050	15	15	4	N	12
41	SS15C390	39.00	4.00	1050	15	15	4	N	12
42	SS15C400	40.00	4.00	1050	15	15	4	N	12

Figure 9 – Dyanamic and Static Friction Coefficients vs Number of Cycles

Annex II. Disc Files

Name: 118-7181	Description: Brake Paper
Material:	Wellman Friction Products 266-4
Groove Pattern:	2-37 Multiple Parallel
Miscellaneous:	Use with 1Y0726 steel plate
Outer Diam (mm):	285.80
Inner Diam (mm):	223.20
Mean Radius (mm):	128.21

Annex III. Plate Files

Name: 1Y0726	Description
Surface:	0.30 micron maximum roughness
Misc.:	Install the side marked with the average roughness toward the friction disc; the side marked “Do Not Use” toward the torque arm.

Annex IV. Report Format Files

Name: REP1274 Description: Brake Paper

1	6	0 - 0	
2	3	6 - 6	
3	1	0 - 0	15 - 19
4	2	20 - 42	
5	5	20 - 42	

Annex V. Report Format Files

Page	Plot Type	Phase Range 1	Phase Range 2
Name: MULT1274			
1	6	0 - 0	
2	3	6 - 6	
3	1	0 - 0	15 - 19
4	2	20 - 42	