INTRODUCTION

From the early 1970's through 1990, Caterpillar Inc. has recommended that its customers use API CD oils meeting Caterpillar's TO-2 Friction Performance Specification to lubricate Powershift transmissions and final drives. The fluids that met this specification were engine oils that provided good oxidation stability, foam and rust control and piece part cleanliness. In addition to these features, the TO-2 specification ensured good clutch performance wherever bronze friction discs were used.

Caterpillar machines are continuously updated to meet customer needs. Significant improvements in transmissions and final drives have increased equipment durability and productivity. New and diverse friction materials are being developed to enhance performance. Providing the correct lubricants to support these new designs is critical for maximum life and performance.

In the early 1990's, Caterpillar introduced a new set of Transmission And Drive Train Fluid Requirements, "Caterpillar TO-4", which replaced CD/TO-2. For maximum performance and life, Caterpillar has recommended TO-4 oils for use in Caterpillar equipment since 01Feb91. Caterpillar no longer supports the CD/TO-2 test specification and considers CD/TO-2 obsolete.

Subsequently, Caterpillar introduced TDTO (TMS), a multi-grade oil intended primarily for use in transmissions in locations where a wide range of ambient temperatures are encountered.

All TO-4M oils must comply with the viscometric properties described in Section 4. The requirements for friction properties are described in Section 6. The requirements for wear properties are in Section 5.

This document contains all of the performance requirements that a finished lubricant must meet before it legitimately can be marketed as meeting the Caterpillar TO-4M requirements.

Caterpillar Inc. will not monitor or approve any fluid, other than its own branded fluid, marketed under the TO-4M designation. Each supplier is responsible for the performance of its own product and the associated liabilities.

Caterpillar Inc.
Fluids Engineering
Bldg. H3000
Old Galena Road
Mossville, IL 61552

OBJECTIVE:

These requirements are intended to communicate the minimum performance requirements for a lubricant that is intended for use in Caterpillar equipment, wherever TO-4 or TO-4M fluids are recommended. The primary use of these fluids will be Powershift transmissions, final drives, hydrostatic transmissions, torque converters, wheel brakes, and steering clutches and brakes.

GENERAL DESCRIPTION:

The Caterpillar TO-4M requirements are divided into six principal areas: physical properties, elastomer compatibility, oxidation stability, viscometrics, wear, and friction material performance.

TEST EQUIPMENT REQUIRED:

The following list of equipment is for your convenience. It does not include all of the equipment that is needed, but does include those items that may not be common laboratory test equipment:

- Link Engineering Co. Model M1158 Oil/ Friction Test Machine
- FZG Gear Oil Test Machine 100 Rpm Capability
- Instrument Capable of Measuring Elastomer Elongation in 10% Increments Such as Instron Model No. 2610-001 Incremental Extensometer or Equivalent.
- ASTM D412 DIE C
- Vickers 35VQ25A-11*20 (Cartridge Kit 413421)
- Turbo Hydra-Matic THM-4L60 Transmission
- Caterpillar Test Parts:
- 8E4103 Clutch Group (Oil Test Kit)
- Reference oils
    - Cat® MTO
    - Cat® HYDO™ (SAE 10W)
    - Cat® BIO HYDO (HEES)™; ISO 46
    - Cat® FDAO™ (SAE 50)
    - CAT® TDTO ™

SUMMARY AND TABLE OF CONTENTS:

The following information is a summary of the performance requirements that define a fluid that meets the Caterpillar TO-4 transmission and drive train fluid requirements. Information regarding the appropriate test methods and the applicable limits for each can be found in the referenced section.

SECTION 7 MULTIGRADE OIL REQUIREMENTS

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 16/13 is allowed for oil being added to the vehicle compartment.

Homogeneity

1.0 Scope:

This method will be used to evaluate the compatibility of additives with the 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:

High-speed centrifuge capable of producing 6000 g.

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:

No sedimentation or precipitation is allowed.

Fluid Compatibility

1.0 Scope:

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

2.0 Test Method:

The test oil is mixed with Caterpillar Inc. 1E493 (HYDO), MTO, 1E1829 (TDTO), 1E2750 (Biodegradable), and 1E2945 (FDAO) 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:

Pour a 50 mL sample of the test fluid and 50 mL of one of the four reference fluids 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 oil 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 TO-4M 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

3.0 Test Procedure:

ASTM D892 or IP 146 standard test method will be used to evaluate the foaming characteristics of 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 accumulated in hydraulic applications.

Part I	The standard ASTM D892 or IP Foam test method without water added.
PART II	Foaming of fluids having 0.1 volume percent added water.

This procedure measures the effect of a small amount of water on the foaming of fluids. Water is mixed with the test fluid and the foaming characteristics are measured by the above methods.

Procedure: Mix 500 mL of the fluid to be tested with 0.5 mL of distilled water in a blender for five minutes at low speed (1000 RPM) and then for one 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 TO-4M 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 $\pm$ 1°C
Water jacket
Drill or lathe rated at 2500 revolutions per minute
Bath, controlled at 27 $\pm$ 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 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 (9°F) differential over the length of the rod.

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

6.0 Acceptance Limits:

Minimum time to failure is 200 hours. 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 of this requirement.

Copper Strip Corrosion

1.0 SCOPE:

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

2.0 Test Method:

ASTM D130

IP 154

3.0 Conditions:

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

4.0 Acceptance Limits:

A rating of 1b (slight tarnish) is allowed.

A rating of 1c or worse constitutes a failure.

Low-Temperature Storage

1.0 Scope:

This test method will be used to evaluate the low-temperature storage stability of 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 and 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 ± 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.

Emulsibility

1.0 Scope:

This test method will be used to evaluate the ability of TO-4M fluids to retain water in suspension.

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 retain water sufficiently that no more than 5 mL free water separates from the emulsion after 30 min.

Flash and Fire Points

1.0 Scope:

This test method will be used to evaluate the flash and fire points of 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	200°C or legal limit, whichever is greater.
Fire Point	200°C or legal limit, whichever is greater.

Pour Point

1.0 Scope:

This test method will be used to determine the minimum temperature at which 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 Limits:

The maximum pour point, as measured by ASTM D97, must be below or equal to –30 ^{o}C.

Water Content

1.0 Scope:

The Karl Fischer test method will be used to determine the amount of water in a candidate 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 water content as measured by ASTM D6304 must 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.

Note: Volume change in percent; hardness change in Durometer A units.

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 Hardness	+20 -20	+30 -15

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OXIDATION STABILITY

1.0 SCOPE:

This test method will be used to evaluate the thermal oxidation stability of lubricating oils.

2.0 TEST METHOD:

Same as General Motors GM 6137, October 1990, Appendix E except for viscosity measurements, copper corrosion and elastomer compatibility.

3.0 ACCEPTANCE CRITERIA:

Same as Allison C-4, with the following modifications: .

For each oil tested, report the following data to Caterpillar Inc, Fluids Engineering (address in Introduction):

1. Kinematic viscosity at 100°C (J300).
2. Viscosity (cP) at 150°C and 10^{6} s^{-1} (ASTM D4683).

Viscosity

1.0 Scope:

This test method will be used to evaluate the ability of TO-4M fluids to provide acceptable viscometric properties in cold and hot ambient conditions when used in hydraulic systems. Viscosities are for SAE J300 10W and multi-viscosity grades.

2.0 Test Methods:

Various.

3.0 Test Procedure:

The various standard test methods should be followed as given.

4.0 Acceptance Limits:

Temp, ^{o}C	ASTM Method	Description	Viscosity
40	D445	Kinematic, cSt	107 Typ
100	D445	Kinematic, cSt	14.0 Min
-30	D2983	Brookfield, cP	150000 Max
-35	D2983	Brookfield,	-35
-30	D4684	Pumpability	43000 cP
150	D4683	HTHS (10^6 s^{-1}), Min cP	2.4

Vane Pump

1.0 Scope:

This test method will be used to evaluate the ability of a multigrade TO-4 fluid (TO-4M) to provide acceptable vane 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 fluids when used in conjunction with fluid pump applications in Caterpillar Inc. vehicle 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:

Weight loss of rings plus vanes from individual cartridges tested should be less than 90 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 TO-4M 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 TO-4M fluids when used in all applications in Caterpillar Inc. products.

4.0 Acceptance Limits:

The test must achieve a passing rating through a minimum of eight load stages.

Four-Ball Wear Test

1.0 Scope:

This test method will be used to evaluate the relative wear preventative properties of 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.

Friction Properties

Introduction:

This test method, VC70, will be used to evaluate the ability of a lubricant to provide acceptable friction performance characteristics when used in conjunction with various oil-cooled friction mechanisms in Caterpillar brakes, transmissions, and final drives, or wherever TO-4 is specified for service fill.

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

TO-4 Oil/Friction Test
Caterpillar Inc., Fluids Engineering Division
Bldg. H3000

(For First Class Mail:)
Old Galena Road
Mossville, IL 61552

Phone (309) 578-9229

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

1.0 Scope:

1.1 This procedure defines the test method for evaluation of the lubrication and frictional performance characteristics of a TO-4M 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 a TO-4M rating.

1.3 This procedure defines the requirements for qualification of a Link Model 1158 oil/friction test machine used for oil testing.

1.4 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.

1.5 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

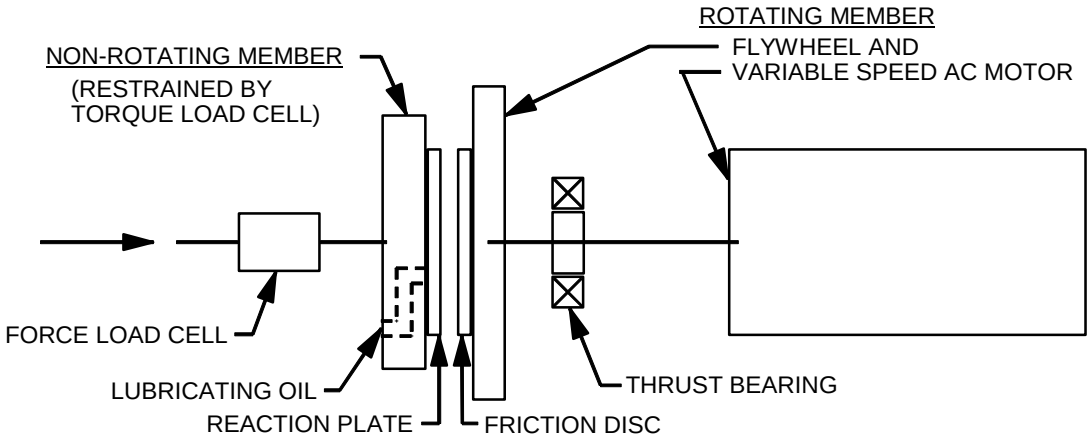
EXAMPLE: B0589023

- 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

Friction retention with bronze

3.3 A complete oil test consists of seven runs, which are made using the friction discs and reaction plates from a single 8E4103 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 8E4103 kit, may be used to designate the test oil as an TO-4M 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 and reaction plates are supplied by Raybestos Products Company and Caterpillar Inc., and are packaged by Raybestos Products Company as 8E4103 clutch group (oil test kit). The kits are available through the Caterpillar parts distribution system.

6.2.1 Each 8E4103 kit contains enough material for a reference test and twelve 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 an 8E4103 kit:

8E1219 Clutch Group
1Y0708 Disc (Elastomeric) and 1Y3610 Plate

8E1220 Clutch Group
1Y0709 Disc (Sintered Bronze) and 8E4095 Plate

8E1221 Clutch Group
1Y0710 Disc (Steering Brake Paper) and 1Y3610 Plate

8E1222 Clutch Group
1Y0711 Disc (Wheel Brake Paper) and 1Y0726 Plate

8E1223 Clutch Group
1Y0712 Disc (Transmission Paper) and 1Y0726 Plate

8E1224 Clutch Group
1Y0713 Disc (Elastomeric) and 8E4095 Plate

8E7351 Clutch Group [For Friction Retention]
1Y0709 Disc (Sintered Bronze) 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. SEQ1224 or SEQ1219 (To be used with 8E1224 and 8E1219 groups, respectively)

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

Perform inertia and coast-down-time checks as part of SEQ1224.

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	22.5	1050	15
24	15	25	1050	15
25	15	27.5	1050	15
26	15	30	1050	15
27	15	32.5	1050	15
28	15	35	1050	15
29	15	36	1050	15
30	15	37	1050	15
31	15	38	1050	15
32	15	39	1050	15
33	15	40	1050	15
34	15	41	1050	15
35	15	42	1050	15
36	15	43	1050	15
37	15	44	1050	15
38	15	45	1050	15
39	15	46	1050	15
40	15	47	1050	15
41	15	48	1050	15
42	15	49	1050	15
43	15	50	1050	15
44	15	51	1050	15
45	15	52	1050	15
46	15	53	1050	15
47	15	54	1050	15
48	15	55	1050	15

Energy limit detection is based on a 12% change in μ_d compared to the average μ_d of the previous phase. 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.

SEQ1224 includes two tests to verify machine operation: an inertia check and a coast-down-time check. Perform the inertia check immediately following the completion of Phase 6, before the 1Y0713 disc is removed for measurement. Perform the coast-down-time check after the 1Y0713 disc has been removed for measurements after Phase 6.

7.4.2 Sequence No. SEQ1220, SEQ1222 or SEQ1223
(to be used with 8E1220, 8E1222 and 8E1223 groups)
Twenty s Cycle Time: Engaged 4.0 s, Disengaged 16.0 s.

Phase No.	No. of Repetitions	Initial Speed m/s	Unit Press. 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 SEQ1220, it is a 25% change; in SEQ1222 and SEQ1223, it is a 12% change.

7.4.3 Sequence No. SEQ1221 (to be used with 8E1221 group)

Twenty s Cycle Time: Engaged 4.0 s, Disengaged 16.0 s.

Phase No.	No. of Repetitions	Initial Speed m/s	Unit Press. 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	16	1050	15
22	15	17	1050	15
23	15	18	1050	15
24	15	19	1050	15
25	15	20	1050	15
26	15	21	1050	15
27	15	22	1050	15
28	15	23	1050	15
29	15	24	1050	15
30	15	25	1050	15
31	15	26	1050	15
32	15	37	1050	15

33	15	28	1050	15
34	15	29	1050	15
35	15	30	1050	15
36	15	31	1050	15
37	15	32	1050	15
38	15	33	1050	15
39	15	34	1050	15
40	15	35	1050	15

Energy limit detection is based on a 12% change in μ_d compared to the average μ_d of the previous phase. 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.

7.4.4 Sequence No. SEQFRRET . (to be used with 8E7351 group in friction retention test)

Fifteen s Cycle Time: Engaged 5.0 s, Disengaged 10.0 s.
Cooling Oil Temperature: 115 +3/-10 ^{o}C

Phase No.	No. of Repetitions	Initial Speed m/s	Unit Press. kPa	Plot Coefficient Averages and Save Torque Curves at These Cycles:
1	10	15	350	
2	10	15	700	
3	20	15	1050	

Inspect to verify at least 70% contact on reaction plate and disc.

4	10	18	350	
5	50	18	700	
6 through 36	25000	18	1050	50, 100, 200, 300, 400, 500, 1000, 2000, 3000, 4000,... 23000, 24000, 25000.

7.5.1 Each sequence is to proceed without delay between cycles except to measure disc thickness, coast-down time and machine inertia. These pauses are 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 SEQFRRET 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

8.0 CALIBRATION AND STANDARDIZATION:

8.1 Each M1158 machine, when first received, must be evaluated for accuracy and found acceptable through a series of runs as specified by and submitted to the test sponsor. Upon approval, the machine is qualified for oil certification work for six months or 150 runs, whichever comes first.

8.2 If the machine is modified in some way to obtain successful completion of any of the runs for qualification, the qualification series must be started over.

8.3 The limits of acceptability for machine qualification are given in Annex I. If the performance of a machine falls within those limits, it is acceptable. If its performance falls outside of those limits in any run, that material and oil combination must be rerun two times. The machine may be deemed acceptable if it has good repeatability.

8.4 If the physical configuration of the machine is changed for any reason, such as other test work, it must be restored to the original configuration and requalified before use in oil certification.

8.5 When the qualification of a machine has expired, qualification for an additional period of one year or 350 runs may be obtained by submitting to the test sponsor acceptable results from four consecutive runs, the friction materials, plates and oils as specified or provided by the test sponsor.

8.6 Immediately prior to qualification or requalification of a machine, the power supply, transducer and A/D board calibrations must be verified. These must be checked and adjusted following the instructions given in the M1158 operation manual provided by Link Engineering Company.

8.7 The computer and software must always be operating correctly for valid test results.

8.7.1 The sequence definitions must be identical to those shown in Annex II.

8.7.2 The disc parameter files must be identical to those shown in Annex III.

8.7.3 The plate parameter files must be identical to those shown in Annex IV.

8.7.4 The report format files must be identical to those shown in Annex V.
8.7.5 The signal conditioner zero and gain settings must be set correctly as indicated on the panel voltmeter.

8.7.6 The A/D calibration screen accessed through the calibration menu must verify that the signals are being interpreted correctly by the A/D board. For example, concerning the torque signal: at no load, this screen must read zero volts, zero nm and zero counts; with the half scale cal switch actuated, this screen must read 5 volts, 1750 nm and 16384 counts.

8.7.7 The computer must be manipulating the measured values of speed, load, stop time and lockup torque according to the equations in Section 10 as it calculates average dynamic coefficient and static coefficient. The values recorded in a current log file can be used to verify this.

8.7.8 The test pattern which is produced by the testplot limit file and is called up by the testplot format will verify that the plotter is functioning correctly. The testplot files and the limit lines which they generate must be as shown in Annex VI.

8.8 Machine constants

8.8.1 Moment of inertia of the rotating components: 1.003_0.040 Nms²

8.8.2 Coast-down time: 70 s minimum

8.9 Cooling oil . fill requirement: 18.9_0.5 L
flow rate: 3.78_0.06 L/min. (as indicated on the M1158 machine instrumentation)

8.9.1 Operating temperature range . set point +3/ -10 ^{o}C

8.9.1.1 The temperature setting for all runs except SEQFRRET will be based on the viscosity of the test oil as follows:

SAE 10W: 82 ^{o}C
SAE 20: 82 oC
SAE 30: 82 ^{o}C
SAE 40: 93 ^{o}C
SAE 50: 97 ^{o}C
SAE 10W-30: 82 ^{o}C
SAE 15W-40 :82 ^{o}C

8.9.1.2 The temperature setting for SEQFRRET will be 115 ^{o}C for all viscosities.

9.0 Procedure

9.1 Perform the signal conditioner calibration check.

9.2 Perform the force output calibration.

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

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

9.5 Select the sequence to be used.

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

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

9.8 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.

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

9.10 Produce the printed reports and curves.

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

10.0 Calculation and Interpretation of Results:

10.1 Equations and Constants

10.1.1 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

10.1.2 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

10.1.3 In equations 1 and 2 the constants are based on:
Inertia = 1.003 N·m·s²
Friction material area = 0.02499 m²
Mean radius of friction material = 0.1283 m

10.1.4 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.

10.2 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.

10.2.1 The friction discs and reaction plates will be supplied in 8E4103 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 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.

10.2.2 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.

10.2.2.1 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 10.2.4, that reference run is invalid and must be repeated.

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

Before an 8E4103 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. All seven runs will be made, one with each material plus bronze friction retention. At the completion of those runs, the limit files are to be generated or updated as follows:

Go to the print report menu.

Select the reference test.

Select the run which has been completed. This will define the sequence name, disc and plate used in the run.

Select the limit file for that friction material.

Select the report format for the 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.

10.2.3 An oil, to be certified as a TO-4 oil, must be tested following the VC70 procedure with all six friction materials and seven runs listed below, and within a given oil test kit, and have performance characteristics relative to those of the TMS reference oil, as defined in Figure 3.

Sequence SEQ1219 with 8E1219 clutch group (1Y0708 disc and 1Y3610 plate)
Sequence SEQ1220 with 8E1220 clutch group (1Y0709 disc and 8E4095 plate)
Sequence SEQ1221 with 8E1221 clutch group (1Y0710 disc and 1Y3610 plate)

Sequence SEQ1222 with 8E1222 clutch group (1Y0711 disc and 1Y0726 plate)
Sequence SEC1223 with 8E1223 clutch group (1Y0712 disc and 1Y0726 plate)
Sequence SEQ1224 with 8E1224 clutch group (1Y0713 disc and 8E4095 plate)
Sequence SEQFRRET with 8E7351 clutch group (1Y0709 disc and 1Y0726 plate)

10.2.4 The energy limit must not occur at (during an engagement from) a speed lower than that indicated below for each material:

Group	Friction Material	Minimum Allowable Energy Limit – m/s
8E1219	1Y0708	40
8E1220	1Y0709	25
8E1221	1Y0710	25
8E1222	1Y0711	28
8E1223	1Y0712	25
8E1224	1Y0713	40

(These speeds are plotted as vertical limit lines on the coefficient vs. speed plots.)

10.2.5 Total wear of the friction disc must not exceed the amount indicated below for each material:

Group	Friction Material	Maximum Wear – mm
8E1219	1Y0708	0.03
8E1220	1Y0709	0.04
8E1221	1Y0710	0.07
8E1222	1Y0711	0.07
8E1223	1Y0712	0.07
8E1224	1Y0713	0.04

10.2.6 Successful completion means that for each material and sequence the coefficients stay within the specified ranges, 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.

10.2.7 Except as described in 10.2.8 (multiple-run averaging), any one of the following conditions constitutes failure of a candidate oil: –any of the plotted points of static or average dynamic coefficient of friction fall outside of the allowable ranges as shown by the limit lines on the coefficient plots. –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 for any of the seven runs. –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.

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

10.2.8.1 If the friction data for any of the runs with a candidate oil are slightly outside of the limits, 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 within the limits.

10.2.8.2 If the averaged friction data of two runs of a given material with a candidate oil are slightly outside of the two-run limits, 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 within the limits.

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

10.2.8.4 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 GP	SEQUENCE	1–RUN	2–RUN	3–RUN	1–RUN	MULTIPLE
8E1219	SEQ1219	LIM1219	2LIM1219	3LIM1219	REP1219	MULT1219
8E1220	SEQ1220	LIM1220	2LIM1220	3LIM1220	REP1220	MULT1220
8E1221	SEQ1221	LIM1221	2LIM1221	3LIM1221	REP1221	MULT1221
8E1222	SEQ1222	LIM1222	2LIM1222	3LIM1222	REP1222	MULT1222
8E1223	SEQ1223	LIM1223	2LIM1223	3LIM1223	REP1223	MULT1223
8E1224	SEQ1224	LIM1224	2LIM1224	3LIM1224	REP1224	MULT1224
8E7351	SEQFRRET	LIMFRRET	2LIMFRRET	3LIMFRRET	REPFRRET	MULTFRET

10.3 Machine requirements

10.3.1 Either of the following conditions constitutes failure of a Link M1158 oil/friction test machine which will require repair of the machine and requalification before it can again be used for oil certification work: a) the coast-down time is less than 70 s; or b) the effective inertia falls outside of the acceptable limit of 1.003±0.040 N·m.

10.3.2 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.

11.0 REPORT

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

11.2 Data Presentation

11.2.1 Verification of calibration and setup will be included with each report. Plot Type: 6, example in Figure 4.

11.2.2 Coefficient of friction will be plotted against no. of cycles, unit pressure and speed. Plot types: 3, 1 and 2, examples in Figures 5, 6 and 7, respectively.

11.2.3 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 inFigure 8.

11.2.4 Disc thickness measurements and average wear will be reported in tabular form. Example in Figure 5.

11.2.5 Dynamic and static coefficients will be plotted against no. of cycles for the bronze friction retention run. Plot type 4, example in Figure 9.

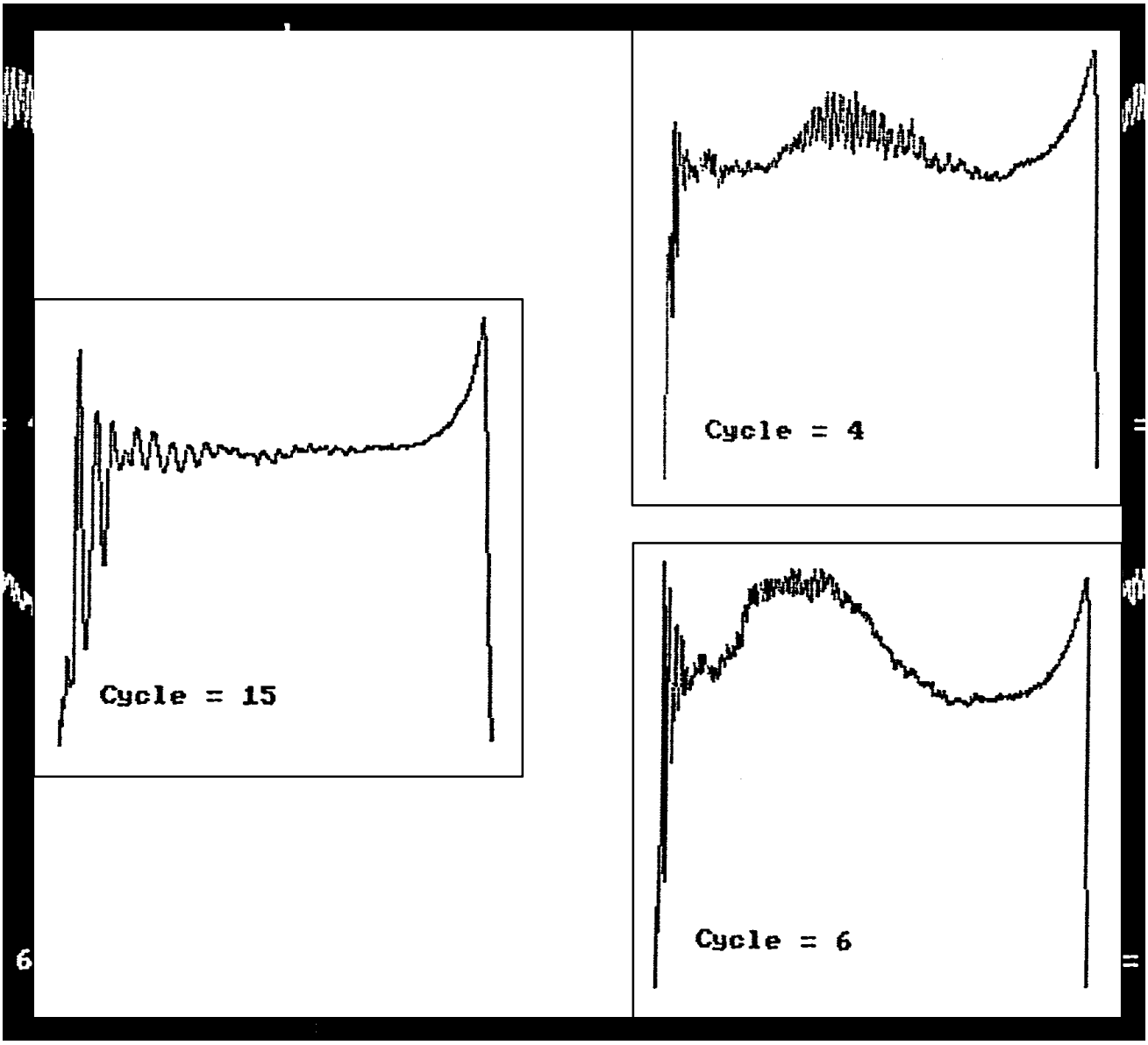
11.2.6 A print-out of the M1158·VAL file will be included with all reference reports. This can be done with the following command entered at the “C” prompt:

Type M1158.VAL>PRN

11.2.7 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 7 years for future reference.

12.0 PRECISION AND BIAS

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



NORMAL OPERATION:
SMOOTH TORQUE CURVE

ENERGY LIMIT EXCEEDED:
ROUGH TORQUE CURVE

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

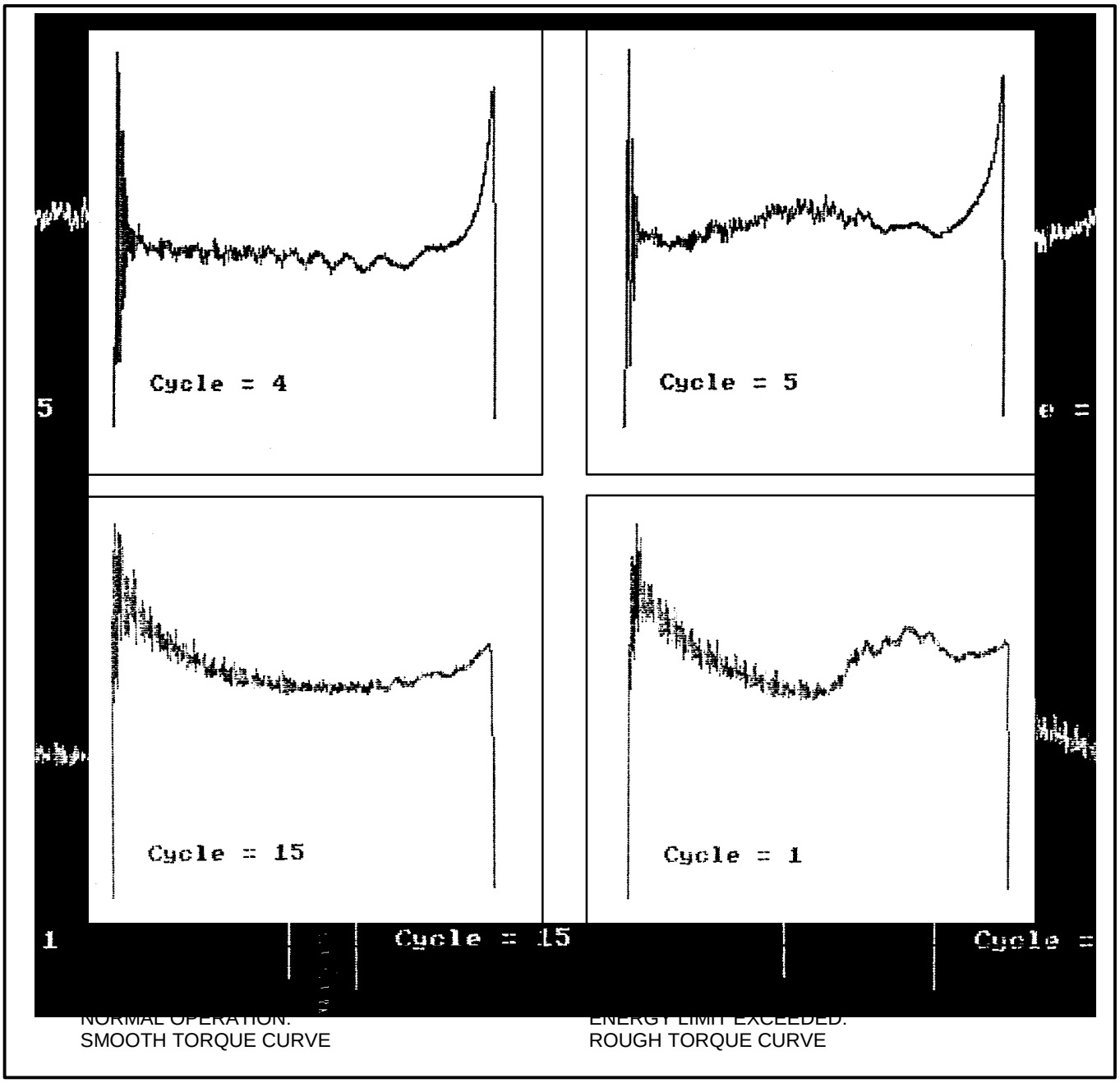


Figure 2 – Typical Torque Traces from the Link 1158 Oil/Friction Test Machine

CLUTCH GP	-	8E1219	8E1220	8E1221	8E1222	8E1223	8E1224
DISC #	-	1Y0708	1Y0709	1Y0710	1Y0711	1Y0712	1Y0713
MATERIAL	-	ELASTOM'C (RPC)	SINTERED BRONZE	STEER. BR PAPER	WHEEL BR PAPER	TRANSM PAPER	ELASTOM'C (CAT)
PLATE #	-	1Y3610	8E4095	1Y3610	1Y0726	1Y0726	8E4095
SEQUENCE #	-	SEQ1219	SEQ1220	SEQ1221	SEQ1222	SEQ1223	SEQ1224
AVG DYN COEF	-						
SINGLE RUN UPPER		130.0%	140.0%	140.0%	125.0%	130.0%	130.0%
SINGLE RUN LOWER		94.0%	90.0%	90.0%	91.0%	95.0%	91.0%
2-RUN AVG UPPER		131.4%	141.4%	141.4%	126.4%	131.4%	131.4%
2-RUN AVG LOWER		92.6%	88.6%	88.6%	89.6%	93.6%	89.6%
3-RUN AVE UPPER		132.1%	142.1%	142.1%	127.1%	132.1%	132.1%
3-RUN AVE LOWER		91.9%	87.9%	87.9%	88.9%	92.9%	88.9%
STATIC COEF	-						
SINGLE RUN UPPER		122.0%	127.0%	117.0%	117.0%	120.0%	123.0%
SINGLE RUN LOWER		92.0%	91.0%	90.0%	93.0%	95.0%	92.0%
2-RUN AVG UPPER		123.4%	128.4%	118.4%	118.4%	121.4%	124.4%
2-RUN AVG LOWER		90.6%	89.6%	88.6%	91.6%	93.6%	90.6%
3-RUN AVG UPPER		124.1%	129.1%	119.1%	119.1%	122.1%	125.1%
3-RUN AVG LOWER		89.9%	88.9%	87.9%	90.9%	92.9%	89.9%

CLUTCH GP	-	8E7351
DISC #	-	1Y0709
MATERIAL	-	SINTERED BRONZE
PLATE #	-	1Y0726
SEQUENCE #	-	SEQFRRET

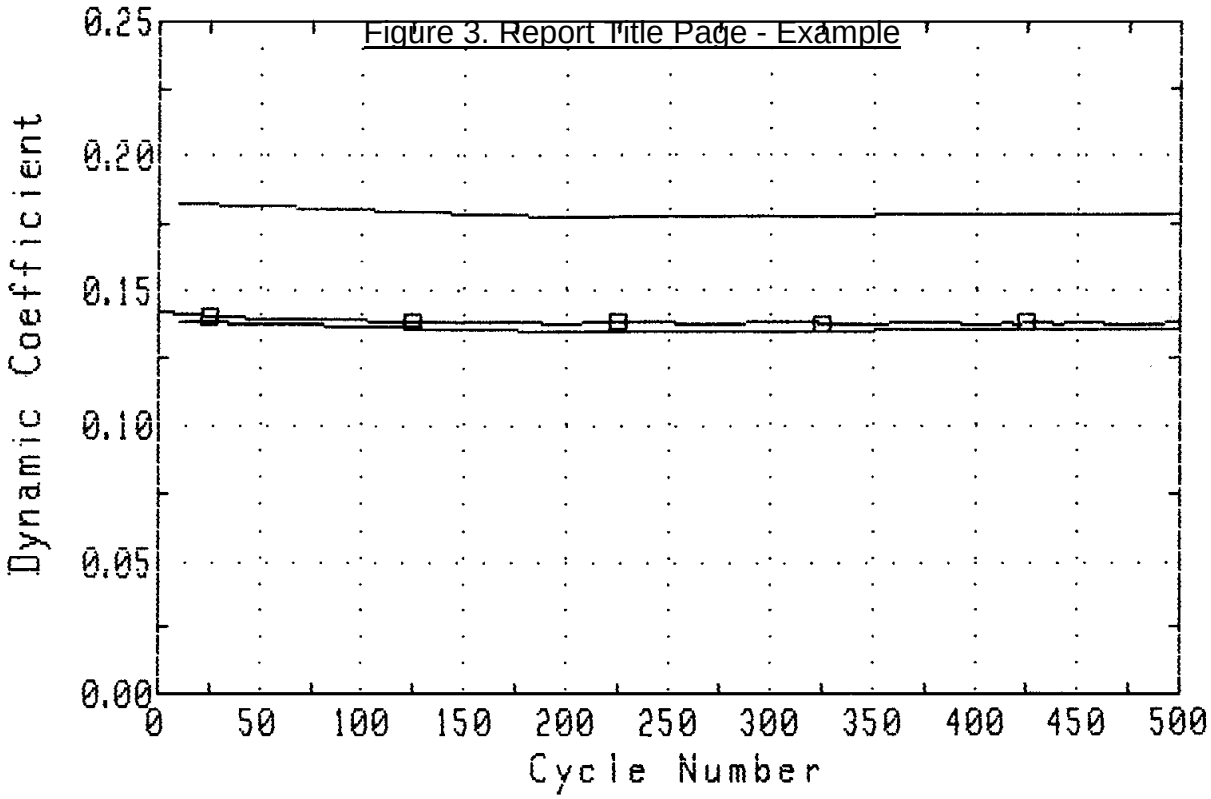
AVG DYN COEF -	AT 3000 CYCLES	AT 8000 CYCLES	AT 15000 CYCLES	AT 25000 CYCLES
SINGLE RUN UPPER	130.0%	125.0%	125.0%	125.0%
SINGLE RUN LOWER	85.0%	90.0%	90.0%	90.0%
2-RUN AVG UPPER	131.4%	126.4%	126.4%	126.4%
2-RUN AVG LOWER	83.6%	88.6%	88.6%	88.6%
3-RUN AVG UPPER	132.1%	127.1%	127.1%	127.1%
3-RUN AVG LOWER	82.9%	87.9%	87.9%	87.9%

XYZ Laboratories

Test Name:	12345C01
Test Date:	08/27/03
Test Description:	First Certification Test of 12345-C
Oil Type:	Hometown Oil Co.
Viscosity:	SAE 30
Miscellaneous:	----
Software Version:	1.2
Run Name & Desc:	N0690032 – 8E1224 Clutch Group
Run Date:	08/27/03
Oil Temperature:	82° C
Oil Flow Rate:	3.78 liter/minute
Operator:	SJones
Remarks:	----
Sequence Name:	SEQ1224
Remarks:	Use 1Y0713 disc and 8E4095 steel plate
Number Of Cycles Run:	1126
Machine:	N
Coast Down Check Run:	08/20/03
Result:	79.88 seconds
Inertia Check Run:	05/20/03
Result:	1.0239 N-m-s^2
Disc Name & Desc:	F37
Material:	Caterpillar Inc. elastomeric
Groove Pattern:	Single-lead spiral, 12 radial
Miscellaneous:	Use with 8E4095 steel plate
Outer Diameter (mm):	285.80
Inner Diameter (mm):	223.20
Mean Radius (mm):	128.21
Batch Number:	C592
Remarks:	----
Plate Name & Desc:	8E4095 - steel plate
Surface:	0.70 To 1.00 micron roughness
Miscellaneous:	----
Batch Number:	----
Remarks:	0.76 micron measured roughness
Report Limit Name:	LIM1224 - Reference Run: N0690018
Limit File Generated:	08/06/03
Report Format Name:	REP1224 – Caterpillar Inc. elastomeric

Fig. 4 - Report Title Page - Example

Figure 3. Report Title Page - Example



1Y0713
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 5 -- Dynamic Coefficient vs Number of Cycles

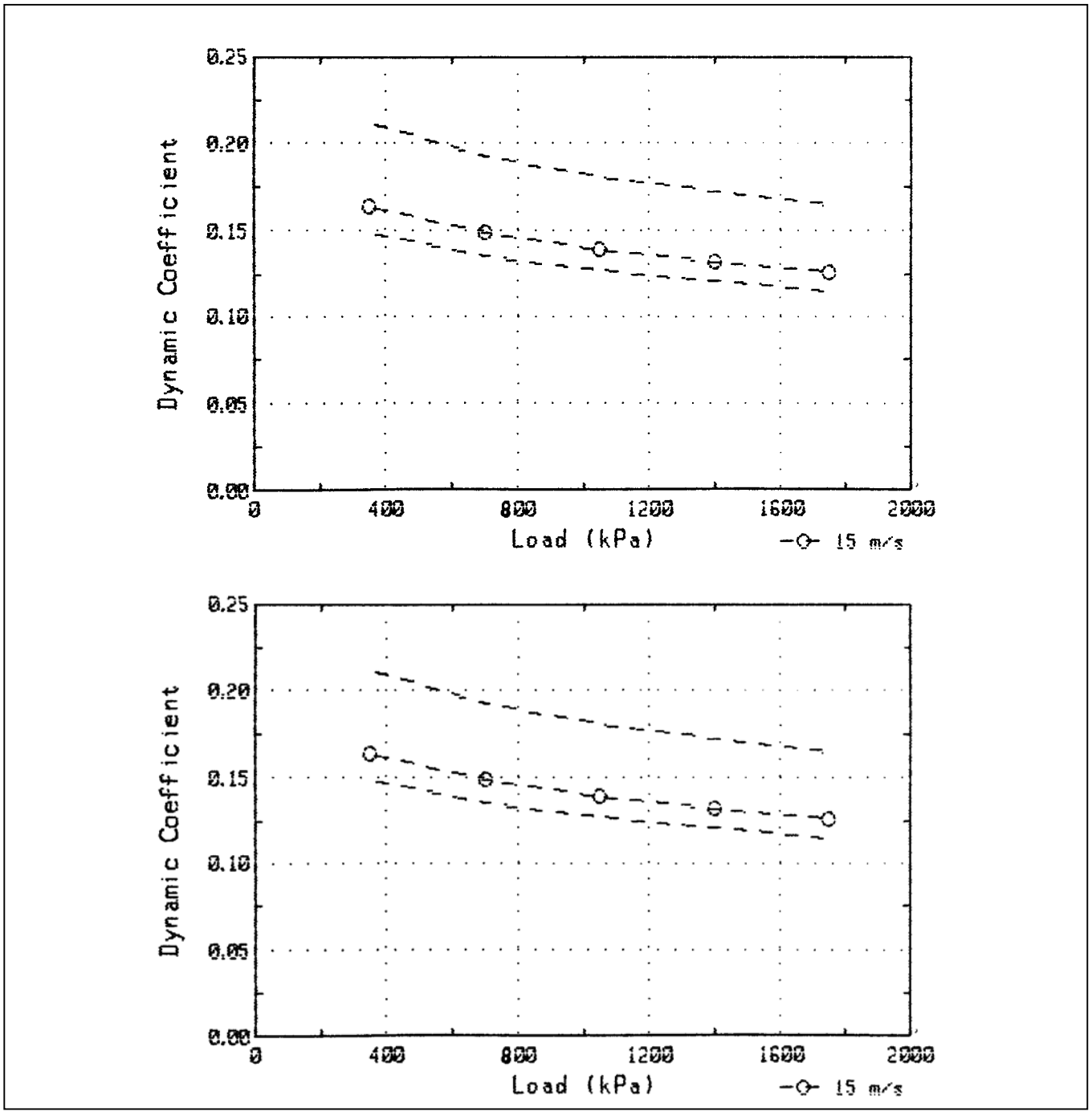


Figure 6 - Dynamic and Static Coefficients vs Unit Pressure

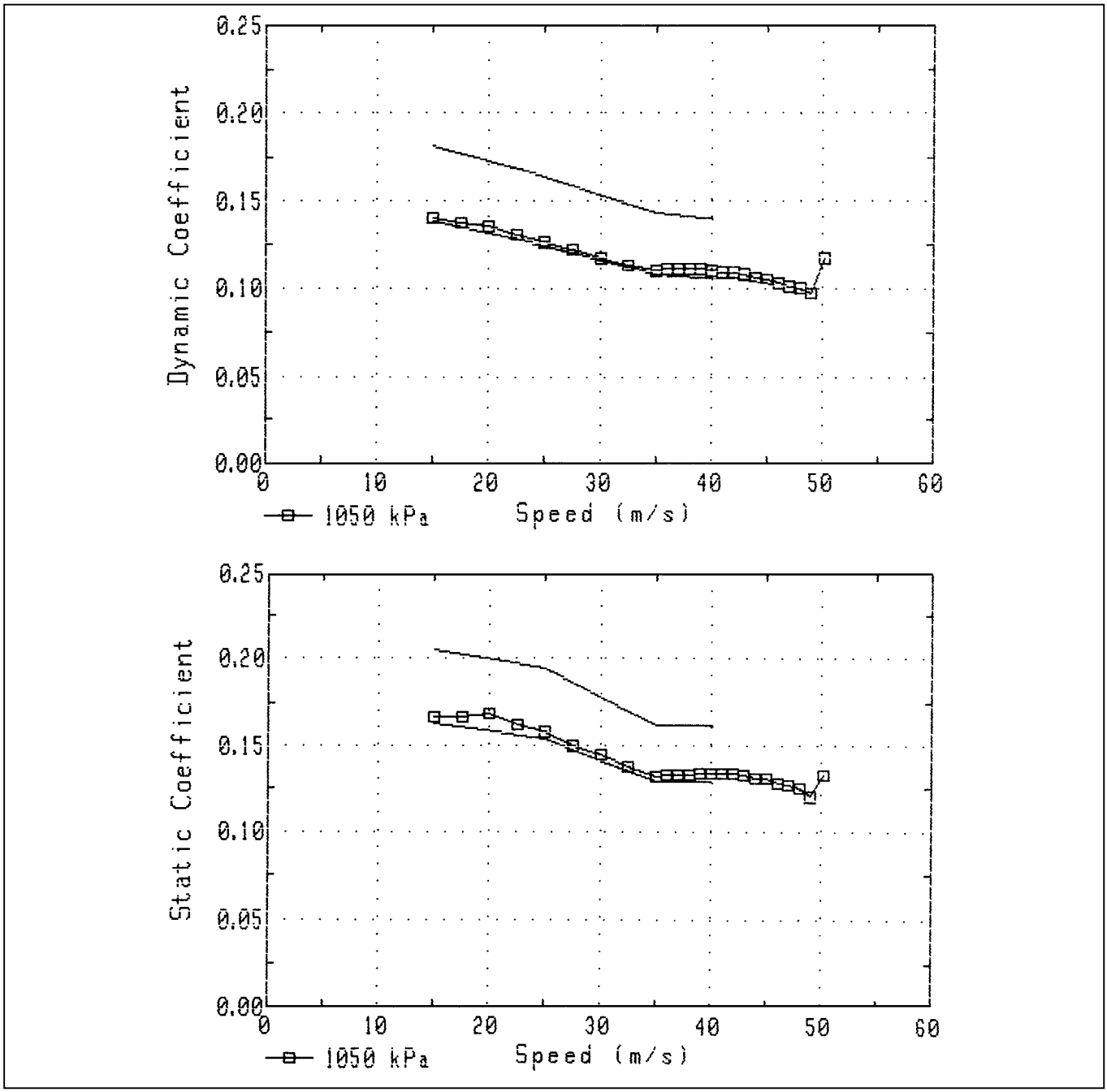


Figure 7 - Dynamic and Static Coefficients vs Initial Speed

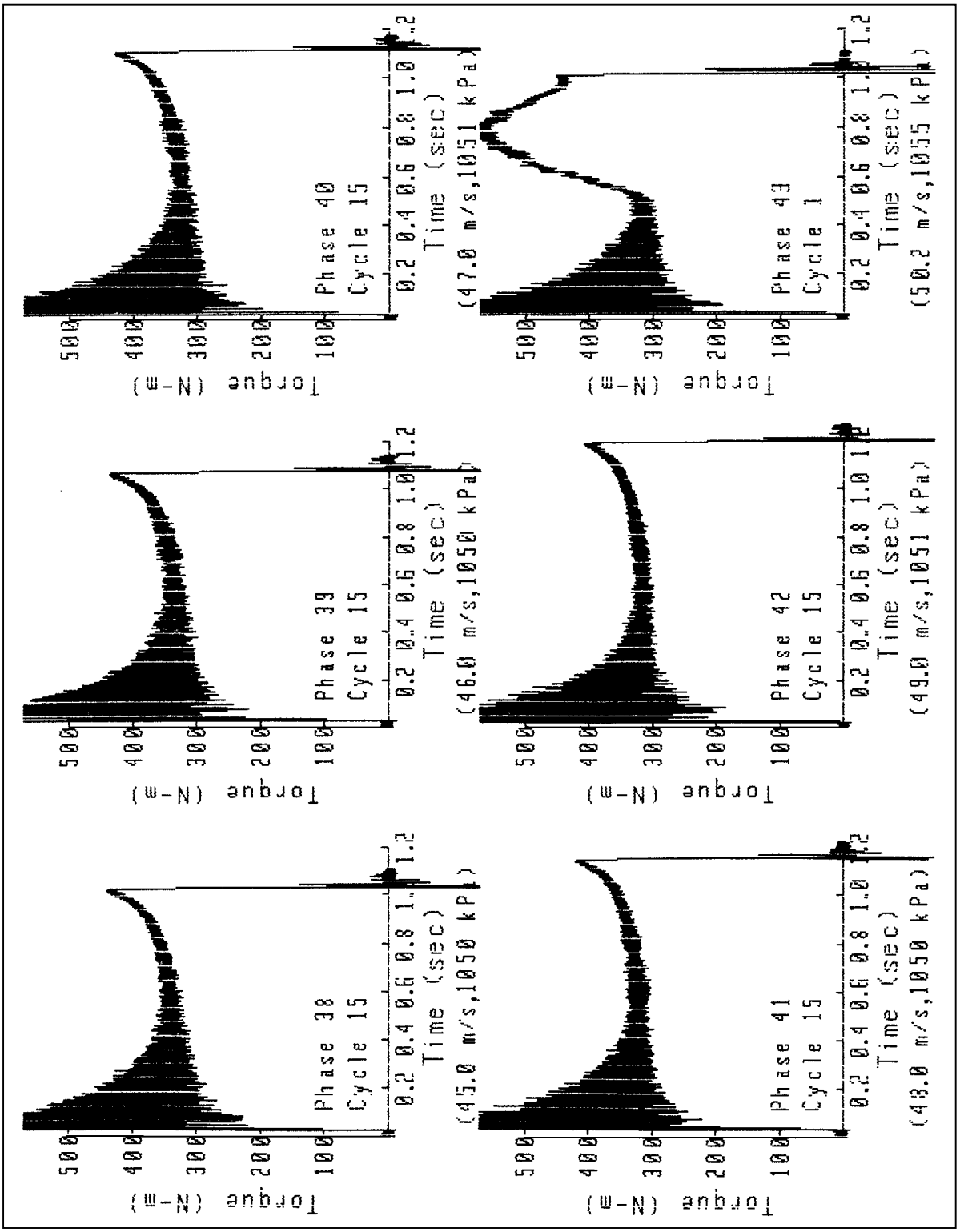


FIGURE 8 – TORQUE VS TIME

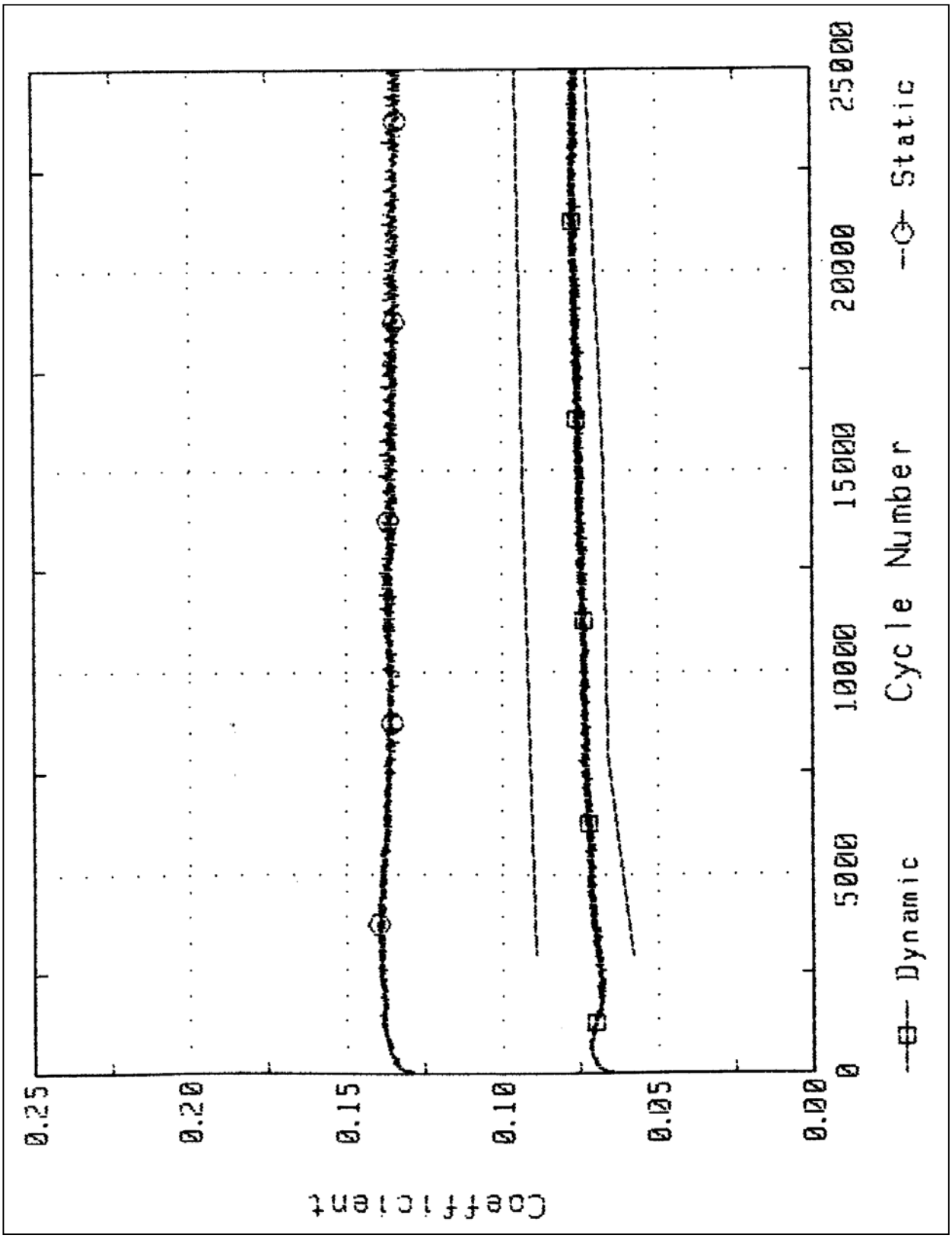


Figure 9 – Dynamic and Static Coefficients Vs Numbers of Cycles (Bronze)

Annex I. Coefficient of friction limits for machine qualification

Limit File: REF1220 Description: 8E1220 CL GP, SEQ1220, CT5021 oil

Plot Type 1 – Static and Dynamic Coefficient of Friction Vs Load

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
15 m/s									
X=kPa	UPPER	350	0.058	1050	0.063	1750	0.065		
Y= μ_d	LOWER	350	0.046	1050	0.053	1750	0.055		
X=kPa	UPPER	350	0.150	1050	0.139	1750	0.133		
Y= μ_s	LOWER	350	0.135	1050	0.128	1750	0.125		

PLOT TYPE 2 – STATIC AND DYNAMIC COEFFICIENT OF FRICTION VS SPEED

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
X=m/s	UPPER	15.0	0.057	20.0	0.058	25.0	0.058		
Y= μ_d	LOWER	15.0	0.049	20.0	0.049	25.0	0.044		
X=kPa	UPPER	15.0	0.140	20.0	0.138	25.0	0.136		
Y= μ_s	LOWER	15.0	0.128	20.0	0.126	25.0	0.124		
ENERGY LIMIT		23.49	0.050	25.00	0.200				

PLOT TYPE 3 – DYNAMIC COEFFICIENT OF FRICTION VS CYCLE NUMBER

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
X=cycle	UPPER	10	0.060	200	0.061	500	0.061		
Y= μ_d	LOWER	10	0.051	200	0.052	500	0.052		

LIMIT FILE: REF1224P DESCRIPTION: 8E1224 CL GP, SEQ1224, CT5021 OIL

PLOT TYPE 1 – STATIC AND DYNAMIC COEFFICIENT OF FRICTION VS LOAD

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
15 m/s									
X=kPa	UPPER	350	0.161	700	0.147	1050	0.137	1750	0.124
Y= μ_d	LOWER	350	0.139	700	0.131	1050	0.126	1750	0.117
X=kPa	UPPER	350	0.188	700	0.175	1050	0.168	1750	0.161
Y= μ_s	LOWER	350	0.165	700	0.160	1050	0.155	1750	0.148

PLOT TYPE 2 – STATIC AND DYNAMIC COEFFICIENT OF FRICTION VS SPEED

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
X=m/s	UPPER	15.0	0.140	25.0	0.130	35.0	0.111	40.0	0.107
Y= μ_d	LOWER	15.0	0.127	25.0	0.115	35.0	0.096	45.0	0.096
X=kPa	UPPER	15.0	0.170	25.0	0.162	35.0	0.136	40.0	0.132
Y= μ_s	LOWER	15.0	0.158	25.0	0.149	35.0	0.121	40.0	0.117
Energy limit		40.02	0.050	40.02	0.200				

(Annex I Cont'd)

PLOT TYPE 3 – DYNAMIC COEFFICIENT OF FRICTION VS CYCLE NUMBER

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
X=cycle	UPPER	10	0.148	200	0.139	500	0.135		
Y= μ_d	LOWER	10	0.128	200	0.127	500	0.126		

LIMIT FILE: REF1224F DESCRIPTION: 8E1224 CL GP, SEQ1224, CT5062 OIL

PLOT TYPE 1 – STATIC AND DYNAMIC COEFFICIENT OF FRICTION VS LOAD

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
15 m/s									
X=kPa	UPPER	350	0.135	700	0.127	1050	0.124	1750	0.116
Y= μ_d	LOWER	350	0.122	700	0.112	1050	0.108	1750	0.101
X=kPa	UPPER	350	0.182	700	0.172	1050	0.164	1750	0.154
Y= μ_s	LOWER	350	0.168	700	0.158	1050	0.149	1750	0.140

PLOT TYPE 2 – STATIC AND DYNAMIC COEFFICIENT OF FRICTION VS SPEED

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
X=m/s	UPPER	15.0	0.124	25.0	0.118	35.0	0.104	40.0	0.094
Y= μ_d	LOWER	15.0	0.108	25.0	0.100	35.0	0.088	40.0	0.077
X=kPa	UPPER	15.0	0.164	25.0	0.153	35.0	0.136	40.0	0.117
Y= μ_s	LOWER	15.0	0.148	25.0	0.137	35.0	0.114	40.0	0.105
ENERGY LIMIT		40.00	0.050	40.00	0.200				

PLOT TYPE 3 – DYNAMIC COEFFICIENT OF FRICTION VS CYCLE NUMBER

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
X=cycle	UPPER	10	0.131	200	0.127	500	0.121		
Y= μ_d	LOWER	10	0.110	200	0.101	500	0.108		

LIMIT FILE: REFFRETP DESCRIPTION: 8E7351 CL GP, SEQFRRET, CT5021 OIL

PLOT TYPE 4 – DYNAMIC COEFFICIENT OF FRICTION VS CYCLE NUMBER

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
X=cycle	UPPER	3000	0.076	8000	0.081	15000	0.081	25000	0.082
Y= μ_d	LOWER	3000	0.065	8000	0.071	15000	0.073	25000	0.074

LIMIT FILE: REFFRETF DESCRIPTION: 8E7351 CL GP, SEQFRRET, CT5071 OIL

PLOT TYPE 4 – DYNAMIC COEFFICIENT OF FRICTION VS CYCLE NUMBER

		P1X	P1Y	P2X	P2Y	P3X	P3Y	P4X	P4Y
X=cycle	UPPER	3000	0.079	8000	0.079	15000	0.077	25000	0.074
Y= μ_d	LOWER	3000	0.063	8000	0.067	15000	0.068	25000	0.065

Annex II. Sequence Definitions
Sequence: SEQ1219 Desc: 8E1219 Group
Remarks: Use 1Y0708 Disc and 1Y3610 Plate
Constant Factors:

Acceleration Time	– 8.00 s	Torque Threshhold	– 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	SS15C225	22.50	4.00	1050	15	15	4	N	12
24	SS15C250	25.00	4.00	1050	15	15	4	N	12
25	SS15C275	27.50	4.00	1050	15	15	4	N	12
26	SS15C300	30.00	4.00	1050	15	15	4	N	12
27	SS15C325	32.50	4.00	1050	15	15	4	N	12
28	SS15C350	35.00	4.00	1050	15	15	4	N	12
29	SS15C360	36.00	4.00	1050	15	15	4	N	12
30	SS15C370	37.00	4.00	1050	15	15	4	N	12
31	SS15C380	38.00	4.00	1050	15	15	4	N	12
32	SS15C390	39.00	4.00	1050	15	15	4	N	12
33	SS15C400	40.00	4.00	1050	15	15	4	N	12
34	SS15C410	41.00	4.00	1050	15	15	4	N	12
35	SS15C420	42.00	4.00	1050	15	15	4	N	12
36	SS15C430	43.00	4.00	1050	15	15	4	N	12
37	SS15C440	44.00	4.00	1050	15	15	4	N	12
38	SS15C450	45.00	4.50	1050	15	15	4	N	12
39	SS15C460	46.00	5.00	1050	15	15	4	N	12
40	SS15C470	47.00	5.50	1050	15	15	4	N	12
41	SS15C480	48.00	6.00	1050	15	15	4	N	12
42	SS15C490	49.00	6.50	1050	15	15	4	N	12
43	SS15C500	50.00	7.00	1050	15	15	4	N	12
44	SS15C510	51.00	7.50	1050	15	15	4	N	12
45	SS15C520	52.00	8.00	1050	15	15	4	N	12
46	SS15C530	53.00	8.50	1050	15	15	4	N	12
47	SS15C540	54.00	9.00	1050	15	15	4	N	12
48	SS15C550	55.00	9.50	1050	15	15	4	N	12

(Annex II. Cont'd)

Sequence: SEQ1220 Desc: 8E1220 Group
Remarks: Use 1Y0709 Disc and 8e4095 Plate
Constant Factors:

Acceleration Time	– 8.00 s	Torque Threshhold	– 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	SB15C175	17.50	4.00	1050	15	15	3	N	25
22	SB15C200	20.00	4.00	1050	15	15	4	N	25
23	SB15C210	21.00	4.00	1050	15	15	4	N	25
24	SB15C220	22.00	4.00	1050	15	15	4	N	25
25	SB15C230	23.00	4.00	1050	15	15	4	N	25
26	SB15C240	24.00	4.00	1050	15	15	4	N	25
27	SB15C250	25.00	4.00	1050	15	15	4	N	25
28	SB15C260	26.00	4.00	1050	15	15	4	N	25
29	SB15C270	27.00	4.00	1050	15	15	4	N	25
30	SB15C280	28.00	4.00	1050	15	15	4	N	25
31	SB15C290	29.00	4.00	1050	15	15	4	N	25
32	SB15C300	30.00	4.00	1050	15	15	4	N	25
33	SB15C310	31.00	4.00	1050	15	15	4	N	25
34	SB15C320	32.00	4.00	1050	15	15	4	N	25
35	SB15C330	33.00	4.00	1050	15	15	4	N	25
36	SB15C340	34.00	4.00	1050	15	15	4	N	25
37	SB15C350	35.00	4.00	1050	15	15	4	N	25
38	SB15C360	36.00	4.00	1050	15	15	4	N	25
39	SB15C370	37.00	4.00	1050	15	15	4	N	25
40	SB15C380	38.00	4.00	1050	15	15	4	N	25
41	SB15C390	39.00	4.00	1050	15	15	4	N	25
42	SB15C400	40.00	4.00	1050	15	15	4	N	25

(Annex II. Cont'd)

Sequence: SEQ1221 Desc: 8E1221 Group

Remarks: Use 1Y0710 Disc and 1Y3610 Plate

Constant Factors:

Acceleration Time	– 8.00 s	Torque Threshhold	– 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	SS15C160	16.00	4.00	1050	15	15	3	N	12
22	SS15C170	17.00	4.00	1050	15	15	4	N	12
23	SS15C180	18.00	4.00	1050	15	15	4	N	12
24	SS15C190	19.00	4.00	1050	15	15	4	N	12
25	SS15C200	20.00	4.00	1050	15	15	4	N	12
26	SS15C210	21.00	4.00	1050	15	15	4	N	12
27	SS15C220	22.00	4.00	1050	15	15	4	N	12
28	SS15C230	23.00	4.00	1050	15	15	4	N	12
29	SS15C240	24.00	4.00	1050	15	15	4	N	12
30	SS15C250	25.00	4.00	1050	15	15	4	N	12
31	SS15C260	26.00	4.00	1050	15	15	4	N	12
32	SS15C270	27.00	4.00	1050	15	15	4	N	12
33	SS15C280	28.00	4.00	1050	15	15	4	N	12
34	SS15C290	29.00	4.00	1050	15	15	4	N	12
35	SS15C300	30.00	4.00	1050	15	15	4	N	12
36	SS15C310	31.00	4.00	1050	15	15	4	N	12
37	SS15C320	32.00	4.00	1050	15	15	4	N	12
38	SS15C330	33.00	4.00	1050	15	15	4	N	12
39	SS15C340	34.00	4.00	1050	15	15	4	N	12
40	SS15C350	35.00	4.00	1050	15	15	4	N	12

(Annex II. Cont'd)

Sequence: SEQ1222 Desc: 8E1222 Group

Remarks: Use 1Y0711 Disc and 1Y0726 Plate

Constant Factors:

Acceleration Time	– 8.00 s	Torque Threshhold	– 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

(Annex II. Cont'd)

Sequence: SEQ1223 Desc: 8E1223 Group

Remarks: Use 1Y0712 Disc and 1Y0726 Plate

Constant Factors:

Acceleration Time	– 8.00 s	Torque Threshhold	– 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

(Annex II. Cont'd)

Sequence: SEQ1224 Desc: 8E1224 Group

Remarks: Use 1Y0713 Disc and 8E4095 Plate

Constant Factors:

Acceleration Time	– 8.00 s	Torque Threshhold	– 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	SS15C225	22.50	4.00	1050	15	15	4	N	12
24	SS15C250	25.00	4.00	1050	15	15	4	N	12
25	SS15C275	27.50	4.00	1050	15	15	4	N	12
26	SS15C300	30.00	4.00	1050	15	15	4	N	12
27	SS15C325	32.50	4.00	1050	15	15	4	N	12
28	SS15C350	35.00	4.00	1050	15	15	4	N	12
29	SS15C360	36.00	4.00	1050	15	15	4	N	12
30	SS15C370	37.00	4.00	1050	15	15	4	N	12
31	SS15C380	38.00	4.00	1050	15	15	4	N	12
32	SS15C390	39.00	4.00	1050	15	15	4	N	12
33	SS15C400	40.00	4.00	1050	15	15	4	N	12
34	SS15C410	41.00	4.00	1050	15	15	4	N	12
35	SS15C420	42.00	4.00	1050	15	15	4	N	12
36	SS15C430	43.00	4.00	1050	15	15	4	N	12
37	SS15C440	44.00	4.00	1050	15	15	4	N	12
38	SS15C450	45.00	4.50	1050	15	15	4	N	12
39	SS15C460	46.00	5.00	1050	15	15	4	N	12
40	SS15C470	47.00	5.50	1050	15	15	4	N	12
41	SS15C480	48.00	6.00	1050	15	15	4	N	12
42	SS15C490	49.00	6.50	1050	15	15	4	N	12
43	SS15C500	50.00	7.00	1050	15	15	4	N	12
44	SS15C510	51.00	7.50	1050	15	15	4	N	12
45	SS15C520	52.00	8.00	1050	15	15	4	N	12
46	SS15C530	53.00	8.50	1050	15	15	4	N	12
47	SS15C540	54.00	9.00	1050	15	15	4	N	12
48	SS15C550	55.00	9.50	1050	15	15	4	N	12

(Annex II. Cont'd)

Sequence: SEQFRRET Desc: Bronze Friction Retention

Remarks: Use 1Y0726 Plate (8E7351 Group)

Constant Factors:

Acceleration Time	– 5.00 s	Torque Threshhold	– 50 N·m
Soak Time	– 5.00 s	Sample Rate	– 5000/s
Cycle Time	– 15.00 s	Cycle Type	– normal

No.	Phase Name	Apply Speed	Cool. Speed	Load	No. of Cycles	Store Intv.	Det. Type	Pause	Allow. Var.
1	FRB1XA15	15.00	2.00	350	10	0	0	N	0
2	FRB1XB15	15.00	2.00	700	10	0	0	N	0
3	FRB2XC15	15.00	2.00	1050	20	0	0	Y	0
4	FRWUXA18	18.00	2.00	350	10	0	0	N	0
5	FRWULB18	18.00	2.00	700	50	0	0	N	0
6	AFR5XC18	18.00	2.00	1050	50	50	0	N	0
7	BFR5XC18	18.00	2.00	1050	50	50	4	N	25
8	CFR1CC18	18.00	2.00	1050	100	100	4	N	25
9	CFR1CC18	18.00	2.00	1050	100	100	4	N	25
10	CFR1CC18	18.00	2.00	1050	100	100	4	N	25
11	CFR1CC18	18.00	2.00	1050	100	100	4	N	25
12	DFR5CC18	18.00	2.00	1050	500	500	4	N	25
13	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
14	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
15	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
16	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
17	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
18	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
19	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
20	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
21	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
22	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
23	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
24	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
25	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
26	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
27	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
28	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
29	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
30	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
31	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
32	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
33	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
34	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
35	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25
36	EFR1MC18	18.00	2.00	1050	1000	500	4	N	25

Annex III. Disc Files

Name: 1Y0708	Description: Elastomeric Disc
Material:	Raybestos 6475-4, Rayflex
Groove Pattern:	Single Lead Spiral – 12 Radial
Miscellaneous:	Use With 1Y3610 Steel Plate
Outer Diam (mm):	285.80
Inner Diam (mm):	223.20
Mean Radius (mm):	128.21

Name: 1Y0709	Description: Sintered Bronze Disc
Material:	Raybestos 1349-ET
Groove Pattern:	Single Lead Spiral – 12 Radial
Miscellaneous:	Use With 8E4095 Steel Plate for Performance Run
Miscellaneous:	Use With 1Y0726 Steel Plate for Fr Retention Run
Outer Diam (mm):	285.80
Inner Diam (mm):	223.20
Mean Radius (mm):	128.21

Name: 1Y0710	Description: Steering Brake Paper
Material:	Raybestos 7894-4
Groove Pattern:	2-37 Multiple Parallel
Miscellaneous:	Use With 1Y3610 Steel Plate
Outer Diam (mm):	285.80
Inner Diam (mm):	223.20
Mean Radius (mm):	128.21

Name: 1Y0711	Description: Wheel Brake Paper
Material:	Raybestos 7902-1
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

Name: 1Y0712	Description: Transmission Paper
Material:	Raybestos 7901-2
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

Name: 1Y0713	Description: Elastomeric Disc
Material:	Caterpillar F37
Groove Pattern:	Single Lead Spiral – 12 Radial
Miscellaneous:	Use With 8E4095 Steel Plate
Outer Diam (mm):	285.80
Inner Diam (mm):	223.20
Mean Radius (mm):	128.21

Annex IV. 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.

Name: 1Y3610	Description
Surface:	0.70 to 1.30 Micron Roughness
Misc.:	Install the Side Marked with the Average Roughness Toward The Friction Disc; The Side Marked “Do Not Use” Toward the Torque Arm.

Name: 8E4095	Description
Surface:	0.70 to 1.00 Micron 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 V. Report Format Files

Page	Plot Type	Phase Range 1	Phase Range 2
Name: REP1219	Description: Elastomeric, Rayflex		
1	6	0 – 0	
2	3	6 – 6	
3	1	0 – 0	15 – 19
4	2	20 – 48	
5	5	20 – 48	
Name: REP1220	Description: Bronze – Performance		
1	6	0 – 0	
2	3	6 – 6	
3	1	0 – 0	15 – 19
4	2	20 – 42	
5	5	20 – 42	
Name: REP1221	Description: Steering Brake Paper		
1	6	0 – 0	
2	3	6 – 6	
3	1	0 – 0	15 – 19
4	2	20 – 40	
5	5	20 – 40	
Name: REP1222	Description: Wheel Brake Paper		
1	6	0 – 0	
2	3	6 – 6	
3	1	0 – 0	15 – 19
4	2	20 – 42	
5	5	20 – 42	
Name: REP1223	Description: Transmission Paper		
1	6	0 – 0	
2	3	6 – 6	
3	1	0 – 0	15 – 19
4	2	20 – 42	
5	5	20 – 42	
Name: REP1224	Description: Elastomeric, F37		
1	6	0 – 0	
2	3	6 – 6	
3	1	0 – 0	15 – 19
4	2	20 – 48	
5	5	20 – 48	
Name: REPFRRET	Description: Bronze – Fr Retention		
1	6	0 – 0	
2	4	6 – 36	

Annex V. Report Format Files (continued)

	Page	Plot Type	Phase Range 1	Phase Range 2
MULT1219				
	1	6	0 – 0	
	2	3	6 – 6	
	3	1	0 – 0	15 – 19
	4	2	20 – 48	
MULT1220				
	1	6	0 – 0	
	2	3	6 – 6	
	3	1	0 – 0	15 – 19
	4	2	20 – 42	
MULT1221				
	1	6	0 – 0	
	2	3	6 – 6	
	3	1	0 – 0	15 – 19
	4	2	20 – 40	
MULT1222				
	1	6	0 – 0	
	2	3	6 – 6	
	3	1	0 – 0	15 – 19
	4	2	20 – 42	
MULT1223				
	1	6	0 – 0	
	2	3	6 – 6	
	3	1	0 – 0	15 – 19
	4	2	20 – 42	
MULT1224				
	1	6	0 – 0	
	2	3	6 – 6	
	3	1	0 – 0	15 – 19
	4	2	20 – 48	

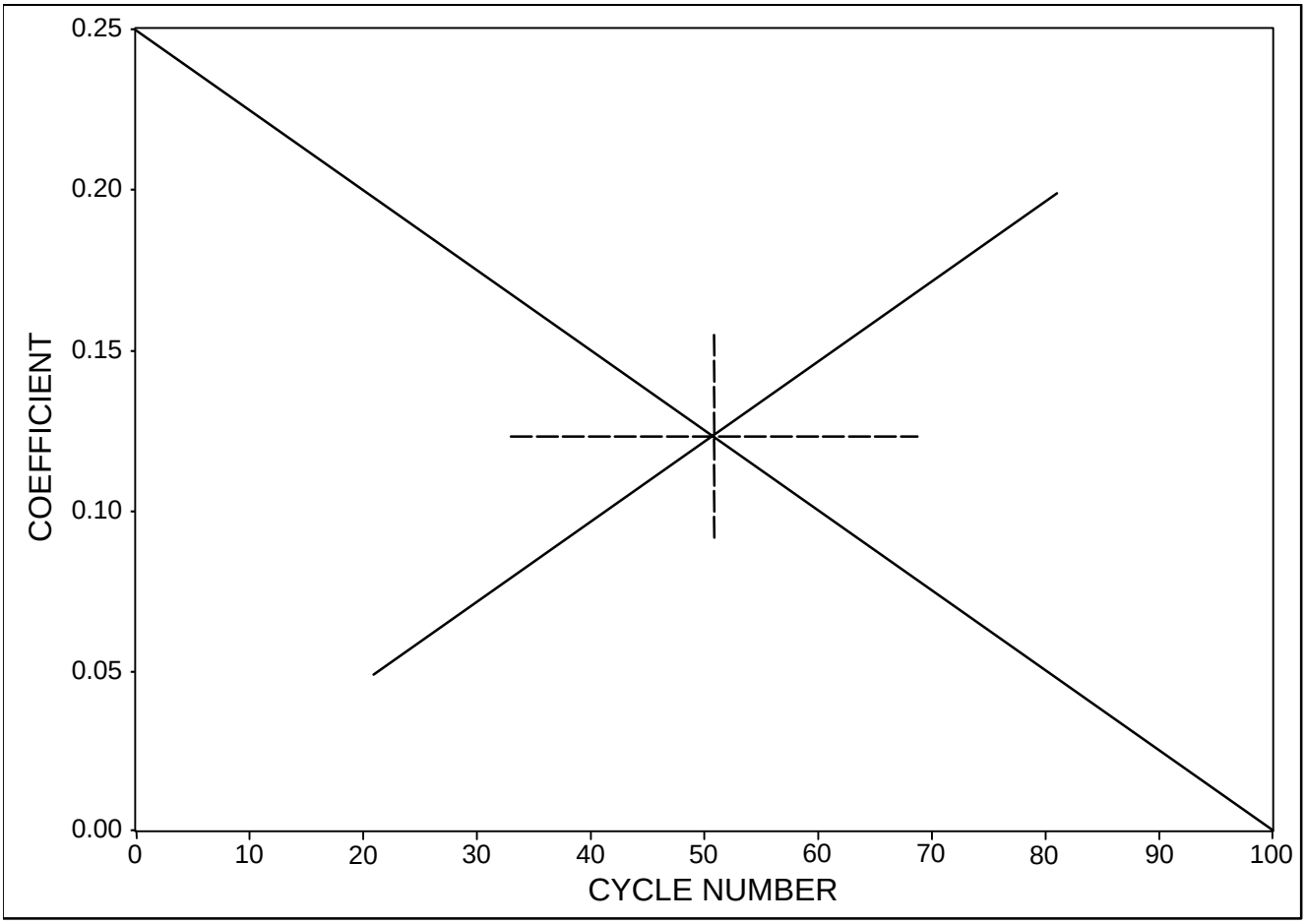
Annex VI. Plotter Test

Format File Name: Testplot Description: Plotter Test Pattern

Page	Plot Type	Phase Range 1	Phase Range 2
1	4	3 – 3	

Limit File Name: Testplot Description: Plotter Test Pattern
Page Plot Type – Static and Dynamic Coefficient of Friction Vs Cycle Number

		P1X	P1Y	P2X	P2Y
X=cycle	UPPER	0	0.250	100	0.000
Y= μ_d	LOWER	20	0.050	80	0.200
X=cycle	UPPER	30	0.125	70	0.125
Y= μ_s	LOWER	50	0.100	50	0.150



Plotter Test Pattern

1.0 SCOPE

1.1 This specification defines the test method for evaluation of the lubrication and frictional performance of a multigrade oil for use in Caterpillar Inc. oil-cooled friction mechanisms.

1.2 This specification defines acceptance criteria which qualify an oil for a TO-4M rating. Acceptance criteria include lubrication, frictional, shear stability and low-temperature fluidity requirements.

1.3 This standard might 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. The requirements of TO-4 apply to TO-4M except as superceded by TO-4M.

2.0 FILM THICKNESS

2.1 This test method will be used to evaluate the ability of a lubricating oil to provide a film thickness at all temperatures.

2.2 The test will be EHD Film-Forming Capability Test on the WAM4 test machine at Wedeven Associates, Inc. The following test conditions will apply:

Ball	13/16 inch dia. M50 steel (grade 5), $R_a < 1$ μ in.
Disc	5 inch dia. X 0.625 inch, Pyrex 7740 with optical coatings
Max. Hertz Stress	0.59 Gpa (86,000 psi), 10 lb load
Entraining Velocity	Variable, defined as ½ sum of surface velocities
Sliding Velocity	Near zero; tests are run with disc driving the ball
Nominal Temperatures	70 °C, 100 °C, and 130 °C

2.3 The candidate oil is run in sequence with a Caterpillar supplied reference fluid, CT5268. The procedure used is one developed and administered by Wedeven, Associates, Inc. For more information regarding testing and procedure contact:

Wedeven Associates, Inc.
5072 West Chester Pike
Edgmont, PA 19028

Phone: 610-356-7161
Fax: 610-325-0687

2.4 The EHD film thickness of the candidate must meet or exceed each and all of the following acceptability criteria at 2 m/s:

90% of reference fluid EHD at 70°C
96% of reference fluid EHD at 100°C
98% of reference fluid EHD at 130°C

At each temperature, the fluid must meet the above acceptance criteria on the first test, or as the arithmetic average of up to three tests.

3.0 SHEAR STABILITY

3.1 The test method shall be KRL Shear, Procedure CEC L-45-T-53, run for twenty hours.

3.2 The average viscosity reduction from two tests must be a maximum of 12.5%.

4.0 VISCOSITY

4.1 High-Temperature Viscosity

4.1.1 The test method shall be ASTM D 445

4.1.2 The maximum kinematic viscosity of new oil at 100 ^{o}C shall be 15.0 cSt.

4.1.3 The minimum kinematic viscosity of new oil at 100 ^{o}C shall be 14.0 cSt.

4.2 Low-Temperature Viscosity

4.2.1 The acceptability criterion shall be a maximum Brookfield viscosity (Test method ASTM D 2983) of 60,000 cP at –30 ^{o}C.

4.2.2 The acceptability criterion shall be a maximum pumping viscosity (test method ASTM D 4684) of 10,000 cP at –20 $^{\circ}$C.

5.0 FRICTION LEVEL

5.1 The test method is identical to that described in Section 6 of “TO-4 Transmission and Drive Train Fluid Requirements”.

5.2 The acceptability criteria consist of the same maximum wear and minimum allowable energy limits as those prescribed in 10.2 of Section 6, but slightly different specifications of

coefficient levels. Those levels will be generated from tests with the Caterpillar TO-4M oil, rather than the SAE 30 reference oil. To be certified as a TO-4M oil, a candidate must be tested with all six friction materials (seven tests total), as described in 10.2.3 of Section 6. The candidate must perform relative to the TO-4M oil as defined in Section 6, Figure 3.