Standard Test Method for Determination of Lubricity of Two-Stroke-Cycle Gasoline Engine Lubricants[1]

1. Scope

1.1 This test method[2] evaluates the ability of lubricants to minimize piston and bore scuffing in two-stroke-cycle spark-ignition gasoline engines.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

B152/B152M Specification for Copper Sheet, Strip, Plate, and Rolled Bar

D439 Specification for Automotive Gasoline[4]

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration

D874 Test Method for Sulfated Ash from Lubricating Oils and Additives

D2270 Practice for Calculating Viscosity Index from Kinematic Viscosity at 40 and 100°C

D2700 Test Method for Motor Octane Number of Spark-Ignition Engine Fuel

D2885 Test Method for Determination of Octane Number of Spark-Ignition Engine Fuels by On-Line Direct Comparison Technique

D2896 Test Method for Base Number of Petroleum Products by Potentiometric Perchloric Acid Titration

D4857 Test Method for Determination of the Ability of Lubricants to Minimize Ring Sticking and Piston Deposits in Two-Stroke-Cycle Gasoline Engines Other Than Outboards

D4858 Test Method for Determination of the Tendency of Lubricants to Promote Preignition in Two-Stroke-Cycle Gasoline Engines

E178 Practice for Dealing With Outlying Observations

2.2 *Coordinating European Council (CEC) Standard*[5]

CEC L-19-T-77 The Evaluation of the Lubricity of Two-Stroke Engine Oils

3. Terminology

3.1 *Definitions:*

3.1.1 *combustion chamber—in reciprocating internal combustion engines*, the volume bounded by the piston crown and any portion of the cylinder walls extending above the piston crown when in the top dead center position, and the inner surface of the cylinder head including any spark plugs and other inserted components. **D4858**

3.1.2 *lubricity*—a qualitative term describing the ability of a lubricant to minimize friction between and damage to surfaces in relative motion under load.

3.1.3 *preignition—in a spark-ignition engine*, ignition of the mixture of fuel and air in the combustion chamber before the passage of the spark. **D4858**

3.1.4 *scuff, scuffing—in lubrication*, damage caused by instantaneous localized welding between surfaces in relative motion which does not result in immobilization of the parts.

3.1.5 *spark plug fouling*—deposition of essentially nonconducting material onto the electrodes of a spark plug that may,

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.B0.06 on Two-Stroke Cycle Gasoline.

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[2] Until the next revision of this test method, the ASTM Test Monitoring Center will update changes in this test method by means of Information Letters. These can be obtained from the ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206–4489. ATT: Administrator. This edition incorporates revisions in all Information Letters through No. 01–4.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

[5] Order from the Coordinating European Council, 61 New Cavendish Street, London W1M 8AR, England.

but will not necessarily, prevent the plug from operating. **D4857**

3.1.6 *spark plug whiskering, or spark plug bridging*—a deposit of conductive material on the spark plug electrodes which tends to form a bridge between them, thus shorting out the plug. **D4857**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *benchmark reference oil*—a reference oil that represents an acceptable level of performance with regard to the property evaluated in an engine test and whose performance in the test is equaled, within the tolerance allowed, or exceeded by that of the non-reference oil.

4. Summary of Test Method

4.1 The test has been developed to replace the CEC L-19-T-77 Lubricity Test, for which test engines are no longer available. It is run in a 49 cm^3 single-cylinder air-cooled two-stroke-cycle engine operated at 4000 rpm wide open throttle (WOT) using a 150:1 mixture of gasoline and oil by volume. After conditions have stabilized, the cooling air is cut off. The output torque is measured when the spark plug gasket temperature reaches 200°C and again when it reaches 350°C, at which point the cooling air is restored. The smaller the reduction in torque output during this period, the better the ability of the oil to lubricate the piston. This test is not normally damaging to the engine. Sets of five such tightenings are normally run, using alternately a benchmark reference oil and the non-reference oil for each set.

NOTE 1—*Pass-fail Criterion*—Obtain the mean torque drop with a non–reference oil that is the same or less than that with the reference oil as calculated by the procedures of Annex A4.

5. Significance and Use

5.1 The oil in a two-stroke-cycle gasoline engine is either mixed with the fuel prior to use or is metered into the fuel supply at, or at some point prior to, its passage into the engine crankcase. The possibility of the amount of oil actually present in the engine being less than optimum always exists. Also, with some oil metering systems short periods of operation with less oil than desirable can occur when the power is increased suddenly. It has also been found that the incidence of piston scuff early in the life of the engine may be related to the lubricity of the oil used as defined by test procedures of this type.

6. Apparatus

6.1 *Test Engine and Stand*:

6.1.1 *Test Engine Configuration*—A Yamaha CE-50 49 cm^3 loop-scavenged air-cooled two-stroke-cycle engine is used. This has 40 mm bore, 39.2 mm stroke, with an aluminum piston operating in a cast iron cylinder bore. The cylinder head is removable, with a hemispherical combustion chamber. Further details are given in Annex A1. For the purposes of this test the standard piston-to-bore clearance is increased as specified in 6.1.2. The engine is no longer produced. Small quantities of parts can be obtained through Yamaha dealers. Special arrangements must be made through Yamaha for the production of large quantities of test parts.

NOTE 2—The engine designation normally includes a final letter indicating the model, such as CE-50S, the model on which this test was developed. If this model is not available check the suitability for this test of available models with the manufacturer.[6]

6.1.2 *Adjustment of Piston Clearance*— For the purposes of this test method, the cylinder bore shall be honed to give a 0.10 to 0.13 mm piston skirt diametral clearance with a 0.45 to 0.7 µm arithmetic mean roughness finish, as specified in A3.4. It is recommended that a number of cylinders be honed out as it is normally necessary to use a new piston for each test and a new cylinder after every three tests. The modified cylinders shall be clearly marked as such.

(1) The power and specific fuel consumption curves at 500 rpm intervals over the range from 3000 to 6000 rpm.

(2) The spark plug gasket temperatures for each point of the power curve.

(3) Modified piston clearance, with measurements of the piston and cylinder bore dimensions. Additional modified piston and cylinder assemblies can also be supplied.

(4) Measurements of the piston rings, ring grooves, ring clearances, and ring gaps.

6.2 *Test Stand*—The dynamometer shall be able to absorb 2.5 kW at 4000 rpm with an inherent torque measurement accuracy of ±0.5 % or better, and be capable of maintaining 4000 ± 30 rpm with varying power input. A direct shaft drive or a belt drive from the engine crankshaft may be used. A complete test stand assembly, as shown in Fig. 1, is available.[7]

6.3 *Cooling Blower*—The original internal engine fan shall be removed or have its blades machined off. A variable delivery blower with a free flow capacity of about 34 m^3/min of air is recommended. The flow from the blower shall be directed toward the intake side of the engine, as may be seen in Fig. 1.

6.4 *Fuel System*—Quick disconnects or other means to facilitate rapid interchange of fuel supply shall be provided as near to the carburetor as practicable. When local regulations permit their use, outboard portable fuel tanks of about 20 to 25 L capacity and flexible fuel hoses are suitable. In any case three fuel sources will be needed for a test, one for the non-reference oil fuel mix, one for the reference oil fuel mix, and one supplying test gasoline only with no oil. The temperature of the fuel entering the carburetor shall not exceed 25°C, and this may require cooling in hot climates.

6.5 *Instrumentation*:

6.5.1 *Tachometer*—An electronic or vibration tachometer accurate to ±25 rpm.

6.5.2 *Measurement of Ambient Conditions*—It is assumed in this section that the engine draws ambient air from the test room. If it is supplied with air from a controlled source, references to ambient temperature, pressure and humidity apply to the air from the controlled source.

6.5.2.1 *Temperature*—A thermocouple or thermometer shall be provided to read air temperature in the range 10 to 50°C.

[6] Obtainable from Engineering and Service Dept., Yamaha Motor Corp., 6555 Katella Ave Cypress, CA 90630. Parts, but not complete engines, are obtainable from Yamaha motorcycle dealers.

[7] A thermocouple gasket that has been found satisfactory may be obtained from The Lewis Engineering Company, 238 Water St., Naugatuck, CT 06770.

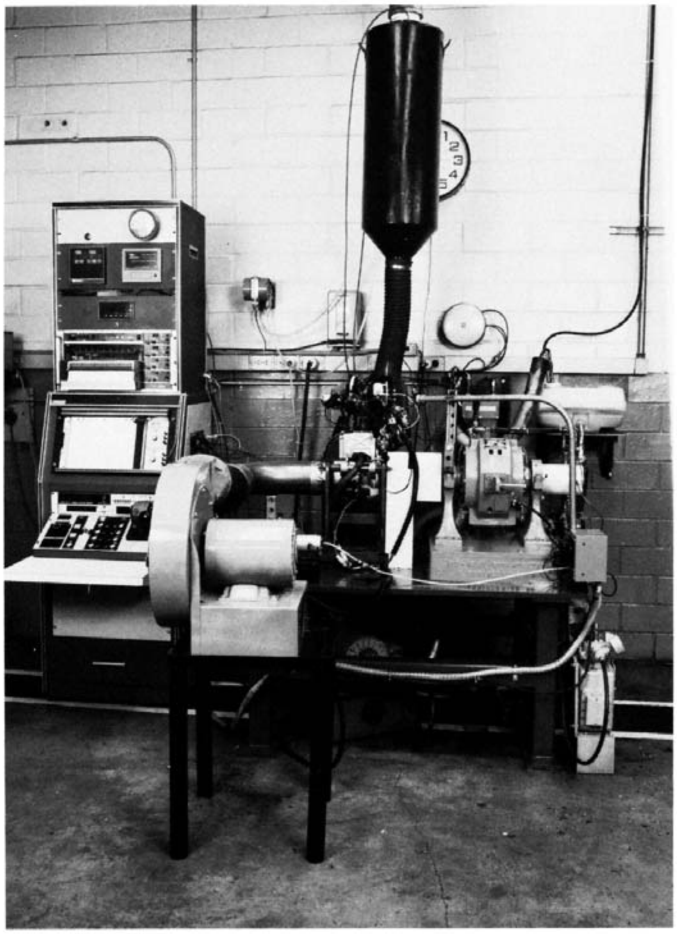


FIG. 1 Test Stand

The overall accuracy of temperature measurement, including that of recorders, shall be within ±1°C.

6.5.2.2 *Barometric Pressure*—A barometer measuring the pressure in the test room is required. Its overall accuracy, including the recorder, shall be within ±0.1 kPa.

6.5.2.3 *Humidity*—A hygrometer accurate to ±3 % or a wet and dry bulb thermometer accurate to ±1°C is also required.

6.5.2.4 *Calibration*—Calibrate the tachometer, ambient temperature, and pressure measurement devices every 90 days. The calibration standard shall be traceable to NIST.

6.5.2.5 *Recorder*—Continuous recording of the ambient conditions is recommended.

6.5.3 *Engine and System Temperatures*:

6.5.3.1 *Spark Plug Gasket Temperature*—The spark plug gasket may be fitted with one or two thermocouples, the number depending on the instrumentation used. A design that has been found satisfactory is described in Appendix X1.[7]

6.5.3.2 *Exhaust Temperature*—A thermocouple is required in the exhaust elbow within approximately 65 mm from the cylinder exhaust port to monitor exhaust temperature.[8] The thermocouple junction shall be located within ±3 mm of the center of the pipe.

6.5.3.3 *Spark Plug Gasket and Exhaust Temperature Recorders*—These temperatures shall be recorded using a system capable of storing the data for later retrieval. Maximum interval between successive recordings of the spark plug gasket temperature shall not exceed 1 s, those of the exhaust temperature should not exceed 10 s. A recorder with a range of 40 to 750°C and an overall accuracy of ±1°C is suitable. An alarm or automatic shut-down device may be provided.

6.5.3.4 *Calibration*—Calibrate the exhaust and spark plug gasket temperature measurement devices every 90 days. The calibration standard shall be traceable to NIST.

7. Materials and Reagents

7.1 *Test Fuel*:

7.1.1 Phillips J is the preferred test fuel.[9] It consists essentially of hydrocarbons and contains trace amounts only of lead.

7.1.2 If Phillips J is not available, use gasoline containing 0.013 g/L maximum of lead, free of non-lead metallic antiknock additives and oxygenated blending components such as alcohols or ethers, with a minimum Motor Octane number of 82 as determined by Test Method D2700 or D2885 and otherwise conforming to the requirements of Specification D439 Class A or Class B. It may contain conventional anticorrosion, anti-icing, and so forth, additives and oxidation inhibitors in normal concentration. Any such alternative gasoline shall be tested by the procedure of 9.6 before it is adopted as a test fuel as it has been found that adequate differentiation between reference oils cannot be obtained with some fuels, some as *iso*octane, that otherwise meet the requirements of this section.

7.1.3 About 72 L of fuel are required for a complete test, including 15 L for the break-in.

7.2 *Reference Oils*—ASTM 604 and 602 reference oils are used for calibration purposes.[10] ASTM 600 reference oil is used for break-in and as an assembly lubricant, and can be specified as the benchmark reference oil. About 0.4 L of each reference oil is required to run a calibration test, and 0.4 L of 600 for a break-in. The properties of these oils are summarized in Annex A2.

7.3 *Non-reference Oil*—About 0.4 L is required for a test. At least twice this amount should be provided in case the test is rerun.

8. Procedure

8.1 *Assembly of Engine*:

8.1.1 *Initial Build*—The test engine is initially built up using a new piston, rings, cylinder (modified as specified in 6.1.2), and cylinder base and head gaskets (see Annex A3). The test is not sensitive to compression ratio and this need not be determined.

8.1.2 *Rebuild After Test*—It is not necessary to use new parts after each test other than gaskets, a new piston, new piston rings and a new or reconditioned muffler, provided that all parts are clean and within specification with no sign of

[8] A suitable instrument is available from Omega Engineering Inc., P.O. Box 4047, One Omega Dr., Stanford, CT 06907.

[9] Available from Phillips Chemical Co., Specialty Chemicals, P.O. Box 968, Borger, TX 79008-0968.

[10] Available from ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206–4489.

damage. The cylinder will usually require replacement after 3 to 5 complete tests (approximately 60 tightenings). After 125 to 175 complete tests (about 1000 to 1500 running hours) the entire engine will normally require replacement or a complete rebuild.

9. Operating Instructions

9.1 *Fuel Temperature and Pressure*—The temperature of the fuel entering the carburetor shall not exceed 25°C and fuel delivery pressure shall be maintained at 19 to 21 kPa.

9.2 *Break-In*—Each time that the cylinder is replaced the engine shall be broken in for 2 h using a 20:1 (5 % oil) by volume mixture of test gasoline and ASTM 600 reference oil under the conditions of Table 1. After break-in the piston and cylinder shall be removed and examined. If there is any sign of piston scuff, ring sticking, or other malfunction the parts involved shall be replaced and the break-in repeated. On completion of break-in and before the engine is opened for inspection, run for 5 min at 4000 rpm at no load using oil-free test gasoline.

9.3 *Test*:

9.3.1 All testing is performed using a 150:1 (0.67 % oil) fuel to oil volumetric mixture. The temperature of the fuel entering the carburetor shall not exceed 25°C. Run at 4000 rpm and WOT for 25 to 30 min to establish thermal equilibrium, delivering about 1.4 kW. Regulate the cooling air to give a spark plug gasket temperature of 169 to 171°C. The cooling air is then shut off. As soon as the spark plug gasket temperature reaches 200°C, record the output torque, and when it reaches 350°C, record the torque again and restore the cooling air. The torque drop between 200°C and 350°C spark plug gasket temperature is determined. It is recommended that the torque and the corresponding spark plug gasket temperature be recorded simultaneously on a *X-Y* plotter and the torque drop determined from this record. After the cooling air has been restored, stabilize the plug gasket temperature again at 169 to 171°C. Run for 3 to 4 min and again shut off the cooling air to repeat the test. To obtain good repeatability it is advisable to run at an ambient temperature of about 23 to 27°C, and it is very important to protect the engine from drafts, especially during the period that the cooling air is cut off. A typical recording of torque against spark plug gasket temperature is shown as Fig. 2. Repeat to give a set of at least five tightenings. Under the conditions of 9.3.3, a set may consist of up to seven tightenings.

9.3.2 Alternate the non-reference oil and reference oil sets, running a series of two non-reference and two reference sets as indicated in Table 2. Each set shall be run without interruption, and the interval between sets shall not exceed 1 h. If the test is interrupted for any longer period the entire test shall be rerun as set-to-set comparisons are then not reliable.

9.3.3 *Range of Torque Drops*—For each set of tightenings, keep a running record of the range (difference between the highest and lowest values). If this exceeds 0.085 N·m, run an additional tightening in case one is rejected. If, after replacing the most deviant value in the set, the range is still greater than 0.085 N·m, run one more tightening. No more than seven tightenings per set may be run. If an acceptable range cannot be obtained by discarding two out of seven tightenings terminate the test, rebuild the engine, and rerun.

9.3.4 *Change-Over Engine Flush*—After completing each set run the carburetor dry and change or flush out the fuel supply lines. Then restart and run for 5 min at 4000 rpm at no load on oil-free test fuel before beginning the next set.

TABLE 1 Break-In

Duration Minutes	rpm	Throttle Position	Spark Plug Gasket Temperature, °C
2	1900–2100	closed	record
2	3900–4100	⅓ open	125 max
2	5400–5600	⅓ open	125 max
2	3400–3600	⅓ open	125 max
2	4400–4600	⅓ open	125 max
Repeat for a total of 2 cycles, or 20 min running time.			
Duration Minutes	rpm	Throttle Position	Spark Plug Gasket Temperature, °C
2	1900–2100	closed	record
2	3900–4100	½ open	140 max
2	5400–5600	½ open	140 max
2	3400–3600	½ open	140 max
2	4400–4600	½ open	140 max
Repeat for a total of 4 cycles, or 40 min running time.			
Duration Minutes	rpm	Throttle Position	Spark Plug Gasket Temperature, °C
2	1900–2100	closed	record
2	3900–4100	¾ open	155 max
2	5400–5600	¾ open	155 max
2	3400–3600	¾ open	155 max
2	4400–4600	¾ open	155 max
Repeat for a total of 4 cycles, or 40 min running time.			
Duration Minutes	rpm	Throttle Position	Spark Plug Gasket Temperature, °C
2	1900–2100	closed	record
2	3900–4100	WOT	170 max
2	5400–5600	WOT	170 max
2	3400–3600	WOT	170 max
2	4400–4600	WOT	170 max
Repeat for a total of 2 cycles, or 20 min running time.			

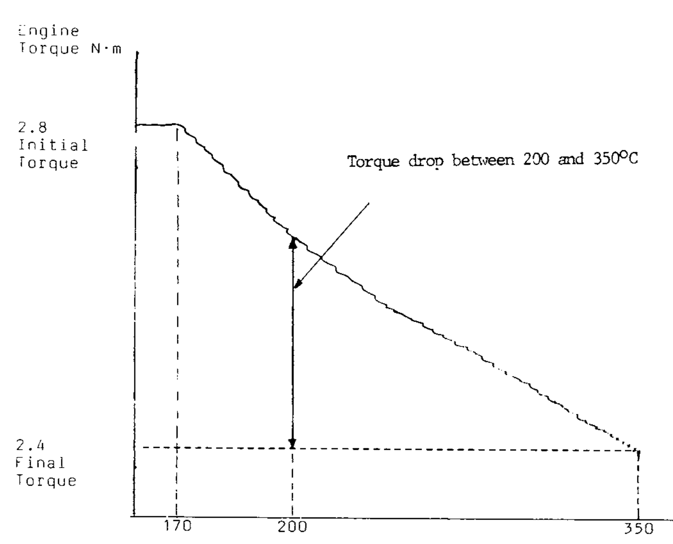


FIG. 2 Torque/Temperature Trace

TABLE 2 Test Running Procedure

Oil	Runs Number	Set No.
Reference (benchmark)	1–5	1
Non-reference oil	6–10	2
Reference (benchmark)	11–15	3
Non-reference oil	16–20	4

9.3.5 *Spark Plug Malfunction*—Malfunctioning plugs are replaced and the test continued, repeating any set of tightenings during which this occurs (see Note 4).

9.4 *Calculation*—The mean (average) value and standard deviation of the torque drop are calculated separately for the reference and the non-reference oil. These values are used to determine whether there is a significant difference between the results obtained with the two oils. A sample calculation is found in Annex A4.

9.5 *Anomalous Results*—Check for apparent outliers, especially if the range of the results in any set of tightenings exceeds the value specified in 9.3.3. If these are suspected but are not obvious the procedures of Practice E178 are used to test their validity. See Annex A4.

NOTE 3—*Pass-Fail Criterion*—If the average torque drop obtained with a candidate oil is equal to or less than that obtained with the benchmark reference oil, as calculated by the procedures specified in Annex A4, the candidate passes.

9.6 *Calibration*:

9.6.1 After 30 tests or 180 days, whichever comes first, or any time a new or completely rebuilt engine is put in service, evaluate reference oils 604 and 602 oils as if they were a non-reference oil, using the 600 reference oil as the benchmark oil. For an acceptable calibration, the performance of the 602 reference oil, as determined by the procedures called for in 9.5 and 9.6, shall be rated as a pass, equal to or better than that of the 600 reference oil, and the performance of the 604 oil shall be rated as a fail.

9.6.2 In order for a test stand to be acceptable for non-reference oil evaluation it shall have been calibrated by the procedure of 9.6.1.

10. Report

10.1 *Report Forms*—The required report forms and data dictionary are available from the ASTM Test Monitoring Center.

10.2 The detailed results obtained from tests on any of the reference oils shall be made available to ASTM Test Monitoring Center upon request so that statistical analysis of test consistency may be made.

11. Retention of Parts and Records

11.1 The testing laboratory shall retain for a minimum of 3 years the log sheets, recordings, and other test records from both non-reference and reference tests, and the original of the Report. A 1-L retain sample from each batch of reference oil and from each batch of test gasoline shall also be retained, recording the amount and type of inhibitors added to the gasoline if such addition is considered to be advisable.

12. Precision and Bias

12.1 *Precision*—No precision statement can be made as this test determines only that the lubricity of a non-reference oil is or is not equal to or greater than that of a reference oil.

12.2 *Bias*—The procedure of this test method has no bias because lubricity is defined only in terms of the test method.

NOTE 4—As stated in 9.3.2, tests run using the same engine cannot be validly compared if they are separated by a shutdown of more than about 1 h. Statistically valid comparisons can be made between sets of tightenings on different oils if, and only if, they have been run as an essentially continuous series. This limitation is well established for the CEC L-19 test on which this test is based, and appears also to apply to this test method.

ANNEXES

(Mandatory Information)

A1. SPECIFICATION OF THE TEST ENGINE

A1.1 Specification of the Yamaha CE-508 Test Engine

A1.1.1 *General*:
Single-cylinder, loop scavenge
Aluminum piston, slightly concave head
Two pegged rings, 1.1 mm thick
Cast iron bore in aluminum
Removable hemispherical head
Built-up crank, solid connecting rod
Antifriction bearings throughout
Tikai Kikaki Y12P carburetor
Idle setting 1500 to 2100 rpm

A1.1.2 *Dimensions*:

Cylinder bore	40 mm
Stroke	39.2 mm
Compression rate	7.0:1 to 8.0:1

A1.1.3 *Ignition Settings*:
Timing 18° BTDC (not adjustable)
Breakerless CDI ignition

A1.1.4 *Spark Plug*:
NGK BP6HS, or equivalent.
Plug gap setting 0.9 mm
Plug torque 19 to 20 N·m

NOTE A1.1—The average compression ratio determined on a random sample of 10 engines was 7.53:1. The range was 7.01:1 to 8.10:1. This test procedure does not call for any specific compression ratio.

A2. REFERENCE OILS

A2.1 Reference Oils—Typical Properties

Designation (ASTM)	600	604	602
Viscosity mm^2/s, D445:			
40°C	34.2–38.2	56.6	107.9
100°C	6.1–6.6	8.2	12.4
Viscosity index, D2270	128	114	106
TAN mg KOH/g, D664	1.7	N/A	0.9
TBN mg KOH/g, D2896	6.5	N/A	5.7
Sulfated Ash, mass %, D874	<0.005	<0.005	0.75
Calcium mass %	0	0	0.25
Nitrogen mass %	0.58	0.40	0.02
Approximate Oil Composition, vol %			
150 Bright stock	9.00	0	60
650 Neutral	61.65	72.55	0
400 Neutral	0	0	40
Stoddard solvent	20.00	20.0	0
Additives	9.35[A]	7.45[A]	N/A[B]

[A] Principally an ashless dispersant.
[B] Principally a metallic-organic detergent.

A2.2 The applications of the reference oils used in this test method are described in 7.2 and 9.6.1.

A3. YAMAHA CE-50S ENGINE BUILD PROCEDURE

A3.1 *General:*

A3.1.1 This annex summarizes the inspection of a new Yamaha CE-50S test engine prior to test and the inspection and part replacement required between tests. For greater detail and for operations other than those summarized here, refer to the Yamaha CE-50S Service Manual.[6]

A3.2 *Disassembly:*

A3.2.1 *Cylinder and Piston*—Remove the engine cowling and spark plug. Using a cross-over pattern, loosen the cylinder head nuts ¼ turn at a time until free, then remove the nuts and cylinder head. Remove the intake manifold and reed valve assembly. Remove the cylinder. Place a clean shop towel into the crankcase opening around the connecting rod. Remove the piston pin locks using suitable pliers. Gently tap or, preferably, press out the piston pin using a piloted driver. If it will not come out readily heat the piston, as the use of force may damage both the piston and the connecting rod. Remove the piston and ring assembly. If this is a new unit, proceed as specified by A3.3 and A3.4. If the engine has been run on test, replace the piston and rings and, if desired, the cylinder. See A3.4 for matching of pistons and cylinders. Use a new or cleaned cylinder head.

A3.2.2 *Crankcase*—If it is necessary to disassemble the crankcase, refer to the Yamaha CE-50S Service Manual. This is not normally required every 10 runs.

A3.3 *Inspection of Parts:*

A3.3.1 *Cylinder Gasket Surface*—Place the cylinder head gasket surface of the cylinder on a surface plate and try to wobble it. If it is possible to insert a 0.05 mm feeler gage between the surface plate and the gasket surface it shall be corrected or the cylinder rejected.

A3.3.2 *Cylinder Head*—Check its gasket surface for flatness as for the cylinder gasket surface, and correct or discard if necessary.

A3.3.3 *Connecting Rod and Crankpin Bearing*—Remove the towel from the crankcase opening and wash out the crankcase assembly with Stoddard solvent. Inspect the crankpin bearing for signs of discoloration. Measure and record the side clearance between the connecting rod and the crankthrow face. If this exceeds 0.5 mm or there is any sign of bearing distress, either replace the crankshaft, rod, and associated bearings and seals or discard and replace the entire engine. Lubricate thoroughly with 600 reference oil after inspection to prevent rust.

A3.3.4 *Induction System*—Inspect the intake manifold for cracks or warpage. Check the reed petals for cracks or chipping. Hold the reed valve assembly against a light source to check for leakage. Replace any defective parts.

A3.3.5 *Other Components*—Make a general inspection of the air filter, carburetor and ignition wiring; cleaning, repairing, or replacing as necessary.

A3.4 *Rework of Engine Parts:*

A3.4.1 *Piston Clearance*—The diametral piston to bore clearance, determined as specified in A3.4.2-A3.4.4, shall be between 0.10 and 0.13 mm. This will require the bore to be honed out to a 0.45 to 0.7 µm arithmetic average finish. The use of a 150 grit stone for initial honing and a 280 grit finish stone is recommended. After honing is complete, the cylinder shall be labeled or marked with its maximum and minimum bore diameter, as determined by A3.4.2.

A3.4.2 *Cylinder Bore*—After honing (before, if desired), measure and record the cylinder bore along the crank axis and at 90° to it to the nearest 0.01 mm in the following locations.

7 mm below the top of the bore.
12 mm below the top of the bore.
32 mm below the top of the bore.

Record the maximum out-of-round and the taper.

A3.4.3 *Piston*—Measure and record the piston diameter along the crank axis and at 90° to it to the nearest 0.01 mm in the following locations.

The middle of the top land.
12 mm from the top of the piston.
32 mm from the top of the piston.

Label or mark the piston with its maximum and minimum diameter.

A3.4.4 *Piston Clearance*—Before running a piston in a specific cylinder, calculate the following:

$$\text{Minimum Clearance} = \text{Smallest bore dia.} - \text{Maximum piston dia.}$$

$$\text{Maximum Clearance} = \text{Maximum bore dia.} - \text{Minimum piston dia.}$$

If these fall outside the limits of A3.4.1, exchange or reject the parts.

A3.4.5 *Piston Rings*—Insert each ring separately into the bore 15 mm from the top, using a piston or a ring positioning plug to ensure that it is square with the bore. Measure and record the end gap. End gaps shall be 0.15 to 0.45 mm. Assemble the rings onto the piston. Ring side clearance shall be 0.03 to 0.05 mm. If these limits are not met, reject or select other parts as necessary.

A3.4.6 *Ports*—Inspect the ports for sharp edges or burrs. When found, file by hand to remove the sharp edge. Do not enlarge the ports.

A3.5 *Assembly:*

A3.5.1 *Power Section*—Lubricate all bearings with ASTM 600 reference oil. Mount the piston on the rod *with the arrow on the crown facing the exhaust side* of the engine. Apply gasket sealer to both sides of the cylinder base gasket and mount it on the crankcase. Locate the ring gaps over the locating pins in the ring grooves. Lubricate the piston assembly and bore with 600 reference oil and mount the cylinder over the piston assembly. Mount the head, tightening the nuts first to 5 to 6 N·m and then to 10.5 to 11.5 N·m using a cross-over pattern. Determination of the compression ratio of the engine is not required for this test.

A3.6 *Ignition System*—Check that the ignition timing is between 17° and 19° BTDC. This is electronically controlled and is not mechanically adjustable.

A3.7 *Induction System*—Apply a thin coat of sealant to both sides of the reed block gasket and install it to the cylinder. Install the reed block assembly and the intake manifold. Tighten the bolts to 0.7 N·m. Mount the carburetor, with a new gasket, and tighten also to 0.7 N·m.

A3.8 Install the air shroud and fan cover. Tighten the bolts to 0.7 N·m.

A3.9 *Spark Plug*—Gap a new NGK BP6HS or equivalent spark plug to 0.9 mm. Lubricate the threads with antiseize compound, taking care to keep the electrodes clean. Install the plug, tightening to 1.7 N·m.

A3.10 *Exhaust*—Install the exhaust system, using a new gasket.

A4. COMPUTATION OF RESULTS

A4.1 As noted in 9.4 of the procedure, the mean (average) value $\bar{x}$ and the estimate of standard deviation s of the torque drop are calculated separately for each of the two sets of benchmark reference oil tightenings and for the two sets run with the non-reference oil. Any consistent units may be used.

A4.2 *Experimental Results:*

A4.2.1 In a set of tightenings, the following torque reductions were obtained.

Oil	*Delta Torque, N·m*
Benchmark	0.275 (0.336) 0.258 0.249 0.244 0.260
Non-reference	0.264 0.251 0.263 0.247 0.256
Benchmark	0.262 0.248 0.268 0.272 0.248
Non-reference	0.263 0.259 0.267 0.270 0.265

A4.2.2 It is evident before the completion of the first set of tightenings that the range is greater than 0.085 N·m, and an extra tightening run is made as required by 9.3.3. In this case the second value, in parentheses, is obviously out of line and can be discarded without further analysis. Such individual anomalous values are frequently the result of a misfire. Should the second value have been 0.321 N·m it would still be suspiciously high, but not so far as to be automatically thrown out. In such a case use the procedure of Practice E178, as specified in A4.5, to determine the validity of a suspect result. If more than two out-of-line data points are found in any set of results discontinue the test: investigate and correct the cause before re-running.

A4.3 *Calculation*—It is strongly advised that the calculations of this section, together with the running determination of the range of values in a set, be set up in a computer or calculator accessible to the operator of the test.

NOTE A4.1—Many pocket calculators have a built-in routine for mean and estimated standard deviation, but some of these (and some handbooks) use the divisor $\sqrt{n}$ rather than $\sqrt{(n-1)}$. This gives the *universe* or *large sample* estimate of standard deviation s rather than the *small sample* estimate s appropriate in this case, and for $n \leq 20$ the difference is significant. If you are not sure calculate the estimate of standard deviation for the data set 1, 2, 3. If the answer is 1.0 all is well. If it is about 0.816 all results obtained using that calculator shall be multiplied by $\sqrt{n} / \sqrt{(n-1)}$.

TABLE A4.1 Critical Values of the *t*-Distribution[A]

Degrees of Freedom[B]	Degrees of Confidence				
	90 %	95 %	97.5 %	99 %	99.5 %
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
30	1.310	1.697	2.042	2.457	2.750

[A] This table is not complete, listing only a range of values slightly greater than that applicable to the Annex A4 procedure.

[B] For non-grouped data as used in the procedure of Annex A4, the degree of freedom equals the total number of data points minus the number of samples. For a single sample of size n the degree of freedom equals $(n - 1)$. If two samples of size n_1 and n_2 are combined the degree of freedom is $(n_1 + n_2 - 2)$.

A4.3.1 Means and estimates of standard deviation are calculated from the expressions:

$$\text{Mean } \bar{x} = \frac{\Sigma X_n}{n} \quad \text{(A4.1)}$$

$$\text{Estimate of Standard Deviation } s = \frac{\sqrt{\Sigma(X_n - \bar{x})^2}}{\sqrt{(n-1)}} \quad \text{(A4.2)}$$

The estimate of standard deviation can be also be calculated using the mathematically equivalent form:

$$s = \frac{\sqrt{((\Sigma X_n{}^2) - (\Sigma X_n)^2/n)}}{\sqrt{(n-1)}} \quad \text{(A4.3)}$$

where:

X_n = individual data points, and
n = number of data points.

Using the data of A4.2.1, after rejection of the outlier, this gives:

For the benchmark oil mean = 0.2584
standard deviation = 0.01096

For the non−reference oil mean = 0.2605
standard deviation = 0.00725

A4.4 *Determination of Result:*

A4.4.1 The non-reference oil shows a slightly greater mean torque loss (0.2605) than does the reference oil (0.2584). Because of the relatively small number of readings for either oil, this can be a statistical accident and their performance can in fact be equivalent. This possibility can be evaluated using the one-tail Student small-sample t test for significance of difference of means.[11]

A4.4.2 On the assumption that experimental errors are the same for both oils, a combined estimate of the standard deviation s_{cb} can be calculated from the expression:

$$V_{cb} = ((n_b - 1)\cdot v_b + (n_c - 1) x v_c))/(n_b + n_c - 2) \quad \text{(A4.4)}$$

where $v = s^2$

and the subscripts c and b refer to the non-reference and benchmark oils. Do not calculate s_{cb} directly from the pooled data for both oils, as this procedure includes the difference between the means of the two samples as if it were part of the variance, tending to give too large a value. In the present example the error is insignificant as the means of the two samples are essentially identical, but if they were significantly different an improperly high value of s_{cb} in the denominator of Eq A4.5 would make the value of t^* smaller than it should be which could cause an oil to pass when it should have failed.

$$t^* = |x_c - x_b| S_{cb}\cdot(1/n_c + 1/n_b)^{1/2} \quad \text{(A4.5)}$$

A4.4.3 *Worked Example—* Using Eq A4.4 the estimate of s_{cb} is:

$$s_{cb} = ((9 \times 0.00012012 + 9 \times 0.0005256)/18)^{1/2} = 0.0093 \quad \text{(A4.6)}$$

The value of t^* is obtained from Eq A4.5:

$$t^* = |\,0.2584 - 0.2605\,|/(0.0093 \times (0.2)^{1/2}) = 0.505 \quad \text{(A4.7)}$$

From Table A4.1, t_{crit} = 1.734 for 95 % confidence and 18 degrees of freedom $(n_c + n_b - 2)$. As $t^* < t_{crit}$, the difference between the mean torque drops is not significant and the non-reference oil passes.

A4.5 *Investigation of an Out-of-Line Value*—In the case where the range of values in a set is less than 0.085 N·m, but one or two values appear suspect, use the procedures of Practice E178 Section 4 to check their validity. If one or both are rejected and no additional tightening has been run, recompute $\bar{x}$, s and t^* using the remaining data points. If more than two are rejected, rerun.

[11] This is the normally accepted procedure for this type of evaluation. Explanation and discussion can be found in most textbooks on statistical theory.

APPENDIX

(Nonmandatory Information)

X1. PREPARATION OF SPARK PLUG GASKET THERMOCOUPLES

X1.1 *Material:*

X1.1.1 *Gasket*—Use nominally pure (99.9 %) copper such as Specification B152/B152M. The use of quarter hard material (Grade H01 or 081) is recommended to facilitate machining. The method by which the gaskets are produced, turning, stamping from sheet, etc. is not critical.

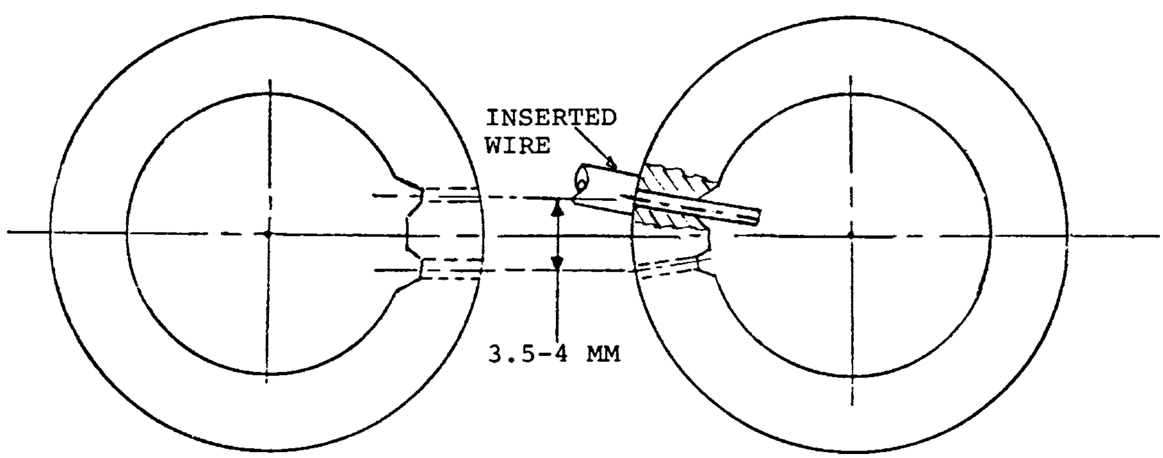
X1.1.2 *Thermocouple Wires*—One iron and one constantan Type J solid core glass or silica double-insulated thermocouple wire of 0.8 to 1 mm diameter and of any convenient length are required for each thermocouple. Up to four thermocouples can be installed in a single gasket.

X1.2 *Manufacture:*

X1.2.1 Make gaskets (rings), drilled and notched as shown in Fig. X1.1, as necessary to supply each spark plug of the unit to be tested. The notches in the inner diameter of the gasket at the ends of the radial holes are only required if the wires are soldered in place and, if used, are not critical as to size or finish. The drilled holes may be parallel or drilled radially, and their diameter such as to allow easy insertion of the thermocouple wires with minimum clearance.

X1.2.2 Remove insulation from the ends of the thermocouple wires so that the bare ends of the wires protrude beyond the inner diameter of the gasket when they are inserted into the holes from the outer diameter. Insert the wires as shown, and either apply silver solder to the inside ends or secure them with a crush fit. When the wires have been secured restore the inner diameter of the gasket by filing or grinding. If necessary, use shrink tubing to repair damaged insulation. Remove any silver solder that is on the faces of the gasket.

X1.3 Check the completed thermocouple gasket against a known standard. A reading within ±1°C of the standard is acceptable.



NOTE 1—The inserted wire is shown prior to silver soldering.
NOTE 2—Material copper—¼ hard.
NOTE 3—Outside diameter 20.8 – 21 mm. Inside diameter 14.3 – 14.6 mm. Thickness 1.8 – 2.2 mm. For other dimensions, see the text.

FIG. X1.1 Spark Plug Thermocouple Gasket