KNOCK-RATING OF MOTOR FUEL[1]— I.P. MOTOR METHOD

I.P.—44/44 (Tentative) Revised
A.S.T.M. : D 357–43 T (Modified)

INTRODUCTION

1. (*a*) This method of test is intended for determining the knock characteristics, in terms of an arbitrary scale of octane numbers, of fuels for use in spark-ignition engines.

(*b*) The field of knock testing is complex, and the following statement of fact, while well known to the expert, is presented as a warning to others who might assume that the test may be used without limitations to evaluate motor fuels in service.

(*c*) It has been demonstrated through years of research that no single laboratory test can be used as an accurate measure of the knock characteristics of a motor fuel. The tendency of a fuel to knock varies in different engines and depends on the weather conditions, the adjustment of the spark, carburettor, etc., and the design, condition, load, and particularly the speed of the engine. When used in a given engine, the complete knock characteristics of a given motor fuel can be determined only by running the fuel in that engine under varying operating conditions. The motor method octane number is an evaluation of the knock characteristics of the fuel in the C.F.R. engine under arbitrarily prescribed test conditions. Deviations of ratings of fuels on the road from ratings by the motor method may be large. In general, these deviations are less than plus or minus 3 octane units, although in exceptional cases they may amount to as much as 10 octane units.

I.P. MOTOR METHOD OCTANE NUMBER[2]

2. The I.P. motor method octane number of a fuel is stated as the whole number nearest to the percentage by volume of *iso*-octane (2 : 2 : 4-trimethylpentane) in a blend of *iso*-octane and normal heptane that the fuel matches in knock characteristics when compared by the procedure prescribed in this method.

APPARATUS

3. The knock-testing unit described in Appendix I shall be used without modification for determining I.P. motor method octane numbers.

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[1] This method, hitherto known as the C.F.R. Motor Method, is based on the apparatus and procedure developed by the Co-ordinating Fuel Research Committee and by the Standardization Committee of the Institute of Petroleum.

[2] The I.P. motor method octane number is identical with the A.S.T.M. motor octane number and the I.P. method differs from the A.S.T.M. method mainly in that further secondary reference fuels are made available and that the use of the spring tension measuring apparatus for setting the bouncing pin is preferred.

REFERENCE FUELS

4. (*a*) *Primary Reference Fuels.*—The primary reference fuels shall be *iso*-octane (2 : 2 : 4-trimethylpentane) and normal heptane. Only primary reference fuels certified by the National Bureau of Standards and supplied by manufacturers designated by the A.S.T.M. shall be used.[3]

(*b*) *Secondary Reference Fuels.*—To ensure a greater degree of reproducibility in testing, it is preferable to use secondary reference fuels[4] which have been calibrated against the primary reference fuels on a large number of engines. The calibration shall be expressed in terms of the octane-number scale, shall be based on results by this method from at least ten laboratories, and shall be certified by the National Bureau of Standards,[5] or by the Standardization Committee of the Institute of Petroleum.

(*c*) *Choice of Secondary Reference Fuels.*—Whenever possible, unleaded samples should be tested against blends of clear secondary reference fuels and leaded samples against secondary reference fuels to which T.E.L. has been added. The secondary reference fuels recommended are C and A, F and C, C + T.E.L. (up to 4-ml. T.E.L. per Imp. Gal.) and F + 4-ml. T.E.L. per Imp. Gal. with C + 4-ml. T.E.L. per Imp. Gal.

(*d*) *Storage and Blending of Reference Fuels.*—Cans of reference fuel when received should be removed from their packing cases and inspected for leakage.

Reference fuels should be stored in light-proof containers in a cool building and blended in a room the temperature of which should be below 77° F. (25° C.) and as constant as possible. Care must be taken that the fuels are allowed to reach room temperature before blending is commenced. Any reference fuel remaining in the original 5-gal. container after blending operations have been completed should be transferred to cans which it will completely fill, and should be used first for any subsequent blending before opening a fresh 5-gal. can.

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[3] At present, certification of normal heptane and *iso*-octane is based on tests made by the National Bureau of Standards under the specifications listed in Appendix IV. A certificate is issued to the producers authorizing them to guarantee to the purchasers that the material shipped is part of a batch so tested, and to quote the results of the tests. The designated manufacturers are:

Normal heptane .	Westvaco Chlorine Products Corporation, 405 Lexington Ave., New York, N.Y., or South Charleston, W. Va.
*iso*Octane . .	Röhm & Haas Co., 222 W. Washington Square, Philadelphia, Pa.

[4] Such secondary reference fuels are obtainable from Stanco Distributors, Inc., Chemical Products Department, 26 Broadway, New York, N.Y., with calibration tables as determined in accordance with this method giving A.S.T.M. motor octane numbers for these fuels blended with each other.

[5] This certification is based on tests made by the Motor Fuels Division of the C.F.R. Committee on samples from each batch of secondary reference fuels, and on blends of such secondary fuels against blends of primary reference fuels.

If reference fuels are drawn as required from overhead containers into graduated burettes for the preparation of blends, it is recommended that a closed system be employed to minimize evaporation.

All supplies of Ethyl Fluid must be handled in accordance with the safety precautions issued by the Ethyl Corporation.

STANDARD ENGINE AND OPERATING CONDITIONS

5. The engine shall be operated under the following standard conditions:

(*a*) *Engine Speed.*—900 ± 9 r.p.m. Throughout any one test the engine speed shall not vary more than 9 r.p.m.

(*b*) *Spark Advance.*—Automatically controlled as follows:

> 26·0° at 0·625-in. micrometer setting (basic spark setting),
> 24·0° at 0·500-in. micrometer setting,
> 22·0° at 0·400-in. micrometer setting, and
> 19·0° at 0·250-in. micrometer setting.

(*c*) *Spark Plug Gap.*—0·025 in.

(*d*) *Breaker-Point Gap.*—0·020 in.

(*e*) *Valve Clearances.*—Both intake and exhaust valves shall have hot and running clearances of 0·008 in., with the engine running under standard operating conditions on a reference fuel of 75 octane number.

NOTE 1.—The valves may be adjusted with the engine stopped, either hot or cold, if appropriate allowances are made so that the hot and running clearances will be as specified.

(*f*) *Crankcase Lubricating Oil.*—S.A.E. No. 30 (B.S. No. 210—1939) (viscosity range—130–175 sec. Redwood 1 or 31–43 cs. at 140° F.).

(*g*) *Oil Pressure.*—25–30 lb. per sq. in. under operating conditions.

(*h*) *Oil Temperature.*—120–150° F. (48·9–65·6° C.), with the temperature-sensitive element completely immersed in the crankcase oil.

(*i*) *Coolant Temperature.*—209–215° F. (98·3–101·7° C.). During a test the temperature shall be held constant within plus or minus 1° F. (0·6° C.).

(*j*) *Humidity of Intake Air.*—25–50 grains of water vapour per pound of dry air. (See Appendix I, Section A5 (*a*).) When air of the above humidity prevails in the engine-room through the operation of natural factors or air conditioning, it may be used without further conditioning. Its humidity shall be determined by the use of a suitable sling psychrometer.

(*k*) *Temperature of Intake Air.*—The temperature of the air entering the carburettor shall be between 75° and 125° F. (23·9° and 51·7° C.).

(*l*) *Mixture Temperature.*—300° ± 2° F. (148·9° ± 1·1° C.), as indicated by the mercury thermometer.

(*m*) *Carburettor Venturi.*—The following venturi sizes shall be used in the carburettor, without throttle plate or other restriction, at different altitudes:

Altitude, ft.	Diameter of venturi throat, in.
0–1600 . . .	$\frac{9}{16}$ (0·5625) ± 0·001
1600–3300 . . .	$\frac{19}{32}$ (0·59375) ± 0·001
Over 3300 . . .	$\frac{3}{4}$ (0·75) ± 0·001

(*n*) *Adjustment of Micrometer.*—When the clearance volume to the top face of the bouncing-pin hole is 140 ± 0·5 ml., as measured by the "tilt" method (see Appendix III), with the piston at top dead centre, the micrometer shall be set to read 0·500 in. (5·5 to 1 compression ratio).

(*o*) *Maximum Knock Mixture.*—At each compression ratio and for each fuel being tested, the fuel–air ratio shall be adjusted by varying the carburettor float level in increments, until the adjustment that produces a maximum knockmeter reading is obtained. The fuel level for maximum knockmeter reading shall be between 0·8 and 1·8 in. For some test fuels it may be necessary to change the size of the metering jet in order to meet this requirement. However, if this requirement is not met when using reference fuels, a thorough check of the carburettor and induction system should be made.

(*p*) *Standard Knock Intensity.*—Standard knock intensity shall be that obtained with a blend of reference fuels under the standard operating conditions of this method and at a micrometer reading corresponding to the octane number of the blend used and the prevailing barometric pressure, in accordance with the appropriate standard knock intensity guide table given in Appendix II.

PROCEDURE

OUTLINE OF TEST

6. The octane number of a fuel shall be ascertained by comparing the knock intensity for the fuel with those for various blends of the reference fuels until two blends differing in knock rating by not more than two octane numbers are found, one of which gives a higher knock intensity than the fuel, and the other a lower knock intensity. The knock intensity shall be measured by the bouncing-pin indicator in conjunction with the knockmeter. Before the test sample and the blends of the reference fuels can be compared, the compression ratio shall be set to give standard knock intensity for the test sample with the carburettor adjusted to give maximum knock.

STARTING AND STOPPING THE ENGINE

7. While the engine is being cranked, the ignition shall be turned on and the engine started by setting the carburettor to draw fuel from one float-bowl. To stop the engine, both fuel and ignition shall be turned off and the power-absorption apparatus stopped. To avoid corrosion and warping of valves and seats between operat-

ing periods, the engine should be rotated by hand until both valves are closed.

OBTAINING STANDARD KNOCK INTENSITY

8. With the engine temperature in equilibrium and the carburettor set for maximum knock, standard knock intensity for determining octane numbers shall be obtained (see Section 5 (*p*)) at the micrometer reading given in the appropriate standard knock intensity guide table for the octane number of the blend used and the barometric pressure [6] at time of test (see Appendix II).

ADJUSTING BOUNCING PIN

9. (*a*) *Adjustable Leaf Type Bouncing-pin.*—A description of the adjustable leaf type bouncing-pin is given in the manufacturers' instructions,[7] but the procedure given below for adjustment should be followed exactly, as the attainment of standard test conditions is entirely dependent on scrupulous attention to every detail.

(i) *Checking Bouncing-pin Condition.*—Remove the diaphragm and bouncing-pin to see that the pin is clean and free in its guides and that the diaphragm is of standard dimensions and the retaining-nut face is parallel to the diaphragm seat. Check the fitting of the leaf-spring saddle-pieces to see that they are a snug fit on the springs and that they are fitted close to the columns. See that the leaf-spring contacts are perfectly clean and that the rounded contact (the upper one) has no small " flats " on it.

(ii) *Setting the Bouncing-pin for Octane Rating.*—The pin may be adjusted in accordance with the method described in the manufacturers' instructions,[7] but it is strongly recommended that the spring tension apparatus (see Appendix VI) be employed if reproducible settings are to be obtained. The following are the limits between which the springs may be set:

	Deflection (in.).	Force (g.).
Lower leaf-spring	0·042	180
	0·057	245
Upper leaf-spring	0·114	440
	0·099	380
Plunger pressure, lower limit . .	—	454 (1-lb.)
Plunger pressure, upper limit . .	—	568 (1·25-lb.)

[6] When the barometric pressure is measured by a mercurial barometer having a brass scale, correction shall be made for ambient temperature by the formula:

$$B = B' - 0{\cdot}00009\, B' (t' - 28{\cdot}5),$$

where B = corrected barometric pressure, inches of mercury,
B′ = observed barometric pressure, inches of mercury, and
t' = observed temperature of the barometer in ° F.

Other barometric corrections may be neglected for the present purpose. A properly compensated aneroid barometer does not require correction, but should be calibrated at least once a year.

[7] See " A.S.T.M.–C.F.R. Knock-Testing Unit—Care and Operation," available from the Waukesha Motor Co., Waukesha, Wis.

For setting at 65 octane number for testing up to about 85 octane number, the lower leaf-spring should generally be set at the lower tension of 180 g., while the net balancing force between the upper leaf-spring and the plunger-spring should be about 130 g. For testing fuels above 85 octane number it is necessary to ensure that the bouncing-pin contacts are not closed by combustion pressure rather than by the effects of knocking. This can be determined by ensuring that there is a spread of ten knockmeter divisions between two reference fuels of respectively higher and lower octane number than the sample and differing by two octane numbers. It may be found necessary to increase slightly the contact gap and possibly also the downward tension of the lower leaf-spring. After re-setting the bouncing-pin in this manner, it will be necessary to re-establish standard knock by setting on a 90 or 100 octane number fuel (see Section 8).

For testing at 100 octane number the lower leaf-spring tension will generally have to be increased to its upper limit of 245 g., the standard knock intensity being attained by setting on a 100 octane number fuel (see Section 8).

(iii) *Spring-setting Procedure.*—To set the spring tensions to any required specification, the processes detailed below shall be carried out. The adjusting screws shall be used to set the springs for the particular tensions required.

The Plunger-spring.—In order to measure the plunger tension, the two leaf-springs should be swung aside by undoing their mounting screws at the end of the lower cross-bar. The pin should be raised out of the body until it touches the plunger, and the collar fastened to it at a point which gives $\frac{3}{16}$ in. clearance between the collar and the bouncing-pin platform.

The beam should be loaded until balance is obtained, and the plunger tension read directly from the scale by noting the position of the inner face of the jockey-weight. It should be between 454 and 568 g.

The Lower Leaf-spring.—With the two leaf-springs assembled and the pin-gap reduced to approximately 0·001 in., the beam should be loaded until the points just close by deflection of the lower leaf-spring. This loading should be within the limits 180–245 g.

The Upper Leaf-spring.—As further load is applied to the beam, the lower of the contact points will be thrust against the upper contact point, and eventually this upward thrust will just overcome the downward force of the upper leaf-spring and the plunger-spring. The point of balance is obtained just as the plunger is about to be moved. The reading on the scale gives the total downward force of the lower spring and the combined force of the upper spring and plunger.

The tension of the upper leaf-spring, which acts against the plunger, is given by subtracting the total downward force from the sum of the lower leaf-spring and the plunger-spring tension. It should be within the limits 440 and 380 g.

(iv) *Contact Gap.*—After setting the spring tensions, the contact gap shall be set to 0·003 in.

Notes.—The instrument may be used to calibrate the movement of the adjusting screws against spring tension. The following data have been obtained, but as bouncing-pin parts vary somewhat, it is recommended that the adjusting screws on the individual pins be calibrated. If this is done, then the instrument need not be used again until reassembly of the bouncing-pin after the next cleaning.

> One notch on the plunger screw is equivalent to approximately 15 g. tension on the plunger.
>
> One notch on the lower spring screw is equivalent to approximately 10 g. tension on the pin.
>
> One notch on the upper spring screw is equivalent to approximately 10 g. tension.

Care should be taken that the reading of the number of notches of turn of the upper spring screw is not incorrect on account of backlash.

The friction of the plunger in the guides, which is included in the recording of the tension of the plunger-spring, is static, since the actual movement of the plunger is negligible. Consequently it is considered that a measurement of the tension of the plunger cannot be expected to have an accuracy greater than $\pm$ 5 g. Friction of the plunger or spring may readily be detected by depressing the end of the lever with a finger.

The opinion is held that as the upper leaf-spring and the plunger-spring act in unison, their individual effects can be combined in one force called the net balancing force. The limits of the net balancing force, prescribed by the A.S.T.M., are 20 g. and 180 g., but it has been found that for maximum sensitivity, shown by the knockmeter reading, the net balancing force should be about 130 g. This holds, no matter what the individual forces are so long as their values fall within the limits set down in Section 9 (*a*) (ii).

(*b*) *Old-type Bouncing-pin.*—The old-type bouncing-pin is not recommended, but may be used if the adjustable leaf type is not available. Instructions for setting are as follows:

The gap-setting should be checked (0·003–0·005 in.). The flat spring of the lower contact should touch the insulated pin with slight pressure: too much pressure will reduce its sensitivity. To adjust the pressure accurately, set the points with 0·003–0·005 in. clearance; then remove the diaphragm and bouncing-pin. Bend the lower spring until there is from $\frac{3}{64}$ to $\frac{1}{16}$ in. gap between the points. Remove the upper stop-adjusting screw and bend the upper spring until there is $\frac{5}{32}$-in. gap between the points. Check the tension on the small plunger-spring in upper stop-adjusting screw and see that it has from 1 lb. to 1·25 lb. initial tension. This can be measured by pressing it against any convenient platform scale. The pin should then be reassembled and the adjusting screw set to give 0·003–0·005 in. gap between the points. The final adjustment is made by setting the clearance so that a knockmeter reading between 55 and 60 is obtained, when the engine is operated at the standard knock intensity.

CHECKING TEST CONDITIONS

10. (*a*) Engine conditions shall not be regarded as correct unless a blend of 68 per cent. of one-degree benzene [8] and 32 per cent. of normal heptane by volume matches a blend of 65 $\pm$ 0·3 per cent. *iso*-octane and 35 $\pm$ 0·3 per cent. normal heptane by volume under the procedure specified in this method. If this match cannot be obtained under standard conditions by adjustment of the bouncing-pin, the mechanical condition of the engine shall be checked. This is purely an engine check, and the bouncing-pin setting found to give the above match need not necessarily be used in subsequent tests.

NOTE 2.—If difficulty is encountered in obtaining the proper rating on the standardization fuel, the use of a strong cleaning solution to remove scale and sludge from the cooling jacket is recommended.

For checking both engine and test conditions at this and other octane number levels, secondary standardization fuels have been made available.[4] Conditions can be checked at any desired octane number level by choosing the proper blend. The rating for the blend should fall within plus or minus 0·3 octane unit of the value given in the calibration table.

(*b*) For subsequent tests on fuel samples the micrometer reading shall be set for standard knock intensity, using the knockmeter as a guide, provided no change has been made in the bouncing-pin adjustment in the meantime. The micrometer reading should be within plus or minus 0·020 in. below 85 octane number, and 0·025 in. above 85 octane number, of that given in the guide table for the octane rating of the reference fuel blend that matches the test fuel.

(*c*) In no case shall tests be made if the engine does not cease firing when ignition is interrupted.

ADJUSTING COMPRESSION RATIO AND CARBURETTOR

11. (*a*) *Preliminary Adjustment of Compression Ratio.*—After one bowl of the carburettor has been filled with the fuel sample, a preliminary adjustment of the compression ratio shall be made to give

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[8] " One-degree " benzene is a commercial product conforming to the following requirements:

(*a*) Boiling range not greater than 1° C., embracing the boiling point of chemically pure benzene.
(*b*) Specific gravity at 60° F./60° F. of from 0·882 to 0·886.
(*c*) Free from hydrogen sulphide, carbon disulphide, and thiophene.
(*d*) Free from turbidity, with colour not darker than a solution of 3 mg. of potassium dichromate in 1 litre of water, when compared in 50-ml. Nessler tubes.

a knockmeter reading of 55 ± 3 scale divisions. (As any necessary adjustment will increase the knockmeter reading, time can be saved by setting at 52 or in some cases even lower.)

(*b*) *Mixture Adjustment.*—The fuel level shall then be adjusted for the position of maximum knock as follows: With a setting of the fuel level, for example, of 1·3 in. on the etched glass scale, the knockmeter shall be allowed to reach equilibrium and readings shall then be recorded for this position. Knockmeter readings shall then be obtained and recorded for richer air–fuel ratios by raising the fuel level by 0·1-in. increments to settings of 1·2, 1·1, . . . until the knockmeter reading has decreased at least five divisions from the maximum reading recorded. The fuel level shall then be reset at the position for which the maximum knockmeter reading was recorded in the above, for example, 1·2 in. Starting from this point the same procedure as above shall be followed for leaner air–fuel ratios by setting in turn at 1·3, 1·4, . . . until the knockmeter reading has decreased at least five divisions from the maximum reading recorded. The fuel level shall now be set at the position for which the maximum knockmeter reading has been obtained and recorded, or between the two positions for which the same maximum reading was obtained, for example, 1·25 in. This is the position for maximum knock, but it shall be verified at least once by settings at levels 0·1 in. on either side; in the example just taken, at both 1·15 and 1·35 in. If higher knockmeter readings are obtained at one of these positions, the setting is in error, and the entire procedure shall be repeated. For each setting of the fuel level that is used the knockmeter shall be allowed to reach equilibrium before readings are recorded.

(*c*) *Final Adjustment of Compression Ratio.*—Finally, the compression ratio shall be adjusted to give a knockmeter reading of 55 ± 3 scale divisions. This setting of the compression ratio shall be left unchanged for the remainder of the test.

BRACKETING THE TEST FUEL

12. (*a*) *First Bracketing Reference Fuel.*—A trial blend [9] of the low- and high-octane reference fuels, based on the expected knock rating of the fuel sample under test, shall be placed in another carburettor float bowl and the engine run on this trial blend.

(*b*) *Mixture Adjustment.*—The fuel level of this float bowl shall

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[9] Extreme care is required to insure thorough mixing of the ingredients of all blends used in this test procedure.

As a precaution in changing fuels in the containers and fuel system, the fuel shall be drained completely by opening the drain cock. A small portion of the new fuel should be permitted to flow through the line before closing the drain cock. Air bubbles in the line are sometimes indicated by fluctuations in the fuel level or by unstable engine operation. They can be eliminated by flushing fuel through the drain cock after it has filled the carburettor float bowl. In doing this the drain cock should be rapidly opened and closed repeatedly, and care taken not to permit the level of the fuel to go below the range of the sight glass.

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then be adjusted to the maximum knock position as described in Section 11 (*b*).

(*c*) *Second Bracketing Reference Fuel.*—A second trial blend of reference fuels shall be selected so that the knockmeter reading obtained on the test fuel will lie between those obtained on the reference fuel blends. This second trial blend shall be placed in the third carburettor float-bowl, and the engine shall be run on this trial blend while the level of this float-bowl is adjusted to the maximum knock position as described in Section 11 (*b*). If the octane numbers of the first and second trial blends differ by not more than two units, the test shall be continued; if otherwise, such additional blends of reference fuels as may be necessary shall be prepared and tried in the manner described above until this requirement is met.

(*d*) *Obtaining Knockmeter Readings.*—With the float-bowls set at the air–fuel ratios of maximum knock, series of readings of knock intensity shall be taken on the test sample and on the two reference fuels. In each case the knockmeter shall be allowed to reach equilibrium before the reading is recorded. The test sample shall be bracketed between the two blends of reference fuels at least three times, as determined by knockmeter readings. (A simple procedure for doing this is to record readings in order for the second reference fuel, the test fuel, the first reference fuel, the test fuel, the second reference fuel, the test fuel, the first reference fuel.) In changing from one of these fuels to another, at least 1 min. shall be allowed for the engine and knockmeter to reach equilibrium. With some fuels an appreciably longer time interval may be required. This is particularly so when changing from reference fuels to samples of widely different T.E.L. content.

TEST FUEL RATING

13. The knockmeter readings obtained in accordance with Section 12 (*d*) shall be averaged for the test sample and for each of the reference fuel blends. The I.P. motor method octane number shall be found by interpolation from the averages so obtained, and shall be reported to the nearest integer. When the interpolated figure ends with 0·50, the even number shall be reported, for example, 68·50 shall be reported as 68, not 69.

PRECISION

14. Test results should not differ from the mean by more than the following amounts:

Repeatability.	Reproducibility.
0·5	1

However, the sensitivity of the method may permit the detection of differences as small as 0·2 octane number between two samples of similar characteristics by direct comparison using the procedure described in Section 12 (*d*).

APPENDIX I. APPARATUS

APPARATUS

A1. The knock-testing unit described in this appendix shall be used without modification. The engine shall be known as the " C.F.R. Engine "[10] and shall be marked by plate or other approved means with a combination of the respective emblems of the American Society for Testing Materials and the Co-operative Fuel Research Committee, thus:

The apparatus shall consist of a continuously-variable-compression engine together with suitable loading and accessory equipment, mounted on a base plate. All necessary instruments and accessories are furnished with the unit.[11]

DIMENSIONAL SPECIFICATIONS

A2. *Engine.*—Continuously-variable-compression, one-cylinder, with dimensions as follows:

	Low-speed engine.	High-speed engine.
Compression-ratio scale	4–10	4–10
Bore, in.	3·25	3·25
Stroke, in.	4·50	4·50
Displacement, cu. in.	37·3	37·3
Valve-port diameter, in.	1·187	1·187
Connecting-rod bearing diameter, in.	2·25	2·5
,, ,, length, in.	1·625	1·625
Front main bearing, diameter, in.	2·25	2·5
,, ,, length, in.	2·00	2·25
Rear main bearing, diameter, in.	2·25	2·5
,, ,, length, in.	4·25	4·906
Piston pin, floating, diameter, in.	1·25	1·25
Connecting rod, centre-to-centre, in.	10·00	10·00
Timing-gear face, in.	1·00	1·00
Piston rings, number	5	5
Exhaust pipe, minimum diameter, in.	1·25	1·25
Spark plug, size, mm.	18	18
Weight of engine, lb. (approximate)	475	650
Weight of complete unit, lb. (approximate)	1375	1550

[10] At present the sole authorized manufacturer of the C.F.R. Engine is the Waukesha Motor Co., Waukesha, Wis. Other manufacturers may be approved in the future, but testing laboratories should not purchase knock-testing units except from the Waukesha Motor Co. without ascertaining whether such units have been approved. Inquiries in this connection should be directed to Mr. R. P. Anderson, Secretary of Committee D-2 on Petroleum Products and Lubricants, 50 W. Fiftieth St., New York, N.Y.

[11] A parts list for C.F.R. engines can be obtained from the Waukesha Motor Co., Waukesha, Wis.

POWER SECTION

A3. (*a*) *Crankcase.*—Cast iron, with rigid end walls.

(*b*) *Main Bearings.*—Renewable sleeve bushings, babbitt-lined. The bearings are pinned to the crankcase-bearing bosses.

(*c*) *Crankshaft.*—Fully machined, heat-treated, and counter-balanced.

(*d*) *Connecting Rod.*—Rifle-drilled, S.A.E. No. 1045 steel,[12] heat-treated, bearing alloy cast directly into big end.

(*e*) *Camshaft.*—The 0·238-in. lift, low-speed camshaft is used (see "Valve Timing," Section A4 (*e*)).

CYLINDER ASSEMBLY

A4. (*a*) *Cylinder.*—One-piece, integral with head, cast-iron alloy, bored and honed, Brinell hardness 220 ± 20.

(*b*) *Valves.*—Inlet valve with specially designed shroud. Both inlet and exhaust valves are stellite-faced. Valve-seat inserts are of solid stellite. Valve stem diameter ⅜ in. (see Appendix V for valve overhaul procedure).

(*c*) *Valve Guides.*—Cast iron. The differences in diameter between the valve stems and their guides shall be 0·0025 ± 0·0005 in. for the intake valve and 0·0035 ± 0·0005 in. for the exhaust valve.

(*d*) *Valve Springs.*—Cadmium-plated. Pressure with valve open, 104 ± 6 lb.; pressure with valve closed, 83 ± 6 lb.

(*e*) *Valve Timing.*—For checking the valve timing, the clearance on both valves shall be 0·010 in. Intake valve opens 10° a.t.d.c., closes 34° a.b.d.c. Exhaust valve opens 40° b.b.d.c., closes 15° a.t.d.c. (Note 3.)

NOTE 3.—The recommended method consists of the following steps:

1. Remove the intake and exhaust push rods.
2. Swing the intake and exhaust rocker arms to a vertical position.
3. Mount a dial indicator on the rocker-arm support bracket with the indicating plunger directly over and pointing at the intake tappet.
4. Place a piece of drill rod between the intake tappet and the indicating plunger. This rod should be approximately ¼ in. in diameter, have a spherical end where it rests in the tappet and have an indentation on the other end in which the indicating plunger will rest.
5. Set dial gauge position so its plunger is approximately in the middle of its travel when the tappet is on the base circle of the cam. Then set the dial indicator at zero.
6. Rotate the flywheel in its running direction until the indicator shows that the cam is lifting the tappet. Mark the flywheel directly under the t.d.c. pointer at the angle where the tappet has been lifted 0·010 in. Repeat this operation two or three times to make sure of the angle at which this 0·010-in. lift is obtained. This is the point at which the effective valve opening starts. The part of the cam below the 0·010-in. lift is the quieting ramp and does not contribute to the effective valve opening.
7. This mark should be at the timing line on the flywheel marked "I.O. 0·010," which is 10° a.t.d.c.
8. If the cam timing is not within ⅛ in. of the mark on the flywheel, the camshaft will need retiming either by shifting the cam gear with respect to the crankshaft gear or by relocating the cam gear on its shaft by using one of the other

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[12] 1943 S.A.E. Handbook, p. 303.

two keyways provided. Shifting the timing one full gear tooth will make 1·48 in. change on the flywheel. The extra keyways provided on the camshaft permit adjusting the timing in 0·37 in. and 0·74 in. increments.

(*f*) *Valve Clearances.*—Both intake and exhaust valves shall have hot and running clearances of 0·008 in. with the engine running under standard operating conditions on a fuel of 75 octane number. To avoid possible change in clearances throughout the compression-ratio range, set the top linkage of the rocker-arm carrier and the rocker arms in a horizontal plane at 0·500-in. micrometer setting with valves closed (see Note 1).

(*g*) *Piston.*—A 5-ring cast-iron piston with four plain compression rings and one ventilated oil ring. Piston clearance $0{\cdot}003 \pm 0{\cdot}0005$ in.

(*h*) *Push Rods.*—Mushroom-type push rods with lock-nut adjustments.

(*i*) *Micrometer.*—A suitably mounted micrometer for measuring the height of the cylinder with respect to the crankcase.

INDUCTION SYSTEM

A5. (*a*) *Humidity-control Apparatus.*—Necessary when the air in the room where the engine is operated contains less than 25 or more than 50 grains of water vapour per pound of dry air. The humidity shall be controlled, when necessary, by means of the C.F.R. ice tower (Fig. 1), which consists of an insulated cylindrical tank arranged to pass the engine-inlet air through an ice bed, thus chilling it and delivering saturated air at approximately 32° F. (0·0° C.) with a moisture content of 26–28 grains per pound of dry air.

The tower is arranged to take air in at the top with a down-flow through the ice pack. The air leaves the tower through a tube at the centre of the ice pack, passing up from the bottom. This design permits the addition of ice without interrupting the engine operation. The centre tube provides a chilled outlet passage, thus preventing the evaporation of entrained moisture.

The tank is made of galvanized sheet metal with 2½ in. of rock-wool insulation of sides and bottom. The ice is supported on a ½-in. mesh wire screen held 4 in. above the bottom of the tank to form a surge chamber. The outlet pipe connects through a pipe bend to the pipe, 44¼ in. long, leading to the combination surge tank, capacity 800 cu. in., and air heater located on the carburettor inlet pipe. Flexible rubber hose connections in the air line permit adjustment of the compression ratio. The tower is supported on an angle iron stand to allow convenient drainage through a trap at the bottom. A removable wood cover on the top permits convenient access for filling. The 3-in. opening in the cover is the normal air inlet, which can be closed by a slide cover to economize when the engine is shut down.

The tower shall be charged with 2-in. lump ice. If the size is materially larger, channeling may occur; if smaller, the air supply to the engine may be restricted. The minimum depth of the ice bed shall be 18 in.

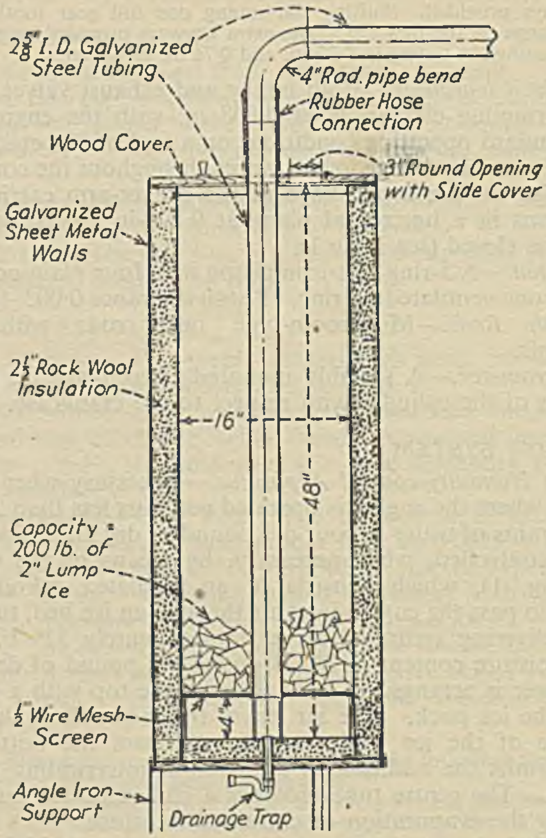

FIG. 1.

C.F.R. ICE-TOWER HUMIDITY APPARATUS.

(*b*) *Air-inlet Heater.*—The air-inlet heater is inserted in the surge tank of the humidity-control apparatus. The temperature of the intake air is controlled by suitably varying the input current to the intake air heater.

(*c*) *Inlet-air Thermometer.*—A special thermometer of suitable range shall be inserted in the base of the intake air tube 3⅛ in. above the carburettor elbow centre line. It shall be horizontal, as provided by the manufacturer, and located so that the centre of the bulb is on the inlet tube centre line.

(*d*) *Carburettor.*[13]—The standard C.F.R. multiple-bowl, variable-

[13] The use of knock-testing apparatus equipped with the carburettor described in the 1933 edition of the method (*Proc. Amer. Soc. Test. Mat.*, 1933, **33**, Part I, p. 746, also 1933 Book of A.S.T.M. Tentative Standards, p. 540) is no longer permissible.

float-level carburettor with fuel containers is furnished. It has a metering jet for each float-bowl and a horizontal atomizing jet in the air stream. Each float-bowl is individually adjustable for fuel level for varying the mixture ratio, the fuel level for a given air–fuel ratio being dependent upon the size of the metering jet. The carburettor intake is fitted with an elbow [14] and vertical tube connecting with the surge tank.

(*e*) *Heat Shield*.—A polished stainless-steel heat shield is furnished which shall be installed with the plate downward and with the concave side towards the manifold between the carburettor and the intake manifold, with a standard copper–asbestos gasket between the shield and the carburettor, and a special copper–asbestos heat-insulating gasket, 0·375 in. in thickness, between the shield and the manifold.[15]

(*f*) *Mixture-heater Assembly*.—As supplied by the manufacturer, consisting of (1) a manifold, (2) an electric immersion heater, rheostat, and automatic safety switch, and (3) a special mercury thermometer of suitable range. The heater element shall be installed so that (*a*) the opening between the two prongs is directly opposite the carburettor inlet, (*b*) the prongs are straight and parallel to each other, centrally located with respect to the manifold walls, and (*c*) the lower ends of the prongs are 0·125–0·250 in. below the horizontal plane through the centre of the manifold outlet. The thermometer shall be vertical and located so that the centre of the bulb is at the centre of the manifold, 1·875 ± 0·010 in. from the centre axis of the vertical section of the manifold and 0·375 ± 0·010 in. from the flush face of the flange of the manifold outlet.

IGNITION SYSTEM

A6. (*a*) *Ignition Unit*.—Either a coil system or a magneto.

(*b*) *Timing Indicator*.—A neon-tube ignition spark indicator is built into the engine.

(*c*) *Spark Plug*.—Type 8 (A–64–S) spark plug manufactured by the Champion Spark Plug Co., Toledo, Ohio, or Feltham, Middlesex (mark CFR on porcelain).

COOLING SYSTEM

A7. An evaporative cooling system with a water-cooled condenser coil above the coolant level shall be used. Distilled water or rain water shall be used to maintain coolant temperature when barometric pressure is sufficient to obtain standard temperature. At lower barometric pressures, sufficient ethylene glycol shall be added to the water to obtain standard coolant temperature.

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[14] Note that this elbow is not the same as the sweeping elbow used in I.P.—42/42.

[15] Note that the throttle plate heretofore inserted between the carburettor and intake manifold has been discarded in the present method.

LUBRICATION SYSTEM

A8. (*a*) *Lubrication.*—Pressure feed to main, connecting-rod, piston-pin, and camshaft bearings, and to idler-gear stud and gears.

(*b*) *Oil Heater and Thermometer.*—Electric heater in base to bring oil to operating temperature quickly, and a thermometer on the instrument panel to indicate when equilibrium temperature has been reached.

(*c*) *Pressure Gauge.*—An oil-pressure gauge of suitable range.

INSTRUMENTS

A9. Knock intensity is measured by means of a bouncing-pin, in conjunction with a knockmeter. The adjustable-leaf bouncing-pin is the preferred type.[16] It consists of a cylindrical steel pin 0·218 ± 0·001 in. in diameter, to the upper end of which is fitted a fibre tip, the combined length of pin and tip being 7·000 ± 0·015 in. The pin is maintained in a vertical position on the engine by two bushings in a hollow barrel. The bottom end rests on a hardened spring-steel diaphragm, 0·543 ± 0·003 in. in diameter and 0·015 ± 0·0005 in. in thickness, which is locked in the end of the barrel with a hollow nut. Attached to the head of the barrel and suitably insulated are two flat leaf springs with contact points immediately above the bouncing-pin. These springs should be 0·021 ± 0·0005 in. in thickness. Adjusting screws are provided for adjustment of the spring tensions and gap clearance. The knockmeter is a device for integrating the current that flows in the bouncing-pin circuit when the contacts are closed by the upward movement of the bouncing-pin that results from knock. Current is supplied from a small direct-current generator, belt-driven from the power-absorbing unit. This current flows through a resistance heating element located near a thermocouple. The potential produced at the thermocouple junction when current flows through the heating element actuates the knockmeter and produces a continuous indication of knock intensity.

EXHAUST SYSTEM

A10. A separate exhaust pipe shall be used for each engine. It shall be made of pipe not less than 1¼ in. in inside diameter, having a maximum of two right-angle bends and a total length not exceeding 20 ft. The use of a short straight-through muffler, or equivalent, with passage equal in diameter to that of the exhaust pipe is permissible.

POWER-ABSORBING UNIT

A11. The engine shall be connected to an electric generator or power-absorbing unit capable of maintaining an engine speed of 900 ± 9 r.p.m.

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[16] The use of the bouncing-pin described in the 1933 edition of the method (*Proc. Amer. Soc. Test. Mat.*, 1933, 33, Part I, 746; also 1933 Book of A.S.T.M. Tentative Standards, p. 540) is permissible.

FOUNDATION

A12. The foundation shall be of concrete, at least 15 in. in height above the floor level, resting, if possible, directly on the ground. Otherwise, special provision must be made to eliminate vibrations that may influence ratings, and the manufacturer should be consulted. For convenience in operation, the foundation should be located at least 2 ft. from any wall. Dimensions are furnished with the apparatus.

INSPECTION AND MAINTENANCE OF APPARATUS

A13. It is recommended that a systematic inspection of the testing apparatus be carried out with the utmost care after not more than 100 hours of operation. If, with the knock intensity defined in Section 8, the standard test conditions as outlined in Section 10 cannot be maintained, it may be necessary to overhaul the engine after less than 100 hours of operation. In the inspection the following points shall be emphasized:

(*a*) *Fuel System.*—Any foreign matter in the fuel containers, float-bowls, lines, or carburettor should be removed. Blowing with air and then flushing the fuel system with gasoline or benzol is a convenient method.

(*b*) *Manifold Assembly.*—The intake manifold, heater blades, and thermometer bulb should be inspected, adjusted, and cleaned if necessary.

(*c*) *Bouncing-pin.*—Lack of sensitivity or fluctuating knockmeter reading may indicate troubles with the diaphragm, contact points, or spring tensions. The diaphragm may be leaking or may have deteriorated and may need to be replaced. Contact points must be smooth and true.

(*d*) *Breaker Points.*—If necessary, pits should be removed and breaker-point clearance adjusted, or new points installed. The spark-advance setting should then be checked and reset if necessary.

(*e*) *Spark Plugs.*—The porcelain should be carefully inspected for cracks, and defective plugs replaced. The spark gap should be carefully checked, and adjusted if necessary. When plugs are re-used, any carbon deposit on the metal body of the plug or on the electrodes should be removed mechanically before making gap adjustments.

(*f*) *Combustion Chamber.*—Carbon deposits should be removed by scraping.

(*g*) *Piston and Rings.*—Carbon should be removed from rings and grooves and from both sides of the crown. When new, the top four rings should have a gap clearance between 0·007 and 0·017 in. The fifth oil-ring gap clearance should be 0·010–0·018 in. The approximate maximum permissible gap clearance after wear is 0·040 in.

(*h*) *Cylinder Wear.*—The cylinder shall be replaced (or re-bored for routine testing) when it shows a wear of 0·006 in. or loses compression due to being out of round. In no case shall cylinders be re-bored to more than 0·03 in. oversize.

(*i*) *Compression Pressure.*—Compression pressure is a useful index of variations in engine condition. The cause of any abnormal change between inspections shall be investigated and corrected.

(*j*) *Valves.*—Valves shall be removed and re-ground unless there is a continuous polished line of contact on both the valve and valve seat (see Appendix V). The shrouded inlet valve shall be inserted with the shroud opening towards the bouncing-pin.

(*k*) *Valve Guides.*—Guides should be inspected and guide holes cleaned if necessary. Valve guides shall be replaced when the upper limits of the clearances (Section A4 (*c*)) are exceeded by more than 0·001 in., as experience has shown that misalignment may result unless particular attention is given to the maintenance of these clearances.

(*l*) *Cooling System.*—The cooling system should be inspected frequently and kept clean and free of leaks.

APPENDIX II. GUIDE TABLES FOR MICROMETER SETTING FOR STANDARD KNOCK INTENSITY

A14. Tables I to IV show the micrometer settings for standard knock intensity with various barometric pressures and sizes of venturi.

TABLE I.

Micrometer Setting for Standard Knock Intensity for Barometric Pressure of 29·92 in. of Mercury and $\frac{7}{16}$-in. Venturi.

Motor method octane number.	Micrometer setting, in.	Motor method octane number.	Micrometer setting, in.	Motor method octane number.	Micrometer setting, in.	Motor method octane number.	Micrometer setting, in.
40	0·738	55	0·655	70	0·533	85	0·352
41	0·733	56	0·648	71	0·523	86	0·338
42	0·728	57	0·641	72	0·512	87	0·324
43	0·723	58	0·634	73	0·502	88	0·310
44	0·718	59	0·627	74	0·491	89	0·296
45	0·713	60	0·620	75	0·479	90	0·281
46	0·708	61	0·612	76	0·468	91	0·267
47	0·702	62	0·604	77	0·456	92	0·252
48	0·697	63	0·596	78	0·444	93	0·238
49	0·691	64	0·588	79	0·432	94	0·223
50	0·686	65	0·580	80	0·419	95	0·209
51	0·680	66	0·571	81	0·406	96	0·195
52	0·674	67	0·562	82	0·393	97	0·181
53	0·668	68	0·552	83	0·380	98	0·167
54	0·661	69	0·543	84	0·366	99	0·154
						100	0·141

Table II.

Micrometer Setting for Standard Knock Intensity for Barometric Pressures of 27 to 31 in. of Mercury and $\frac{1}{16}$-in. Venturi.

Compression ratio at 29·92 in. of mercury . .	4·63	4·80	5·02	5·17	5·36	5·59	5·90	6·28	6·76	7·35	8·02
Micrometer setting at 29·92 in. of mercury . .	0·7380	0·6855	0·6198	0·5795	0·5329	0·4794	0·4190	0·3522	0·2811	0·2090	0·1113
Motor method octane number	40	50	60	65	70	75	80	85	90	95	100
Barometric pressure, in. of mercury.	Micrometer setting, in.										
31·0	0·770	0·718	0·652	0·612	0·565	0·512	0·451	0·385	0·314	0·241	0·174
30·8	0·764	0·712	0·646	0·606	0·559	0·506	0·445	0·379	0·308	0·235	0·168
30·6	0·758	0·706	0·640	0·600	0·553	0·500	0·439	0·373	0·302	0·229	0·162
30·4	0·752	0·700	0·634	0·594	0·547	0·494	0·433	0·367	0·296	0·223	0·156
30·2	0·746	0·694	0·628	0·588	0·541	0·488	0·427	0·361	0·290	0·217	0·150
30·0	0·740	0·688	0·622	0·582	0·535	0·482	0·421	0·355	0·284	0·211	0·144
29·8	0·734	0·682	0·616	0·576	0·529	0·476	0·415	0·349	0·278	0·205	0·138
29·6	0·728	0·676	0·610	0·570	0·523	0·470	0·409	0·343	0·272	0·199	0·132
29·4	0·722	0·670	0·604	0·564	0·517	0·464	0·403	0·337	0·266	0·193	0·126
29·2	0·716	0·664	0·598	0·558	0·511	0·458	0·397	0·331	0·260	0·187	0·120
29·0	0·710	0·658	0·592	0·552	0·505	0·452	0·391	0·325	0·254	0·181	0·114
28·8	0·704	0·652	0·586	0·546	0·499	0·446	0·385	0·319	0·248	0·175	0·108
28·6	0·698	0·646	0·580	0·540	0·493	0·440	0·379	0·313	0·242	0·169	0·102
28·4	0·692	0·640	0·574	0·534	0·487	0·434	0·373	0·307	0·230	0·163	0·096
28·2	0·686	0·634	0·568	0·528	0·481	0·428	0·367	0·301	0·230	0·157	0·090
28·0	0·680	0·628	0·562	0·522	0·475	0·422	0·361	0·295	0·224	0·151	0·084
27·8	0·674	0·622	0·556	0·516	0·469	0·416	0·355	0·289	0·218	0·145	0·078
27·6	0·668	0·616	0·550	0·510	0·463	0·410	0·349	0·283	0·212	0·139	0·072
27·4	0·662	0·610	0·544	0·504	0·457	0·404	0·343	0·277	0·206	0·133	0·066
27·2	0·656	0·604	0·538	0·498	0·451	0·398	0·337	0·271	0·200	0·127	0·060
27·0	0·650	0·598	0·532	0·492	0·445	0·392	0·331	0·265	0·194	0·121	0·054

TABLE III.

Micrometer Setting for Standard Knock Intensity for Barometric Pressures of 25 to 30 in. of Mercury and $\frac{19}{32}$-in. Venturi.

Compression ratio at 29·92 in. of mercury	4·52	4·67	4·87	5·01	5·19	5·41	5·68	6·03	6·47	6·99	7·59
Micrometer setting at 29·92 in. of mercury	0·7800	0·7275	0·6618	0·6215	0·5749	0·5214	0·4610	0·3942	0·3231	0·2510	0·1833
Motor method octane number	40	50	60	65	70	75	80	85	90	95	100
Barometric pressure, in. of mercury.	Micrometer setting, in.										
30·0	0·782	0·730	0·664	0·624	0·577	0·524	0·463	0·397	0·326	0·253	0·186
29·8	0·776	0·724	0·658	0·618	0·571	0·518	0·457	0·391	0·320	0·247	0·180
29·6	0·770	0·718	0·652	0·612	0·565	0·512	0·451	0·385	0·314	0·241	0·174
29·4	0·764	0·712	0·646	0·606	0·559	0·506	0·445	0·379	0·308	0·235	0·168
29·2	0·758	0·706	0·640	0·600	0·553	0·500	0·439	0·373	0·302	0·229	0·162
29·0	0·752	0·700	0·634	0·594	0·547	0·494	0·433	0·367	0·296	0·223	0·156
28·8	0·746	0·694	0·628	0·588	0·541	0·488	0·427	0·361	0·290	0·217	0·150
28·6	0·740	0·688	0·622	0·582	0·535	0·482	0·421	0·355	0·284	0·211	0·144
28·4	0·734	0·682	0·616	0·576	0·529	0·476	0·415	0·349	0·278	0·205	0·138
28·2	0·728	0·676	0·610	0·570	0·523	0·470	0·409	0·343	0·272	0·199	0·132
28·0	0·722	0·670	0·604	0·564	0·517	0·464	0·403	0·337	0·266	0·193	0·126
27·8	0·716	0·664	0·598	0·558	0·511	0·458	0·397	0·331	0·260	0·187	0·120
27·6	0·710	0·658	0·592	0·552	0·505	0·452	0·391	0·325	0·254	0·181	0·114
27·4	0·704	0·652	0·586	0·546	0·499	0·446	0·385	0·319	0·248	0·175	0·108
27·2	0·698	0·646	0·580	0·540	0·493	0·440	0·379	0·313	0·242	0·169	0·102
27·0	0·692	0·640	0·574	0·534	0·487	0·434	0·373	0·307	0·236	0·163	0·096
26·8	0·686	0·634	0·568	0·528	0·481	0·428	0·367	0·301	0·230	0·157	0·090
26·6	0·680	0·628	0·562	0·522	0·475	0·422	0·361	0·295	0·224	0·151	0·084
26·4	0·674	0·622	0·556	0·516	0·469	0·416	0·355	0·289	0·218	0·145	0·078
26·2	0·668	0·616	0·550	0·510	0·463	0·410	0·349	0·283	0·212	0·139	0·072
26·0	0·662	0·610	0·544	0·504	0·457	0·404	0·343	0·277	0·206	0·133	0·066
25·8	0·656	0·604	0·538	0·498	0·451	0·398	0·337	0·271	0·200	0·127	0·060
25·6	0·650	0·598	0·532	0·492	0·445	0·392	0·331	0·265	0·194	0·121	0·054
25·4	0·644	0·592	0·526	0·486	0·439	0·386	0·325	0·259	0·188	0·115	0·048
25·2	0·638	0·586	0·520	0·480	0·433	0·380	0·319	0·253	0·182	0·109	0·042
25·0	0·632	0·580	0·514	0·474	0·427	0·374	0·313	0·247	0·176	0·103	0·036

TABLE IV.

Micrometer Setting for Standard Knock Intensity for Barometric Pressures of 22 to 28 in. of Mercury and $\frac{3}{4}$-in. Venturi.

Compression ratio at 29·92 in. of mercury . .	4·41	4·56	4·75	4·88	5·04	5·25	5·50	5·83	6·23	6·70	7·24
Micrometer setting at 29·92 in. of mercury . .	0·8180	0·7655	0·6998	0·6595	0·6129	0·5594	0·4990	0·4322	0·3611	0·2890	0·2213
Motor method octane number	40	50	60	65	70	75	80	95	90	95	100
Barometric pressure, in. of mercury.	Micrometer setting, in.										
28·0	0·760	0·708	0·642	0·602	0·555	0·502	0·441	0·375	0·304	0·231	0·164
27·8	0·754	0·702	0·636	0·596	0·549	0·496	0·435	0·369	0·298	0·225	0·158
27·6	0·748	0·696	0·630	0·590	0·543	0·490	0·429	0·363	0·292	0·219	0·152
27·4	0·742	0·690	0·624	0·584	0·537	0·484	0·423	0·357	0·286	0·213	0·146
27·2	0·736	0·684	0·618	0·578	0·531	0·478	0·417	0·351	0·280	0·207	0·140
27·0	0·730	0·678	0·612	0·572	0·525	0·472	0·411	0·345	0·274	0·201	0·134
26·8	0·724	0·672	0·606	0·566	0·519	0·466	0·405	0·339	0·268	0·195	0·128
26·6	0·718	0·666	0·600	0·560	0·513	0·460	0·399	0·333	0·262	0·189	0·122
26·4	0·712	0·660	0·594	0·554	0·507	0·454	0·393	0·327	0·256	0·183	0·116
26·2	0·706	0·654	0·588	0·548	0·501	0·448	0·387	0·321	0·250	0·177	0·110
26·0	0·700	0·648	0·582	0·542	0·495	0·442	0·381	0·315	0·244	0·171	0·104
25·8	0·694	0·642	0·576	0·536	0·489	0·436	0·375	0·309	0·238	0·165	0·098
25·6	0·688	0·636	0·570	0·530	0·483	0·430	0·369	0·303	0·232	0·159	0·092
25·4	0·682	0·630	0·564	0·524	0·477	0·424	0·363	0·297	0·226	0·153	0·086
25·2	0·676	0·624	0·558	0·518	0·471	0·418	0·357	0·291	0·220	0·147	0·080
25·0	0·670	0·618	0·552	0·512	0·465	0·412	0·351	0·285	0·214	0·141	0·074
24·8	0·664	0·612	0·546	0·506	0·459	0·406	0·345	0·279	0·208	0·135	0·068
24·6	0·658	0·606	0·540	0·500	0·453	0·400	0·339	0·273	0·202	0·129	0·062
24·4	0·652	0·600	0·534	0·494	0·447	0·394	0·333	0·267	0·196	0·123	0·056
24·2	0·646	0·594	0·528	0·488	0·441	0·388	0·327	0·261	0·190	0·117	0·050
24·0	0·640	0·588	0·522	0·482	0·435	0·382	0·321	0·255	0·184	0·111	0·044
23·8	0·634	0·582	0·516	0·476	0·429	0·376	0·315	0·249	0·178	0·105	0·038
23·6	0·628	0·576	0·510	0·470	0·423	0·370	0·309	0·243	0·172	0·099	0·032
23·4	0·622	0·570	0·504	0·464	0·417	0·364	0·303	0·237	0·166	0·093	0·026
23·2	0·616	0·564	0·498	0·458	0·411	0·358	0·297	0·231	0·160	0·087	0·020
23·0	0·610	0·558	0·492	0·452	0·405	0·352	0·291	0·225	0·154	0·081	0.014
22·8	0·604	0·552	0·486	0·446	0·399	0·346	0·285	0·219	0·148	0.075	0·008
22·6	0·598	0·546	0·480	0·440	0·393	0·340	0·279	0·213	0·142	0·069	0·002
22·4	0·592	0·540	0·474	0·434	0·387	0.334	0·273	0·207	0·136	0·063	*
22·2	0·586	0·534	0·468	0·428	0·381	0·328	0·267	0·201	0·130	0·057	*
22·0	0·580	0·528	0·462	0·422	0·375	0·322	0·261	0·195	0·124	0·051	*

* Less than 0·000.

APPENDIX III. PROCEDURE FOR ADJUSTING MICROMETER

A15. All engines shall be calibrated for volumetric clearance by the " tilt " method, which has been found accurate and reproducible. This procedure is as follows:

(*a*) Clean the engine, especially all parts of the combustion chamber, thoroughly, and grind the valves. In reassembling, the rings should be oiled, but not excessively. Alternatively, the engine may be motored to get oil on the rings, but not sufficiently to raise the temperature of the cylinder and piston above room temperature or to cause oil to collect on the piston top.

(*b*) Remove the engine base fastenings at the end having the oil drain, loosen, but do not remove, the base fastenings at the other end of the base plate, and tilt the engine by blocking up the freed end of the base plate approximately $\frac{3}{4}$ in., thus tilting the entire engine so that the bouncing-pin hole will be the highest point of the combustion chamber.

(*c*) Set the piston on top dead centre on the compression stroke. In doing this it is important that top dead centre be not overrun in order to assure that the rings will be resting on the bottoms of the ring grooves. If the flywheel indication is used in setting the piston on top dead centre, it should be determined, by a precision method, that the flywheel marking is correct.

(*d*) Measure 140 ml.[17] of water from a clean burette into the engine, both water and engine being at room temperature. The cylinder should be adjusted so that 140 ml.[17] will just fill the combustion space to the top face of the bouncing-pin hole. In changing the height of the cylinder, care should be taken that it is last moved in a downward direction so that the rings will rest on the bottoms of the ring grooves.

(*e*) Make certain that the top dead centre position is correct by moving the flywheel back and forth slightly and noting whether there is any rise of the water in the bouncing-pin hole. This can, perhaps, be done more conveniently when not quite the entire amount of water has been introduced.

(*f*) Adjust the micrometer scale to read 0·500 in. at the clearance volume thus established.

(*g*) Remove most of the water from the combustion space through the bouncing-pin hole by suction bulb or siphoning, and then either blow out the remainder with compressed air or motor the engine to do so. If compressed air is used the spark plug should be removed and the engine turned over by hand so as to dry out the water between the piston and the cylinder wall. If the engine is to be motored, it should be lowered to the level position to take up the slack in the belts. Then motor the engine for a few minutes, partially restricting the bouncing-pin hole by means of a cloth to increase the velocity of the outgoing air. Finally, either the spark plug should be removed and dried or the engine run under firing conditions and allowed to cool before proceeding with a repeat measurement, should that be necessary.

(*h*) If it has been necessary to adjust the micrometer scale, the

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[17] For 0·010 oversize use 140·8 ml.
For 0·020 oversize use 141·6 ml.
For 0·030 oversize use 142·5 ml.

These values are based on the assumption that the bottom of the bouncing-pin occupies 4·0 ml. of the bouncing-pin hole when the pin is in position.

engine should be again placed in the tilted position and a repeat measurement made.

(*i*) The engine should always be run under firing conditions after completion of the volume measurements to insure that it is left in a condition free of moisture.

APPENDIX IV. SPECIFICATION REQUIREMENTS FOR *ISO*-OCTANE AND NORMAL HEPTANE

ISO-OCTANE AND NORMAL HEPTANE

A16. The *iso*-octane and normal heptane shall conform to the following requirements:

	iso-Octane.		Normal heptane.	
	Minimum.	Maximum.	Minimum.	Maximum.
A.S.T.M. octane number . .	99·9	100·1	−0·2	+0·2
Density at 68° F. (20° C.) g. per ml.	0·6918	0·6920	0·6837	0·6839
Refractive index at 68° F. (20° C.) .	—	—	1·38770	1·38785
Freezing point * .	−161·55° F. (−107·52° C.)	—	−131·40° F. (−90·78° C.)	—
Distillation :†				
Temperature of 50 per cent. recovery . .	—	210·74° F. (99·30° C.)	209·08° F. (98·38° C.)	209·28° F. (98·49° C.)
Temperature increase from 20 to 80 per cent. recovery . .	—	0·11° F. (0·061° C.)	—	0·36° F. (0·20° C.)

* By means of the apparatus and method given in *Scientific Paper No.* 520, Nat. Bureau Standards, pp. 622–624, except that a platinum resistance thermometer shall be used in place of a thermocouple.

† By distilling 100 ml. of the sample through a 10-in. jacketed column, a platinum resistance thermometer being inserted so as to measure the condensation temperature of the vapour (see *Research Paper No.* 482, *Journal of Research*, Nat. Bureau Standards, 1932, 9, 459). Current through the jacket-heating coil shall be adjusted so that the reflux from the thermometer shall be 5–6 drops per min., and the still-pot heater shall be adjusted to cause distillation to proceed at the rate of 5 ml. per min. The temperature shall be corrected to an atmospheric pressure of 760 mm. of mercury by means of the equations of E. R. Smith and H. Matheson (see *Research Paper No.* 1097, *Journal of Research*, Nat. Bureau Standards, 1938, 20, 641).

APPENDIX V. VALVE OVERHAUL PROCEDURE AND EQUIPMENT FOR C.F.R. ENGINES

VALVE OVERHAUL

A17. The use of stellite valve-seat inserts in C.F.R. engine cylinders requires means other than lapping to centre the valve seat with respect to the guide and to insure proper valve seating. Experience has shown that a machine grinder, employing a grinding stone rotated on an arbor by a high-speed electric motor, is necessary. This apparatus also may be used to advantage for reconditioning cast iron seats.

APPARATUS

A18. The apparatus described herein [18] is preferred by C.F.R. engine owners. Other machine grinders may be used.

The apparatus shall consist of the following:

(*a*) Electric motor, driving linkage and grinding stone assembly.

(*b*) Tapered arbors of the following sizes: For $\frac{3}{8}$ valves, 0·3745 to 0·3780 in. in 0·0005-in. steps.

(*c*) Grinding stones having 45° and 15° faces.

(*d*) A stone dressing unit which is adjustable to different angles.

(*e*) An eccentrimeter or valve seat run-out gauge with special extension barrel for use in C.F.R. engine cylinders.

NOTE 4.—Care is important in the handling of this equipment. Keep the entire apparatus clean and well oiled. Parts should be checked frequently as wear will reduce the accuracy obtainable.

PROCEDURE

A19. (*a*) Remove valves from cylinder. Scrape deposits from cylinder and ports. The use of a motor-driven wire brush is not recommended because of possible damage to the cylinder.

(*b*) Clean valve guides with a guide cleaning tool and by swabbing with acetone (see Section A4 (*c*)). In replacing valve guides it is good practice to chill them in dry ice before insertion into the casting. It is recommended that guides be reamed to size after insertion.

(*c*) Examine valve seats for incomplete or uneven seating, pits or scores, and incorrect seat width. Seats should be between 0·05 and 0·10 in. in width unless an " interference " angle is used.[19]

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[18] " Kwik Way " Valve Seat Grinder modified for C.F.R. engines. Manufactured by Cedar Rapids Engineering Co., Cedar Rapids, Iowa. This equipment may be purchased through the Waukesha Motor Co.

[19] An interference angle is obtained by maintaining the cylinder seat at 45°, but refacing the valve in a refacing machine which has been set at 44° or $44\frac{1}{2}$°. This difference of $\frac{1}{2}$ to 1° will cause the valve to contact the cylinder seat at the area nearest the combustion chamber. The effect is to increase the unit pressure of the valve against its cylinder seat.

(*d*) Install the largest diameter arbor which, when drawn snugly into the guide, will permit proper operation of the stone while not allowing the spindle to strike the shoulder on the arbor.

(*e*) Install the run-out gauge on the arbor and adjust the rider so that contact is made with the centre of the seat. Adjust the rider and dial gauge with respect to the extension barrel so that the dial gauge plunger has moved sufficiently to take out all back-lash. Rotate the assembly and observe the amount of run-out and the position of the high point. Rotate the arbor one-quarter of a turn in the guide and recheck the run-out. A corresponding shift in the position of the highest point indicates that the valve guide may contain dirt or that the arbor may be damaged. If the high point position is unchanged and a run-out exceeding 0·0015 in. is obtained, grinding is necessary. If grinding is not needed proceed as described in Paragraphs (*i*) to (*l*).

(*f*) Install a 45° finishing stone on a grinder assembly and dress with light cuts on the dressing unit. As working clearances in the cylinder are close, grinding stone diameters should not be greater than 1⅜ in. *New stones must be cut to this diameter.*

(*g*) Apply a small amount of oil on the arbor and place the grinding unit on it. Hold the unit so that the stone does not rest on the seat. Start the motor. When the motor has reached speed, touch the stone to the seat with a few light jabbing motions. Stop the motor *but do not remove the unit until it has come to rest.* Wash the arbor and seat thoroughly with solvent.

NOTE 5: *Caution.—Be careful not to contact the seat with the stone either too heavily or too long, since cylinder life may be shortened several hundred hours if care is not used.* Remove only enough material to reach the bottom of pits or imperfections in the seat.

(*h*) Examine the seat to see if pits have been removed and if the surface is now in good condition. Check the run-out and if it is greater than 0·001 in. redress the stone and repeat the operations described in Paragraphs (*g*) and (*h*).

(*i*) If the cylinder seat has been machine-ground the valve should be examined and if there is a contact groove or a run-out of more than 0·001 in., the valve should be refaced before re-using. (The run-out can be determined by suitably mounting a dial gauge on the grinding unit, and rotating the valve slowly. This should be done before removing the valve from the chuck. Care should be taken to apply a gentle end-thrust on the chuck while dialing the valve, to take up end-play.) If refacing results in a sharp edge at the top of the valve, it should be discarded. Apply a very light film of blueing on the valve face, insert it in the guide and rotate it about one-fourth of a turn on the seat. Remove and examine the face for seat width and location of contact. Improper seat width or seat location on the valve face should be corrected by using the 15° grinding stone on the cylinder seat. The top edge of this contact area on the valve should not be closer than 0·03 in. to the top edge of the faced portion of the valve.

Caution is necessary in the use of the 15° stone for narrowing seats, as repeated grinding will result in the removal of some material from the cylinder head.

(*j*) When the cylinder seat is ready the valves may be lapped in the following manner (do not lap when an interference angle is used):

(1) Apply a light film of fine lapping compound (300–600 grit) to the valve face.

(2) Attach valve to lapping tool and insert in the guide.

(3) With a light tapping action, alternately contact the cylinder seat and raise the valve off the seat. The valve should be gradually rotated when it is *off the seat*.

(4) Remove, wash valve and seat with solvent, and inspect surfaces.

(*k*) Wash valve, ports, and cylinder thoroughly to remove all traces of grinding compound before assembling.

(*l*) Valves should be checked for leakage as follows: Fill ports with gasoline and force the piston up into the cylinder. Examine the ports for bubbling. If leakage is observed open and close the valve several times. If leakage persists repeat the operations described in Paragraphs (*j*), (*k*), and (*l*).

(*m*) After reassembling the engine, the valve-tappet clearances shall be adjusted (see Section A4 (*f*)).

APPENDIX VI. THE BOUNCING-PIN SPRING-TENSION APPARATUS

INTRODUCTION

An instrument has been developed [20] to assist in the adjustment of the tensions of the leaf-springs and plunger-spring which control the movement of the C.F.R. bouncing-pin. The A.S.T.M. instructions for the setting of the old type pin give the limits of the free deflections, due to a permanent set of the lower and upper leaf-springs. These deflections are quoted in the A.S.T.M. procedure in sixty-fourths of an inch, and their lower limits are $\frac{3}{64}$ and $\frac{7}{64}$ for the lower and upper springs, respectively. The higher limits are $\frac{4}{64}$ and $\frac{6}{64}$ at any one setting. The plunger-spring tension must be within 1·0–1·25 lb.

The above deflections assume an initial gap of 0·005 in. between the contact points: if measured with no gap they are:

Limits for lower leaf . . .	0·042–0·057 in.
Limits for upper leaf . . .	0·114–0·099 in.

It has been experienced that the deflection-load characteristics of all springs supplied are not similar. Springs in service become

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[20] A description of this instrument appears in *J. Inst. Petrol.*, 1942, 28, 209, and an approved modified form of the instrument is described in *J. Inst. Petrol.*, 1943, 29, 253.

buckled and also lose their elasticity; new springs have not precisely similar dimensions and elasticity. Consequently, there has been no definite knowledge or control of the forces of the springs acting on the pin.

THE INSTRUMENT

The instrument is simply a beam balance 9 in. in length, pivoted on a knife-edge. The knife-edge support is clamped to the flange of the bouncing-pin body by a simple attachment on the lower cross-arm. The attachment is made rigid by the tightening of a thumb-screw. No part of the pin need be dismantled for this purpose. (The bouncing-pin assembly may remain in the engine or it may be held vertically in a vice.)

The inner end of the beam is forked, and bears at two points upon the underside of a thin collar, which is clamped round the tip of the pin protruding from the pin body. The collar should be placed $\frac{3}{16}$ in. clear of the top surface of the flange of the pin body. An imaginary line through the two bearing points on the collar passes through the vertical axis of the pin and the contact points. Hence a true value of the forces required to deflect the lower and upper springs may be determined. A jockey-weight on the outer arm will balance the combined force of the spring to be tested and the weight of the pin and collar. The beam is calibrated in grams from 150 g. to 570 g. at intervals of 10 g. A reading may be made to half a division, which is the limit of accuracy. (The average weight of the pin and the small collar have been allowed for in the calibration of the beam.)

Bouncing-pins are not all of equal length. If the pin in use is short, it will be necessary to raise the knife-edge to allow the beam to swing clear. This is done by placing a $\frac{1}{32}$-in. shim below the knife-edge support.

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