New

Electronic Detonation Meter

For Motor-Fuel Antiknock Rating

Phillips 66

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BARTLESVILLE, OKLAHOMA

An Electronic Detonation Meter For Motor-Fuel Antiknock Rating

by

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THIS report gives a semitechnical description of the mechanical circuit of the bouncing pin and a description of the electronic circuit intended to duplicate its performance.

The aim of the development was to produce an instrument which would retain the desirable features of the bouncing pin but which would eliminate the uncertainty in the adjustment or standardization which is inherent in this complicated mechanical structure.

Tables and graphs are presented which give a comparison between this electronic instrument and the bouncing pin in regard to stability, sensitivity, speed, rating reproducibility, guide curve deviation and ratings.

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1. Introduction

THE knocking characteristic of a fuel may be determined in the laboratory by comparing its tendency to knock in an engine under certain conditions to the tendency of a specific mixture of pure isooctane (2,2,4-trimethyl pentane) and pure normal heptane under the same conditions. These tests are generally made in a single-cylinder, variable-compression engine. Two laboratory procedures have been developed which are widely used to determine the octane ratings of motor fuels, the A.S.T.M. motor and the C.R.C. research methods. An integral part of both of these methods is the mechanical device known as the bouncing pin.[1] A.S.T.M. first proposed a method for comparing the knocking characteristics of fuels in 1932.[2] This first method was similar to the present research method, but the following year it was changed to A.S.T.M. motor method.[3] Both of these methods incorporated the bouncing pin in a form still permitted by the present A.S.T.M. motor method. While refinements have been made in the instrument since that time, all changes have been subjected to the criterion that no effect on the octane number values was produced. Billions of gallons of gasoline have been produced whose antiknock quality has been controlled by the A.S.T.M. motor method employing the bouncing pin, and thousands of man hours have been devoted to the problem of correlation of laboratory results and performance of the fuels in automobiles on the road.

For a number of years the research department of the Phillips Petroleum Co. has been studying the general problem of detonation detection in internal-combustion engines. It is the purpose of this article to describe an instrument which has been developed as a substitute for the bouncing pin in the A.S.T.M. and C.R.C. research test methods. It has long been the desire of those engaged in the testing of motor fuels to eliminate one of the principal causes of lost time in these methods, that is, the uncertainty in the performance of the bouncing pin.[4 5] Consequently, the aim of this development has been to produce a dependable detonation meter to eliminate a source of trouble. The instrument about to be described shows promise of being a useful addition to knock testing. At the present time a number of laboratories are engaged in a program set up to evaluate the performance characteristics of this meter. Since the results of this work will not be generally available for some time, only the data which have been obtained in our own laboratory will be reported here.

It should be remarked that when properly adjusted the bouncing pin has some very desirable features. The stability is very good and yet the time of response is less than the engine equilibrium time. The ability of the pin to repeat its ratings on a given engine is extremely good. Any instrument to displace the bouncing pin should certainly retain as many of the desirable features as possible. Consequently, the goal set was the design of a detonation meter which compared favorably with the bouncing pin on the following points: Stability, sensitivity to small differences in fuel quality, rating reproducibility, and time of response to changes in knock intensity. In addition it was felt that the instrument should be simple from an electrical viewpoint, that it should be rugged in construction, that the ratings should match the bouncing pin within the experimental limits of the test methods, and that little extra training for an operator already familiar with the test procedures should be necessary.

2. Development of an Electrical Analog of the Bouncing Pin

Since the foregoing specifications essentially called for an electrical analog of the bouncing pin, it was necessary to make a theoretical study of the latter. The electrical and mechanical behavior of the pin was studied, with the result that it was possible to derive an equivalent electrical network which embodied all the main operational features of the mechanical counterpart. For the purposes of this discussion the simplified mechanical layout shown in Fig. 1 represents the bouncing pin quite well. This assembly consists of a rod, or pin, (p) with vertical freedom only, normally in contact with an ideal diaphragm (d), the other side of which is acted upon by the gases of the cylinder. A cantilever spring (S_3) acts downward on (p).

Attached to the member (S_2) is an electrical contact. A second pair of springs (S_1 and S_2) are balanced against each other. An electrical contact is also attached to S_2. The operation is briefly as follows:

When the pin is given a certain minimum velocity upward, it leaves the diaphragm and rises until the gap (g) is closed. When g is closed, a pulse of current is sent to the indicating apparatus. All pulses are of the same amplitude, but vary in duration according to the length of time the gap remains closed each engine cycle. These pulses are averaged with respect to time and indicated on a panel meter. The average length of time the gap is closed is related to the rate of change of pressure in the cylinder. It should be noted that it is not necessary to consider the diaphragm behavior since by specifying that a certain rate of change of pressure causes a certain velocity of the pin at the time the pin leaves the diaphragm, only the effect of the spring and gap assembly need be considered. Of course, the diaphragm does affect the response of the entire system and in the quantitative

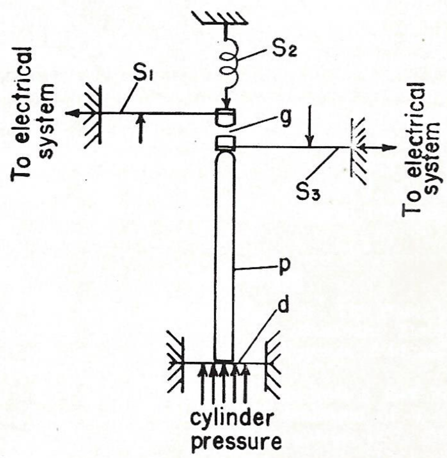

Fig. 1—Approximate representation of bouncing pin

analysis it was necessary to consider this. It was found that the diaphragm affects only the functional relation between the rate of change of pressure in the cylinder and the velocity of the pin at the instant of gap closure. We need not assume here that the rate of change of pressure is

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TABLE 1—A.S.T.M. (MOTOR) KNOCK TEST RESULTS USING THE STANDARD BOUNCING PIN AND PHILLIPS DETONATION METER

Fuel number and octane number and deviation from A.S.T.M. (Motor) guide curve

Composition—	Standard bouncing pin: Rating (octane No.)	Standard bouncing pin: Guide curve deviation (in.)	Phillips detonation meter: Rating (octane No.)	Phillips detonation meter: Guide curve deviation (in.)
1. 49.1% C.P. Benzene + 50.9% n-Heptane	42.8	.007	42.4	.008
2. C-13 + 2.0 ml. TEL/gal.	83.8	.008	84.2	.011
3. 70% X-3 + 30% M-4	73.6	.008	73.5	.003
4. 50% X-3 + 50% M-4 + 3.0 ml. TEL/gal.	75.6	.006	76.2	.006
5. 100% X-3	90.0	.002	89.7	.014
6. 68.4% C.P. Benzene + 31.6% C-13	86.1	.007	85.6	.008
7. 50% X-3 + 35% F-6 + 15% C-13 + 3.0 ml. TEL/gal.	94.2	.014	96.0	.004
8. 50% X-4 + 35% F-6 + 15% C-13 + 3.0 ml. TEL/gal.	96.3	.005	96.4	.040
9. Phillips "66"	73.1	.006	73.0	.002 A36
10. Phillips "66"	73.4	.003	73.0	.007 A42
11. Competitive motor fuel blend No. 1	74.3	.002	74.2	.005 A32
12. Competitive motor fuel blend No. 2	74.2	.001	74.0	.006 A34
13. Competitive motor fuel blend No. 3	77.9	.016	77.9	.010 A41
14. Competitive motor fuel blend No. 4	73.4	.003	73.3	.010 A44

linearly related to the length of time the gap remains closed, but simply that some unique relation exists between these quantities.

In the analogous electrical system shown in Fig. 2 there are three amplifiers, **A**, **B** and **C**. An electromagnetic pickup in the cylinder converts pressure variations into voltages which are introduced into the instrument. **A** corresponds to the spring S_3 and determines the sensitivity since by varying the downward tension of S_3, a given rate of change of pressure will cause more or less deflection of the meter if everything else remains fixed; whereas a change in the gain of the amplifier **A** will have the same effect on the electronic system. **B** corresponds to the gap in that a definite minimum voltage is required to cause any output from **B**, just as a definite velocity must be attained by the pin before it will close the gap. The amplifier **C** corresponds to the upper spring assembly S_1 and S_2. In this instrument **C** determines what a given output from the threshold shall read on the vacuum tube voltmeter **D**, just as S_1 and S_2 influence for a given S_3 setting the length of time the gap shall remain closed for a particular rate of change of pressure in the cylinder. The effect of the diaphragm on the bouncing pin is taken care of in the electronic instrument if the frequency response of the amplifier **A** is made to match that of the bouncing pin since this determines how the rate of change of pressure is related to the meter reading for a given setting of the instrument controls. The integrating time constants have been made to duplicate the response of the electrical circuit of the bouncing pin. The same Weston meter that is normally used in the A.S.T.M. method is employed by this instrument. The only operating controls which must be provided are the gain controls on amplifiers **A** and **C**. These two adjustments allow the operator to standardize the instrument on the engine.

3. Principles Governing Adjustments of Electronic Detonation Meter

In both of the test methods mentioned previously, a fuel is rated by operating the engine with this fuel at the compression ratio which will give a meter reading near mid-scale at the fuel-air ratio at which maximum knock intensity occurs. Then a pair of reference fuels whose ratings are defined or known are selected which will, at the same compression ratio, give meter readings which bracket the unknown fuel reading. The fuel-air ratios of the reference blends are also adjusted for maximum knock intensity. The rating is determined from the three readings by linear interpolation. The difference between the reference fuel knock meter readings is called the spread and is one of the quantities which must be variable in order to meet the requirements of the test methods.

The means by which the spread variation is accomplished in this instrument may be shown by again referring to Fig. 2. The pickup in the engine puts out a voltage which is proportional to the rate of change of pressure in the cylinder, this voltage is amplified by the amplifier **A** to a higher level. The threshold amplifier **B** has the property that it simply subtracts a certain voltage from the output of **A** and passes it on to **C** for further amplification.

Let a = amplification constant of A (Fig. 2)
b = the voltage subtracted by the threshold amplifier B
c = amplification constant of C

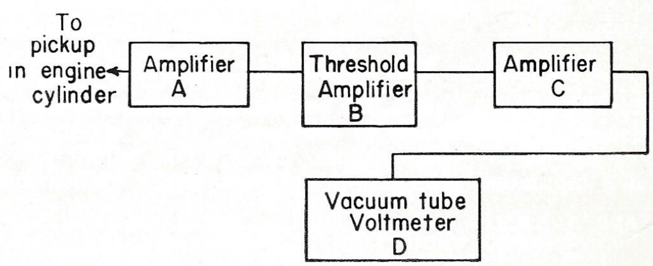

Fig. 2—Block diagram of Phillips electronic detonation meter for motor-fuel rating

TABLE 2—STABILITY-SENSITIVITY TESTS USING PHILLIPS DETONATION METER AND STANDARD BOUNCING PIN

Bouncing pin knockmeter readings

Octane No. of blend	Run number 1	2	3	4	5	Avg.	Stability
64	60	58	54	57	57	57.2	1.44
	60	58	54	57	57	57.2	1.44
	60	58	55	57	57	57.4	1.28
65	50	50	51	51	51	50.6	0.48
	50	50	51	51	51	50.6	0.48
	50	50	50	51	51	50.4	0.48
66	44	44	45	44	45	44.4	0.48
	44	44	46	44	45	44.6	0.72
	45	45	46	44	45	45.0	0.40
							0.80 av.
Computed Oct. No.	65.3	65.2	65.2	64.9	65.0	65.1	

(Sensitivity: 6.3 divisions per octane number)

Knockmeter Readings (Phillips Detonation Meter)

Octane No. of blend	Run number 1	2	3	4	5	Avg.	Stability
64	61	61	61	61	61	61.0	0.00
	61	62	61	61	61	61.2	0.32
	61	61	60	61	62	61.0	0.40
65	56	56	57	57	56	56.4	0.48
	56	56	57	57	56	56.4	0.48
	56	56	57	56	56	56.2	0.32
66	51	52	52	52	52	51.8	0.32
	51	51	52	52	52	51.6	0.48
	51	51	52	52	52	51.6	0.48
							0.36 av.
Computed Oct. No.	65.0	65.1	64.8	65.0	65.1	65.0	

(Sensitivity: 4.7 divisions per octane number)

Fig. 4—Phillips' electronic detonation meter

h_1, h_2 = the voltage output from the pickup for two different knock intensities, h_1 being the larger

D_1, D_2 = meter deflections caused by h_1, h_2

k = constant of the vacuum tube voltmeter

$D_1 = (ah_1 - b)\, c\, k$

$D_2 = (ah_2 - b)\, c\, k$

The ratio of the meter deflections is

$$\frac{D_1}{D_2} = \frac{(ah_1 - b)\, c\, k}{(ah_2 - b)\, c\, k} = \frac{ah_1 - b}{ah_2 - b}$$

As the denominator becomes smaller, the ratio becomes larger. At a glance one can see that when a and b are chosen so that $(ah_2 - b)$ becomes zero the ratio becomes infinite. What this means is that ah_2 is just below the threshold of B and therefore does not come through, so that D_2 is zero. Since h_1 is larger than h_2, ah_1 will pass through B and may be made to read any value on the meter by a choice of a suitable value for c. Thus the difference between D_1 and D_2 could be made to cover the entire scale if desired. In practice the spread is made as large as possible as long as the meter is stable and the spread limits prescribed by the methods are not exceeded. In the electronic instrument the adjustments are the controls which vary a and c so that the above conditions can be met. Their manipulation is so simple that the average operator can learn to make all necessary adjustments in one day. In the accompanying photograph of the instrument the knob marked "Sensitivity" varies the gain of **A** and the knob marked "spread" varies the gain of **C.**

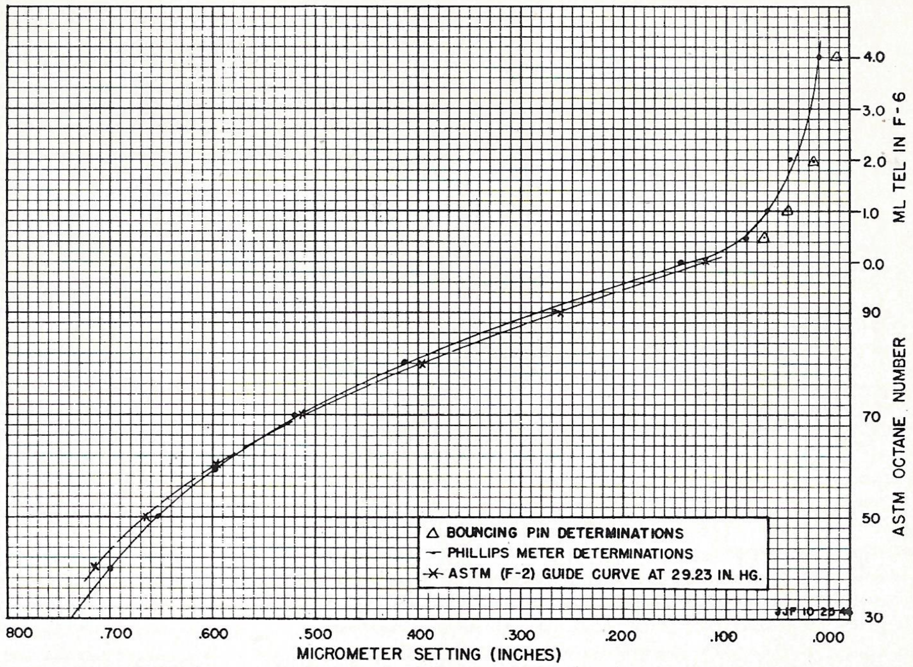

Fig. 3—Guide-curve determinations with Phillips meter and bouncing pin set on A.S.T.M. guide curve at 65 octane number

4. Laboratory Test Results

In Tables 1, 2 and 3 the performance of the instrument is compared with that of the bouncing pin. Table 1 is a tabulation of octane ratings of a group of motor fuels selected to cover the entire range of the A.S.T.M. test method. Both bouncing pin and electronic detonation meter ratings are shown.

Table 2 is a stability test based on that described in the 1946 C.R.C. Handbook, pages 75 and 76. A group of three fuels differing in rating by one octane number steps are placed in the three carburetors. The engine is operated on the lowest octane number fuel first. At the end of 2 minutes a meter reading is taken, 10 seconds later another reading is recorded, and then a third. These three readings are tabulated. The next higher fuel is switched in and the same sequence repeated. Finally the same thing is done using the third fuel. The whole process is repeated five times, giving 45 readings. From these the middle fuel is rated five times, using the averages of each group of three readings and considering the other fuels as reference fuels. By this method an index of the stability is obtained. In Table 3, ratings of a group of fuels which were rated a number of times on different engines are tabulated to compare the reproducibility of the two devices. In Fig. 3 is plotted the standard A.S.T.M. guide curve. The guide curve obtained with the Phillips detonation meter is also plotted in this figure, with the instrument set to cross the standard curve at 65 octane number. It can be seen that the possibility of using this instrument over the entire range of the A.S.T.M. method with one standardization is definitely suggested. It is at present customary to standardize the bouncing pin near the octane level of the fuels to be rated. This multiple standardization is necessary because every bouncing pin will not follow the standard guide curve from 40 to 100 octane number without adjustment.

TABLE 3—A.S.T.M. (MOTOR) KNOCK TESTS RESULTS OBTAINED ON SEVERAL ENGINES USING THE STANDARD BOUNCING PIN AND PHILLIPS DETONATION METER

	A.S.T.M. (Motor) octane number							
	Standard bouncing pin				Phillips detonation meter			
Fuel number and composition—	Engine No. 1	Engine No. 2	Engine No. 3	Avg.	Engine No. 1	Engine No. 2	Engine No. 3	Avg.
1. 68.4% C.P. benzene + 31.6% C-13	86.3	86.3	86.3	...	84.7	85.3	84.6	...
	86.3	86.8	86.7	...	...	85.3	84.6	...
	...	...	...	...	...	85.3	...	...
	...	...	...	86.4	...	...	...	85.0
2. Cyclohexane	77.8	77.1	77.9	..	76.2	76.2	76.0	...
	77.5	77.3	78.0	...	...	76.1	76.2	...
	...	...	...	...	...	76.5	75.7	...
	...	...	...	77.6	...	...	...	76.1
3. Motor fuel blend containing 3.0 ml. TEL/gal.	77.6	77.8	78.6	...	78.2	77.8	77.8	...
	78.1	77.8	78.6	...	...	78.1	...	...
	...	...	...	...	...	78.3	...	...
	...	...	...	78.1	...	...	...	78.0
4. 70% X-4 in M-4	...	74.3	74.2	...	74.2	74.4	74.1	...
	...	...	74.4	...	...	73.8	73.9	...
	...	...	74.2	...	...	...	...	...
	...	...	...	74.3	...	...	...	74.1
5. Competitive motor fuel blend No. 2	...	74.2	74.1	...	73.8	74.2	...	...
	...	...	...	74.2	...	...	...	74.0

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