Dec. 20, 1960 W. A. FORREST 2,964,939

DETONATION RESPONSIVE APPARATUS

Filed Dec. 27, 1956 2 Sheets-Sheet 1

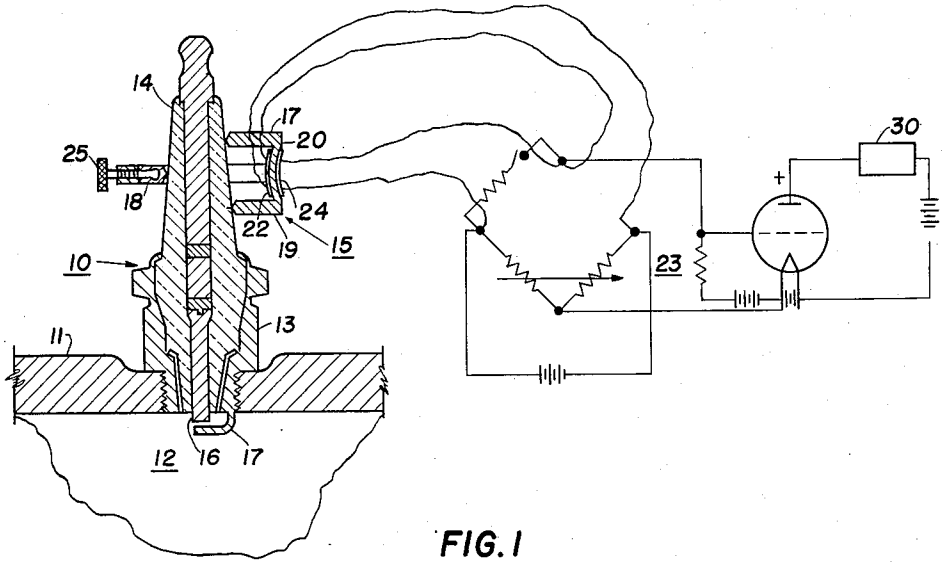


FIG. 1

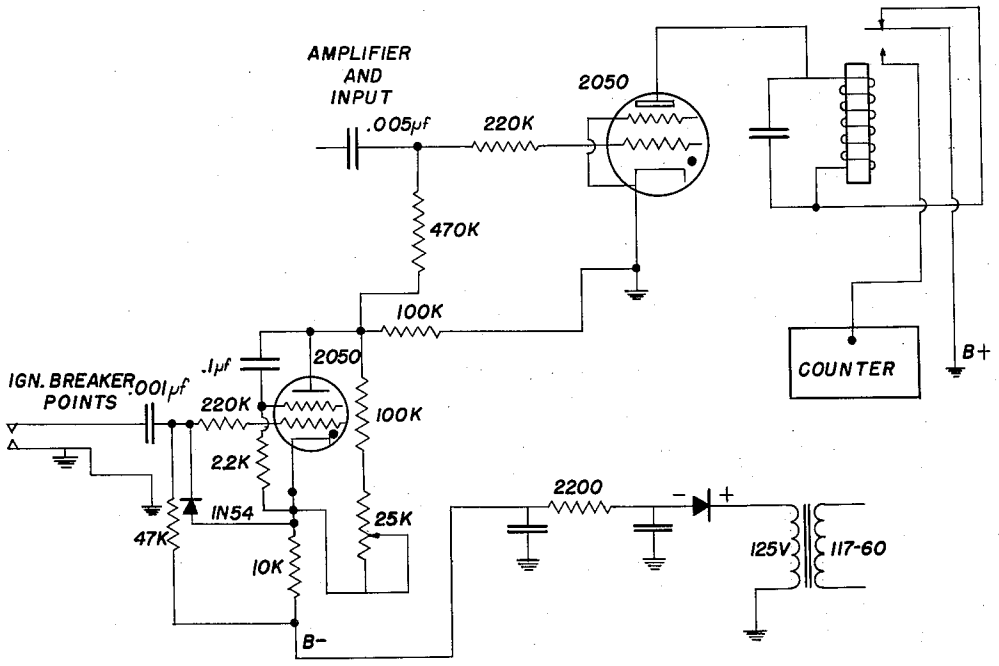


FIG. 7

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Dec. 20, 1960 W. A. FORREST 2,964,939

DETONATION RESPONSIVE APPARATUS

Filed Dec. 27, 1956 2 Sheets-Sheet 2

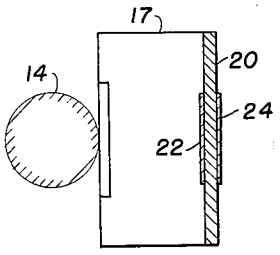


FIG.3

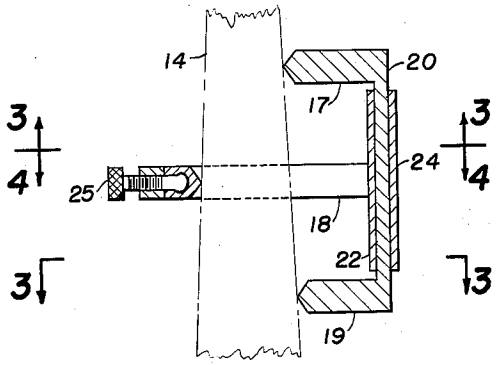


FIG.2

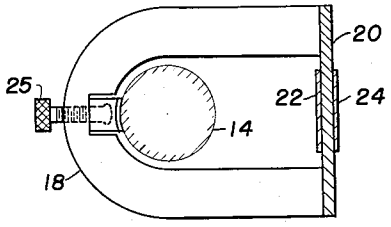


FIG.4

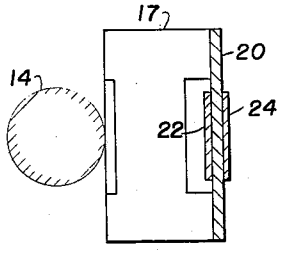


FIG.6

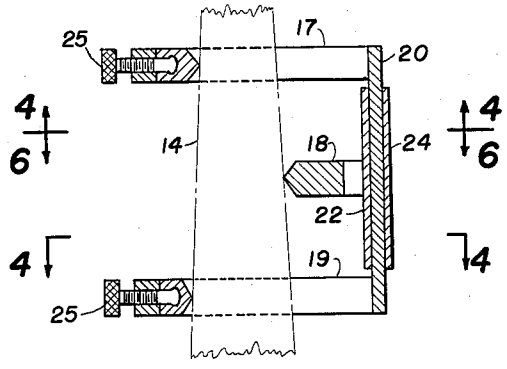


FIG.5

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DETONATION RESPONSIVE APPARATUS

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3 Claims. (Cl. 73—35)

This invention relates to an apparatus for detecting abnormal combustion in a spark-ignited, internal combustion engine. It is especially directed to determining and recording the frequency of auto-ignition in each cylinder of the engine.

Fuel and lubricating compositions for use in modern high-speed, high-output, spark-ignited, internal combustion engines results are developed and formulated as a result of extensive investigations of the requirements of these engines. To conform with these requirements, it is necessary to incorporate in these compositions, additive materials to supplement or complement the characteristics of the base stocks used in the formulation of the fuel and lubricating compositions. Although engine design permits the most efficient consumption of these compositions for their intended use, exposure of them to the complex mechanism of combustion in the engine combustion chamber sometimes produces abnormal combustion phenomena. Normal combustion is initiated solely by a timed spark which ignites the fuel mixture to produce a flame front which moves across the combustion chamber in a uniform manner at a normal velocity. In abnormal combustion or auto-ignition, uncontrolled ignition of the fuel mixture is produced by surface ignition which results from hot spots on the interior surfaces of the combustion chamber, or by combustion chamber deposits. As a result, a flame front is initiated prior to (pre-ignition) or after (post-ignition) the occurrence of normal combustion and conflicts with the normal flame front resulting in power loss, noise phenomena, known as "knocking" or "pinging," excessive pressures, and even structural damage to the engine. Consequently, extensive investigations are being carried out in an effort to determine the causes of abnormal combustion, and to evaluate the auto-ignition propensities of fuel and lubricant compositions.

It is therefore the primary object of this invention to provide an apparatus for accurately detecting and counting auto-ignition in spark-ignited internal combustion engines. A further object of this invention is the utilization of the conventional spark plugs installed in the engine, without modification as part of the sensing element whereby the auto-ignition is detected. Another object of this invention is the detection of auto-ignition in spark-ignited internal combustion engines with minimum modification or alteration of any part of the engine. These and other objects will become apparent from the following detailed description of this invention.

Figure 1 is a schematic presentation of a complete embodiment of the invention as applied to engine testing.

Figure 2 is a cross-sectional elevation view of a specific embodiment of a bracket assembly for mounting the sensing element on the porcelain insulator of a spark plug as shown in Figure 1.

Figure 3 is a cross-sectional plan view through line 3—3 of the bracket assembly shown in Figure 2, showing the stationary loading arm.

Figure 4 is a cross-sectional plan view through line 4—4 of the bracket assembly shown in Figure 2, showing the yoke assembly which provides the adjustable loading point which is also employed in the bracket assembly shown in Figure 5.

Figure 5 illustrates a cross-sectional elevation view of another embodiment of the bracket assembly.

Figure 6 is a cross-sectional plan view through line 6—6 of the stationary loading point employed in the bracket assembly described in Figure 5.

Figure 7 is a schematic wiring diagram showing the sensing element of this invention connected in a suitable measuring and indicating apparatus for abnormal ignition determination.

As a result of the fuel combustion process occurring within the combustion chamber of internal combustion engines, variations in pressures and concussion effects are produced. It has been found that the shock waves that are produced in the combustion chamber when abnormal combustion occurs are transmitted through the spark plug and can be employed for detecting this combustion vagary. This shock wave, in accordance with the instant invention, is detected by means of one or more strain gauges mounted on a suitable bracket that fastens directly to the insulator element of the spark plug mounted in the test engine. It is to be noted that conventional spark plugs are used without modification.

Referring to Figure 1, spark plug **10** is mounted in cylinder head **11** of test engine **12** of which a cutaway section is shown. The engine used in the investigation can be any single-cylinder or multi-cylinder, spark-ignited, internal-combustion engine. In utilizing the instant invention each of the spark plugs installed in the engine is used for separately mounting a sensing element. Spark plug **10** is of conventional design and in general consists of steel shell **13** which is fitted into cylinder head **11**. Insulator **14** constructed of porcelain, alumina, or other similar insulating material is mounted in the steel shell and held in place by a suitable bushing. Coaxially held in insulator **14** is center electrode **16** which cooperates with ground electrode **17** carried in steel shell **13** to form an air gap across which the current from the ignition system passes to ionize the surrounding atmosphere to form the spark for igniting the combustion mixture. To utilize the instant invention, bracket **15** must be directly mounted on insulator **14**. This bracket in the illustrated embodiment is a trifurcated arrangement of loading arms **17**, **18** and **19** mounted in parallel in substantially equi-space relationship to each other and depending laterally from a relatively thin, common base plate **20**. Center arm **18**, shown in the cross-sectional view in Figure 3, has skeletal configuration to provide an open area on the face of the base plate **20**.

In the open area in center arm **18** is mounted surface-strain gauge **22** which is electrically conected into a suitable bridge measuring circuit **23**. Second strain gauge **24** is mounted on the opposite face of the base plate and is also connected to the current-measuring means. While a single strain gauge could be used the preferred arrangement enmploys two strain gauges to provide temperature compensation and increased sensitivity. To hold bracket **15** in position on spark plug **10**, a set screw **25** is provided in center clamping arm **18**.

The outer loading arms **17** and **19** are adapted to engage one side of insulator **14**. The loading points provided by these arms are adapted so that only a narrow area is in contact with the insulator in order to minimize the friction at these points. This is preferably accomplished by the use of conventional knife edges. Bracket **15** is designed to impart an initial flexural stress to base plate **20** prior to operating the engine. To effect this flexural stress in base plate **20** there is also produced a

small, opposed flexural stress in insulator **14**. In the preferred embodiment the desired initial loading is carried out by applying a load intermediate between two, opposed outer points to induce compression in the outer face of base plate **20** in the intermediate section thereof and tension on the opposed inner face of base plate **20**. The magnitude of these induced stresses is a matter of ounces. Generally, however, the positioning of bracket **15** on the spark plug insulator, in a manner such that its dislocation by vibration encountered in the operation of the test engine is prevented, will provide proper pre-stressing of base plate **20** and insulator **14**.

In using the apparatus of this invention in the detection of abnormal ignition in spark-ignited internal combustion engines, bracket **15** is mounted on the porcelain insulator and the set-screw is tightened to clamp the bracket assembly in position and subject the base plate having the strain gauges mounted thereon and the spark plug insulator to an initial stress. Bridge-measuring circuit **23** is balanced for zero output and the engine started. When abnormal combustion occurs in the cylinder a shock wave is produced in the spark plug. As this wave travels up the plug the initial stress on the gauges is altered with a resulting change in the resistance of the strain gauge elements. Accordingly an unbalance of the bridge-measuring circuit results. Detection of this unbalancing in its simplest form is carried out as shown in Figure 1 by means of a conventional Wheatstone bridge circuit in which the voltage occurring when the bridge is unbalanced is amplified to provide an output signal which is metered by means of oscillograph **30** or other similar metering device.

Although simple D.C. potentiometer circuits or D.C. bridges can be used, more sensitive metering and detecting circuits are preferred. Because of the very brief period of time during which the measurement is being made, direct current or high-frequency alternating current is to be used to insure that a potential is impressed across the circuit during the passage of the shock wave. Simple circuits as shown in Figure 1 continuously record not only the shock waves produced by the abnormal combustion but also any shock waves occurring during the propagation of the spark-ignited flame. Although these respective waves can be distinguished visibly, it is more desirable to use a detecting circuit which screens out these normal combustion shock waves and only permits the detection of shock waves produced by abnormal combustion. An exemplary circuit is shown in Figure 7 in which the voltage changes at the bridge are transmitted to a gating amplifier "triggered" by the camshaft-driven breaker-points in the ignition system distributor which provides amplification during the compression phase of the engine cycle prior to "firing" of the spark plug to permit the pre-ignition occurring to be metered and/or recorded. Another technique which can be used is shown in copending application S.N. 400,510 filed December 28, 1953, now Patent No. 2,842,956. In the apparatus described therein a switching arrangement is used wherein the current flow to the spark plug is interrupted during the abnormal combustion measurements. In the absence of a spark-ignited combustion, the only combustion occurring will be abnormal. By providing so-called "gating" circuitry of this nature shock waves from normal combustion producing low frequencies may be electrically filtered out so that only abnormal combustions are indicated by the apparatus.

It is evident from the foregoing description of the apparatus of this invention and its operation that other variations and modifications will be apparent to those skilled in this art and can be made without departing from the basic concepts taught by the illustrative embodiment. Accordingly, the bracket member design can be modified to provide stressing of the base plate in a manner opposite to that shown by the illustrative example. This can be effected by providing the outer clamps with adjustable loading means such as set screws for retaining the bracket assembly in position. By employing these adjustable loading points in combination with an immobile intermediate loading point, such as is shown in Figure 5, a biconcavo, flexural stress pattern opposite to that produced by the hereinbefore-described clamp will be attained.

The bracket can be fabricated from a variety of heat-resistant, rigid materials of construction having a low coefficient of expansion. Materials of this nature having a coefficient of expansion of not larger than 12×10^{-6} @ 250° F. include low carbon steels, nickel steels, molybdenum, etc. Preferably a nickel steel containing 36% nickel and having a coefficient of expansion @ 68° C. of 0.9×10^{-6} (Invar) is used. The dimensions of the face of base plate are such that the selected strain gauge (s) can be easily affixed thereto. Because of the pre-stressing of the base plate member the base should be sufficiently thin to permit the base to flex without causing the opposed, flexural strains produced in the spark plug insulator to be excessive and cause it to crack. Accordingly, this base member, depending upon the ductility of the material of construction used in its preparation, will be about 1/32 to 1/16 inch thick. The clamping arms can be of any appropriate design which will permit the bracket assembly to be mounted on the spark plug insulator with the base plate in a spaced, relationship therefrom and in a flexed position and which will produce an opposed, corresponding flexural stress in the spark plug insulator. Equispacing of the loading arms with respect to the intermediate loading point is preferred; however, pre-stressing of the base plate can be effected with an asymmetrical positioning of these arms with respect to the intermediate loading point.

The bracket assembly illustrated in Figure 2 was fabricated from Invar. The base plate, 1 1/16" x 1" x 3/64", has depending laterally therefrom three equispaced, loading arms, 1/2" x 1 1/4" x 1/8". The outer arms which provided the stationary loading points are 1 1/16" wide and 1/8" thick, having slightly different lengths to accommodate the sloping sides of the spark plug insulator. A 3/16" wide yoke frame with a suitable boss to permit the installatiton of the set screw is used as the center arm. Knife-edge loading points are provided. Separately mounted on opposed faces of the base plate are a pair of type HFA–2, flat grid, etched foil, resistance, surface strain gauges manufactured from 0.005" thick constantan which permit their use in high temperature applications up to 600° F. Gauges of this nature are available from the Baldwin-Lima-Hamilton Corp. and are described in greater detail in "Testing Topics," vol. 11, No. 2, 1956, a periodical published by the Baldwin-Lima-Hamilton Corp. These strain gauges are installed by cementing the gauges to the base plate with a type RX–1 high temperature adhesive supplied by the strain gauge manufacture. By employing the illustrative detecting and measuring bridge network shown in Figure 7, a D.C. potential of about 12 volts is impressed across the bridge circuit. Suitable amplification is provided of the voltage signal occurring during any unbalancing of the bridge circuit to permit suitable detection of abnormal combustion during the operation of a one-cylinder CFR engine used in the investigation of fuels and lubricants.

The resistance strain gauges illustrated in this invention are those which can withstand the elevated temperatures encountered in engine testing. These temperatures in the spark plug area will be about 250°–300° F. Accordingly, appropriate adhesives, resistance-wire backings, etc., which will not fail at these elevated temperatures, are to be used in the construction of the sensing element of this invention. The strain gauges used in this apparatus may be of any known surface type. Especially well suited to the purpose are gauges of the bonded-wire-resistance type, commonly designated as SR–4 gauges. Such gauges are comprehensively discussed in U.S. Patent No. 2,292,-

549 to E. R. Simmons. Fail-type surface-strain gauges may be preferable where cooling is inadequate, but such gauges are less sensitive to small changes in strain and are therefore less preferable unless necessitated by temperature conditions. The nominal resistance of the gauges can be between about 60–135 ohms and a variety of wire materials such as cupro-nickel, Elinvar, Nichrome, constantan, etc., used to prepare the resistance element. For additional details regarding the selection of suitable strain gauges, methods for affixing the gauges to the bracket assembly, appropriate instrumentation, and other information concerning the application of the strain gauges in the instant invention, reference is made to Electrical Resistance Strain Gauges, W. B. Dobie, et al. English University Press, Ltd., 1948, and Testing Topics, a publication of the Baldwin-Lima-Hamilton Corp., vol. 1, October, 1944, et seq. Strain gauges of a capacitance or inductance type, or a differential transformer type, also may be used, but may have the disadvantage of requiring a more bulky assemblage.

From the foregoing detailed description, it is evident that the illustrative embodiments can be used in variety of forms and modifications without departing from the spirit of the invention. Accordingly, it is intended that it be limited only by its definition in the appended claims.

I claim:

1. In an apparatus for detecting abnormal combustion in a cylinder of an internal combustion engine having mounted in the combustion chamber of said engine a spark plug containing as a component element a ceramic insulator in contact with said combustion chamber and having a substantial portion externally projecting therefrom, the combination comprising a flexible, metallic base plate having a low coefficient of expansion, said base plate having opposed faces, a U-shaped clamping arm laterally depending from and integral with one of said faces intermediate the edges thereof and a knife-edged arm extending from said plate in the same direction as said U-shaped, arm, spaced from and on either side of said U-shaped arm, a threaded element projecting through the turn of said U-shaped arm and adapted to contact said insulator whereby said base plate can be coextensively mounted in a substantially fixed position on and in spaced relation to said insulator and a flexural stress induced in the opposed faces of said base plate and said insulator element, and a strain gauge mounted on each of said faces.

2. In an apparatus for detecting abnormal combustion in a cylinder of an internal combustion engine having mounted in the combustion chamber of said engine a spark plug containing as a component element a ceramic insulator in contact with said combustion chamber and having a substantial portion externally projecting therefrom, the combination comprising a flexible, metallic base plate having a low coefficient of expansion, of not more than about 12×10^{-6} @ 250°–300° F., said base plate having opposed faces, two outer knife-edged arms and an intermediate U-shaped clamping arm integrally depending at right angles from and integral with one of said faces for attaching said base plate to said spark plug insulator whereby said base plate is coextensively mounted in a substantially fixed position on and in spaced relation to said insulator and a flexural stress is induced in the opposed faces of said base plate and said insulator element, said intermediate clamping arm having an opening to accommodate said insulator, an adjustable loading means mounted on said U-shaped arm and cooperating with said insulator for firmly attaching said assembly to said insulator, and inducing said flexural stress in said base plate and said insulator, and a strain gauge mounted on each of said faces.

3. In an apparatus for detecting abnormal combustion in a cylinder of an internal combustion engine having mounted in the combustion chamber of said engine a spark plug containing as a component element a ceramic insulator in contact with said combustion chamber and having a substantial portion externally projecting therefrom, the combination comprising a flexible base plate fabricated from Invar, said base plate having opposed faces, two outer U-shaped clamping arms and an intermediate knife-edged arm integrally depending from and integral with one of said faces for attaching said base plate to said spark plug insulator whereby said base plate is coextensively mounted in a substantially fixed position on and in spaced relation to said insulator and a flexural stress is induced in the opposed faces of said base plate and said insulator element, the opening formed by said plate and U-shaped arms being axially aligned to accommodate said insulator, an adjustable loading means mounted on each outer arm for firmly attaching said combination to said insulator and inducing flexural stress in said base plate, and a strain gauge mounted on each of said faces.

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