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Sept. 13, 1966 V. F. MASSA 3,272,005
ENGINE ROUGHNESS TESTER
Filed Jan. 25, 1965 5 Sheets-Sheet 1

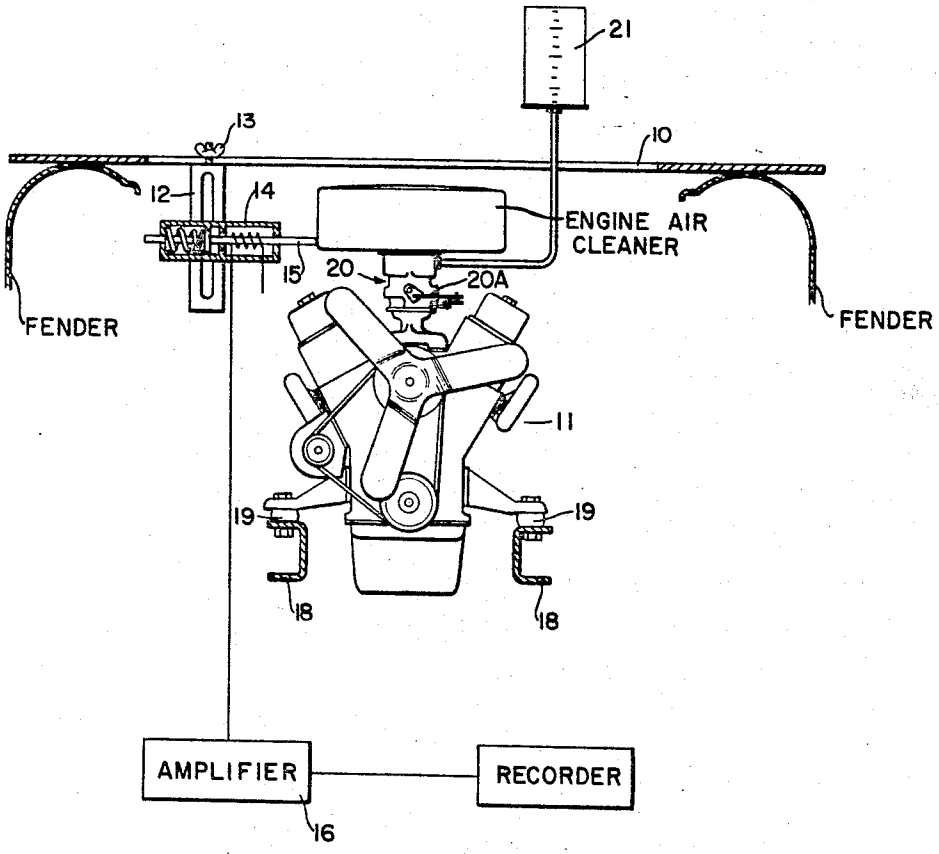

FIG. 1

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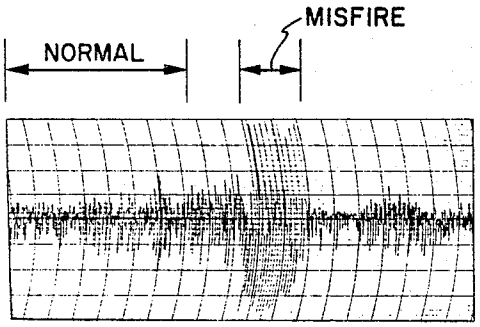
APPENDIX B

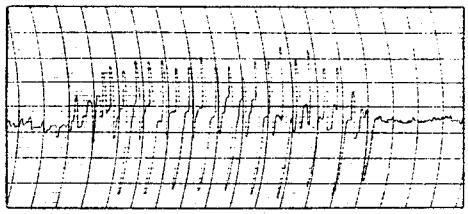
ENGINE ROUGHNESS INDICATOR

SHOWING SPARK PLUG MISFIRE AT IDLE



SPARK PLUG MISFIRE INDUCED
(PAPER SPEED SLOW)

Fig. 8A



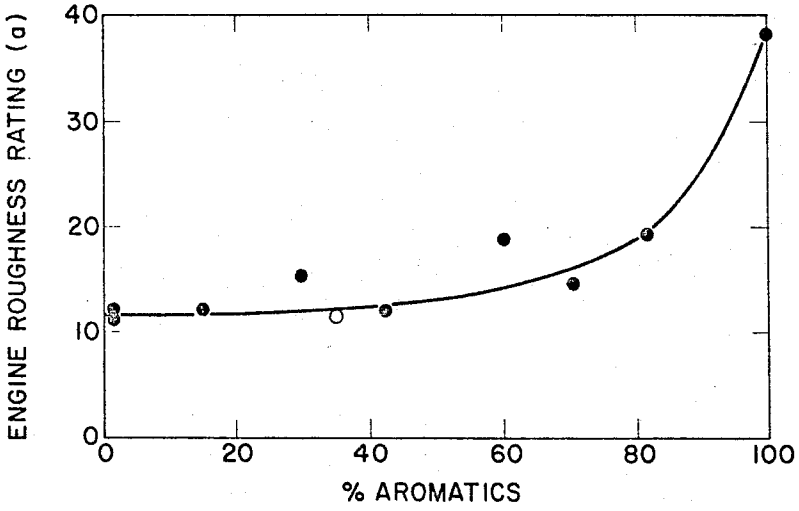
SPARK PLUG MISFIRE INDUCED
(PAPER SPEED INTERMEDIATE)

Fig. 8B

ENGINE ROUGHNESS AT IDLE AS A

FUNCTION OF FUEL AROMATIC CONTENT

(6 CYLINDER CHEVROLET)



(a) 10 = SMOOTHEST POSSIBLE IDLE; 100 = ROUGHEST POSSIBLE IDLE EQUIVALENT TO 2 SPARK PLUGS NOT FIRING

Fig. 2

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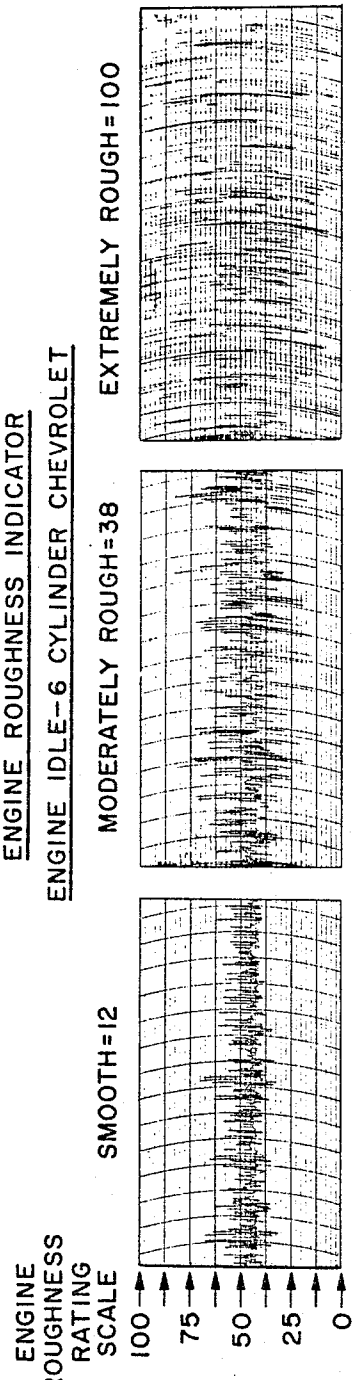

A B C

Fig. 3

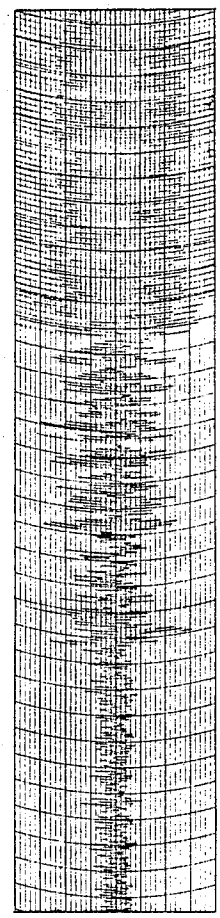

Fig. 4

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ENGINE ROUGHNESS TESTER

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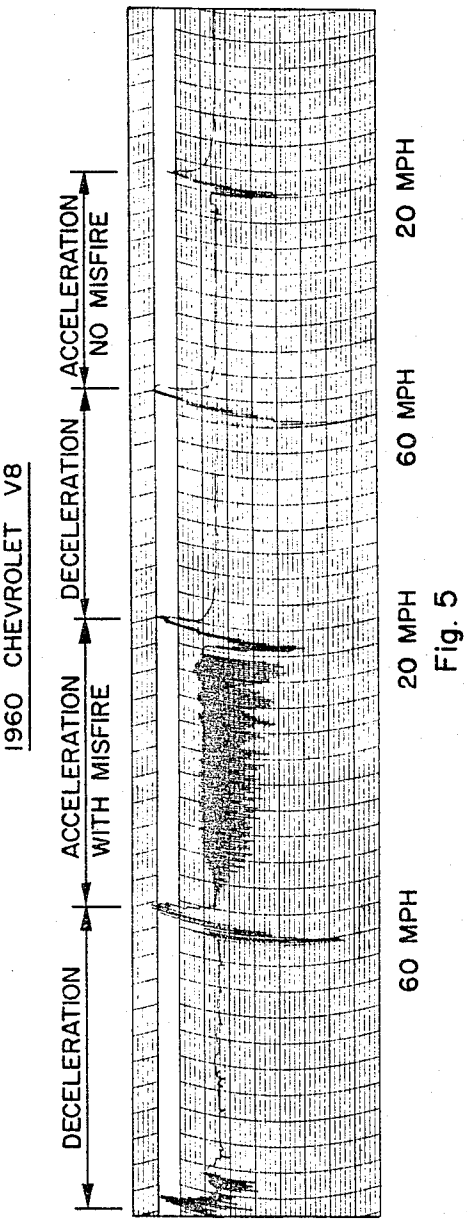

Fig. 5

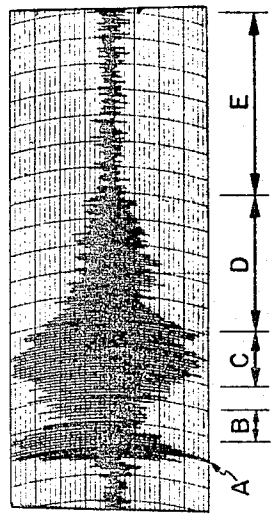

Fig. 7

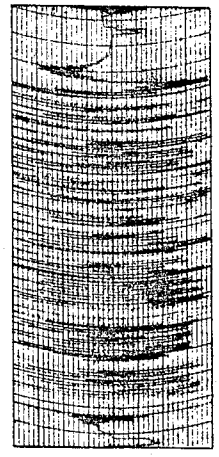

Fig. 6

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ENGINE ROUGHNESS TESTER

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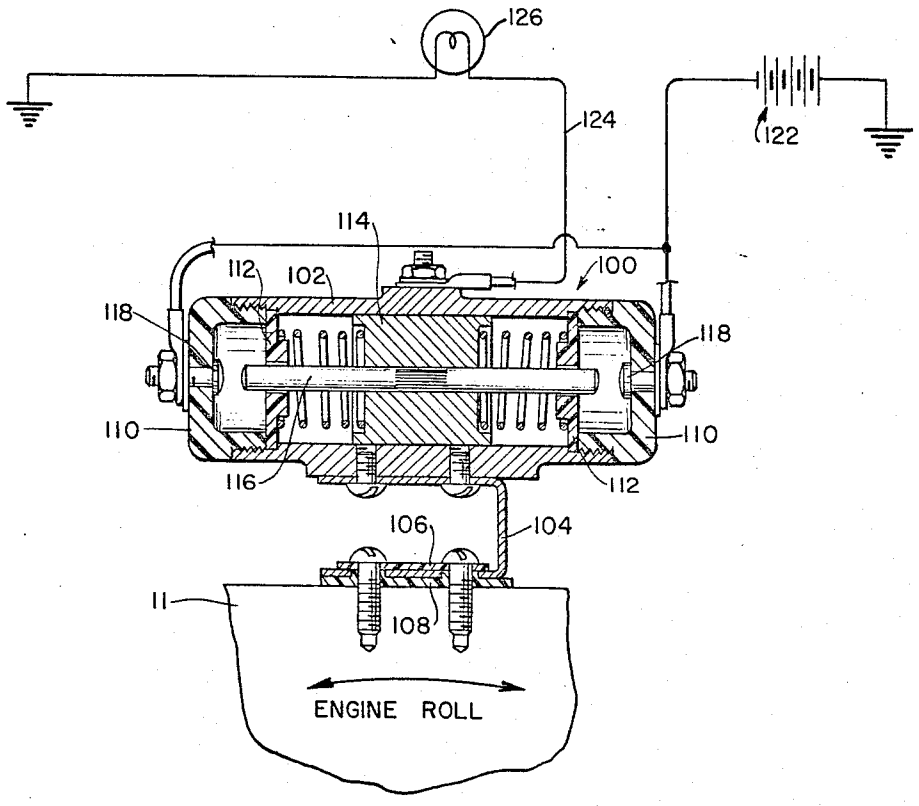

FIG. 9

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United States Patent Office 3,272,005 Patented Sept. 13, 1966

3,272,005

ENGINE ROUGHNESS TESTER

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Filed Jan. 25, 1965, Ser. No. 432,052
2 Claims. (Cl. 73—116)

This application is a continuation-in-part of applicant's prior copending application Serial No. 139,979 filed September 22, 1961, now abandoned.

This invention concerns an apparatus and a process to detect, indicate, and record engine operational roughness, and particularly relates to the detection and evaluation of the roughness operating characteristics of an internal combustion spark ignition engine occasioned by variation in the motor fuel characteristics and engine conditions.

The detection and evaluation of abnormal engine combustion characteristics occasioned by engine operating conditions, the malfunctioning of engine parts, and the variation in fuel quality has been a constant source of study by automotive engineers. Detection of engine difficulties aids in the research of developing better engines and fuels, while at the service station level, instrumentation of this nature allows automotive operating difficulties to be rapidly detected and corrected. In the past, various devices have been developed to aid in detecting particular engine difficulties such as the misfiring of spark plugs, rumble, knock characteristics, and the like. Most of these devices have not proven entirely satisfactory, since they are based on detecting the vibrational frequency of the combustions taking place within the engine itself for a particular purpose. Other devices such as speed indicators and vacuum gauges are useful for a particlular purpose, but fail to detect differences in actual fuel quality or other specific engine factors that cause malfunctioning of the engine. Further, many of these devices required cumbersome, uneconomical, nontransportable, complex equipment which rendered their widespread use at other than the research level impractical and uneconomical.

It is, therefore, an object of this invention to set forth an apparatus and process for the detection, recording, and analysis of engine roughness.

It is more particularly an object of this invention to reveal a simple, portable, and relatively inexpensive multifunctional testing device to detect, record, and evaluate a wide variety of engine characteristics based on the roughness operation of the engine.

It is an additional object to describe an apparatus and method to detect and evaluate variations in roughness of an internal combustion spark ignition engine occasioned by variations in the motor fuel qualities and spark plug misfiring.

Recent studies of motor fuel performance in engines has made it desirable to be able to quantitatively evaluate engine operation roughness or conversely engine smoothness. An apparatus and method have been discovered that detect the variation in amplitude of total engine movement and can be employed to detect a wide variety of engine operational characteristics and defects. It has been found that the amplitude and frequency of an internal combustion engine rocking or twisting on its flexible engine mounts generally about the crankshaft axis when detected and recorded serves as a useful indication of fuel quality and other engine defects during idle, acceleration, and high speeds. The apparatus is particularly important to evaluate variations in hydrocarbon-type fuel performance and correlates exceptionally well with the "seat of the pants" reaction experienced by motorists with variations in engine roughness operation. The total translational motion of an engine may be determined by the

frequency of engine movement on its mounts or preferably by the amplitude of such movement. The apparatus and method differ essentially from the prior art by the employment of information of total engine movement for diagnosing engine operation, while prior concern has been with the frequency or amplitude variations of the internal engine combustion process as, for example, the use of various frequencies of the crankcase vibration to detect a particular engine problem. Engine movement during operation, i.e. the variation in amplitude of the engine about the crankshaft axis, occurs when the torque of the engine attempts to rotate the engine about its axis. Engines, especially internal combustion spark ignition engines employed in automotive vehicles, are normally mounted on flexible shock absorbing mounts, e.g. hard rubber engine mounts, to reduce normal engine vibration caused by the torque forces at work during engine operation and to absorb excessive road shocks. The variation in the quantity of translational movement as measured by the amplitude of the engine movement and its frequency is thus employed to detect a variety of abnormal engine and fuel conditions which affect the torque forces of the engine. Measured from a vertical center line drawn through the engine crankshaft axis, an engine will normally have an absolute amplitude distance from this center line of ⅛" to 1" or even 1½" with extreme malfunctions. Absolute values are difficult to set precisely due to the dependence on the type and character of the engine mounts, etc., but at idle a normal engine vibrates only ⅛–¼".

The invention also concerns improvements in apparatus for the visual indication of engine performance to indicate to the vehicle operator that an engine "tune-up" is required. In this aspect of the invention, novel means are provided which may be directly and permanently attached to the engine block. The novel performance indicator attachment of the invention employs a spring centered inertia mass which is free to oscillate along an axis transverse to the engine crankshaft axis and radially displaced therefrom. When the engine roughness or roll upon its flexible mounts exceeds a predetermined maximum, the inertia mass is effective to control an electrical circuit to flash an indicator light preferably located on the vehicle instrument panel. In this way, vehicle operators who under ordinary circumstances would be unaware of engine mis-operation are forewarned in ample time prior to being stranded on the highway that an engine tune-up is required. The early warning of engine mis-operation and timely maintenance provided by the invention also results in extended engine life.

It is therefore another object of the invention to provide novel means which may be attached to an internal combustion engine to indicate the need for an engine tune-up.

The invention may be illustrated more fully by the accompanying drawings in which:

FIGURE 1 is a diagrammatic drawing of a contact type engine roughness tester in a preferred operating position.

FIGURE 2 is a graphical illustration of the variation in roughness rating with fuel aromacity.

FIGURE 3 is a graphical tracing of variation in engine amplitude with various fuels on a relative roughness scale indication.

FIGURE 4 is a graphical tracing of variation in engine amplitude with variations in engine operating conditions.

FIGURE 5 is a graphical tracing of variation in engine amplitude with variations in acceleration time for normal and misfire engine conditions.

FIGURE 6 is a graphical tracing of variation in engine amplitude demonstrating engine after-running effects.

FIGURE 7 is a graphical tracing of variation in engine amplitude with cranking effort.

FIGURE 8 is a graphical tracing of variation in engine amplitude with induced spark plug misfire on various tracing paper speeds.

FIGURE 9 is a cross-sectional view of another embodiment of engine roughness indicator in accordance with the invention.

Turning first to FIGURE 1, there is shown the preferred form of the apparatus comprising in combination a slotted support bar **10**, the opposite ends of which rest on the fenders of the automobile in which an engine **11** to be tested is mounted. The engine **11** is mounted upon the frame **13** of the automobile by conventional hard rubber mounts **19** which permit the engine to have a degree of oscillatory freedom about its longitudinal axis. The engine is equipped with conventional carburetor **20** and throttle **20A** with a measuring container **21** being connected to the carburetor for feeding predetermined quantities of fuels of different compositions to the engine for purposes which will appear hereinafter. Slidably mounted at right angles for transverse movement on said support bar is a slotted support arm **12** with threaded wing bolt **13** to hold the support arm in a firm position and to which is slidably mounted for vertical adjustment a contact amplitude sensing device **14**. This sensing device **14** comprises a differential transformer having a central spring loaded contact arm **15** which is placed in contact with an engine part, such as the air cleaner shown, that will reflect movement of the engine on its mounts. The differential transformer functions through the variation in the electrical field as the spring loaded magnetic central arm support surrounded by a coil of wire which carries an electrical current moves to follow the engine amplitude. The contact arm may be placed against the valve cover of a six cylinder engine, the air cleaner of an eight cylinder engine, or directly against any engine part that will satisfactorily reflect the movement of the engine on its mounts. It may also be placed against the car body such as the fenders. It is preferred that the contact be made with the engine or its associated parts, since fender contact, although permitting a rapid method of detection without the necessity of opening the engine hood, introduces damping effects which reduce the efficiency of the detection and evaluation procedure. The spring loaded contact arm of the sensing device is maintained in continuous contact with the air cleaner by tensional means and faithfully reflects the changes in amplitude of the engine pivoting about its axis. The movement of the magnetic bar within a coil produces an electrical signal from the differential transformer which is fed to an amplifier **16** and then to a brush electrographic-type recorder where the variations in amplitude are reflected on a continuous, recording graph strip, capable of operating at several speeds.

The sensing means employed can, of course, constitute any means that will sense or detect the variation in engine movement on its mounts. These means may encompass both contact-type and noncontact devices. Contact-type devices can constitute opposing mounted electrical contact points, one contact point being supported on a rigid stationary mount with the other firmly affixed to the engine itself or to the automobile body so as to follow the amplitude of the engine vibration. By imposing an electrical signal in this contact point circuit, together with a recording device to record the changes in electrical signal, e.g. current, as a function of point contact time, the motion of engine amplitude can be determined. It is also possible to detect and record the engine amplitude variation by employing direct mechanical contact of a nonflexible, rigid arm mounted on the engine with the variations in amplitude traced and recorded directly on a rotating graph drum or electrically transmitted to other recording means. A suitable, noncontact sensing element can comprise the use of a commercially available sensing

device wherein the sensing element measures and detects the variation in distance between the vibratory element of the car body, e.g. the engine or fender, and a non-vibratory element such as by detecting the change in the capacitance or inductance and the like between the noncontacting surfaces. Other suitable sensing means include detecting engine movement by means of light reflectance, the pressure changes in a fluid bellows in contact with the engine and a fixed non-moving point, and like means. The recording and display devices can be a rotating direct contact graph drum, or any instrument which will produce a visible, audible, or thermal trace of the amplitude variations of the engine.

Employing the devices described and, in particular, the apparatus of FIGURE 1, abnormalities in both fuel and engine performance can be detected and evaluated. Gasoline fuel characteristics detected include, but are not limited to, detecting differences in the hydrocarbon-type of motor fuels, both at idle and at high speeds, e.g. from 20, 60 or even to 80 m.p.h.; differences in front end and over-all fuel volatility at idle, acceleration and high speeds whereby stalling tendencies can be evaluated in response to fuel volatility; differences in vapor lock characteristics of fuels; cold starting and warmup characteristics; cranking torque effort with various alkyl lead antiknock additives; and other pertinent fuel characteristics. Engine abnormalities detectable by the apparatus include spark plug misfiring or malfunctioning, both at low pressure or idle, and under operating pressure or high speeds and acceleration; cranking and hot cranking difficulties as described in "Starting and Stopping Modern Engines," New Combustion Problems, by V. F. Massa, annular report of the SAE, Atlantic City, New Jersey, meeting of June 8–13, 1958; abnormal cylinder pressure such as low cylinder pressure caused by leaking valves, poor rings, differences in actual and incipient carburetion difficulties, both of fuel rich and fuel lean mixtures, thus is a tune-up accessory; after-running occassioned by compression ignition and hot combustion chamber deposits; and other engine abnormalities.

The engines to be tested by the inventive apparatus and process are not restricted to internal combustion engines operating on the Otto cycle or two stroke cycle, but include all varieties of liquid and gaseous fueled combustion engines for automobile, marine, aviation, and power usage, such as compression ignition engines such as diesel engines, aviation turbine jet engines, fuel ignition engines such as dual fuel gas-diesel oil engines, Nordberg dual fuel engines, engines wherein ignition is accomplished by mechanical or electrical means such as by spark or glow plugs, and the like provided only that the engine is not so rigidly supported to preclude the detection of any external engine movement. The gasoline fuel spark ignition internal combustion engine operating on the Otto cycle and mounted in a car or truck body upon flexible shock absorbing mounts is the preferred engine for detecting abnormalities. The inventive process may also be usefully employed with electrical operated engines, generators, and other power sources which are subject to external movement which varies with the efficiency of operation.

Fuels employed in these engines include hydrocarbonaceous fuels like liquid petroleum motor fuels boiling in the gasoline boiling range, e.g. 70 to 450° F., as set forth by ASTM D439–58T, aviation fuels of ASTM D910–57T, diesel fuels of ASTM specification D975–59T, aviation turbine fuels of ASTM specification D1655–59A, gaseous fuels such as LPG, natural gas and those fuels containing over 60%, e.g. 90%, methane and the like.

The method of employing the described appartus can be ascertained by FIGURE 2 wherein is shown a graphical plot obtained by the recorded variation in roughness rating with the variation in aromaticity content of gasoline fuels having the characteristics shown in Table I.

Table I

ENGINE IDLE BEHAVIOR AS INFLUENCED BY FUEL AROMATIC CONTENT, 6 CYLINDER CHEVROLET

Fuels Tested	Percent Aromatics	Air/Fuel,[a] Percent Stoichiometric	Engine Roughness Rating [b]
Isooctane	0	85.5	12
Aviation Alkylate	0	85.5	12
76.5% Alkylate, 23.5% Light Hydroformate	15	84.2	12
53% Alkylate, 47% Light Hydroformate	30	85.0	15
Commercial Premium Gasoline	36	85.3	12
30% Alkylate, 70% Light Hydroformate	45	86.0	12
7% Alkylate, 93% Light Hydroformate	60	87.0	19
80% Light Hydroformate, 20% Benzol	71.5	87.0	15
50% Light Hydroformate, 50% Benzol	82.0	87.6	19
Benzol	100	88.5	38

[a] Based on the Air/Fuel ratio observed during test.
[b] 10=smoothest possible idle; 100=roughest possible idle, equivalent to two spark plugs not firing.

The data were obtained by operating a 6-cylinder Chevrolet engine at idle with fuels of increasing aromaticity obtained by blending additional amounts of a hydroformate with an aviation alkylate and also blends of the hydroformate with benzol as shown in Table I. The roughness rating is a relative quantitative measure of the variation in engine amplitude at idle. This rating is obtained by using a roughness rating of 100 to indicate amplitude variations which extended to the upper and lower limits of the tracing chart which has been determined to be the equivalent of the misfiring of two spark plugs, with a rating of 10 determined as the normal amplitude variation of a perfectly tuned engine at idle. By means of a transparent plastic scaled overlay, a quantitative measure of the roughness rating at various conditions can be easily determined. As graphically demonstrated, the variation in engine amplitude can readily and quickly distinguish between a high (over 80%) and a low aromatic fuel.

FIGURES 3 through 8 are actual brush recording traces of various engine roughness traces obtained through the electrical signals received with the contact-type of spring loaded differential transformer. These traces represent typical standard graphic patterns obtained from an otherwise smooth running and well tuned engine. As such, in accordance with the invention, they may be used as standards against which the trace of an engine having an unknown type of mis-operation may be compared in order to diagnose the cause of mis-operation of the engine under test. FIGURE 3A illustrates the trace of isooctane which has a roughness rating of 12 indicating smooth engine operation, while FIGURE 3B demonstrates the same engine operating on benzol giving a rating of 38 called moderately rough, and FIGURE 3C shows the variation in engine amplitude of an extremely rough operating engine at a rating of 100.

The detection of a variety of difficulties of a Chevrolet engine first operating in a normal idle manner, then with a rich air fuel mixture caused by restricting the air flow to the carburetor, and then with misfiring of a spark plug artificially induced by shorting out one spark plug is shown in FIGURE 4.

FIGURE 5 illustrates changes in engine movement amplitude during acceleration and subsequent deceleration from 20 to 60 m.p.h. of an engine with and without a spark plug malfunctioning. A comparison of the time abscissa of the acceleration with and without spark plug misfiring will show that acceleration to 60 m.p.h. without misfiring occurred in a shorter time than with misfiring. In this manner, the detection of misfiring spark plugs under acceleration or high cylinder pressure can be easily detected and corrected.

FIGURE 6 demonstrates the trace received when an engine motor is stopped, but after-running occurs due to compression ignition of the fuel. Thus, detection of combustion chamber deposits or low ignition fuel components may be readily ascertained.

FIGURE 7 shows the engine amplitude trace received during the cranking effort. Thus, initially, the load on the cranking motor produces a large amplitude (A) followed by (B) the one or two of the engine cylinders starting to fire, reducing the load on the motor, with a subsequent stoppage in engine firing (C) and the cranking effort continuing at the initial engine amplitude. This action is followed by the rapid progressive firing of the cylinders (D) and the normal idling motion of the engine. This simplified method of examining and correcting cranking difficulties may be rendered even more precise by speeding up the recording means so that the individual amplitude variations may be examined in detail. This feature is illustrated in FIGURE 8 wherein an induced misfire of a spark plug is shown at normal tracing speeds of 5 mm./sec. (A) and then the same misfire with a higher paper speed of 25 mm./sec. (B). In this manner, once a difficulty has been noticed, the cylinder or plug at fault can be closely evaluated.

Referring to FIGURE 9, a further embodiment of engine performance indicator is shown. In this embodiment a simple warning or performance indicator generally designated **100** is secured via a bracket **104** and insulator strips **106** and **108** by screws to the engine block **11**. The indicator **100** includes a central metallic barrel portion **102** and a pair of end caps **110** of insulation material threadably engaged to opposite ends of the barrel. Each end cap **110** secures a washer **112** within the barrel **102** and includes a centrally aligned fixed contact **118**. An electrically conductive inertia mass **114** is slidably positioned within the barrel **102** and carries therewith a central pin member **116**. A pair of coil springs **120** having outboard ends in contact with the washers **112** are effective to centralize the mass and rod assembly within the barrel. An electrical circuit is included in the roughness warning indicator **100** and comprises a battery **122** supplying current in parallel to the contacts **118**. An electrical lead **124** connects the central barrel **102** to an indicator light **126** which is in turn connected to ground. In operation as the engine block and the indicator **100** are subjected to engine roll in the direction of the arrows, the inertia mass **114** will oscillate within the barrel **102**. When the engine roughness is minimal, the relative movement of the mass **114** and rod **116** will be insufficient to cause contact between the end of the rod and the contacts **118**. However, upon reaching a predetermined undesirable level of engine roughness, the reaction of the mass **114** will be such as to place the ends of the rod **116** into alternating end contact with the contacts **118**. Upon making of this contact, an electrical circuit is completed from the battery **122** through the conductive rod **116**, mass **114**, barrel **102**, lead **124**, light **126** to ground, to thereby flash the indicator light. As the undesirable level of engine roughness persists, the oscillating inertia mass **114** will continue making and breaking the electrical circuit at opposite ends of the rod **116** to display a flashing

light on the dashboard of the vehicle or other suitable control for the engine should the latter be in a stationary application.

The indicator as described is mounted with the spring centered inertia mass free to oscillate along an axis transverse to the engine crankshaft axis and preferably radially displaced therefrom. In this way when the engine roughness or roll exceeds a predetermined level, the flashing indicator light will alert an inexperienced vehicle operator to a condition of engine mis-operation to indicate the need for routine maintenance and engine tune-up well prior to a time when irreparable damage may be done to the engine.

Thus a novel apparatus and method has been discovered which provides a quick, simple, inexpensive method to diagnose, indicate and analyze the cause of abnormal engine operation, which method is flexible enough to permit the detection of a wide variety of difficulties.

What is claimed is:

1. Apparatus for analyzing and diagnosing the mis-operation of an internal combustion engine of the piston-driven crankshaft type wherein said engine is subjected to periodic impulses generally about the crankshaft axis and wherein means are provided for mounting said engine to permit limited oscillatory freedom thereof about said axis to reflect said impulses; comprising in combination, means for sensing rotational oscillations of said engine upon its mounting means, support means for said sensing means, said support means including a generally horizontal bar arranged to be positioned above said engine and having an elongated slot therein, an arm, means for mounting one end of said arm in the slot of said bar and for adjusting the lateral position of said arm with respect to said bar, said sensing means being secured to said arm and including a plunger having one end thereof in contact with a portion of said engine radially displaced from said crankshaft axis, and means responsive to movement of said plunger for providing a permanent recording of the oscillatory movement of said engine about said crankshaft axis whereby a graph is produced for subsequent comparison and analysis in relationship to known predetermined graphic patterns associated with known types of engine mis-operation.

2. Apparatus for analyzing and diagnosing the mis-operation of an internal combustion engine of the piston-driven crankshaft type wherein said engine is subjected to periodic impulses generally about the crankshaft axis and wherein means are provided for mounting said engine to permit limited oscillatory freedom thereof about said axis to reflect said impulses; comprising in combination, means for sensing rotational oscillations of said engine about its crankshaft axis; said sensing means including, a generally horizontal bar arranged to be positioned above said engine and having an elongaed slot therein, an arm, means for mounting one end of said arm in the slot of said bar and for adjusting the lateral position of said arm with respect to said bar, induction coil vibration pick-up means, means for adjustably mounting said pick-up means upon said arm; said pick-up means including an electrical coil, a permanent magnet plunger arranged to be reciprocated within said coil in a direction generally parallel to said bar, spring means for biasing said plunger into contact with a portion of the engine to be analyzed displaced from the crankshaft axis; means for amplifying the output of said coil, and means responsive to the output of said amplifier for producing a permanent recording of the oscillatory movement of said engine about said crankshaft axis whereby a graph is produced for subsequent comparison and analysis in relationship to known predetermined graphic patterns associated with known types of engine mis-operation.

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