United States Patent [19]

McBride, Jr. et al.

[11] **3,893,108**

[45] **July 1, 1975**

[54] **INTERNAL COMBUSTION ENGINE PROTECTION CIRCUIT**

[75] Inventors: **Lyle E. McBride, Jr.**, Norton; **William W. Bowman**, North Easton, both of Mass.

[73] Assignee: **Texas Instruments Incorporated**, Dallas, Tex.

[22] Filed: **Dec. 20, 1973**

[21] Appl. No.: **426,850**

[52] **U.S. Cl.** ..... **340/420;** 340/52 F; 340/57; 340/60; 180/105 E

[51] **Int. Cl.** **G08b 23/00**

[58] **Field of Search** ..... 340/52 F, 53, 57, 60, 27 B, 340/420; 180/82 R, 103, 105 E; 317/13, 36 R, 40, 141

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Primary Examiner—Thomas B. Habecker

Attorney, Agent, or Firm—James P. McAndrews; John A. Haug; Russell E. Baumann

[57] **ABSTRACT**

Four sensor input circuits continuously and simultaneously monitor liquid coolant temperature, liquid coolant level, engine speed and engine oil pressure. When predetermined conditions are reached in either the liquid coolant temperature or level input circuits an alarm signal is provided directly to a trip circuit which simultaneously operates one alarm which is a continuous visual or audible alarm and a second alarm which shuts down the engine and is itself de-energized after a predetermined time interval. The liquid coolant temperature and level input circuits are fail safe, indicating an alarm in the event of a short or open circuit in either sensor. The signal from the speed input circuit is compared to a predetermined value representative of maximum desired engine speed in a separate high speed trip circuit to trip the said alarms in the event of an overspeed. The output signals from the speed input circuit and the pressure input circuit are each variable DC signals which are adjustable in relation to each other and which are compared in a comparator to generate an alarm signal to the trip circuit whenever the oil pressure falls below a predetermined value for a given engine speed. Notwithstanding provision of a variable battery power supply, all units are operated at a predetermined regulated voltage level. Also provided are circuits for protecting against false trips and for protecting electrical units from accidental reverse application of supply power.

28 Claims, 6 Drawing Figures

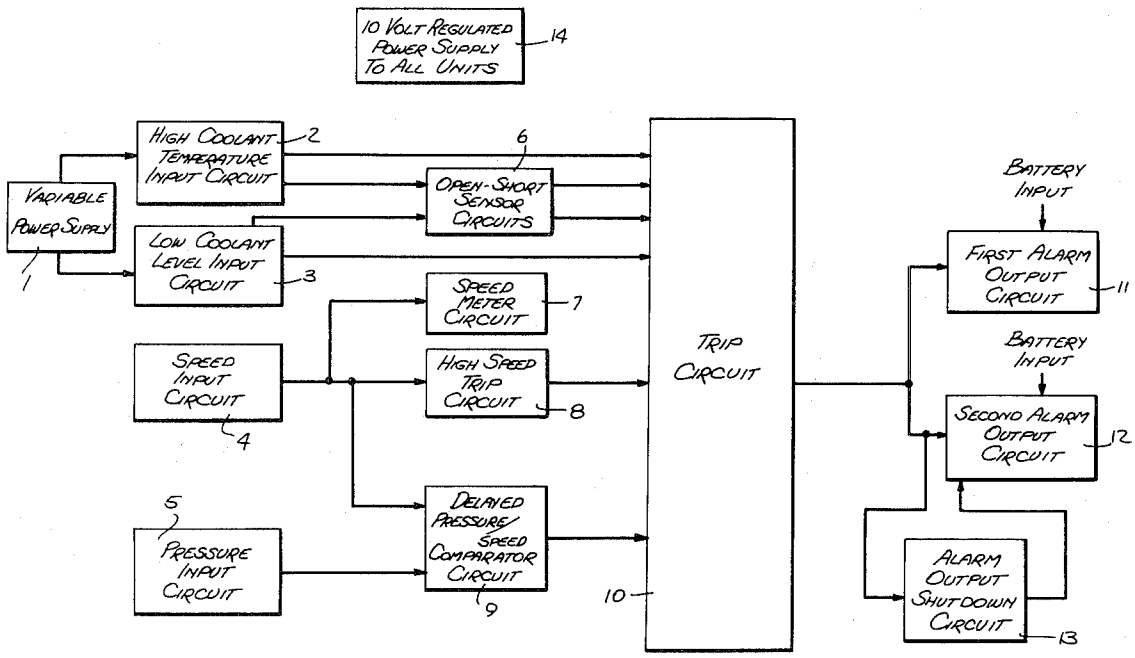
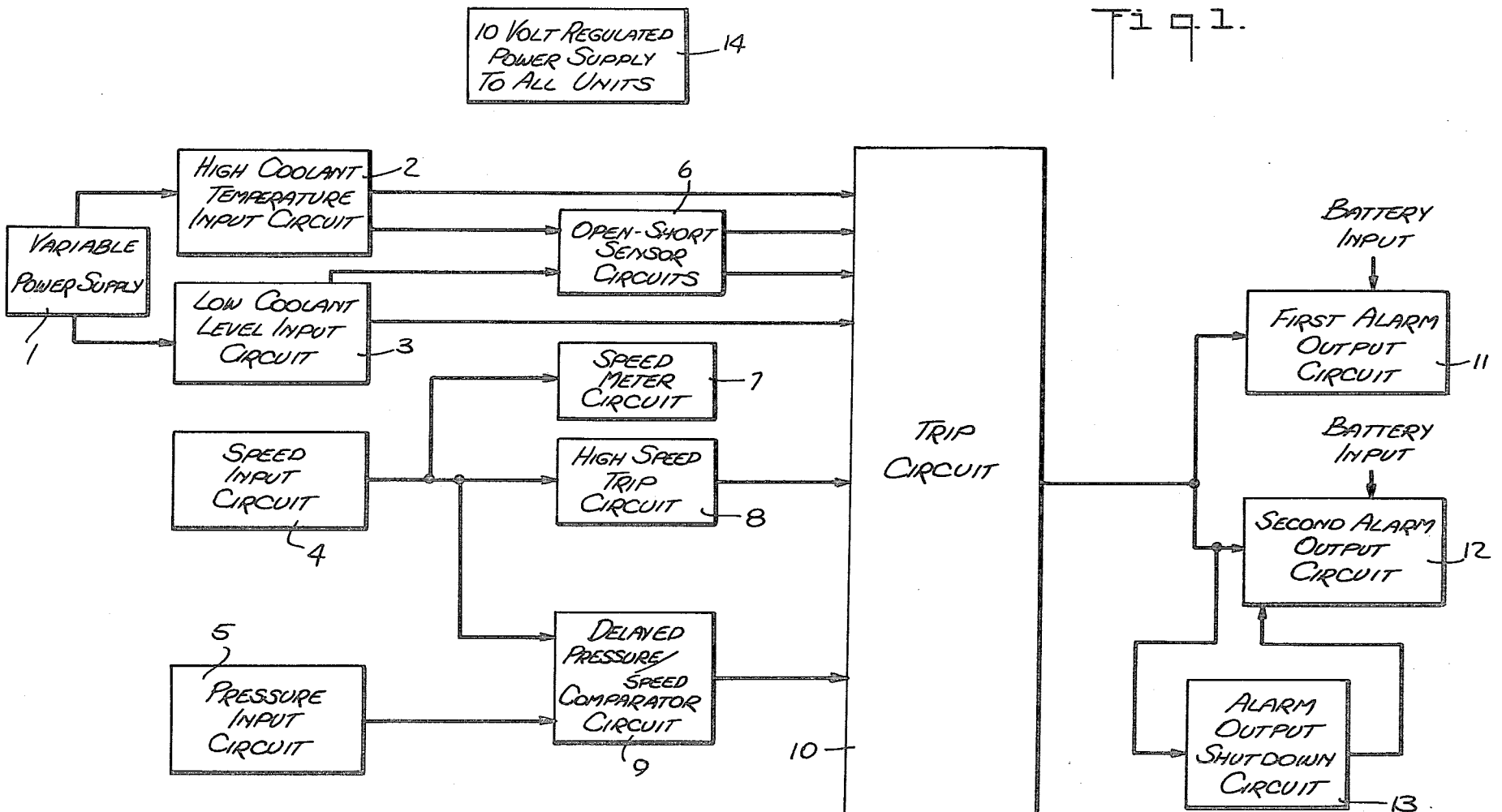


Fig. 1.



SHEET 1

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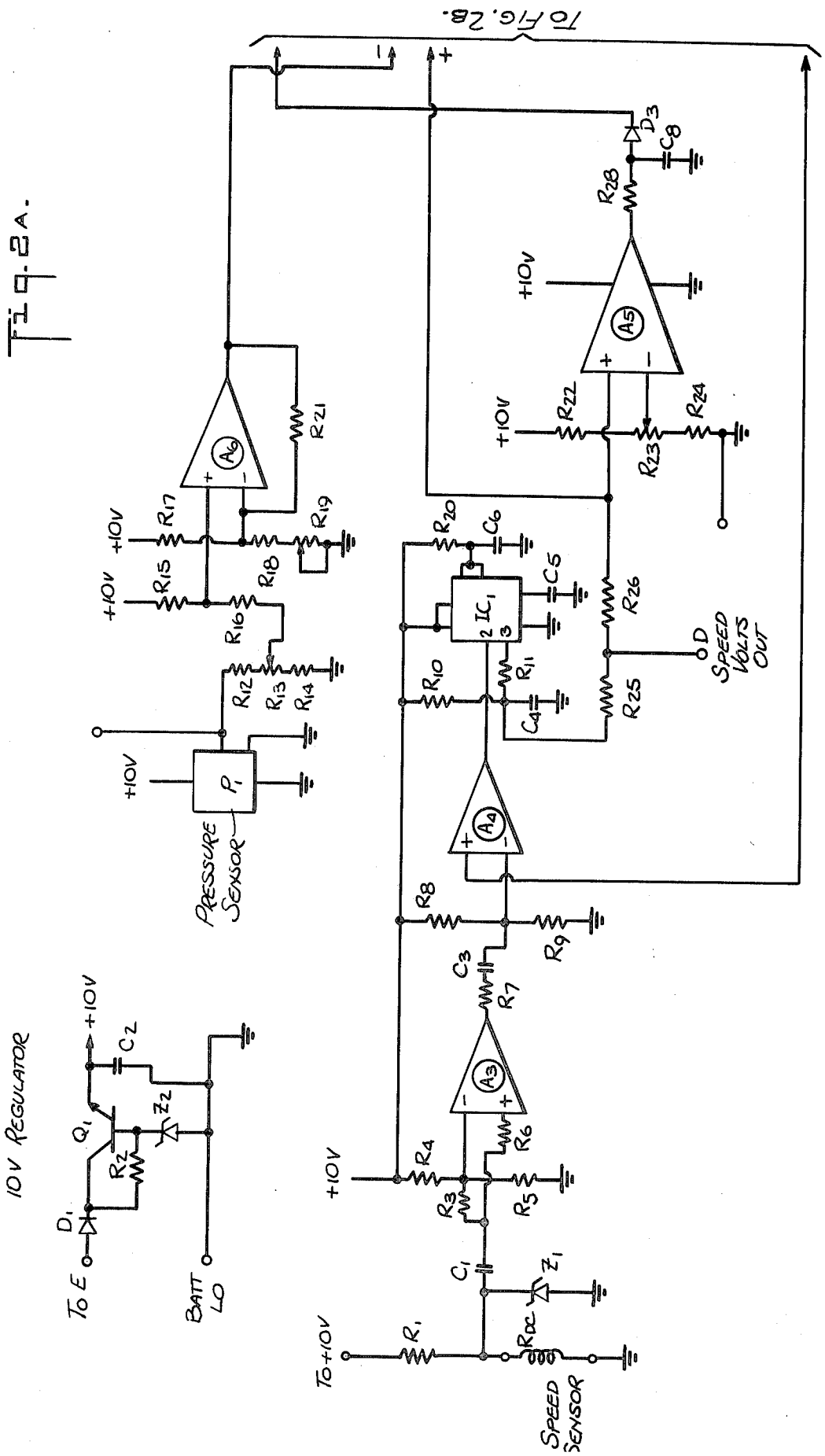

To Fig. 2B.
+
-
D3
C8
R28
+10V
A5
R22
R24
R23
R21
A6
R17
R19
R20
C6
R15
R18
C5
IC1
R26
R16
R10
R11
R12
R13
R14
R25
C4
P1
+10V
Pressure Sensor
D
Speed Volts Out
A4
R8
R9
C3
R7
A3
R4
R6
R3
R5
C1
Z1
R1
Rdc
To +10V
Speed Sensor
10V Regulator
C2
Q1
Z2
R2
D1
To E
Batt Lo

Fig. 2A.

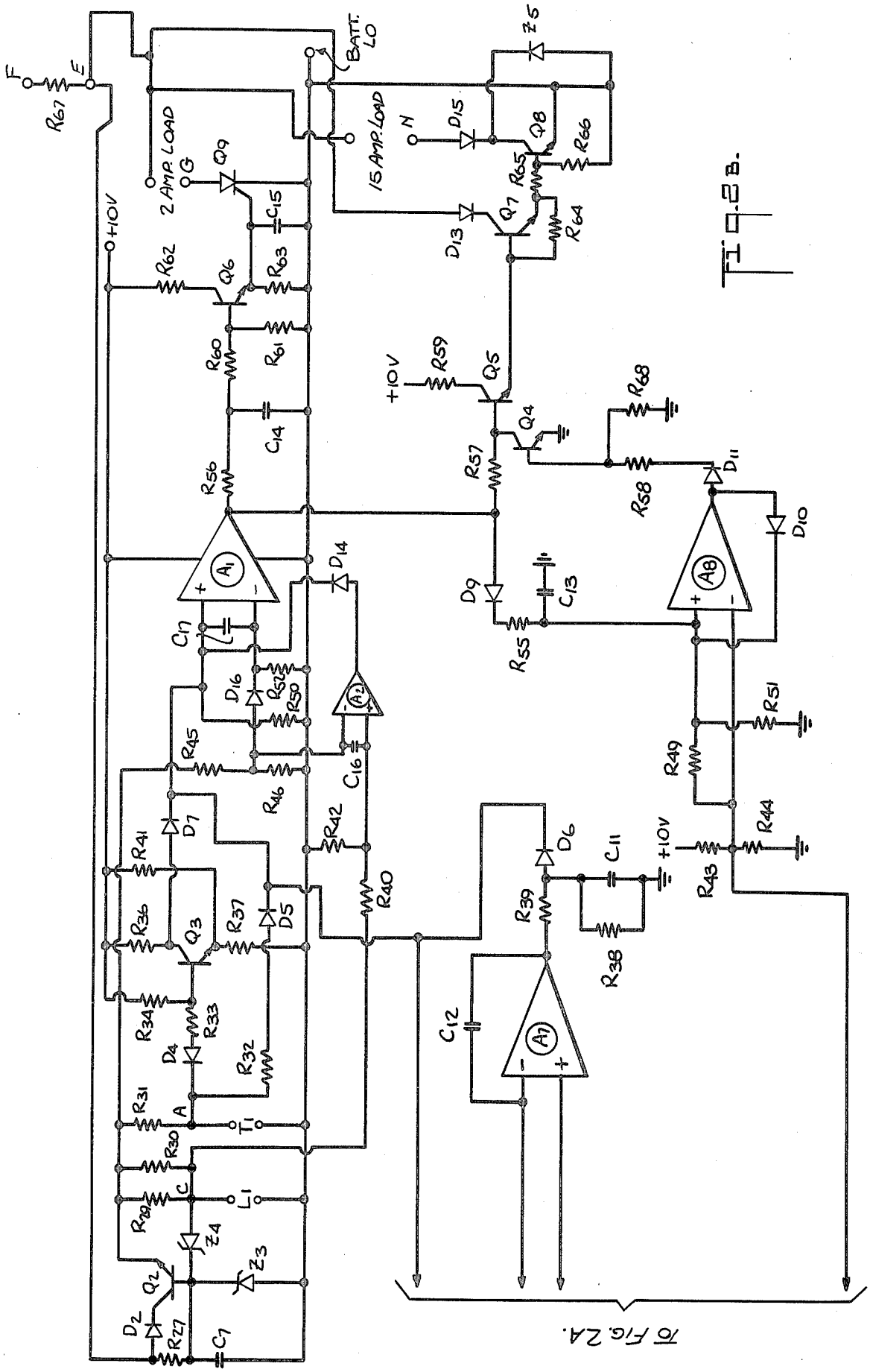

F
E
R67
2 AMP. LOAD
G
Q9
C15
+10V
R62
Q6
R63
R60
R61
C14
R56
A1
C17
D16
R52
R50
D14
A2
C16
R45
R46
R42
R40
D7
R41
R36
Q3
R37
D5
R34
R33
D4
R32
R31
A
T1
R30
C
L1
R29
Z4
Z3
Q2
D2
R27
C7
BATT. LO
15 AMP. LOAD
N
D15
Q8
R66
R65
Z5
Q7
R64
D13
+10V
R59
Q5
Q4
R68
R57
R58
D11
D10
A8
D9
C13
R55
R51
R49
R44
R43
+10V
D6
C11
R39
R38
C12
A7
To Fig. 2A.

FIG. 2B.

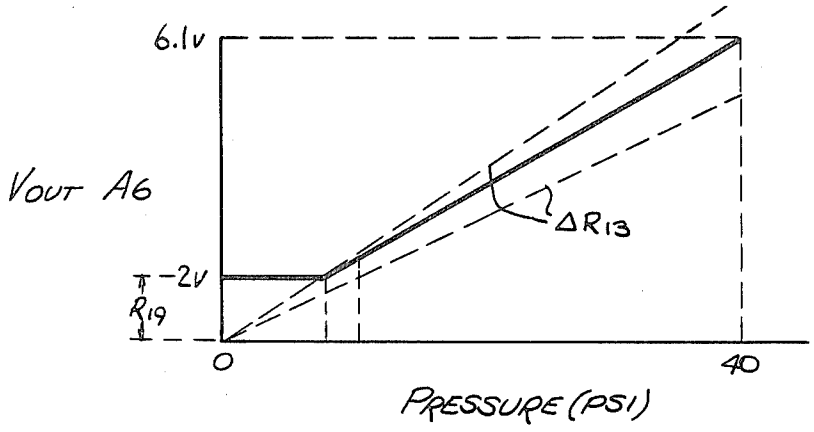


Fig. 3.

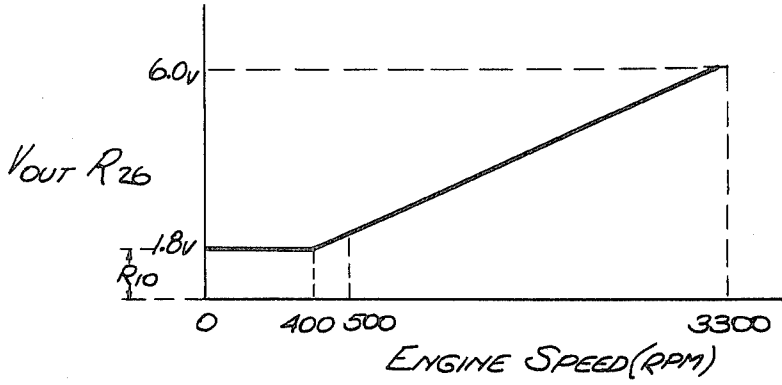


Fig. 4.

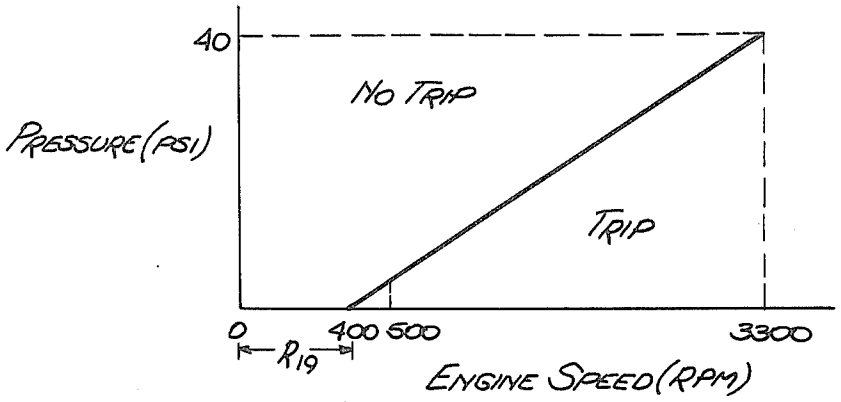


Fig. 5.

INTERNAL COMBUSTION ENGINE PROTECTION CIRCUIT

BACKGROUND OF THE INVENTION

1. Field Of The Invention

This invention relates to an electronic protection system for an internal combustion engine, and, more particularly to a protection circuit capable of sensing multiple alarm conditions and simultaneously operating multiple alarm circuits continuously or momentarily or both.

2. Description Of The Prior Art

Electronic protection circuits to monitor operating parameters of equipment have been used for a variety of purposes with varying degrees of success.

Furnace control circuits are known which use a time dependent thermistor responsive to temperature in a circuit which shuts off the fuel supply to the furnace if fuel in the furnace is not ignited by the time the thermistor reaches a predetermined temperature. See, for example, U.S. Pat. No. 3,549,088.

Various protection circuits for electrical loads are also known. One such circuit uses a PTC or NTC thermistor to sense an overheat condition in the electric motor and generate a shut down signal to a normally conducting semiconductor to de-energize the motor. See, for example, U.S. Pat. No. 3,569,781. Similarly, another circuit monitors the actual current drawn by an electric motor during start-up and compares the result with a reference value, the two inputs being in the form of variable DC signals applied to the input terminals of a differential amplifier, to de-energize the motor and prevent it from being operated in an undersired mode thereby limiting the steady state current carrying capacity needed in semi-conductors used in the circuit. See, for example, U.S. Pat. No. 3,609,461. Another such circuit uses multiple PTC sensors in a circuit to sense high impedance changes in a sensor resistance and operate a double alarm indicator such as a pop-up flag which requires manual reset and an overload light. The latter circuit includes protection against a short circuit in the sensors and a lockout feature preventing reapplication of power unless the entire circuit is de-energized. See, for example, commonly owned pending application Ser. No. 316,194 filed Dec. 18, 1972.

As part of an effort to increase safety devices in consumer products, particularly automobiles, a protection circuit has been developed which monitors the brake fluid level in the master cylinder of a vehicle and actuates a lamp when the liquid level is too low. This circuit uses a temperature sensitive sensor which has a low resistance in liquid and a high resistance in air. See, for example, U.S. Pat. No. 3,760,352. See also, U.S. Pat. No. 3,766,395.

A protection circuit is known which, after a predetermined delay following start-up of an air conditioning compressor, shuts down the compressor if a pressure switch fails to close indicating that the oil pressure has failed to reach a minimum operating level. The circuit includes simultaneous continuous monitoring of the temperature of the windings of the compressor with shut down being triggered upon sensing an overheat condition. See, for example, U.S. Pat. No. 3,753,043.

The above devices, though useful in their own fields, have not found application in continuous monitoring of internal combustion engine primary operating parameters for initiating automatic action upon the detection

of an unsafe condition. Normally the coolant temperature, engine speed and oil pressure of an internal combustion engine have in the past been indicated on a gauge, or, by an on-off light which signals a safe operating level. Liquid coolant level has generally not been monitored in the past. These indicators require observation of the indicated condition being measured, recognition of an unsafe condition and then corrective action by the driver or operator. In unattended installations, none of the aforesaid functions can be performed. In attended installations frequently the human element fails to act, or fails to act quickly enough to prevent damage to the equipment or injury to personnel. For example, though oil pressure and engine speed are both indicated on a gauge and observed, the operator may be unaware that the oil pressure is unsafe for the particular speed at which the equipment is operating and would fail to recognize that the equipment should be shut down.

These shortcomings are overcome in the present invention. There is provided a protection system for simultaneously and continuously monitoring all four primary engine parameters — coolant temperature, coolant level, engine speed and oil pressure as a function of engine speed — and for automatically indicating alarm conditions while automatically taking action to protect the equipment.

SUMMARY OF THE INVENTION

A speed sensor input circuit generates a variable DC signal which is used as one input to a differential speed-pressure comparator. The other input to the comparator is a variable DC signal representative of engine oil pressure. The latter signal is adjusted in relation to the first signal so that whenever the oil pressure signal falls below the speed signal, the comparator senses the difference and generates an alarm signal representing insufficient oil pressure for a given speed. The alarm signal is first delayed to filter out false alarms and is then sensed by a biased differential amplifier which provides an output signal which simultaneously operates a continuous visual or audible alarm, a solenoid means for shutting down the engine and an alarm shut down circuit to de-energize the solenoid after a predetermined time interval. A high speed trip circuit compares the speed input signal to a predetermined value representative of the maximum desired speed and provides an alarm signal. Additional input circuits continuously monitor liquid coolant temperature and level and generate an alarm signal when excessive temperature or low level conditions are reached. Steering diodes prevent interference between any of the aforesaid alarms, and any of the alarms will trip the differential amplifier and operate both the audible/visual alarm and the solenoid. Provision is made to signal an alarm upon a short or open circuit in the sensors of the coolant temperature and level input circuits. The fail safe circuit of the level input circuit has a primary channel which operates by lowering the voltage level at the positive terminal of an operational amplifier below two volts to cause the output of the amplifier to go high generating an alarm signal which reaches the aforesaid biased differential amplifier prior to a nearly simultaneous alarm signal generated in the secondary or back-up channel of the fail safe circuit.

Accordingly, it is an object of the present invention to operate a low power, continuous audible or visual

alarm upon the sensing of any one of four predetermined alarm conditions which are:

1. The oil pressure for any given speed falls below a predetermined pressure for a given engine speed.

2. The speed of the engine exceeds a predetermined RPM.

3. The temperature of the liquid coolant exceeds a predetermined temperature.

4. The level of the liquid coolant in the engine drops below a predetermined level.

Additional objects of the present invention are as follows:

1. To provide affirmative automatic action in the form of shutting down the engine upon the occurrence of any of the four aforesaid alarm conditions.

2. To provide for turning off of the high power action mode alarm to avoid draining supply power on unattended equipment installations.

3. To provide for avoidance of false alarms.

4. To provide for failsafe protection of the sensor input circuits. Other objects will become apparent from the description of the drawings and the preferred embodiments which are set forth below.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of the protection circuit of the present invention.

FIGS. **2A** and **2B** are circuit diagrams of one embodiment of the present invention.

FIG. **3** is a chart showing the output voltage of the pressure input circuit.

FIG. **4** is a chart showing the output voltage of the speed input circuit.

FIG. **5** is a chart showing the relation of pressure to speed which causes the delayed pressure speed comparator to trip.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Overall Operation

Referring first to FIG. **1** there is shown a block diagram of the four sensor protection system of the present invention. The power supply **1** includes a replaceable, externally mounted, dropping resistor which permits operation of the entire circuit with either a 12, 24 or 36 volt supply battery. Input circuit **2** includes the sensor and associated circuitry for sensing high temperature of the coolant liquid and provides an alarm signal to the trip circuit **10** whenever the temperature exceeds a predetermined temperature. Input circuit **3** includes the sensor and associated circuitry for sensing the low level of the coolant liquid and provides an alarm signal to the trip circuit **10** whenever the liquid level falls below a predetermined level. Open-short sensor circuits **6** provide fail safe protection against open or short circuits in the temperature and level sensors of input circuits **2, 3.** Input circuit **4** includes the sensor and associated circuitry for sensing the speed of the engine and generating a variable DC signal which is representative of the speed of the engine. This signal is read directly on a meter in circuit **7.** The speed signal generated by input circuit **4** is also provided to a high speed trip circuit **8** which provides an alarm signal to the trip circuit **10** when the speed of the engine exceeds a predetermined value. The output signal of circuit **4** is also provided as the reference input signal to the pressure-speed comparator circuit **9.** Input circuit **5** includes the sensor and associated circuitry for generating an adjustable, variable DC signal which is representative of the actual oil pressure of the engine. The signal is provided as an input signal to the pressure-speed comparator circuit **9** which generates an alarm signal to trip circuit **10** whenever the actual oil pressure for a given engine speed falls below a predetermined value. Trip circuit **10** prevents interference between the alarm signals from the four input circuits and, in a genuine alarm condition, simultaneously operates both alarm circuits **11** and **12** and alarm output shutdown circuit **13.** The first alarm output circuit **11** is a continuous audible or visual alarm. The second alarm output circuit **12** is a momentary alarm which shuts down the engine. After a few seconds of operation alarm circuit **12** is shut down by alarm shutdown circuit **13.** The protection system further includes a **10**v regulator circuit for all units requiring supply power, circuits for protection against false alarms being generated in circuits **8** and **9** and protection against accidental reverse application of supply power.

High Coolant Temperature Alarm Circuit

The purpose of this circuit is to sense an overtemperature condition in the liquid coolant and generate an alarm signal. This circuit includes thermistor T_1, resistors R_{31} and R_{32} and diode D_5. Refer to FIG. **2B.**

The characteristics of thermistor T_1 which is a PTC sensor are well known in the art. Any known sensing device capable of presenting a sharply increased electrical resistance in response to an increase in temperature may be used.

Thermistor T_1 and resistor R_{31} are connected across a special **10** volt power supply provided by transistor Q_2 and Zener diode Z_3, as indicated at **1** in FIG. **1** and as described more fully below, and perform as a voltage divider. The junction between T_1 and R_{31} is connected to the positive terminal of differential comparator amplifier A_1 through R_{32} and D_5. When a predetermined temperature is exceeded and sensed by T_1, the voltage at A goes high and is reflected proportionately to D_5 and at the positive terminal of A_1 in the trip circuit **10** as an alarm signal, as described in greater detail below.

An open-short sensor circuit is included as a fail safe protective device for the high coolant temperature alarm circuit. The fail safe circuit functions to provide an alarm signal in the event T_1 is short circuited. The shorted sensor circuit includes resistors $R_{33, 34, 36, 37}$ and $_{41}$, transistor Q_3 and diodes D_4 and D_7. During normal operation transistor Q_3 is turned on by **10** volt regulator **14** indicated in FIG. **1,** the current flow being from supply through R_{34}, the base-emitter junction of Q_3 and R_{37} to ground. The current flow from the collector to emitter of Q_3 is limited by R_{36}. The voltage level at the collector of Q_3 in normal operation, as determined by the constants of the circuit, is insufficient to constitute an alarm signal to comparator A_1 of the trip circuit. If T_1 short circuits, however, the voltage level at A goes to ground. Current flow is then through R_{34}, R_{33}, D_4 and then to ground. The voltage level at the base of Q_3 goes down and Q_3 is turned off causing the voltage at the collector of Q_3 to go high to supply voltage level which is reflected proportionately to D_7 and then at the positive terminal of A_1 in the trip circuit as an alarm signal as described in greater detail below. R_{41} clamps the voltage level at the emitter of Q_3 at a stable level so that when the base of Q_3 goes low due to a short circuit, Q_3

turns off. If the high temperature coolant sensor opens, voltage at point A goes high and trips comparator A_1 as in the normal mode of operation.

Low Coolant Level Alarm Circuit

The purpose of this circuit is to sense a low liquid level condition in the coolant system and to generate an alarm signal in response thereto. This circuit includes level sensor L_1, resistors R_{29}, R_{30}, R_{40}, R_{42}, comparator A_2, capacitor C_{16} and diode D_{14}. Refer to FIG. 2B.

The low coolant level alarm circuit works similarly to the high coolant temperature alarm circuit, and although the level sensor is more sensitive to voltage and operates at a higher power level, it utilizes the special voltage supply indicated at 1 of FIG. 1. The special voltage is provided by transistor Q_2 and Zener diode Z_3, as is more fully described below.

Level sensor L_1 may be any known sensing device which is capable of presenting an increased electrical resistance in response to a decrease in coolant liquid level. Such sensing devices are usually cooled by a liquid and electrically heated in air to present an increased electrical resistance.* Parallel resistors R_{29} and R_{30} are connected in series with sensor L_1 and form a voltage divider the junction of which is connected to the positive terminal of amplifier A_2 through a voltage divider comprising R_{40} and R_{42}. The reference level of amplifier A_2 is set by voltage divider R_{45}, R_{46}, which is the same voltage divider setting the reference level for differential comparator A_1 as more fully described below. C_{16} is a noise filter. The separate amplifier A_2 is needed in order to regulate the signal generated by the level sensor and provide an accurate alarm signal. The output signal from amplifier A_2 drives comparator A_1 through steering diode D_{14}.

* A similar type temperature sensitive sensor known as an NTC sensor presents a decrease in electrical resistance in response to increased temperature. Given applicants' disclosure, it would be obvious to substitute such a sensor in a circuit to generate an alarm signal in response to either an increase in coolant temperature or a decrease in coolant level.

In operation, when the level of the coolant liquid in the engine goes below a certain predetermined level, L_1 heats up and the voltage level at point C goes high raising the voltage level at the positive terminal of comparator A_2. A_2 senses the alarm condition and generates an output alarm signal which is reflected proportionately to diode D_{14} and at the positive terminal of comparator A_1 of the trip circuit, as more fully described below.

The voltage supply portion of the low coolant level alarm circuit receives power from pin E and functions to regulate the supply voltage applied to L_1 and includes transistor Q_2, diode D_2, Zener diode Z_3, resistor R_{27} and capacitor C_7. In operation Q_2 is normally conducting and its output voltage at the emitter is regulated at 10v by Zener diode Z_3 which is set at about 11v. C_7 filters out transient noises. R_{27} sets the level of the base current to Q_2. Diode D_2 protects transistor Q_2 against accidental reverse connection of the supply battery.

The level sensing alarm circuit also includes a fail safe circuit which functions to provide an alarm signal in the event L_1 is short circuited. The fail safe circuits include a primary fail safe circuit and back-up fail safe circuit.

The primary fail safe circuit includes the same elements as the normal alarm circuit, namely L_1, R_{29}, $_{30}$, $_{40}$ and $_{42}$. A_2, C_{16} and D_{14}. When L_1 approaches a short circuit, the voltage level at point C goes toward ground, lowering the voltage level at the positive terminal of A_2 to about .7 volts, well below the voltage level at the negative terminal of A_2. One would normally expect the output signal of operational amplifier A_2 to go low. Such is normally the result when the voltage level at the positive terminal goes below the voltage level at the negative terminal, except for an unusual characteristic of operational amplifiers which is taken advantage of in the present circuit. That is, when the voltage level at the plus terminal of an operational amplifier goes below common mode voltage, the voltage output of the amplifier goes high, even though the voltage level at the negative terminal exceeds the voltage level at the positive terminal. Normally operational amplifiers are operated above the 2 volt level specifically to avoid this unusual result. Here, however, this abnormality is used to advantage. The constants of the circuit are selected so that upon a short circuit of L_1, the voltage level applied to the positive terminal of A_2 goes below common mode voltage, causing the output of A_2 to go high generating an alarm signal which is reflected proportionately to D_{14} and the positive terminal of amplifier A_2 in the trip circuit, as more fully described below.

The backup fail safe circuit includes Zener diode Z_4 which normally is not conducting. If L_1 short circuits, the voltage at point C goes to ground, placing Z_4 in parallel with Z_3 and lowering the voltage level at the base of Q_2. The output voltage of Q_2 at the emitter is thereby lowered sufficiently that the voltage level at the junction of voltage divider R_{45}, R_{46} and at the negative terminal of A_1 goes down sufficiently to constitute an alarm signal.

Furthermore, the circuit constants are selected such that the alarm signal provided by the primary fail safe circuit through A_2 and D_{14} to the positive terminal of A_1 arrives prior to the alarm signal provided by the secondary fail safe circuit through Z_4, Q_2 and R_{45} to the negative terminal of A_1. By providing primary and back-up alarm signals, additional reliability is built into the circuit, since A_1 will still trip in the event L_1 shorts, even if amplifier A_2 fails. Z_4 is selected to conduct at about 4v as compared to the 11v level of Z_3 and performs an additional function of limiting current flow from Q_2, through R_{29} to ground during a short circuit of L_1 which permits using a simpler heatsink for Q_2 and reduces construction costs. If level sensor L_1 opens, voltage at point C goes high and trips A_2 and then A_1 as in the normal mode of operation.

Overspeed Alarm Circuit

The purpose of this circuit is to sense an overspeed condition of the engine and generate an alarm signal. The overspeed alarm circuit includes the speed input circuit, the speed meter circuit, and the high speed trip circuit.

The speed input circuit includes speed sensor R_{DC}, resistors R_1, R_3, R_4, R_5, R_6, R_7, R_8, R_9, R_{10}, R_{11}, R_{20} and R_{25}, capacitors C_1, C_3, C_4, C_5 and C_6, hi gain amplifiers A_3 and A_4, integrated circuit IC_1 and Zener diode Z_1. Refer to FIG. 2A.

The operation of the speed circuit is as follows:

Speed sensor R_{DC} is a wound core which is physically placed adjacent to the ring gears of the engine flywheel. As each tooth of the ring gear passes the wound core of R_{DC}, the magnetic flux in the core changes generating an AC signal, the frequency of which is proportional to the speed of the engine. Zener diode Z_1 is cou-

pled between the junction of R_1 and R_{DC} and ground and functions to limit the amplitude of the AC signal generated by R_{DC} in the event of a high voltage spike. Thus, capacitor C_1, a DC blocking capacitor, is presented with a variable frequency AC signal, the frequency of the signal being proportional to the speed of the engine. C_1 is coupled to the positive terminal of high gain amplifier A_3.

The negative terminal of amplifier A_3 is set by voltage divider R_4 and R_5. The positive terminal of A_3 is connected in series with the negative terminal through R_3 and R_6. R_3 is much larger than R_6. When capacitor C_1 is not conducting, both terminals of amplifier A_3 are at the same voltage level. When capacitor C_1 conducts, most of the signal goes through R_6 to the plus terminal of amplifier A_3 generating a large increase in the output signal of the amplifier. Thus, the output of A_3 is an amplified signal closely approximating a square wave and having a constant amplitude and variable frequency which follows the AC signal generated by R_{DC}. The output of A_3 is differentiated in R_7 and C_3 and applied to the negative terminal of hi gain amplifier A_4 which performs in a manner similar to amplifier A_3. Voltage divider R_8 and R_9 holds the negative terminal of amplifier A_4 at an operating level. The output of amplifier A_4 is a square wave AC signal, i.e., a constant amplitude, variable frequency signal, the frequency being proportional to the speed of the engine. This signal is fed into integrated circuit IC_1 at pin **2.** IC_1 is a monostable multivibrator well known in the art which converts the input signal to a constant pulse width, constant amplitude AC signal, the number of pulses per unit of time being a function of the speed of the engine. The output of IC_1, at pin **3** is integrated in RC circuit R_{11}, C_4 the output of which is a variable DC voltage proportional to the speed of the engine.

This variable DC output signal is applied to three locations. First it is read at a meter at terminal D which comprises the speed meter circuit.

Second, the same signal is applied to a high speed trip circuit the purpose of which is to sense an overspeed condition, such as would be caused by a governor failure, and to generate an alarm signal in response thereto. The high speed trip circuit includes resistors R_{22}, R_{23}, R_{24}, R_{26} and R_{28}, comparator amplifier A_5, capacitor C_8 and diode D_3. In operation the variable DC output signal from IC_1 is connected through R_{26} to the positive terminal of comparator A_5. The reference voltage level at the negative terminal of comparator A_5 is set by voltage divider R_{22}, R_{23} and R_{24}. R_{23} is an adjustable resistor so that a predetermined level representative of a selected maximum speed can be set at the negative terminal of amplifier A_5. When the voltage at the positive terminal exceeds the reference voltage, the output of A_5 goes high and is reflected proportionately to diode D_3 and at the positive terminal of A_1 in trip circuit **10** as an alarm signal, as described more fully below. RC circuit $R_{28}C_8$ functions as a small delay circuit for the high speed trip circuit and filters out noise which might generate a false alarm.

Third, the variable DC voltage output signal from the speed circuit is applied through R_{26} as a reference input signal to the positive terminal of the pressure-speed comparator A_7 as described in greater detail below.

Low Oil Pressure Alarm Circuit

The low oil pressure alarm circuit includes the pressure input circuit and the delayed pressure-speed comparator circuit.

The pressure input circuit functions to provide an adjustable, variable DC voltage which is representative of the variation in oil pressure of the engine as a function of engine speed. This circuit comprises a pressure sensor P_1, resistors R_{12}, R_{13}, R_{14}, R_{15}, R_{16}, R_{17}, R_{18}, R_{19} and R_{21} and amplifier A_6. Resistors R_{13} and R_{19} are variable resistors. Refer to FIG. **2A.**

P_1 is a sensor whose characteristics are known in the art. P_1 senses pressure changes and generates a variable DC voltage in response thereto. P_1 is located in the oil line of the engine and is powered by **10** volt regulator **14** as indicated in FIG. **1.**

The output of P_1 is coupled through R_{12} and one branch of a bridge network comprising R_{15}, R_{16}, R_{13} and R_{14} to the positive terminal of amplifier A_6. The level of the reference voltage applied to the negative terminal of amplifier A_6 is set by the other branch of the bridge network comprising R_{17}, R_{18} and R_{19}. When the voltage level of the variable DC signal from P_1 exceeds the reference voltage, amplifier A_6 senses the difference and generates a variable DC voltage output signal which is proportional thereto. This variable DC output signal from A_6 is applied as the input signal to the negative terminal of pressure-speed comparator A_7 and is a signal representative of the oil pressure of the engine at any given moment.

As described above, the variable DC output signal from the speed circuit is applied as the input signal to the positive terminal of pressure-speed comparator A_7 and is a signal representative of the speed of the engine at any given moment.

Thus, pressure-speed comparator A_7 has two variable DC voltages applied to its input terminals. Comparator A_7 senses any difference in these DC voltages. So long as the variable DC voltage applied to the negative terminal of A_7 representative of actual oil pressure is at any instant equal to or greater than the variable DC voltage applied to the positive terminal of A_7 representative of engine speed, no alarm signal is sensed by A_7 and oil pressure for the given speed is satisfactory for continual operation. But, when the DC voltage applied to the negative terminal of A_7 at any instant is lower than that which is applied to the positive terminal, A_7 generates an alarm signal which is an indication of insufficient oil pressure for a given speed or vice versa. The alarm signal is reflected proportionately to diode D_6 and at the positive terminal of comparator A_1 as an alarm signal, as more fully described below.

The pressure-speed comparator A_7 operates in the manner described above because the variable DC voltage output signal from amplifier A_6 of the pressure input circuit indicative of engine oil pressure has been matched to engine specifications as a function of speed represented by the variable DC voltage output signal from the speed input circuit. The matching is done by adjustment to R_{13} in the pressure input circuit and by the value selected for R_{10} in the speed input circuit.

R_{10} sets the bias on comparator A_7 so that the signal applied to the positive terminal of A_7 never goes below a predetermined value, for example 1.8v. Referring to FIG. **4,** there is shown the output voltage from R_{26} plotted as a function of engine speed. At idle, 500 rpm, the output voltage is 2.0v, for example. When the engine is shut down, the voltage decreases until it reaches 1.8v

at 400 rpm, and then remains constant at 1.8v until the engine stops. This bias of Vout is set by R_{10}.

R_{19} unbalances the bridge network of the pressure input circuit so that the output signal of A_6 applied to negative terminal A_7 never goes below a predetermined value, for example, 2v, which is slightly higher than the bias applied to the positive terminal of A_7. Referring to FIG. 3, there is shown this minimum output voltage level of A_6 which represents zero oil pressure and still prevents A_7 from tripping at speeds of 400 rpm and lower, a condition existing only during unwinding of the engine after shutdown.

R_{13} changes the gain of amplifier A_6 so that the slope of the line representing the variable output voltage of A_6 shown in FIG. 3 can be changed (indicated by dotted lines in FIG. 3) to match the slope of the variable DC output voltage at R_{26} shown in FIG. 4. It is readily apparent that under normal operating conditions Vout at A_6 is always slightly higher than Vout at R_{26}.

In FIG. 5 there is shown the curve representing the conditions under which A_7 will trip. So long as the actual oil pressure remains on or above the minimum oil pressure line, no trip occurs. When the actual oil pressure for a given speed falls below the minimum oil pressure line, A_7 is tripped.

An additional feature of the pressure-speed comparator is a delay circuit which functions to prevent a trip of A_7 during surges of low pressure or high speed i.e., prevents false trips. The time constant of the delay circuit is defined by $R_{39}C_{11}$. In operation, when A_7 generates an output signal, C_{11} is charged until its voltage exceeds the forward voltage of D_6 and then the alarm signal is passed to A_1 in the trip circuit. C_{11} discharges through R_{38}, recycling for the next alarm signal. An 8-10 second delay is imposed on the output of A_7. C_{12} is a negative feedback capacitor which dampens AC noise vibrations contained in the input signal applied to the negative terminal of A_7.

Trip Circuit

The purpose of the trip circuit is to detect an alarm signal generated from signals originating in any of the input circuits and trigger the first and second alarm circuits and the alarm output shutdown circuit. The trip circuit includes diodes D_3, D_5, D_6, D_7 and D_{14}, resistors R_{45}, R_{46}, R_{50}, R_{52}, capacitor C_{17}, diode D_{16} and differential comparator A_1. Refer to FIG. 2B.

Diodes D_5, D_7, D_{14}, D_3 and D_6 are steering diodes which prevent interference between the alarm signals from the high temperature coolant circuit, the open-short sensor circuit, the low coolant level input circuit, the high speed trip circuit and the delayed pressure-speed comparator circuit respectively.

R_{50} and R_{52} provide biasing for the input terminals of amplifier A_1. R_{45} and R_{46} constitute a voltage divider setting the reference voltage level of the negative terminal of A_1. Whenever the voltage level at the positive terminal of A_1 is higher than the reference voltage level at the negative terminal, A_1 senses an alarm condition and the output of A_1 goes high triggering both alarm circuits and the alarm shutdown circuit simultaneously. C_{17} is a noise filter whereby noise on one input line is shunted to the other line so that a false alarm is avoided. D_{16} compensates for temperature changes in the steering diodes and follows them.

Alarm Output Circuits

When the output of comparator A_1 goes high, both alarm output circuits are tripped. The A_1 output signal voltage is used to operate two alarm circuits. One alarm is a 2 ampere load, and the other is a 15 ampere load. The 2 ampere load is usually an audible or visual alarm, i.e., a lamp, a whistle or similar type load, whereas the 15 ampere load is, for example, a solenoid which is used to shut down the engine such as by operating an air valve in the engine intake system. The small load is continuous, whereas the large load is momentary. Refer to FIG. 2B.

The first alarm output circuit includes resistors R_{56}, R_{60}, R_{61}, R_{62} and R_{63}, capacitors C_{14} and C_{15}, transistor Q_6, SCR Q_9 and a 2 amp load at terminal G. In operation, the output of comparator A_1, when it goes high, turns on transistor Q_6 through R_{56} and R_{60}. Capacitor C_{14} filters out transient noises to prevent false trips of the alarm. R_{62} limits the current flow through Q_6. R_{63} sets the source impedence to the gate of SCR Q_9. When Q_6 turns on, gating current is supplied to SCR Q_9 which is switched on. Q_9 is a silicon controlled rectifier, the characteristic of which is that once it is turned on, it remains on until the whole circuit is de-energized, such as by disconnecting the supply battery. Thus, the 2 amp load connected at terminal G remains in continuous operation until the battery is disconnected.

The second alarm output circuit includes resistors R_{57}, R_{59}, R_{64}, R_{65} and R_{66}, transistors Q_5, Q_7 and Q_8, diodes D_{13} and D_{15}, Zener diode Z_5 and a 15 amp load at terminal N. In operation, when the voltage output of comparator A_1 goes high, Q_5 is turned on through R_{57}. R_{59} limits the current flow through Q_5. Q_5 turns on transistor Q_7 which turns on transistor Q_8. Three transistors are used so that the current level outputs from comparator A_1 is amplified significantly in order to operate the 15 amp load connected in series with Q_8. When Q_8 is turned on, the 15 ampere load is operated. Transistors Q_7 and Q_8 are connected to diodes D_{13} and D_{15}, respectively which protect the transistors against accidental reversal of the battery voltage. Resistors R_{64} and R_{66} protect transistors Q_7 and Q_8, respectively, from thermal runaway by drainage leakage current out of the transistors. R_{65} limits the base current of Q_8.

There is good reason for only momentarily operating the 15 amp load of the second alarm output circuit. The solenoid and Q_7 and Q_8 draw a lot of power. Should that load stay on for any prolonged period of time, the solenoid would overheat, the transistors would overheat, and the battery would be drained. This would be very undesirable, particularly, for example, in unattended generators. Therefore, an alarm shut down circuit is provided in order to turn off the second alarm output circuit after a few seconds. The alarm shut down circuit includes resistors R_{43}, R_{44}, R_{49}, R_{51}, R_{55}, R_{58} and R_{68}, capacitor C_{13}, diodes D_9, D_{10} and D_{11}, comparator A_8 and transistor Q_4. When the output voltage of comparator A_1 goes high turning on the 15 amp load alarm as discussed above, current also flows through diode D_9 and R_{55} to timing capacitor C_{13} which is charged. It takes several seconds to charge C_{13}. C_{13} is connected to the positive terminal of comparator A_8. R_{49} and R_{51} are a voltage divider biasing the positive terminal of A_8. The negative terminal of A_8 has its level set by voltage divider R_{43}, R_{44}. Thus, when C_{13} goes high, the output of A_8 goes high, and an output signal is generated turn-

ing on transistor Q_4 through diode D_{11}. R_{58} and R_{68} are a voltage divider biasing Q_4. When Q_4 turns on, it grounds the base terminal of Q_5, turning off Q_5 which in turn turns off Q_7 and Q_8 deactivating the 15 amp load alarm. $R_{55}C_{13}$ defines an RC circuit which takes approximately 2 to 3½ seconds to charge. During that time interval, the second alarm is operative until A_8 is triggered, de-energizing that alarm. The 2 to 3½ second interval is sufficient to shut down the engine. By limiting the heatsinking capacity of the **15** amp output alarm, an additional advantage is obtained in that the entire unit can be made smaller and cheaper. D_{10} is a lockout circuit which keeps A_8 on, once it is triggered, until power to the entire circuit is disconnected.

Supply Voltage

The supply voltage is provided by a **12, 24** or **36** volt battery at pin F. The entire circuit is designed to work at **10** volts regardless of which size battery is used. Therefore, it is necessary to provide a replaceable dropping resistor R_{67} mounted on the outside of the supply box such that a resistor may be selected having either 0, 24 or 47 ohms depending on whether the supply battery is 12, 24 or 36 volts, respectively.

Ten Volt Regulator

The voltage regulator circuit comprises D_1, Q_1, R_2, Z_2 and C_2. The operation of the regulator circuit is as follows:

Diode D_1 is connected between the transistor collector and supply and protects against damage to the transistor in the event of accidental reverse battery connection. Zener diode Z_2 is set at a level slightly above the voltage level which it is desired to maintain. In this instance it is set at slightly above 10 volts. Supply voltage is applied to the base of Q_1 through resistor R_2 turning on Q_1. When the supply voltage exceeds 12v, Z_2 conducts more, maintaining the base voltage of Q_1 constant. Setting Z_2 at about 11v maintains the voltage output of Q_1 at 10v. C_2 filters out transient noises. All components of the protection system which require a regulated supply voltage are connected to the plus 10 volt regulator.

We claim:

1. A protection circuit for an internal combustion engine comprising

a power source, ,

means for providing a first input signal which varies as function of a first engine parameter,

means for providing a second input signal which varies as a function of a second engine parameter,

means for manually adjusting the second input signal so that selected variations of said second input signal are representative of predetermined variations of said second engine parameter to adapt said protection circuit to said engine,

comparator means for comparing the second input signal to the first input signal to provide an alarm signal in response to a predetermined difference between the two input signals,

means for sensing the alarm signal and for providing an alarm indication, and

power source means connected to said first and second input signal means, to said adjusting means, to said comparator means and to said alarm signal sensing means for energization thereof.

2. The protection circuit of claim **1** wherein the means for sensing the alarm signal and for providing an alarm indication comprises

tripping means for generating an output signal in response to the alarm signal,

a first alarm means for continuously indicating the alarm condition in response to the output signal from the tripping means,

a second alarm means for shutting down the engine in response to the output signal from the tripping means, and

means for de-energizing the second alarm means after a predetermined time interval.

3. The protection circuit of claim **2** further comprising means for delaying the alarm signal from the comparator means a predetermined time interval to prevent false alarms.

4. The protection circuit of claim **1** wherein the first engine parameter is engine speed, the second engine parameter is oil pressure, and the alarm condition is that the actual oil pressure is below a desired level for a given engine speed.

5. The protection circuit of claim **1** wherein the comparator means is an operational amplifier.

6. The protection circuit of claim **1** further comprising

means for comparing the first input signal to a predetermined limiting value to provide an alarm signal whenever the predetermined value is exceeded.

7. The protection circuit of claim **6** wherein the predetermined value is representative of a desired maximum speed of the engine and the alarm signal represents an overspeed condition of the engine.

8. The protection circuit of claim **6** further comprising

means responsive to a third engine parameter for providing an alarm signal to the tripping means when a predetermined condition is reached.

9. The protection circuit of claim **8** further comprising

means responsive to a fourth engine parameter for providing an alarm signal to the tripping means when a predetermined condition is reached.

10. The protection circuit of claim **9** wherein the third and fourth engine parameters are liquid coolant temperature and liquid coolant level, respectively, and the predetermined conditions are liquid coolant temperature above a desired temperature and liquid coolant level below a desired level, respectively.

11. The protection circuit of claim **10** further comprising

fail safe means for providing an alarm signal to the tripping means in response to a short or open circuit in either of the means responsive to coolant temperature and level.

12. The protection circuit of claim **11** further comprising

means for preventing interference between any of the alarm signals, and wherein

the tripping means is responsive to any of the alarm signals.

13. The protection circuit of claim **9** further comprising

fail safe means for providing an alarm signal to the tripping means in response to a short or open circuit in the means responsive to the fourth engine

parameter, being liquid coolant level, said fail safe means comprising

a primary fail safe circuit which includes an operational amplifier,

a secondary fail safe circuit,

the alarm signal being generated through the primary fail safe circuit by reducing the voltage level at the positive terminal of the amplifier below a predetermined level and reaching the tripping circuit prior to the alarm signal being generated through the secondary fail safe circuit.

14. The protection circuit of claim **9** wherein said power supply means includes variable power supply means connected to said means responsive to the third and fourth engine parameters for energizing said means responsive to said third and fourth engine parameters at a predetermined voltage lower than the voltage applied to energize said first and second input signal means.

15. The protection circuit of claim **1** wherein said power supply means includes means connected to said first and second signal means, to said adjusting means, to said comparator means, and to said alarm signal sensing means for providing a regulated supply voltage thereto.

16. The protection circuit of claim **1** further comprising means for protecting against accidental reverse application of supply power.

17. The protection circuit of claim **1** wherein the means for adjusting the second input signal in relation to the first input signal includes

a resistor which sets the minimum voltage level of the first input signal applied to the comparator means,

a first variable resistor which sets the minimum voltage level of the second input signal applied to the comparator means,

a second variable resistor which sets the rate of change of the voltage level of the second input signal applied to the comparator means.

18. The protection circuit of claim **2** wherein the first alarm means includes a silicon controlled rectifier in series with the load for holding the load in an energized condition until the supply power is disconnected.

19. The protection circuit of claim **2** wherein the means for de-energizing the second alarm includes lockout means for holding the second alarm in de-energized condition until the supply power is disconnected.

20. A protection circuit for an internal combustion engine comprising

means for providing a regulated power source,

tripping means for sensing an alarm signal and for generating an output signal in response thereto,

alarm means for providing an alarm indication in response to an output signal from the tripping means,

first input means responsive to a first engine parameter for providing an alarm signal to the tripping means when a predetermined condition is reached,

second input means responsive to a second engine parameter for providing an alarm signal to the tripping means when a predetermined condition is reached, and

fail safe means for providing an alarm signal to the tripping means in response to a short or open circuit in either the first input means or the second input means, said tripping means, alarm means, said first and second input means and said fail safe means being connected to said power source for receiving power therefrom.

21. The protection circuit of claim **20** wherein the alarm means comprises

a first alarm means for continuously indicating the alarm condition in response to the output signal from the tripping means,

a second alarm means for shutting down the engine in response to the output signal from the tripping means, and

means for de-energizing the second alarm means after a predetermined time interval.

22. The protection circuit of claim **20** further comprising

means for preventing interference between any of the alarm signals, and wherein

the tripping means is responsive to any of the alarm signals.

23. The protection circuit of claim **20** wherein the first and second engine parameters are liquid coolant temperature and liquid coolant level, respectively, and the predetermined conditions are liquid coolant temperature above a desired temperature and liquid coolant level below a desired level, respectively.

24. The protection circuit of claim **20** wherein the fail safe means for providing an alarm signal to the tripping means in response to a short or open circuit in the second input means comprises

a primary fail safe circuit which includes an operational amplifier in addition to the tripping means,

a secondary fail safe circuit,

the alarm signal being generated through the primary fail safe circuit by reducing the voltage level at the positive terminal of the amplifier below a predetermined level and reaching the tripping means prior to the arrival at the tripping means of the alarm signal being generated through the secondary fail safe circuit.

25. The protection circuit of claim **24** wherein the second engine parameter is liquid coolant level.

26. The protection circuit of claim **25** wherein

the primary fail safe circuit for providing an alarm signal in the event of an open or short circuit in the liquid coolant level sensing means is the same circuit which provides the alarm signal in the event of low liquid coolant level.

27. The protection circuit of claim **24** wherein the alarm signal being provided by the secondary fail safe circuit is a significantly reduced reference voltage level for the tripping means.

28. The protection circuit of claim **24** wherein the secondary fail safe circuit includes means to reduce the base voltage level of a normally conducting semiconductor which reduces its voltage output level which is reflected proportionately at a reference terminal in the tripping means.

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