(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 October 2017 (26.10.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/184492 A1

(51) International Patent Classification:
*F02D 19/02* (2006.01) *F02D 19/10* (2006.01)
*F02D 19/06* (2006.01)

(21) International Application Number:
PCT/US2017/027892

(22) International Filing Date:
17 April 2017 (17.04.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/325,179 20 April 2016 (20.04.2016) US

(71) Applicant: **CUMMINS INC.** [US/US]; 500 Jackson Street, Columbus, Indiana 47201 (US).

(72) Inventors; and
(71) Applicants: **ACHARYA, Kaushik O.** [IN/US]; 2950 Park View Drive, Columbus, Indiana 47201 (US). **DOUGLAS, Kenneth C.** [US/US]; 2813 31st St., Seymour, Indiana 47274 (US). **SALO, Damon C.** [US/US]; 927 Junco Drive, Columbus, Indiana 47203 (US). **MUKUNDAN, Sudharsan** [US/US]; 15610 60th Avenue N, Plymouth, Minnesota 55446 (US). **ABON, Jason R.** [US/US]; 1741 Washington St., Columbus, Indiana 47201 (US).

(74) Agent: **VAN DALEN, Jessica**; 300 North Meridian Street, Suite 2700, Indianpolis, Indiana 46204 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC,

WO 2017/184492 A1

(54) Title: METHOD AND SYSTEM FOR CONTROLLING USAGE OF NATURAL GAS AND LOW BTU GASEOUS FUELS IN SPARK IGNITED ENGINES

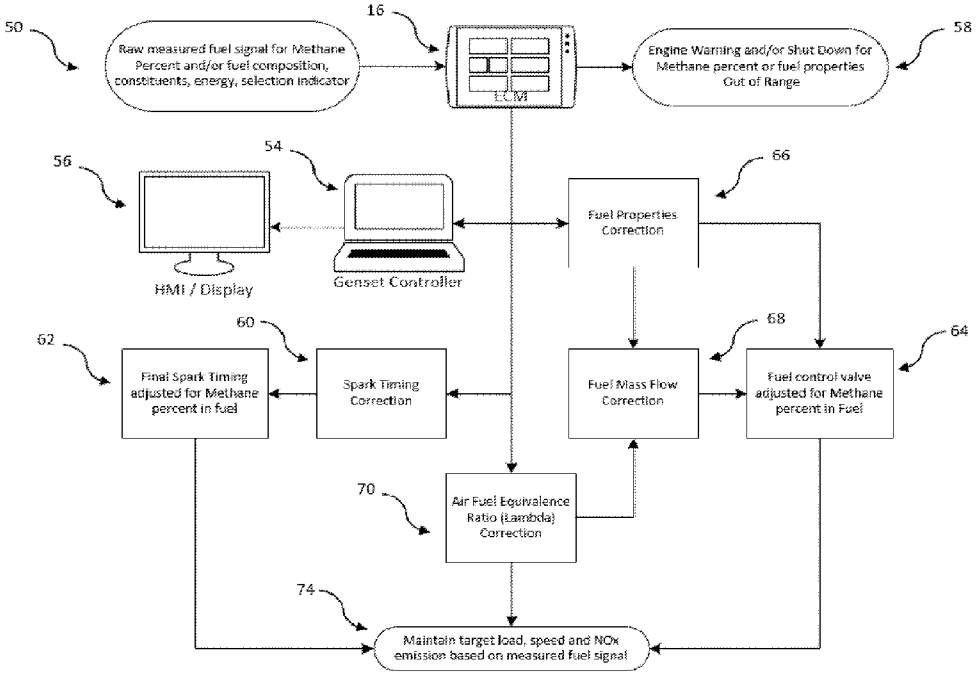


FIG. 3

(57) Abstract: A method is provided for controlling a spark-ignited engine in response to variations in quality of a gaseous fuel provided to the engine. The method comprises receiving a fuel energy value representing a quality of the fuel, determining whether the fuel energy value is sufficiently changed relative to one of an earlier fuel energy value and an expected fuel energy value, responding to a fuel energy value that is sufficiently changed relative to one of an earlier fuel energy value and an expected fuel energy value by accessing control values from a memory, computing adjustment commands for operational components of the engine using the control values, and controlling the operational parameters of the engine using the adjustment commands.

*[Continued on next page]*

SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

**(84) Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published:**

— *with international search report (Art. 21(3))*

# METHOD AND SYSTEM FOR CONTROLLING USAGE OF NATURAL GAS AND LOW BTU GASEOUS FUELS IN SPARK IGNITED ENGINES

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** The present application claims priority to U.S. Provisional Patent Application Serial No. 62/325,179, filed April 20, 2016, and titled "METHOD AND SYSTEM FOR CONTROLLING USAGE OF NATURAL GAS AND LOW BTU GASEOUS FUELS IN SPARK IGNITED ENGINES," the complete disclosure of which is expressly incorporated by reference herein.

## TECHNICAL FIELD

**[0002]** The present invention relates generally to fuel controls, and more particularly to implementations of real time adjustment of operational parameters to maintain acceptable speed, load, and emissions for varying fuel quality.

## BACKGROUND

**[0003]** In some applications, such as in fracking applications or biomass plants, engines for powering machinery are powered by fuel from an on-site fuel source. Such pipeline fuels include natural gas, which is composed mostly of methane. While routing a gaseous fuel supply to an engine on-site is desirable for a variety of reasons, it is known that the "quality" of the fuel varies on a regional and seasonal basis, and over time as a result of storage. The "quality" of the fuel may be viewed as the amount of energy contained in a unit of fuel, which is sometimes referred to as its heating value, and may be represented in units of BTU/lb. In natural gas applications, the quality of the fuel may be represented as a percentage of methane, among other methods.

**[0004]** Depending upon the methane percent and/or fuel composition, constituents, energy, selection indicator, etc. of the fuel supply, various operational components of the engine must be controlled to achieve sufficient power to accommodate the load and speed on the engine and to result in combustion that yields acceptable emissions. Thus, in many applications when the engine is installed the fuel source is tested for methane percent as well as all other gas constituents. Using this representative methane percent, the engine is then calibrated with certain control values, which are used to control operational components of the engine (e.g., the

ignition system, fuel control valve(s), etc.) in a manner that yields the desired power, speed and emissions level.

**[0005]** When the methane percent with other gas constituents measured or assumed for the site/application gas, and/or expected constituents other than methane percent of the fuel change(s), the originally calibrated control values no longer result in the desired engine performance. This may result in engine knock and/or excessive emissions, among other things. Thus, to address changes in fuel quality (i.e., methane percent), service personnel have to go on-site, determine the change in methane percent and/or fuel composition, constituents, energy, selection indicator, etc., and request a new set of calibrated control values. Conventionally, engineering personnel determine the new control values and send them out to the field. The service personnel must then shut down the engine and download the calibrated control values into the engine control module ("ECM").

**[0006]** In some other applications, conventional engines include knock control features which enable the ECM to derate the engine (i.e., reduce the load) when fuel is being supplied with a higher heating value than that assumed by the calibrated control values. In this manner, the ECM may prevent excessive emissions while maintaining engine speed and load.

**[0007]** In any case, conventional control systems for gaseous fuel powered spark ignited engines are not capable of on-the-fly adjustments to operational components of the engine in response to fuel quality changes to maintain engine speed, load, and acceptable emissions. These conventional approaches require that the engine be stopped and restarted or that the load be varied, both of which are undesirable. Therefore, there exists a need for a control approach for gaseous fuel powered spark ignited engines that permits operational component adjustments in response to fuel quality changes without the need for recalibration or derating the engine.

## SUMMARY

**[0008]** According to one embodiment of the present disclosure, a method is provided for controlling a spark-ignited engine in response to variations in quality of a gaseous fuel provided to the engine, comprising receiving a fuel energy value representing a quality of the fuel, determining whether the fuel energy value is sufficiently changed relative to one of an earlier fuel energy value and an expected fuel energy value, responding to a fuel energy value that is sufficiently changed relative to one of an earlier fuel energy value and an expected fuel energy

value by accessing control values from a memory, computing adjustment commands for operational components of the engine using the control values, and controlling the operational parameters of the engine using the adjustment commands.

**[0009]** According to another embodiment of the present disclosure, a control system for an engine comprises a sensor configured to determine at least one of a plurality of properties of a gaseous fuel for the engine and a controller including a processor operably coupled to a memory and configured to receive determinations from the sensor. The controller is configured to receive a fuel energy value from the sensor representing a quality of the fuel; determine whether the fuel energy value is sufficiently changed relative to one of an earlier fuel energy value and an expected fuel energy value; respond to a fuel energy value that is sufficiently changed relative to one of an earlier fuel energy value and an expected fuel energy value by accessing control values from the memory; compute adjustment commands for operational components of the engine using the control values; and control the operational parameters of the engine using the adjustment commands.

**[0010]** While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0011]** The above-mentioned and other features of this disclosure and the manner of obtaining them will become more apparent and the disclosure itself will be better understood by reference to the following description of embodiments of the present disclosure taken in conjunction with the accompanying drawings, wherein:

**[0012]** Fig. 1 is a conceptual diagram of a system according to one embodiment of the present disclosure;

**[0013]** Fig. 2 is a flow diagram of a method according to one embodiment of the present disclosure; and

**[0014]** Fig. 3 is a conceptual diagram of the system and method of Figs. 1 and 2.

**[0015]** While the present disclosure is amenable to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and are

described in detail below. The present disclosure, however, is not to limit the particular embodiments described. On the contrary, the present disclosure is intended to cover all modifications, equivalents, and alternatives falling within the scope of the appended claims.

DETAILED DESCRIPTION

**[0017]** The embodiments disclosed below are not intended to be exhaustive or to limit the disclosure to the precise forms disclosed in the following detailed description. Rather, the embodiments are chosen and described so that others skilled in the art may utilize their teachings.

**[0018]** One of ordinary skill in the art will realize that the embodiments provided can be implemented in hardware, software, firmware, and/or a combination thereof. For example, the controller disclosed herein may form a portion of a processing subsystem including one or more computing devices having memory, processing, and communication hardware. The controller may be a single device or a distributed device, and the functions of the controller may be performed by hardware and/or as computer instructions on a non-transient computer readable storage medium. For example, the computer instructions or programming code in the controller (e.g., an electronic control module ("ECM")) may be implemented in any viable programming language such as C, C++, HTML, XTML, JAVA or any other viable high-level programming language, or a combination of a high-level programming language and a lower level programming language.

**[0019]** In certain embodiments, the controller includes one or more determiners that functionally execute the operations of the controller. The description herein including determiners emphasizes the structural independence of certain aspects of the controller 36, and illustrates one grouping of operations and responsibilities of the controller. Other groupings that execute similar overall operations are understood within the scope of the present application. Determiners may be implemented in hardware and/or as computer instructions on a non-transient computer readable storage medium, and may be distributed across various hardware or computer based components.

**[0016]** Example and non-limiting implementation elements that functionally execute the operations of the controller include sensors providing any value determined herein, sensors

providing any value that is a precursor to a value determined herein, datalink and/or network hardware including communication chips, oscillating crystals, communication links, cables, twisted pair wiring, coaxial wiring, shielded wiring, transmitters, receivers, and/or transceivers, logic circuits, hard-wired logic circuits, reconfigurable logic circuits in a particular non-transient state configured according to the module specification, any actuator including at least an electrical, hydraulic, or pneumatic actuator, a solenoid, an op-amp, analog control elements (springs, filters, integrators, adders, dividers, gain elements), and/or digital control elements.

**[0017]** In various embodiments, the processing hardware can include a processor in electrical communication with the sensor. In various embodiments the controller may also include non-transitory memory hardware having instructions that, in response to an execution by the processor, cause the processor to perform the various operations described herein.

**[0018]** Referring now to Fig. 1, a system 10 according to one embodiment of the present disclosure is shown. System 10 includes a sensor 12 that, in one embodiment, senses the raw level of methane of fuel being provided to an engine 13 by a natural gas fuel source 14. It should be understood that sensor 12 may be configured to sense other components of other fluid fuel sources and/or fuel composition, constituents, energy, selection indicator, etc. according to the principles of the present disclosure. For example, it should be understood that in one embodiment, sensor 12 is configured to determine a fuel energy value which may be a processed version of the sensed Methane percent from sensor 12. The fuel energy value, however, may represent other fuel energy values such as processed or unprocessed versions of sensed Propane percent of the fuel, sensed Hydrogen percent of the fuel, sensed inert percent of the fuel, mass flow of fuel(s) and/or inert(s), sensed or manually input Methane Number or Methane Index of the fuel, a detailed composition of fuel constituents, etc. Sensor 12 may be any suitable sensor such as an Ultramat 6 or Ultramat 23 manufactured by Siemens. The output of sensor 12 is a raw measured signal representing the percentage of Methane in the fuel supply and/or fuel composition, constituents, energy, selection indicator, etc. Engine 13 may be any gaseous fuel powered spark-ignited engine / genset.

**[0019]** As shown, sensor 12 provides the above-described Methane percent and/or fuel composition, constituents, energy, selection indicator, etc. signal to a controller 16, such as an ECM. As indicated above, controller 16 may be of a number of various configurations, and is depicted for simplicity as including only a processor 18 which is in communication with a

memory 20. As is further described below, memory 20 includes a calibration table(s) 22 used by the processor to determine a plurality of adjustment commands. As is also further described below, controller 16 communicates the plurality of adjustment commands to a corresponding plurality of operational components of engine 13 to control the operation of the components. In the embodiment depicted in Fig. 1, the operational components include ignition system 24 which controls the spark timing of the spark plug(s) of engine 13, and fuel control valve(s) 26 which controls the air-to-fuel ratio provided to engine 13.

**[0020]** If, on the other hand, the newly acquired fuel energy value is sufficiently different from a previous or expected value, then processor 18 accesses calibration table(s) 22 of memory 20 to obtain a new set of control values at step 38. In this case, the new control values are used at step 36 to compute new adjustment commands.

**[0021]** Additionally, and referring still to Fig. 2, method 30 is depicted for controlling operational components of a spark-ignited engine in response to a sensed Methane percent in the fuel source and/or fuel composition, constituents, energy, selection indicator, etc. for the engine. It should be understood that method 30 may be performed periodically, according to a predetermined schedule, continuously, or on an event-basis, such as in response to the sensed Methane percent and/or fuel composition, constituents, energy, selection indicator, etc. change(s). At step 32, a Methane percent and/or fuel composition, constituents, energy, selection indicator, etc. value is received. It should be understood that in one embodiment, if only Methane percent is available from sensor(s) 12, and no other gas constituent information is measured, then in the creation of the calibration table(s) 22, the other gas constituent information is assumed, depending on the expected (e.g., measured or predetermined) other gas constituents in the supply gas at the operating site of the genset/engine. If other gas constituent information is measured by sensor(s) 12, besides Methane percent, then those other sensed gas constituent measurements would be used in conjunction with the Methane percent measurement (if available) in creation of the calibration table(s) 22, with any other gas constituents not measured to be assumed, as before, depending on the expected (e.g., measured or predetermined) other gas constituents in the supply gas at the operating site of the genset/engine.

**[0022]** In general, the adjustment command for ignition system 24 is a timing variable which determines when a signal is provided by controller 16 to ignition system 24 to energize a spark plug. The timing is typically expressed in crank angle degrees before the piston (not

shown) corresponding to the spark plug reaches a top-dead-center ("TDC") position. If the fuel has a higher fuel energy value than expected, then controller 16 will provide a signal to ignition system 24 causing a spark to ignite the fuel later relative to the TDC position of the piston. Alternatively, if the fuel has a lower fuel energy value than expected, then controller 16 causes the spark to ignite the fuel earlier relative to the TDC position of the piston. In other words, Various in-cylinder combustion characteristics (including but not limited to ignition delay, start of ignition, in-cylinder pressure and rate of pressure change, heat release and rate of heat release change, etc.) vary in response to the fuel energy value of the fuel. The adjustment commands for fuel control valve 26 are derived parameters as explained below with reference to Fig. 3. The end result of the adjustment command for fuel control valve 26 is a modification to the percentage the valve is opened (e.g., 50% opened, 45% opened, etc.).

**[0023]** A more detailed conceptual diagram of system 10 and method 30 is depicted in Fig. 3. As shown, a raw measured signal for Methane percent and/or fuel composition, constituents, energy, selection indicator, etc. is generated at block 50. This signal may be provided by sensor 12 as described above. The signal processing (i.e., conversion, filtering and adjustment, etc.) of fuel input signal from block 50 may be performed by controller 16 or other hardware and/or software associated therewith. Such processing includes, but is not limited to, comparing raw signal values with predetermined low and high limit thresholds to determine unusual or out-of-range erroneous signals, analog raw count input conversion to electric current (mA), unfiltered signal multiplication with a pre-determined or calibrated gain value and/or adjusting the signal value using a positive or negative offset value, averaging the signal for a predetermined amount to reduce undesired fluctuations of the signal, etc. Fig. 3 also depicts (block 58) a function of controller 16 wherein in response to an out-of-range Methane percent and/or fuel composition, constituents, energy, selection indicator, etc. value, controller 16 may cause engine 13 to encounter warning(s) and/or to shut down. In certain cases, the amount of Methane percent and/or fuel composition, constituents, energy, heating value etc., for example, in the fuel supply may be too low and/or unsuitable for proper engine operation.

**[0024]** Additionally, in a further embodiment, the fuel energy value may be provided to a genset controller 54 which may function to control engine load or derate in the extreme event as required by the overall safety parameters of generator operation and/or as desired by the end

user. Additionally, the fuel energy value may be provided to an HMI/display device 56 which may function to display the value to an end user.

**[0025]** Blocks 60 and 62 represent the operation of controller 16 using control values from calibration table(s) 22 to determine and provide adjustment commands for ignition system 24. Block 62 represents controller 16 providing the determined adjustment command to ignition system 24. Additionally, in one embodiment, at block 60, controller 16 uses either a new control value from calibration table 22 to determine a timing signal for ignition coil 24 when the current fuel energy value has changed sufficiently from a previous or expected fuel energy value, or uses a previous or expected fuel energy value when the current fuel energy value has not changed sufficiently from a previous or expected fuel energy value.

**[0026]** Block 64 represents controller 16 providing a determined adjustment command to fuel control valve 26. This adjustment command is determined by controller 16 by performing a fuel properties correction in response to the Methane percent and/or fuel composition, constituents, energy, selection indicator, etc. value at block 66, performing a fuel mass flow correction in response to the Methane percent and/or fuel composition, constituents, energy, selection indicator, etc. value at block 68, and performing an air/fuel equivalence ratio (Lambda) correction at block 70. Fuel properties correction 66 includes changes to estimated molecular weight, specific heat ratio, lower heating value and stoichiometric air fuel ratio. Fuel mass flow correction 68 includes changes to desired (or target) total gas flow, as well as to gas mass flow feedback measured by a sensor(s) (or sensing mechanism(s)) affected in the air, fuel and/or charge flow stream(s) as a result. Air/fuel equivalence ratio correction 70 includes changes to desired (or target) lambda and/or closed loop emissions fueling target(s). These corrections 66, 68, 70 are used to determine the adjustment command for fuel control valve 26. As the air flow to engine 13 is substantially constant at given speed and load conditions, the adjustment made in response to changes in Methane percent and/or fuel composition, constituents, energy, selection indicator, etc. value to the air/fuel ratio is made in this embodiment by adjusting the percent opening of fuel control valve 26.

**[0027]** In one embodiment, controller 16 may be configured for providing a determined adjustment command to throttle valve 28. This adjustment command may be determined by controller 16 by first performing the air/fuel equivalence ratio (Lambda) correction at block 70

and then transmitting an adjustment command to throttle valve 28 to adjust the combined mixture of fuel and air provided to engine 13 to maintain load and emissions.

**[0028]** Collectively (and as represented by block 74), the adjustment commands represented by blocks 62, 64 and 70 result in relatively constant engine speed, load and emissions (e.g., NOx) for a range of Methane percent and/or fuel composition, constituents, energy, selection indicator, etc. values without requiring stopping of engine 13 for recalibration or derating of engine 13 and enables effective start-up of engine 13 from a stopped or non-running state. Thus, in the manner described above, system 10 and method 30 permit real-time, on-the-fly use of calibration control values in response to changes in Methane percent and/or fuel composition, constituents, energy, selection indicator, etc. values to maintain substantially constant engine speed, load and emissions (e.g., NOx) without the need to download new calibration values, stop the engine or lower the load on the engine.

**[0029]** Various modifications and additions can be made to the exemplary embodiments discussed without departing from the scope of the present invention. For example, while the embodiments described above refer to particular features, the scope of this invention also includes embodiments having different combinations of features and embodiments that do not include all of the described features. Accordingly, the scope of the present invention is intended to embrace all such alternatives, modifications, and variations as fall within the scope of the claims, together with all equivalents thereof.

**[0030]** Furthermore, the connecting lines shown in the various figures contained herein are intended to represent exemplary functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections may be present in a practical system. However, the benefits, advantages, solutions to problems, and any elements that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential features or elements. The scope is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean “one and only one” unless explicitly so stated, but rather “one or more.” Moreover, where a phrase similar to “at least one of A, B, or C” is used in the claims, it is intended that the phrase be interpreted to mean that A alone may be present in an embodiment, B alone may be present in an embodiment, C alone may be present in an embodiment, or that any combination of

the elements A, B or C may be present in a single embodiment; for example, A and B, A and C, B and C, or A and B and C.

**[0031]** In the detailed description herein, references to "one embodiment," "an embodiment," "an example embodiment," etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art with the benefit of the present disclosure to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. After reading the description, it will be apparent to one skilled in the relevant art(s) how to implement the disclosure in alternative embodiments.

**[0032]** Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. § 112(f), unless the element is expressly recited using the phrase "means for." As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

CLAIMS

We claim:

1. A method for controlling a spark-ignited engine in response to variations in quality of a gaseous fuel provided to the engine, comprising:

receiving a fuel energy value representing a quality of the fuel;

determining whether the fuel energy value is sufficiently changed relative to one of an earlier fuel energy value and an expected fuel energy value;

responding to a fuel energy value that is sufficiently changed relative to one of an earlier fuel energy value and an expected fuel energy value by accessing control values from a memory;

computing adjustment commands for operational components of the engine using the control values; and

controlling the operational parameters of the engine using the adjustment commands.

2. The method of claim 1, wherein receiving the fuel energy value includes sensing a raw value of a constituent component present in the fuel.

3. The method of claim 2, wherein the raw value includes a methane level of the fuel.

4. The method of claim 1, wherein controlling the operational parameters of the engine includes adjusting a timing variable for an ignition system of the engine.

5. The method of claim 4, wherein adjusting the timing variable for the ignition system includes delaying an ignition event when the fuel energy level is greater than the expected fuel energy value.

6. The method of claim 4, wherein adjusting the timing variable for the ignition system includes accelerating a start of an ignition event when the fuel energy level is less than the expected fuel energy value.

7. The method of claim 1, wherein controlling the operational parameters of the engine includes transmitting a signal to the engine which includes one of a warning message and a shutdown command.

8. The method of claim 1, further comprising operating the engine while receiving the fuel energy value, determining whether the fuel energy value is sufficiently changed, responding to the fuel energy value that is sufficiently changed, computing adjustment commands, and controlling the operational parameters of the engine using the adjustment commands.

9. The method of claim 1, wherein determining whether the fuel energy value is sufficiently changed includes comparing a raw measurement of the fuel energy value to a predetermined maximum fuel energy value and a predetermined minimum fuel energy value.

10. The method of claim 9, further comprising terminating operation of the engine in response to a raw measurement of the fuel energy value which is one of above the predetermined maximum fuel energy value and below the predetermined minimum fuel energy value.

11. A control system for an engine, comprising:

a sensor configured to determine at least one of a plurality of properties of a gaseous fuel for the engine; and

a controller including a processor operably coupled to a memory and configured to receive determinations from the sensor, and the controller is configured to:

receive a fuel energy value from the sensor representing a quality of the fuel;

determine whether the fuel energy value is sufficiently changed relative to one of an earlier fuel energy value and an expected fuel energy value;

respond to a fuel energy value that is sufficiently changed relative to one of an earlier fuel energy value and an expected fuel energy value by accessing control values from the memory;

compute adjustment commands for operational components of the engine using the control values; and

control the operational parameters of the engine using the adjustment commands.

12. The method of claim 11, wherein the sensor is configured to determine a raw value of a constituent component present in the fuel.

13. The method of claim 12, wherein the raw value includes a methane level of the fuel.

14. The method of claim 11, wherein the controller is configured to adjust a timing variable for an ignition system of the engine.

15. The method of claim 14, wherein the controller is configured to delay an ignition event when the fuel energy level is greater than the expected fuel energy value.

16. The method of claim 14, w wherein the controller is configured to accelerate a start of an ignition event when the fuel energy level is less than the expected fuel energy value.

17. The method of claim 11, wherein the controller is configured to transmit a signal to the engine which includes one of a warning message and a shutdown command.

18. The method of claim 11, wherein the controller is configured to receive the fuel energy value, determine whether the fuel energy value is sufficiently changed, respond to the fuel energy value that is sufficiently changed, compute adjustment commands, and control the operational parameters of the engine using the adjustment commands during operation of the engine.

19. The method of claim 11, wherein the controller is configured to compare a raw measurement of the fuel energy value to a predetermined maximum fuel energy value and a predetermined minimum fuel energy value.

20. The method of claim 19, wherein the controller is configured to terminate operation of the engine in response to a raw measurement of the fuel energy value which is one of above the predetermined maximum fuel energy value and below the predetermined minimum fuel energy value.

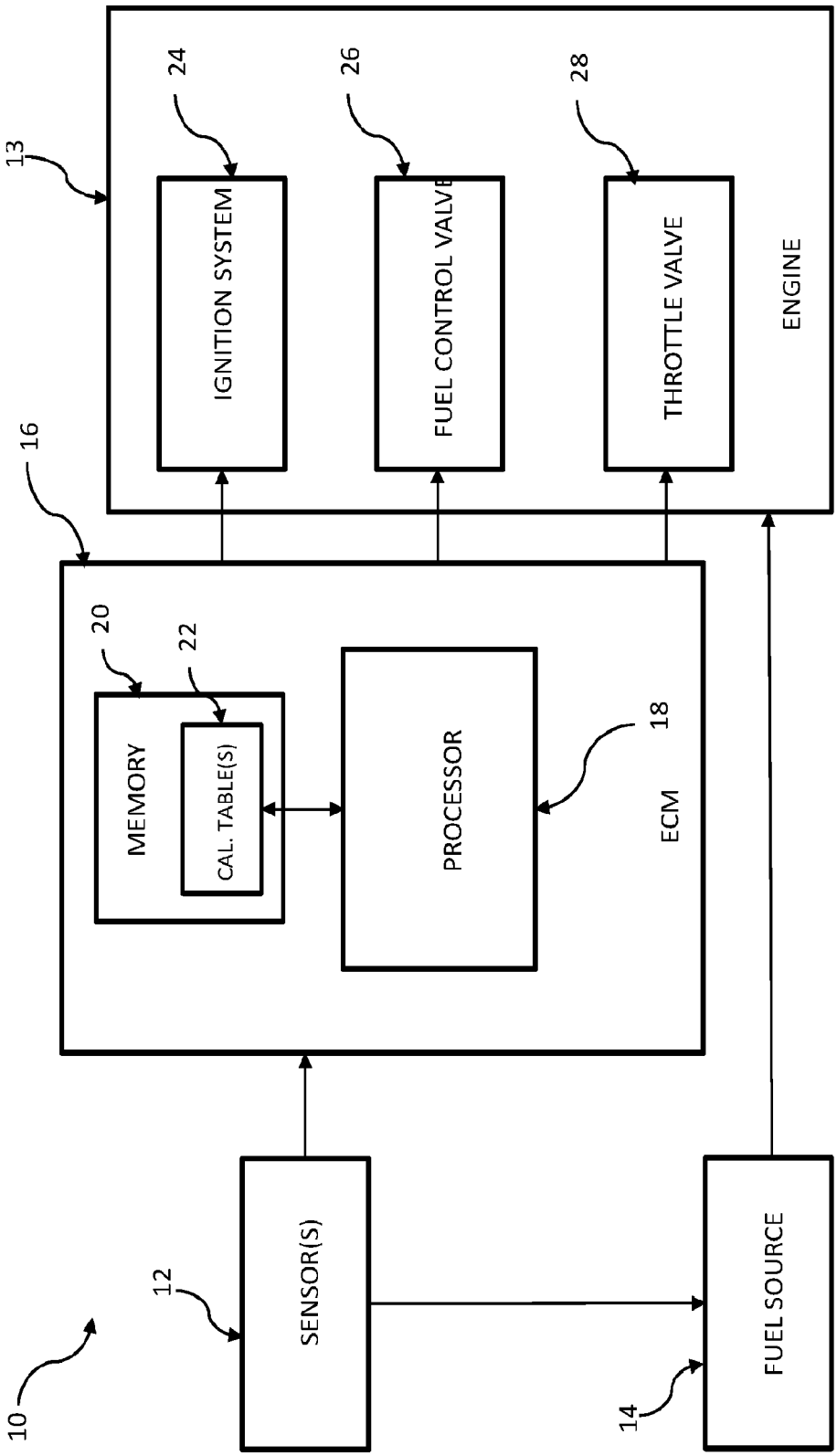
13
24
26
28
IGNITION SYSTEM
FUEL CONTROL VALVE
THROTTLE VALVE
ENGINE
16
20
22
MEMORY
CAL. TABLE(S)
PROCESSOR
18
ECM
12
SENSOR(S)
FUEL SOURCE
14
10

FIG. 1

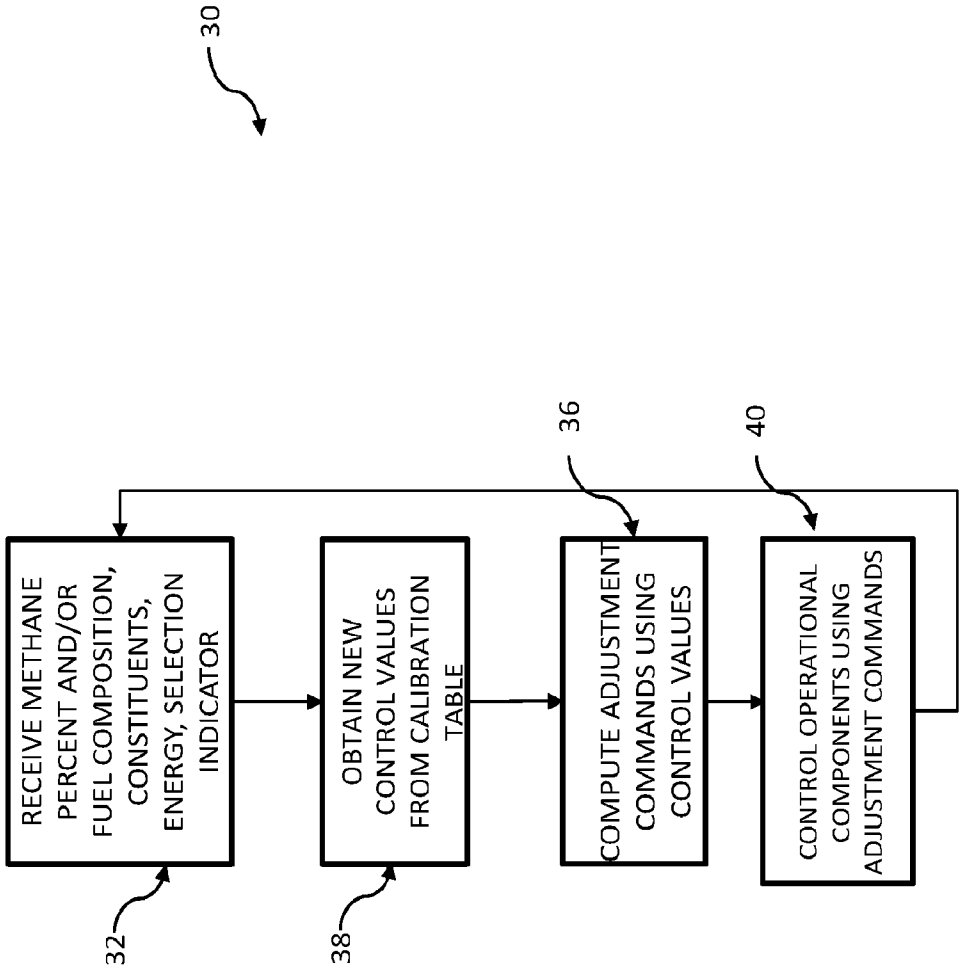
30
RECEIVE METHANE PERCENT AND/OR FUEL COMPOSITION, CONSTITUENTS, ENERGY, SELECTION INDICATOR
OBTAIN NEW CONTROL VALUES FROM CALIBRATION TABLE
COMPUTE ADJUSTMENT COMMANDS USING CONTROL VALUES
CONTROL OPERATIONAL COMPONENTS USING ADJUSTMENT COMMANDS
32
38
36
40

FIG. 2

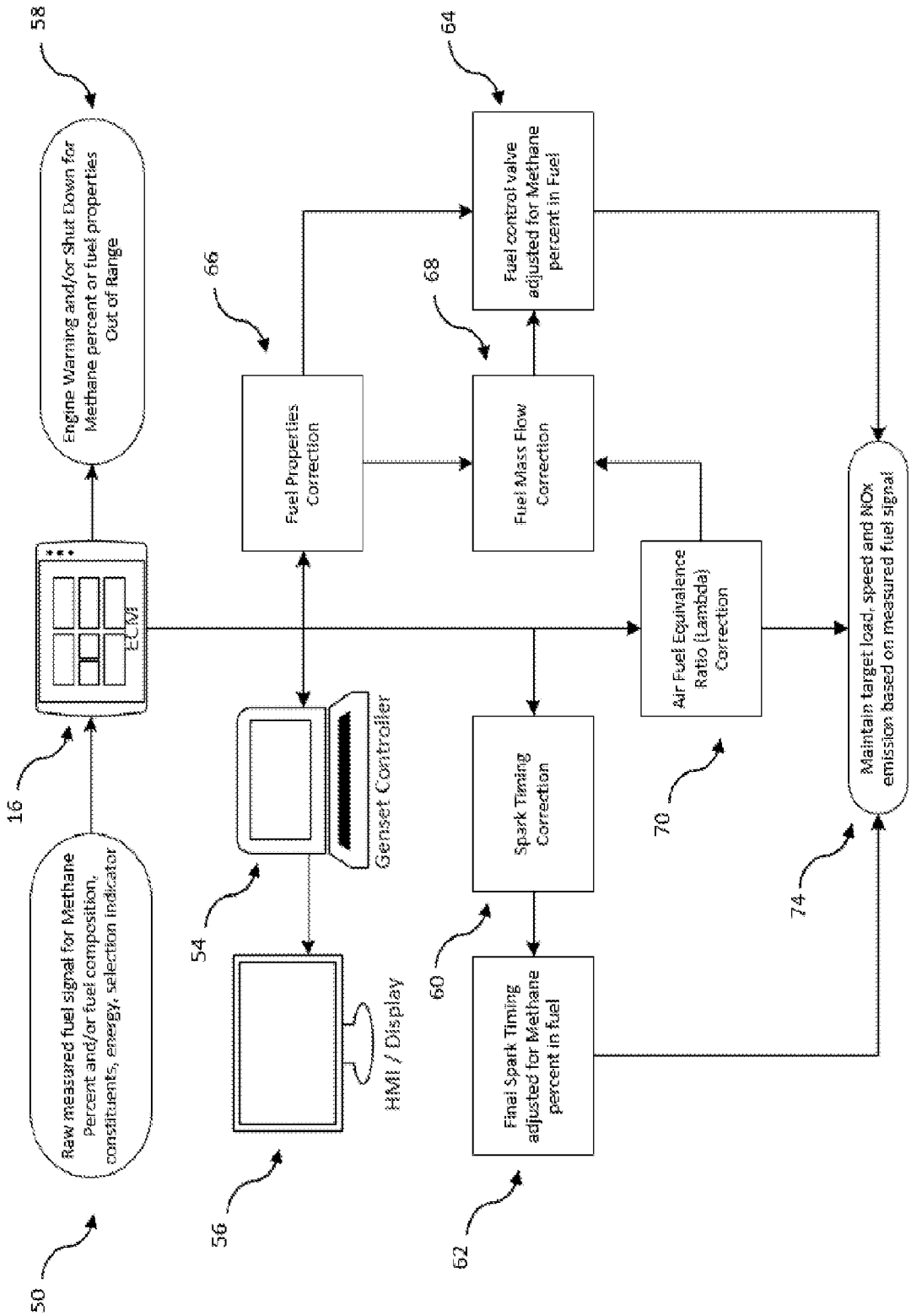
58
Engine Warning and/or Shut Down for Methane percent or fuel properties Out of Range
64
Fuel control valve adjusted for Methane percent in Fuel
66
Fuel Properties Correction
68
Fuel Mass Flow Correction
16
ECM
Air Fuel Equivalence Ratio (Lambda) Correction
70
Maintain target load, speed and NOx emission based on measured fuel signal
74
Genset Controller
54
HMI / Display
56
Spark Timing Correction
60
Final Spark Timing adjusted for Methane percent in fuel
62
Raw measured fuel signal for Methane Percent and/or fuel composition, constituents, energy, selection indicator
50

FIG. 3

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/027892

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F02D 19/02; F02D 19/06; F02D 19/10 (2017.01)

CPC - F02D 19/02; F02D 19/029; F02D 19/06; F02D 19/0626; F02D 19/0634; F02D 19/10; F02D 33/006; F02D 41/0027; F02D 41/04; F02D 41/042 (2017.05)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 123/480; 701/101; 701/105; 701/112; 701/115 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br>---<br>Y | US 2015/0300273 A1 (AVL POWERTRAIN ENGINEERING INC) 22 October 2015 (22.10.2015) entire document | 1-4, 8, 9, 11-14, 18, 19<br>---<br>5-7, 10, 15-17, 20 |
| Y | US 2015/0330290 A1 (FORD GLOBAL TECHNOLOGIES, LLC) 19 November 2015 (19.11.2015) entire document | 5, 15 |
| Y | US 2010/0183993 A1 (MCALISTER) 22 July 2010 (22.07.2010) entire document | 6, 16 |
| Y | WO 2015/075244 A1 (JAGUAR LAND ROVER LIMITED) 28 May 2015 (28.05.2015) entire document | 7, 10, 17, 20 |
| A | US 2005/0172942 A1 (HERDIN et al) 11 August 2005 (11.08.2005) entire document | 1-20 |
| A | US 2007/0000456 A1 (WONG) 04 January 2007 (04.01.2007) entire document | 1-20 |
| A | US 8,155,868 B1 (XING et al) 10 April 2012 (10.04.2012) entire document | 1-20 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 16 June 2017 | 05 JUL 2017 |
| Name and mailing address of the ISA/US<br>Mail Stop PCT, Attn: ISA/US, Commissioner for Patents<br>P.O. Box 1450, Alexandria, VA 22313-1450<br>Facsimile No. 571-273-8300 | Authorized officer<br>Blaine R. Copenheaver<br>PCT Helpdesk: 571-272-4300<br>PCT OSP: 571-272-7774 |