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(54) **METHOD AND STRUCTURE FOR CONTROLLING AN APPARATUS, SUCH AS A FUEL INJECTOR, USING ELECTRONIC TRIMMING**

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(58) **Field of Search** .... 123/357, 478, 123/480, 501, 502; 73/119 A

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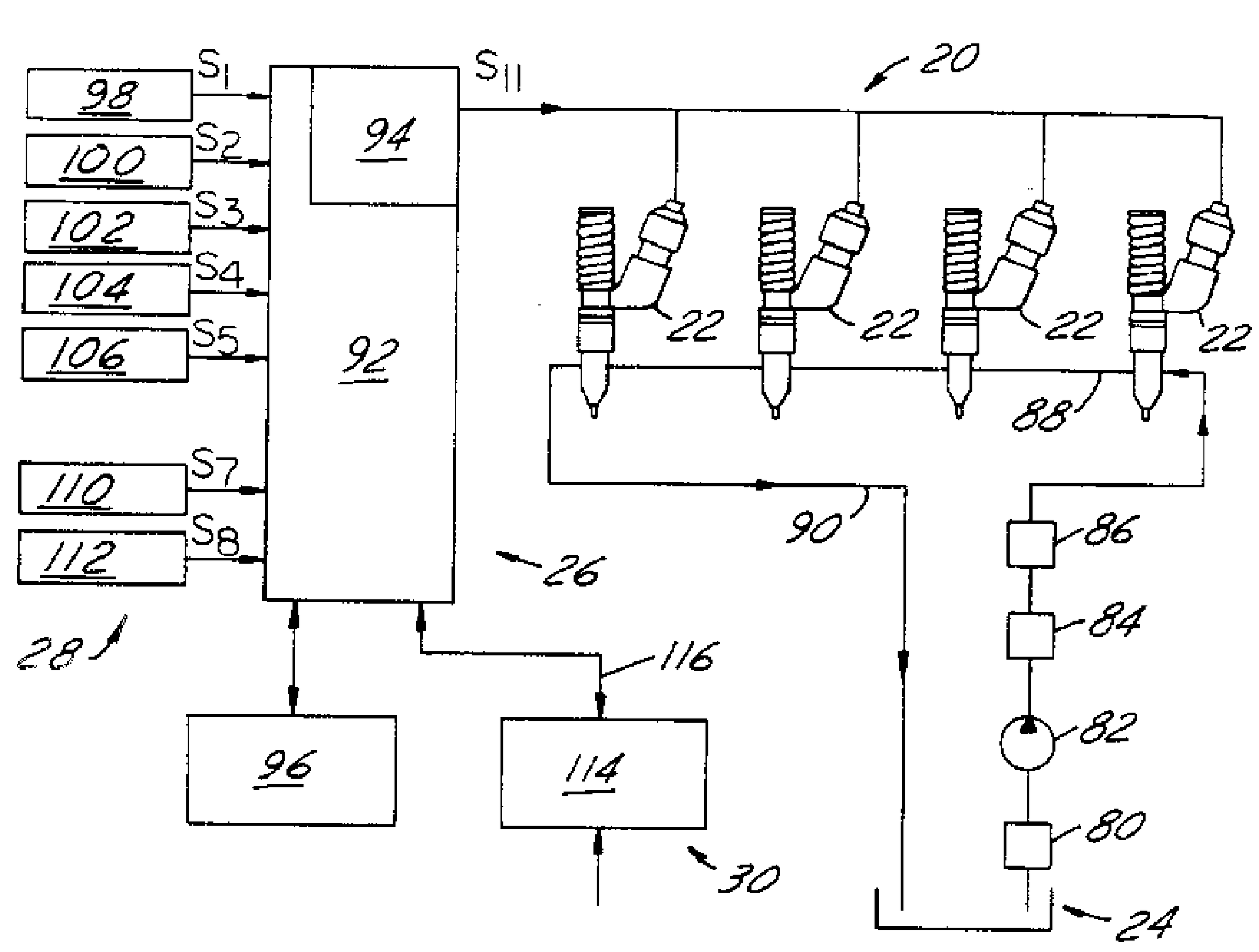
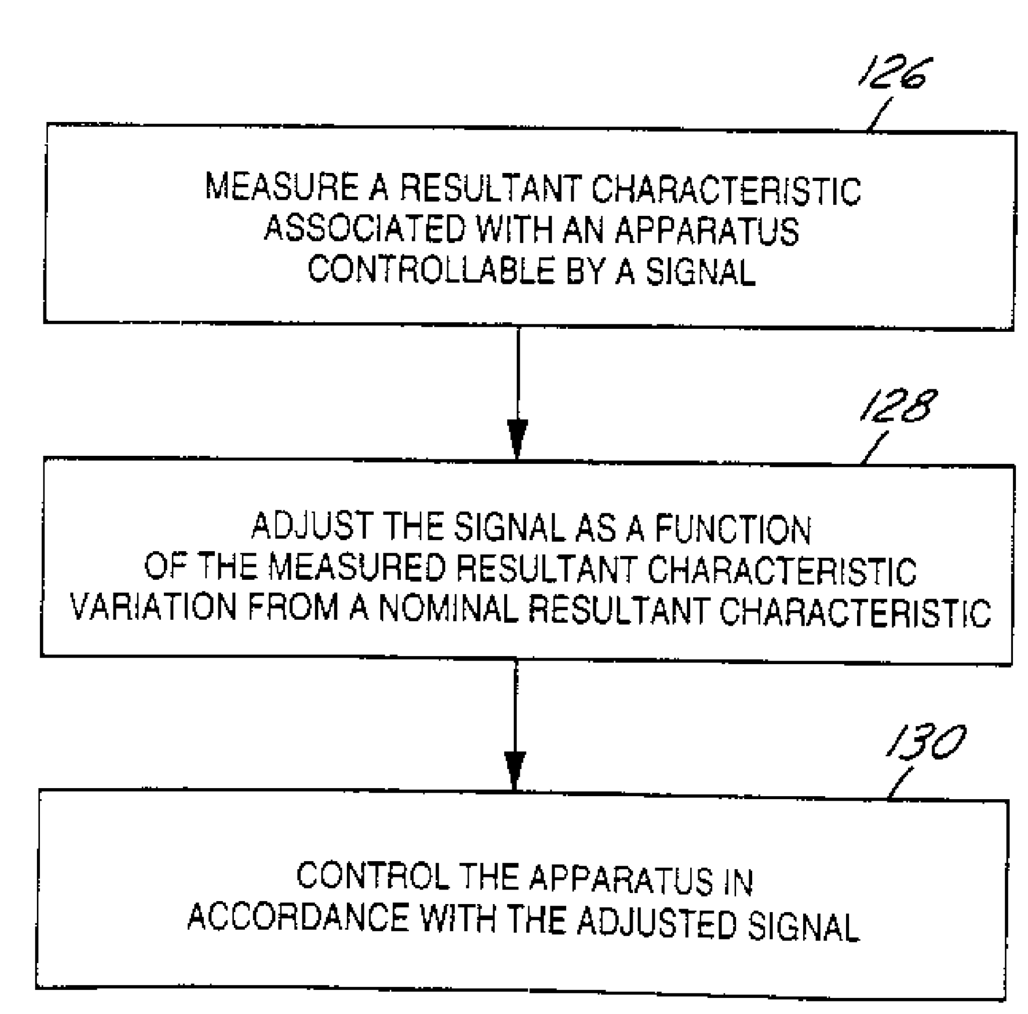
(57) **ABSTRACT**

A structure and method for electronically minimizing or eliminating performance variation of an apparatus controllable by a control signal, such as an electronically-controlled fuel injector, is disclosed. The method includes the steps of measuring the resultant characteristics of the apparatus at a plurality of operating conditions, such as timing and delivery characteristics of the fuel injector, adjusting the control signal as a function of the measured resultant characteristics, such as by adjusting a base timing and duration or pulse width of a fuel delivery command signal for a fuel injector, and controlling the apparatus in accordance with the adjusted control signal to reduce performance variation. A structure is disclosed to compensate or trim for individual injector variation, includes an electronic control module having a memory for storing trim signals for each injector, the trim signals being derived from observed performance parameter values taken at a plurality of operating conditions, a plurality of sensors for detecting at least one, and preferably a plurality of operating parameters and generating a respective one, and preferably a plurality of, operating parameter signals, and a means for communicating the trim signals to the memory. The electronic control module adjusts a base fuel delivery signal for each injector as a function of the trim data signals for each injector.

47 Claims, 7 Drawing Sheets





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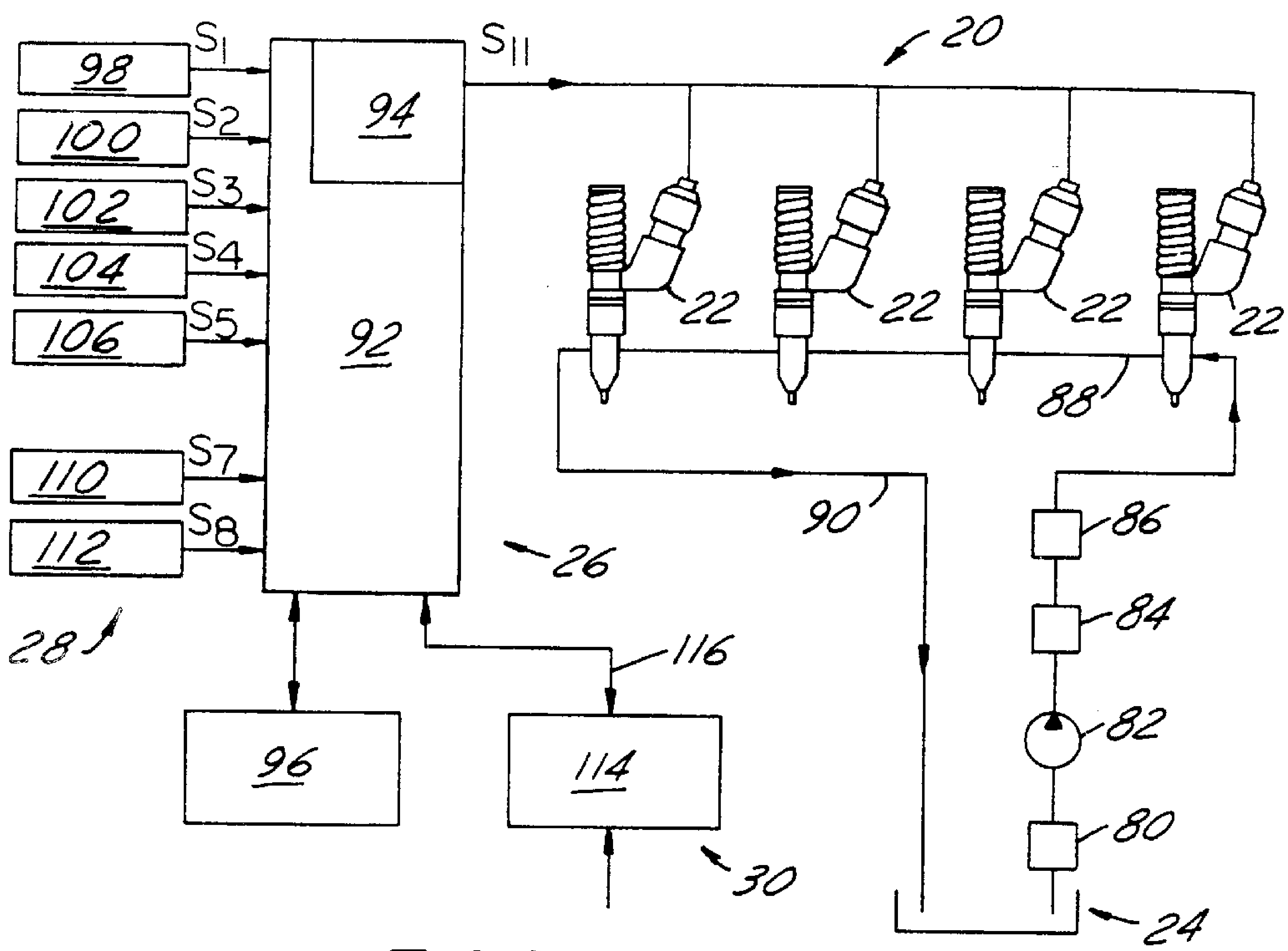
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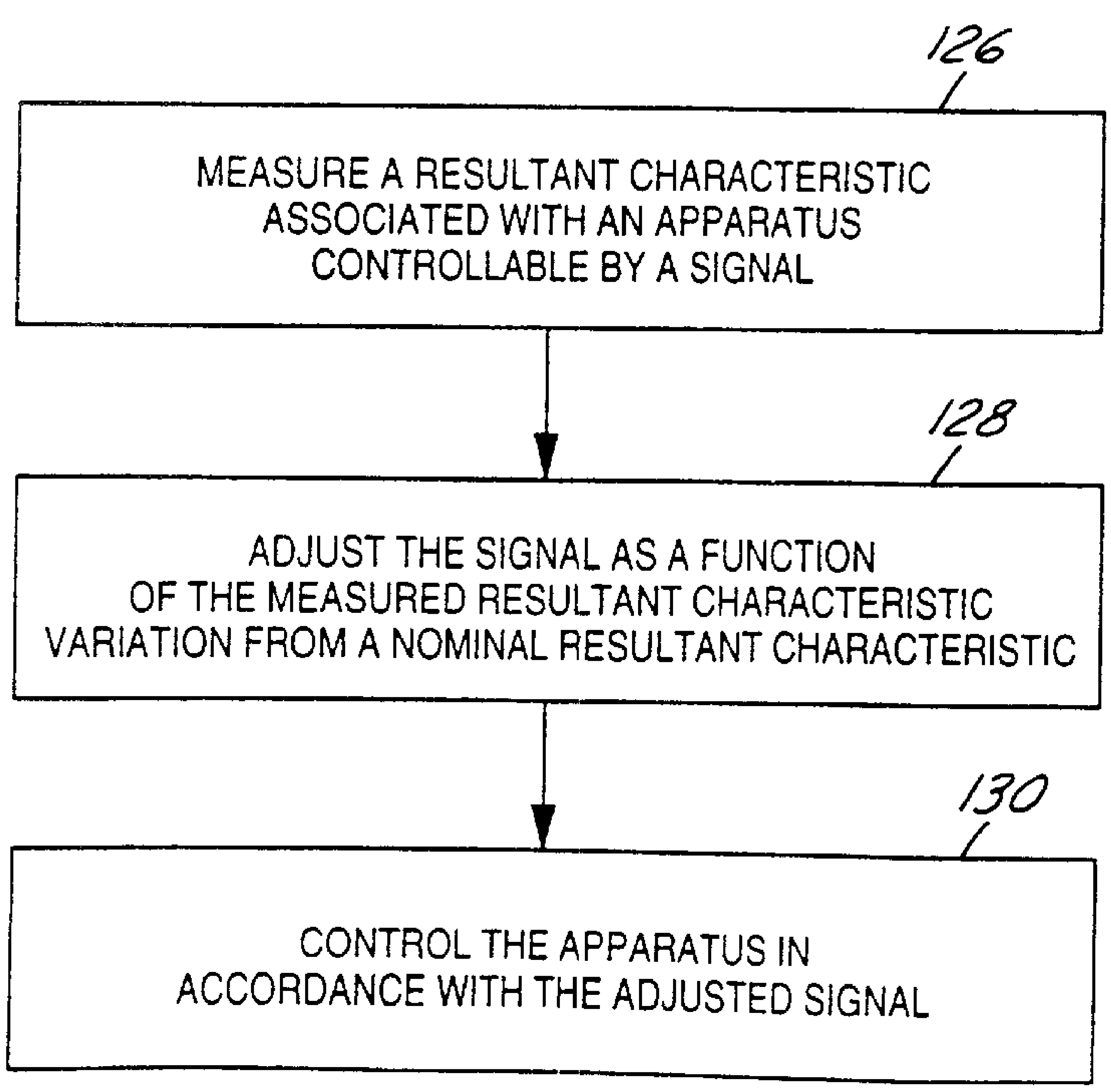
FIG. 1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MEASURE A RESULTANT CHARACTERISTIC ASSOCIATED WITH AN APPARATUS CONTROLLABLE BY A SIGNAL
128
ADJUST THE SIGNAL AS A FUNCTION OF THE MEASURED RESULTANT CHARACTERISTIC VARIATION FROM A NOMINAL RESULTANT CHARACTERISTIC
130
CONTROL THE APPARATUS IN ACCORDANCE WITH THE ADJUSTED SIGNAL

FIG. 4

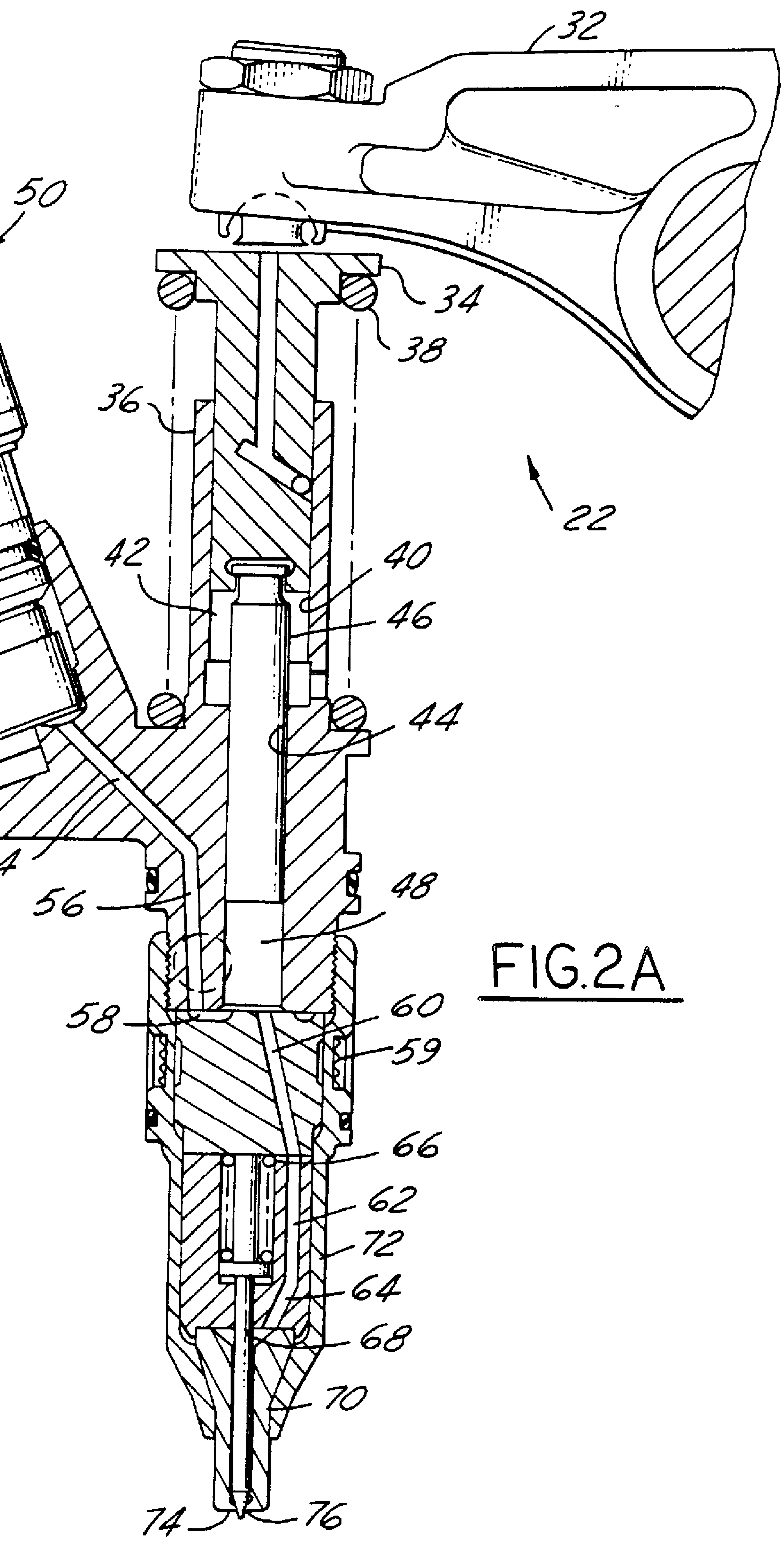
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FIG.2A

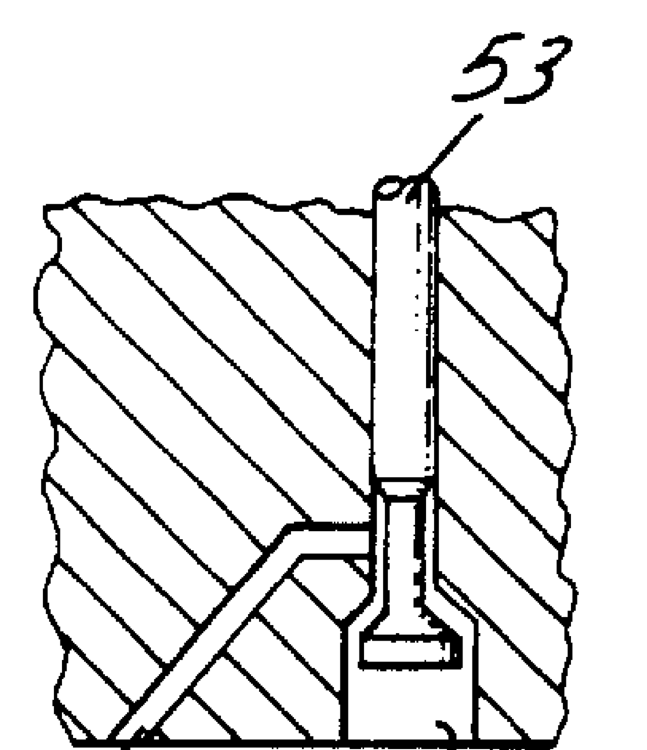
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FIG.2B

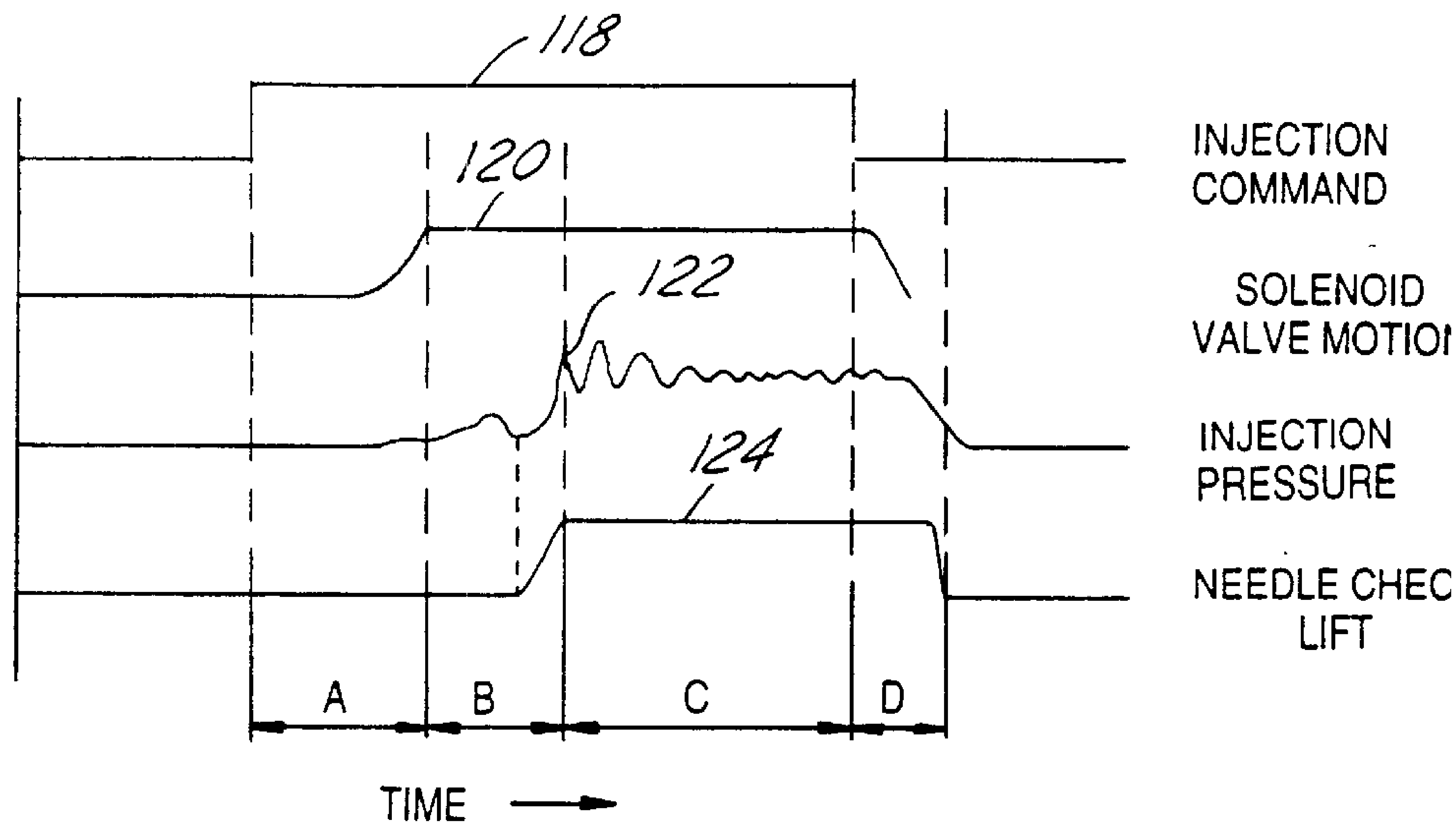

FIG.3

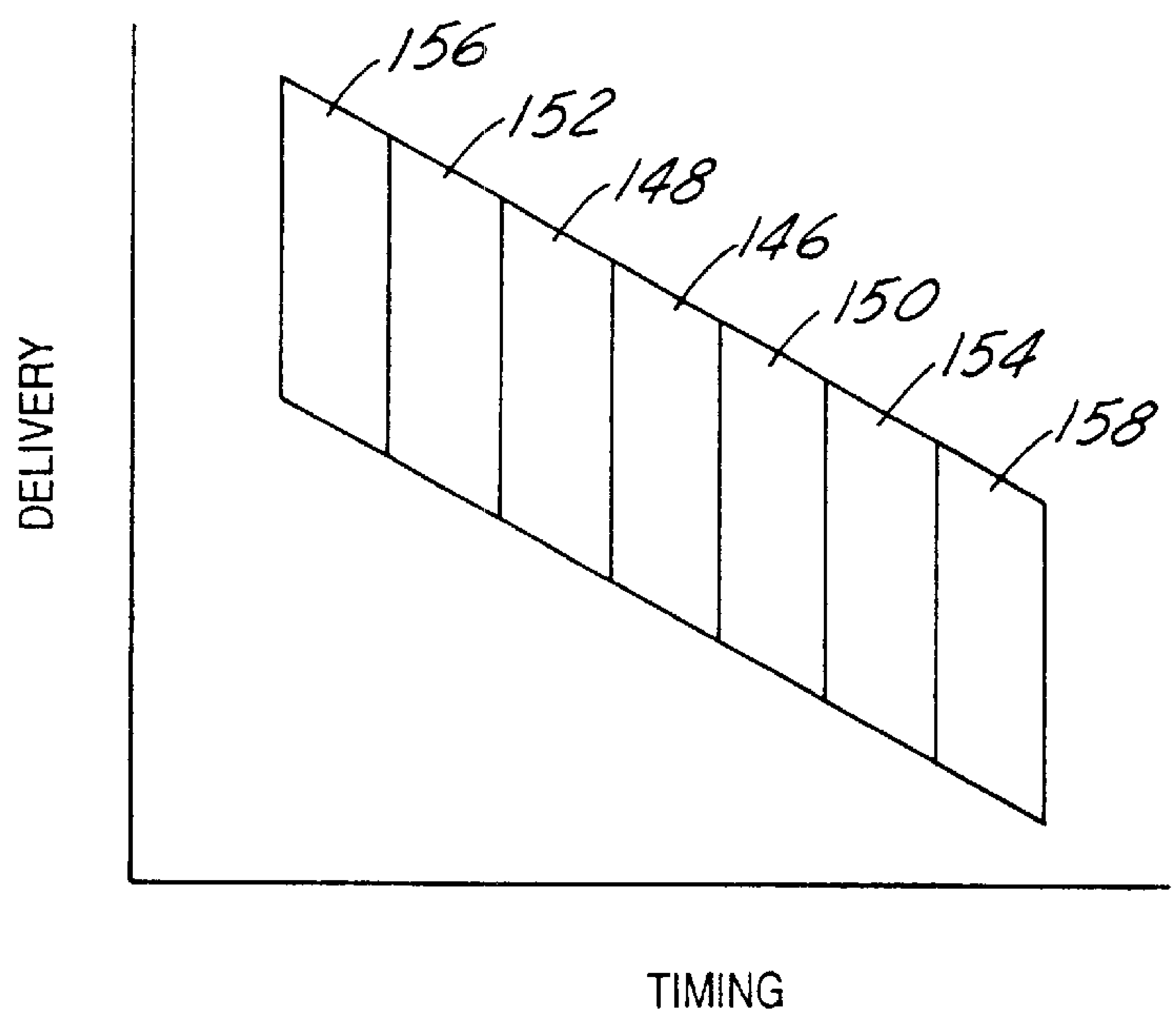

FIG.5

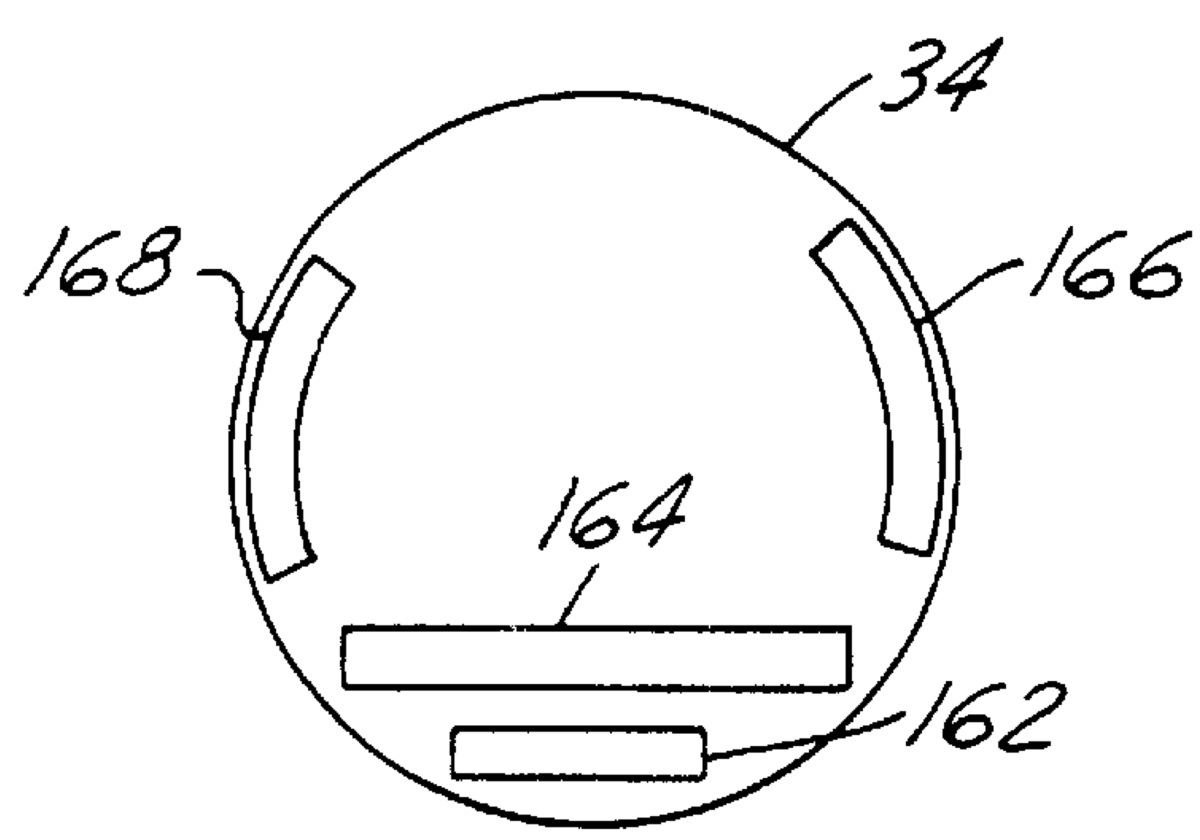

FIG.6

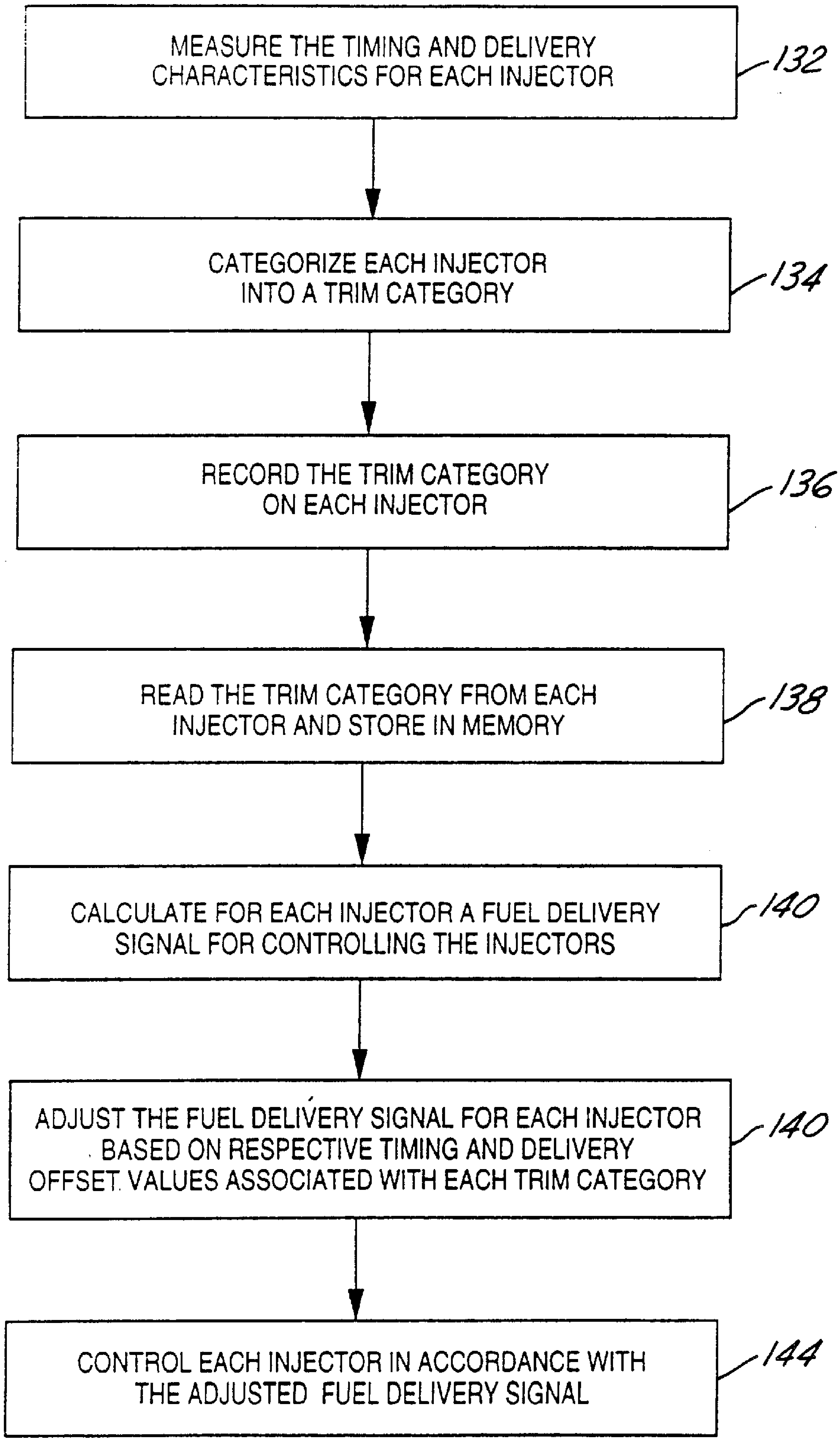
MEASURE THE TIMING AND DELIVERY CHARACTERISTICS FOR EACH INJECTOR
132
CATEGORIZE EACH INJECTOR INTO A TRIM CATEGORY
134
RECORD THE TRIM CATEGORY ON EACH INJECTOR
136
READ THE TRIM CATEGORY FROM EACH INJECTOR AND STORE IN MEMORY
138
CALCULATE FOR EACH INJECTOR A FUEL DELIVERY SIGNAL FOR CONTROLLING THE INJECTORS
140
ADJUST THE FUEL DELIVERY SIGNAL FOR EACH INJECTOR BASED ON RESPECTIVE TIMING AND DELIVERY OFFSET VALUES ASSOCIATED WITH EACH TRIM CATEGORY
140
CONTROL EACH INJECTOR IN ACCORDANCE WITH THE ADJUSTED FUEL DELIVERY SIGNAL
144

FIG.7

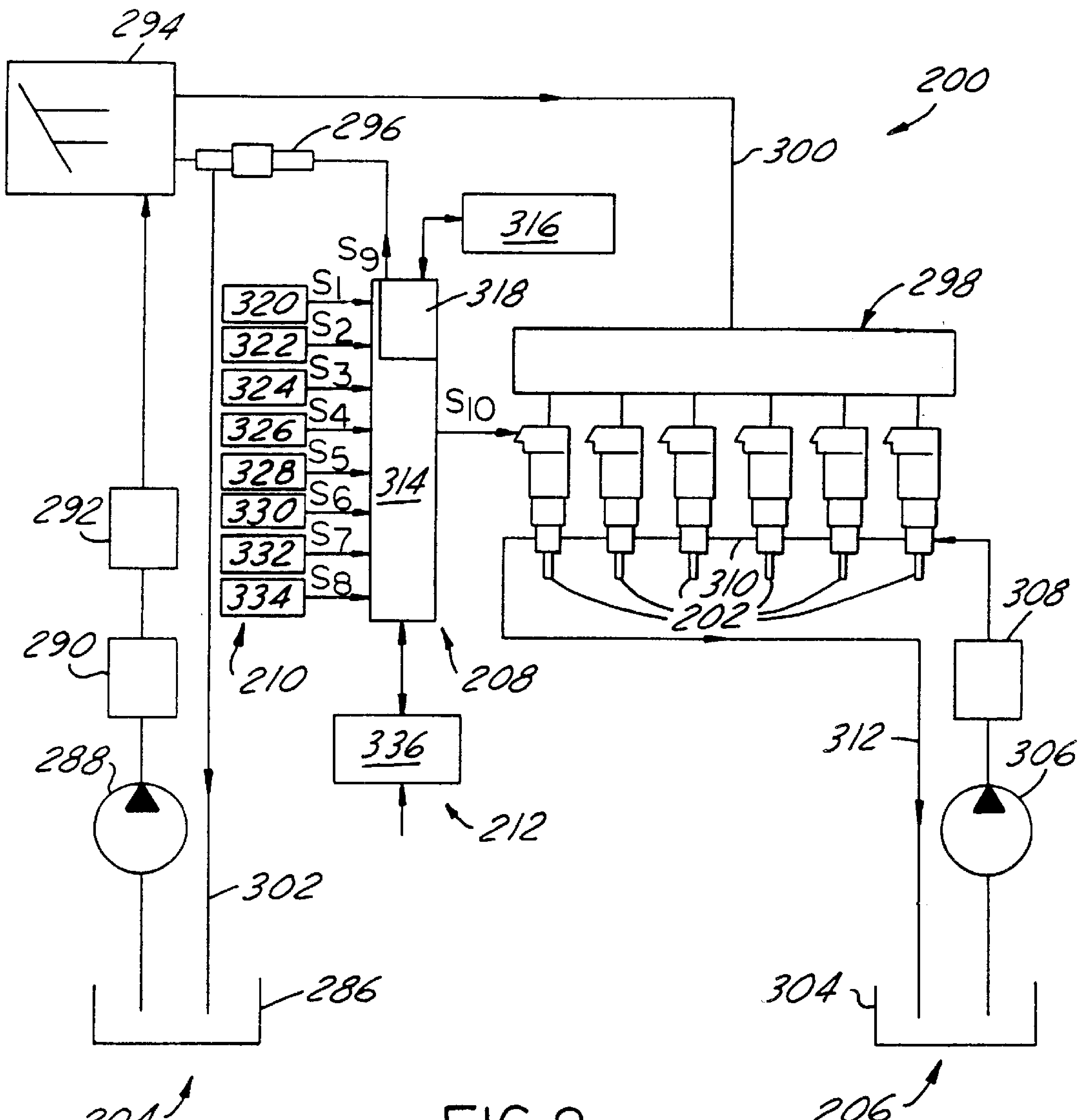
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FIG. 8

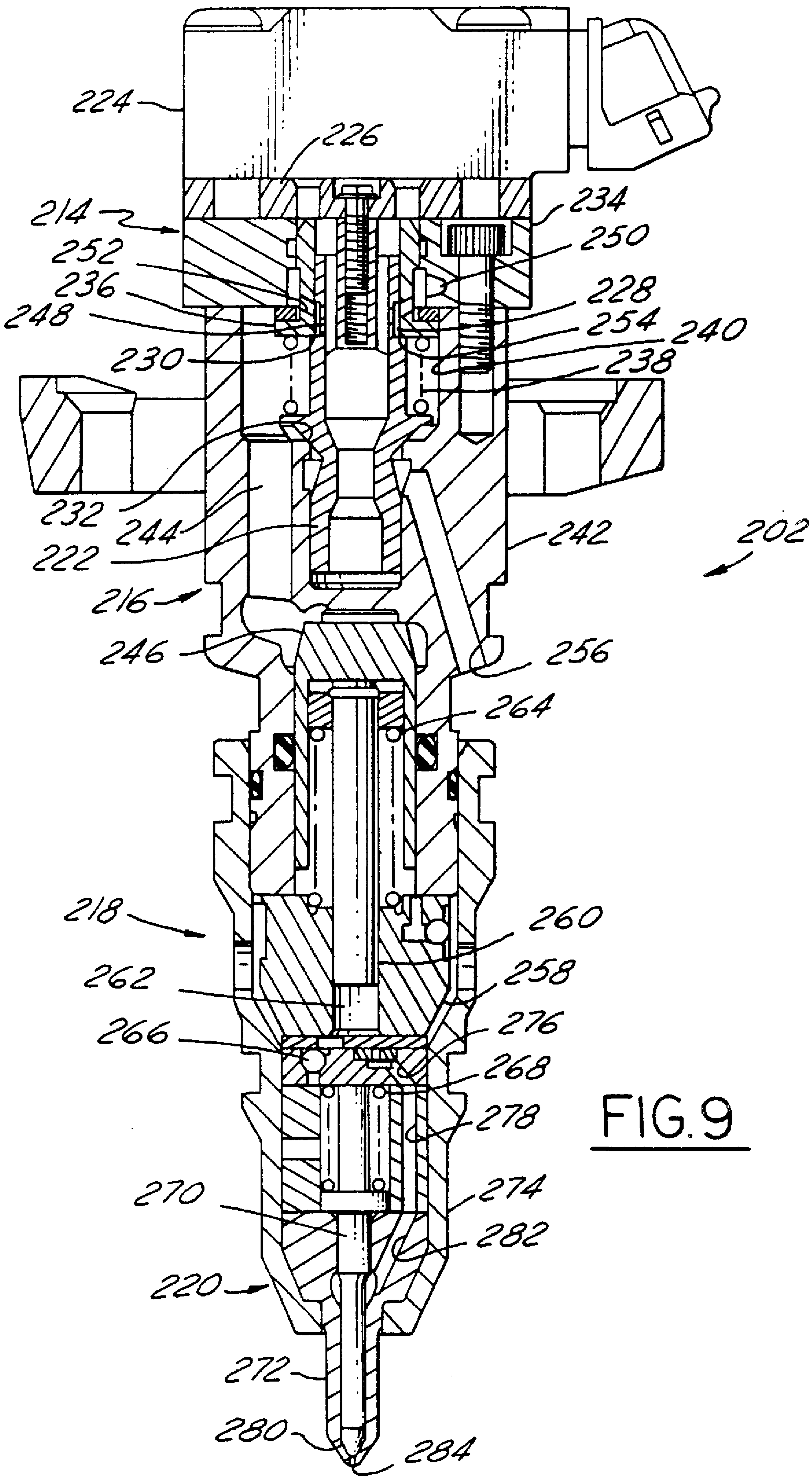
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FIG. 9

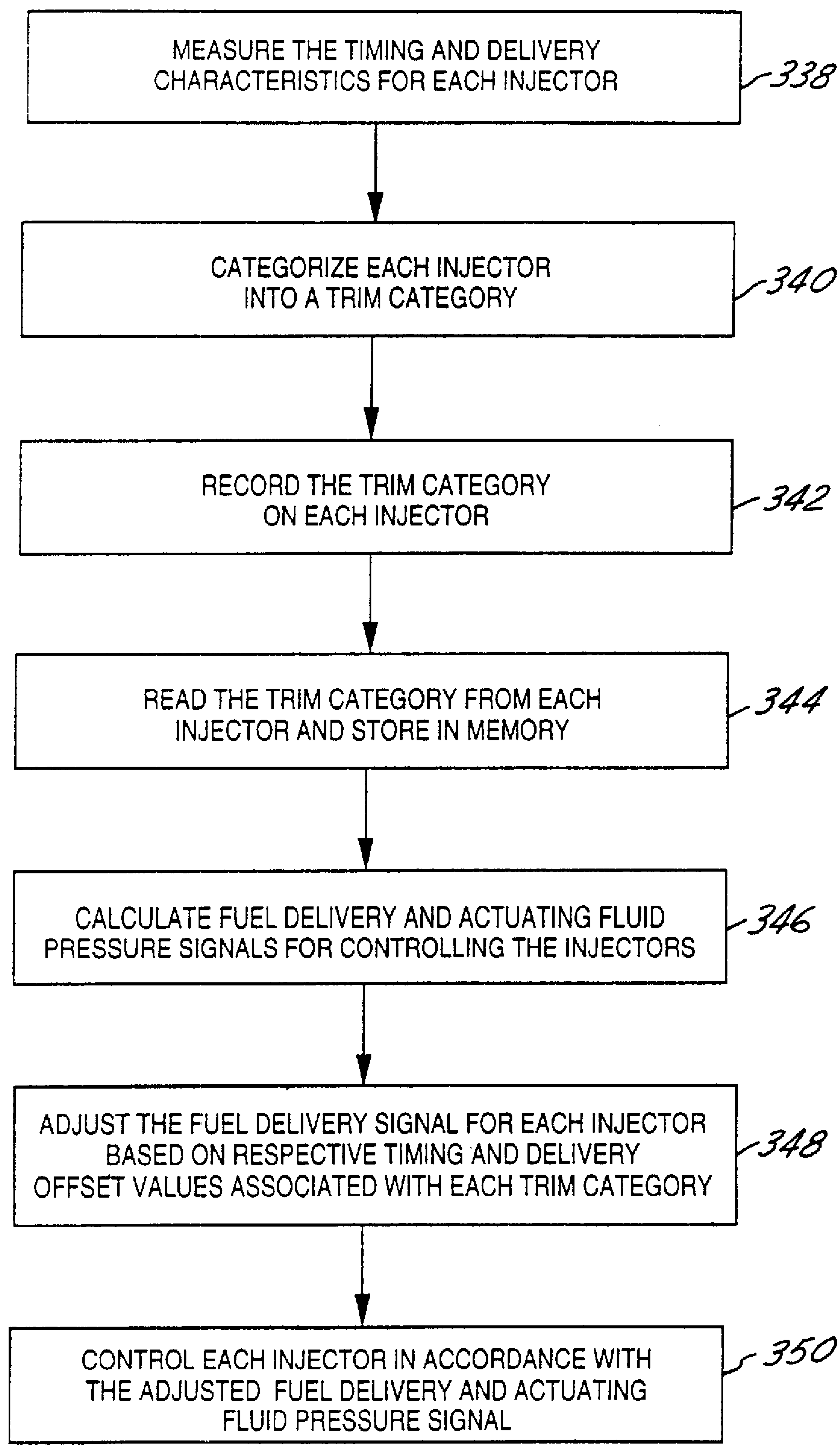
MEASURE THE TIMING AND DELIVERY CHARACTERISTICS FOR EACH INJECTOR
338
CATEGORIZE EACH INJECTOR INTO A TRIM CATEGORY
340
RECORD THE TRIM CATEGORY ON EACH INJECTOR
342
READ THE TRIM CATEGORY FROM EACH INJECTOR AND STORE IN MEMORY
344
CALCULATE FUEL DELIVERY AND ACTUATING FLUID PRESSURE SIGNALS FOR CONTROLLING THE INJECTORS
346
ADJUST THE FUEL DELIVERY SIGNAL FOR EACH INJECTOR BASED ON RESPECTIVE TIMING AND DELIVERY OFFSET VALUES ASSOCIATED WITH EACH TRIM CATEGORY
348
CONTROL EACH INJECTOR IN ACCORDANCE WITH THE ADJUSTED FUEL DELIVERY AND ACTUATING FLUID PRESSURE SIGNAL
350

FIG. 10

METHOD AND STRUCTURE FOR CONTROLLING AN APPARATUS, SUCH AS A FUEL INJECTOR, USING ELECTRONIC TRIMMING

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

TECHNICAL FIELD

The present invention relates generally to a method and structure of controlling an apparatus and, more particularly, to a method and structure of controlling a fuel injector via electronic trimming.

BACKGROUND ART

In an engine fuel system having a plurality of fuel injectors, it is typically desirable that each injector deliver approximately the same quantity of fuel in approximately the same timed relationship to the engine for proper operation. Several problems arise when the performance, or, more particularly, the timing (i.e., the time between the application of a fuel delivery command and the Start of Injection (SOI)) and delivery (i.e., the quantity and pressure of the delivered fuel) of the injectors diverge beyond acceptable limits. One problem caused by injector performance deviation or variability is that different torques are generated between cylinders due to unequal fuel amounts being injected, or from the relative timing of such fuel injection. Further, knowledge that such variations are inevitable require engine system designers to account for this variability; accordingly, many engine systems are designed not for peak or maximum cylinder pressures or output, but rather, are designed to provide an output equal to the maximum theoretical output less an amount due to the worst case fuel injector variability.

One approach for solving these problems in unit injectors is the so-called select fit manufacturing process. Generally, a common procedure involves flowing fluid through each unit injector nozzle and pumping mechanism and categorizing each nozzle and pumping mechanism accordingly. During assembly, nozzles are matched with pumping mechanisms knee to be compatible, depending on the category into which each was categorized. The disadvantage associated with this approach is the relatively high cost involved with sorting the nozzles and pumping mechanisms and maintaining these groupings for the duration of the manufacturing and assembly process,

Another approach for solving these problems involves extremely rigid manufacturing procedures for achieving high manufacturing precision necessary to meet the desired design specification. Such high manufacturing precision has the disadvantage of increasing the manufacturing cost, including the cost involved in manufacturing precision components and subassemblies and the costs related to the subsequent assembly process. Further, neither of the above-mentioned manufacturing-oriented solutions satisfactorily controls rejection of completely assembled injectors that fail to fall within the timing and delivery tolerances of the design specification. Thus, excess scrap remains a problem with these manufacturing-oriented approaches.

With the advent of increasingly sophisticated electronic control, a new approach to the problem of timing and delivery variations has emerged. In known electronic fuel injection systems, especially diesel-cycle internal combustion engine systems, the timing or start of injection, as well as the end of injection, or duration (delivery) is controlled by as electronic control, which controls these parameters for all of the engine cylinders.

An early attempt at using an electronic control to compensate for individual injector timing and delivery variations in an engine system involved measuring the flow characteristics of a particular injector at a single operating condition, and obtaining constants from this empirical testing, relative to an ideal fuel injector, and using these constants to modify a nominal control signal to compensate for the measured variation. This approach has proven unsatisfactory because it does not take into account the fact that timing and delivery variations exist not only between injectors, but as a function of the particular operating condition at which the injectors are operated. For example, it may be observed that at a low speed, low load condition, an individual injector may have greater variability from nominal specifications than at a high speed, high load condition. Thus, this approach has failed to provide a reduced injector to injector and injector to nominal performance variation necessary to meet today's increasingly strict emission standards.

Others have tried to compensate for variation in the start of injection characteristic of individual injectors in an engine system by designating a proxy of the timing or the start of injection characteristic of the injector. In general, these methods first electrically detect the closure of a valve used in controlling the start and duration of fuel injection, in response to an injection command. These methods further assume that the time between valve closure and the start of injection is fixed. Given these two time intervals, the injection command can be modified to compensate for variation in the time between the injection command and valve closure. The problem that remains with this type of approach is that the detected valve closure does not precede the start of injection by a fixed time period. Many factors, including manufacturing and assembly variations, contribute to vary the actual start of injection from a nominal value. Thus, this approach does not eliminate injector to injector and injector to nominal variation due to variations of the valve-closure to start of injection time interval.

Accordingly, there is a need to provide an improved method and structure for controlling an apparatus, such as a fuel injector, that minimizes or eliminates one or more of the problems as set forth above.

DISCLOSURE OF THE INVENTION

This invention provides for reduced variation of a resultant characteristic of an apparatus with respect to a nominal resultant characteristic, and further with respect to a resultant characteristic of another apparatus, without the prohibitive expense and inherent limitations associated with prior art manufacturing electronic control approaches. In general, the method of this invention is performed in conjunction with an apparatus of the type having a nominal resultant characteristic at a plurality of operating conditions, and controllable in accordance with a control signal to achieve the nominal resultant characteristics. The method comprises three basic steps. The first step includes measuring the resultant characteristic associated with the apparatus at a plurality of operating conditions.

In the second step, a control signal is adjusted as a function of the resultant characteristics of the apparatus measured in the first step. Finally, in the third step, the apparatus is controlled in accordance with the adjusted signal such that the resultant characteristics of the apparatus, when operated, approach the nominal resultant characteristics expected of an apparatus of that type.

The method of the present invention is advantageously employed in the control of a plurality of fuel injectors of the type having a nominal start of injection characteristics, and where fuel injection is controlled by a fuel delivery signal. The method of the present invention, as applied to electronically-controlled fuel injectors, simply and inexpensively reduces the start of injection variation as between a plurality of fuel injectors, and with respect to a nominal start of injection characteristic of injectors of this type. The method comprises four basic steps. The first step includes measuring, for each injector, a respective start of injection characteristic. The next step comprises associating, for each injector, the measured start of injection characteristic with the respective injector. The third step includes adjusting the fuel delivery signal, for each injector, as a function of the variation of the measured start of injection characteristic from the nominal start of injection characteristic for injectors of that type. The fourth and final basic step of the method of this invention includes controlling each injector in accordance with a respective adjusted fuel delivery signal to reduce start of injection and variation.

A problem with prior art manufacturing-oriented approaches for reducing performance variations involved costly nozzle/pumping mechanism sorting and matching. Accordingly, in a further aspect of the present invention, the basic step of associating the measured start of injection characteristic with the respective injector includes the substep of categorizing each injector, based on a respective measured start of injection characteristic, into one of a plurality of trim categories. The trim category designation into which the injection has been categorized is then permanently recorded on the injector itself. The above-mentioned basic step of adjusting the fuel delivery signal accordingly further includes the substeps of reading the data (trim category designation) recorded on the injector and inputting this data into a control means, which is provided for generating the fuel delivery signal. These aspects of the present invention eliminate costly sorting, matching, and tracking the resulting assembly. One way in which the trim category designation is permanently recorded on each injector is through the use of a unique identifier such as a bar code. Accordingly, the steps of reading the data recorded on the injector and inputting this data into the control means are performed by the substeps of seeing the bar codes recorded on the injectors, interpreting each bar code to reconstruct the trim category designation, and transmitting the reconstructed trim category designation into the control means.

A further application to which the present invention may be advantageously employed, is the operation of a plurality of electronically-controlled fuel injectors of the type having a nominal delivery characteristic as a function of operating conditions, where each injector is controlled to deliver fuel by a fuel delivery signal. This method of the present invention comprises four basic steps. The first step includes measuring, for each injector, a respective delivery characteristic at a plurality of operating conditions. The next step of this method comprises associating, for each injector, the measured delivery characteristic with the injector so measured. In the third step, the fuel delivery signal for each injector is adjusted as a function of the variation of the associated measured delivery characteristic from the nominal delivery characteristic for the measured operating conditions. Finally, in the fourth basic step, each injector is controlled in accordance with the respective adjusted fuel delivery signal to minimize delivery variation. A significant aspect of the above-described method of the invention is the step of measuring a delivery characteristic at a plurality of operating conditions. The ability to "trim" injector fuel delivery variations as a function of operating conditions permits a control system to optimize timing and delivery control to advantageously reduce emissions at all operating conditions, as well as increase performance beyond that achievable through prior art mechanically-trimmed methods.

In a further aspect of the present invention, a method is provided for accurately and inexpensively reducing start of injection and delivery variation of electronically-controlled fuel injectors of the type having a nominal start of injection and nominal delivery characteristics. This method of operating a plurality of fuel injectors comprises the steps of measuring, for each injector, a respective start of injection characteristic and delivery characteristic. Next, each injector is categorized into one of a plurality of trim categories as a function of the variation of the measured start of injection and delivery characteristics from the respective nominal start of injection and delivery characteristics for injectors of that type. Each trim category has associated therewith a start of injection offset value and a delivery offset value to be used in a later step for calculating a fuel delivery signal to control the fuel injector. The next step includes recording the category into which each injector was categorized on the respective injector. The fourth step includes storing the respective category recorded on each injector in a memory means of a control means. The control means generates the fuel delivery signal that controls the fuel injectors. The next step includes calculating the fuel delivery signal as a function of actual operating conditions based on nominal start of injection and delivery characteristics. In the next step, the fuel delivery signal for each injector is adjusted as a function of the respective start of injection and delivery offset values. Finally, each injector is controlled in accordance with a respective adjusted fuel delivery signal to reduce the start of injection and delivery variations from injector to injector, as well as from injector to nominal.

In a further aspect of the invention, the last-discussed method is further applied to a hydraulically-actuated electronically-controlled injector having a second signal, in addition to the fuel delivery signal, by which it may be controlled. This second signal is an actuating fluid pressure command signal. Accordingly, this method of the invention further comprises the step of adjusting the actuating fluid pressure command signal for each hydraulically-actuated injector as a function of the respective start of injection and delivery offset values.

Novel structure is used to implement the above described methods of this invention. Accordingly, in a further aspect of the present invention, a system for controlling the delivery of fuel through a plurality of fuel injectors to an engine is disclosed where each injector so controlled if of the type characterized by at least one observed performance parameter. The system comprises sensor means for detecting at least one, and preferably a plurality of, operating parameters and generating signals indicative of each parameter detected, control means for generating a base fuel delivery signal for each injector, memory means coupled to the control means for storing trim data signals for each injector, the trim data signals being derived from observed performance parameter values taken at a plurality of operating conditions, wherein the control means is provided in the system for trimming the base fuel delivery signal for each injector as a function of the trim data signals for reducing performance parameter variation as between the injectors controlled by the system, as well as variation relative to a nominal performance parameter value.

The present invention provides a structure and method of controlling the operation of an apparatus, such as, for example, a plurality of fuel injectors, to reduce fuel injection timing and delivery variation as required to meet emissions and performance goals by compensating for or "trimming" the fuel injection timing and delivery variations of each injector via an electronic control responsive to previously measured resultant or performance characteristics of each fuel injector so controlled by the structure or method herein described.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a combined block and diagrammatic view of a mechanically-actuated electronically-controlled injector fuel system embodiment of the present invention;

FIG. **2**A is a diagrammatic, fragmentary, cross-sectional view showing one of the fuel injectors of FIG. **1**;

FIG. **2**B is a diagrammatic, fragmentary, cross-sectional view showing the poppet valve control of the solenoid assembly of FIG. **2**A;

FIG. **3** is a diagrammatic, partial, simplified timing diagram showing the sequence of events resulting from application of a fuel delivery command to a fuel injector, including the solenoid valve motion and the needle check lift;

FIG. **4** is a flow chart depicting the general method steps of the present invention for an apparatus;

FIG. **5** is a category chart showing a plurality of trim categories as used in one embodiment of the present invention;

FIG. **6** is a diagrammatic view showing the face of an injector tappet of the injector of FIG. **2**A, including a trim code for a trim category designation;

FIG. **7** is a flow chart depicting the steps of the method of the present invention for a mechanically-actuated electronically-controlled embodiment shown in FIGS. **1** and **2**A;

FIG. **8** is a combined block and diagrammatic view of a hydraulically-actuated electronically-controlled injector fuel system embodiment of the present invention;

FIG. **9** is a diagrammatic, fragmentary, cross-sectional view showing the fuel injector of FIG. **8**;

FIG. **10** is a flow chart depicting method steps of the present invention for a second embodiment shown in FIGS. **8–9**.

BEST MODE FOR CARRYING OUT THE INVENTION

Before proceeding to a description of the present invention, an exemplary environment for employing this invention will be described with reference to FIGS. **1–3**.

Referring now to drawings wherein like reference numerals are used to reference identical components in various views, FIG. **1** shows a mechanically-actuated electronically-controlled fuel injection system **20** utilizing a plurality of mechanically-actuated electronically-controlled (MEUI) fuel injectors **22** operated in accordance with the present invention. Fuel injection system **20** is preferably adapted for use in a diesel-cycle direct injection internal combustion engine (not illustrated). Although a four cylinder engine is indicated in FIG. **1**, it should be understood that the present invention can also be used in other types and configurations of engines. The MEUI fuel system **20** includes at least one injector **22** for each combustion chamber or cylinder of the engine, means or a circuit **24** for supplying fuel to each injector **22**, means or a device **26** for electronically-controlling the fuel system **20**, sensor means **28** for detecting at least one, and preferably a plurality of, system operating parameters and generating a signals indicative of the respective parameter detected, and means or a device **30** for communicating information to controlling means **26**.

Referring now to FIG. **2**A, injector **22** includes injector rocker arm **32**, injector tappet or follower **34**, injector body **36**, and injector follower spring **38**. Injector body **36** includes a centrally-disposed stepped bore **40** having a larger diameter portion **42**, and a smaller diameter portion **44**.

Injector rocker arm **32** is driven by an engine cam shaft (not illustrated) and bears on injector follower **34**. Follower **34** is slidably received in bore **40** for reciprocal movement therein. Compression spring **38** bears against body **36** and against an annular step formed on the upper portion of injector follower **34** and is provided for urging follower **34** upwardly relative to body **36**.

Injector **22** further includes a plunger **46** slidably received in the smaller diameter portion **44** and connected with injector follower **34** for reciprocal motion therewith. Injector body **36** and the bottom face of plunger **46** define a plunger chamber **48**. Injector **22** further includes a solenoid and valve assembly **50**, which includes electrical terminals **52** for actuating solenoid assembly **50**.

Referring to FIG. **2**B, a functional, diagrammatic representation of solenoid and valve assembly **50** is depicted. The solenoid assembly **50** includes a poppet valve **53**, a first fuel passage **54**, and a passage **55** to a fuel supply.

Referring to FIG. **2**A, injector body **36** further includes a second fuel spill passage **56**, annular passage **58**, fuel inlet **59**, first discharge passage **60**, second discharge passage **62**, third discharge passage **64**, needle check spring **66**, axially movable needle check or valve **68**, needle check tip **70**, case **72**, annular seat **74**, and fuel injection spray orifices **76**.

As shown in FIG. **1**, means or device **24** for supplying fuel to injector **22** comprises a fuel tank or supply **78**, a primary filter **80**, a fuel transfer and priming pump **82**, an electronic cooling means **84**, a secondary filter **86**, a fuel manifold **88**, and a fuel return line **90**.

The means or device **26** for electronically controlling the MEUI fuel system **20** preferably includes a programmable electronic control module **92** having an output means **94** for generating a fuel delivery command signal S_{11}. The fuel delivery command signal is supplied to each injector **22** and determines the time for starting fuel injection and the quantity of such fuel injection (by the duration of the Signal S_{11}) during each injection event. Further coupled with controlling module **92** is memory means **96**, which may take the form of a non-volatile random access memory (NVRAM). The memory means **96** is provided for storing various "trim" data signals for each of the injectors **22** so that variation of the timing and delivery characteristics of each injector **22** relative to the other injectors, and relative to a nominal timing and delivery characteristic for injectors of this type, can be reduced through appropriate control by electronic controlling means **26**. Further, memory means **96** may include Read-Only Memory (ROM) for storing and reading predetermined operating data and the various programmed control strategies.

The sensor means **28** is provided in fuel system **20** for detecting various operating parameters and generating a respective parameter indicative signal S_{1-8}, hereinafter referred to as input data signals, the data signals being indicative of the respective parameter detected. Sensor means **28** preferably includes one or more conventional sensors or transducers which periodically detect directly or indirectly one or more parameters and generate corresponding data signals that are provided as inputs to electronic control module **92**. Preferably, sensor means **28** includes an engine speed sensor **98** adapted to detect engine speed and generate an engine speed signal S_1, an engine crank shaft position sensor **100** adapted to detect engine crank shaft position and generate an engine crank shaft position signal S_1, an engine coolant temperature sensor **102** adapted to detect engine coolant temperature and generate engine coolant temperature signal S_3, an engine exhaust back pressure sensor **104** adapted to detect engine exhaust back pressure and generate an engine exhaust back pressure signal S_4, an air intake manifold pressure sensor **106** adapted to detect air intake manifold pressure and generate air intake manifold pressure signal S_5, a throttle position setting sensor **110** adapted to detect a throttle position setting and generate a throttle position setting signal S_7, and a transmission gear setting sensor **112** adapted to detect the setting of an automatic transmission and to generate an automatic transmission setting signal S_8 (for those controls so equipped).

The means or device **30** for communicating information to controlling means **92** may, for example, take the form of a bar code reader or scanner **114** coupled to controlling module **92** via a communication link **116**, which may take the form of a serial link. Alternatively, communicating means **30** may take the form of a keyboard and a conventional general purpose computer, a "dumb" terminal, or a specialized tool adapted to interface with control module **92**. It should be appreciated by those skilled in the art that the means **30** for communicating the information may take various forms and not depart from the spirit and scope of this invention.

In operation, fuel under pressure enters injector **22** via fuel inlet **59**. The fuel passes through passages in injector **22** to the fuel plunger chamber **48**. The plunger **46** operates up and down in smaller diameter portion **44** of body **36**. Fuel plunger chamber **48** is open to the fuel supply by passages **58**, **56**, **54**, and **55** when valve **53** is open.

The Motion of injector rocket arm **32** is transmitted to plunger **46** by the injector follower **34** which bears against follower spring **38**. Thus, so long as poppet valve **53** is not closed, passage **54** communicates with fuel supply passage **55** and no injection pressure is generated by the downward motion of plunger **46**.

The timing and metering functions of injector **22** are implemented by operation of solenoid valve assembly **50**. As mentioned above, so long as valve **53** remains open, no injection pressure is generated by the downward movement of plunger **46**. Closure of the valve **53**, however, initiates pressurization and fuel injection. When a fuel delivery command is applied across terminals **52** of solenoid assembly **50**, the electrically-energized solenoid valve **53**, shown in FIG. 2B, moves relatively upwardly to cut off communication of plunger chamber **48**, via passages **54**, **56**, and **58**, with the passage **55** to the fuel supply. As plunger **46** moves downward, under pressure of injector rocker arm **32**, the trapped fuel under plunger **48** is subjected to increased pressure by the continued downward movement of plunger **46**. The pressurized fuel in chamber **48** is communicated via passages **60**, **62**, and **64** to the upper portion of needle check tip **70**. The pressurized fuel further passes through a diametrical clearance between needle check **68** and needle check tip **70** to the portion of needle check **68** abutting annular seat **74**. When sufficient pressure is built up by the downward movement of plunger **46**, the resulting upward force on needle check **68** overcomes an opposing force exerted by needle check spring **66**, wherein the pressurized fuel acts on needle check **68** to lift fuel cheek **68** from annular seat **74**. The pressurized fuel is then discharged through one or more fuel injection spray orifices **76**.

The duration of valve **53** closure determines the duration of fuel injection, and thus, defines the quantity of fuel injected by injector **22**.

To end injection, the fuel delivery signal is discontinued, thus electrically de-energizing the solenoid valve **53** and allowing valve **53** to open. Since the pressurized fuel chamber **48** again communicates with the fuel passage **55** to the fuel supply via passages **58**, **56**, and **54**, the fluid pressure therein decays such that the force of the compressed needle check spring **66** moves needle check **68** downwardly against annular seat **74** of needle check tip **70** to end injection. The upwardly traveling plunger **46** allows inlet fuel to refill plunger chamber **48** via inlet **59**.

Referring now to FIG. **3**, an exemplary timing diagram depicting in greater detail, the sequence of events resulting from the application of fuel delivery command S_{11} across terminals **52** of solenoid valve **50**. Trace **118** depicts a fuel delivery command S_{11} as applied across terminals **52** of injector **22**, and is a signal which may be controlled by control module **92** to carry out the present invention. Trace **120** represents the motion of valve **53** in response to fuel delivery signal S_{11}. Trace **122** represents the injection pressure of fuel in injector **22**. It should be understood that in the embodiment shown it is the downward travel of plunger **46** that generates injection pressure shown in trace **122** which is by a camshaft/rocker arm **32** assembly and which is not directly controlled by module **92**; accordingly, the application of fuel delivery injection command S_{11} must be made in timed relation with the reciprocal motion of plunger **46**. Trace **124**, depicts the motion or lift of needle check or valve **68**. The terminal upward destination of needle check **68** is the position where full injection occurs. (i.e., the interface between intervals B & C is the point wherein the actual start of injection (SOI) begins.) Prior art systems have endeavored to measure, electrically, valve **53** closure, indicated by the A B interface. Those control strategies then assume that time interval B is a fixed and constant time. However, knowledge of the valve closure does not define, by mere addition of a time constant, when the start of injection will occur. There are a plurality of factors related to the manufacture and assembly of injector **22** that cause interval B to vary from unit to unit and from unit to nominal. These factors include the flow characteristics of the injector nozzle assembly itself, housing dead volumes associated with the injector assembly, variations in the needle check spring bias force, etc. Accordingly, prior art systems that seek to measure only interval A while maintaining interval B constant do not reduce satisfactorily variation in timing (i.e. the time interval between the application of fuel delivery command S_{11} and the time fuel injection begins, or, in other words, interval A plus B).

It should also be appreciated that there is a time lag associated with the discontinuance of fuel delivery command S_{11} and the end of injection (EOI), indicated by interval D of FIG. **3**. In this embodiment of the present invention, the duration of fuel injection defines the quantity of fuel injected by an individual injector **22**, and is defined as the sum of intervals C and D, as shown in FIG. **3**. Accordingly, to reduce variations between injectors due to turn-off lag (interval D), the interval D may also be characterized and compensated or corrected for in each one of the plurality of injectors **22** in fuel systems **20**. Although this lag can be measured, as indicated above, the commercial implementation of this embodiment of the invention does not "trim" for this aspect of injector **22** variation.

Having now described in exemplary environment for employing this invention, attention is directed to FIG. **4** which depicts the general method steps of the present invention. In step **126**, the initial step is to measure a resultant characteristic associated with an apparatus controllable by a signal. The scope of the present invention is broader than the exemplary embodiment. Any actuatable mechanism may be advantageously controlled or operated in accordance with the present invention. Therefore, the present invention may be applied to any apparatus having a resultant characteristic that may be measured and be controlled. Significantly, step **126** may be performed at a plurality of operating conditions. Accordingly, resultant characteristic variation can be reduced over the entire operating range of the controlled apparatus.

Once the resultant characteristic has been measured in step **126**, the method of the present invention proceeds to step **128**, where the signal used to control the apparatus is adjusted as a function of the measured resultant characteristic variation from a nominal resultant characteristic. In general, a control signal is generated based on current operating conditions, as well as nominal operating or resultant characteristics of the apparatus under control. Step **128** adjusts this nominal or base signal to compensate or "trim", electronically, the measured resultant characteristic variation of the apparatus.

The final step of the general method of the present invention includes controlling the apparatus in accordance with the adjusted signal. The adjusted signal from step **128** is determined so as to reduce at least one, and preferably two, types of variations. The first type of variation deals with variation of a particular unit from other units of that type. The second type of a variation deals with the variation of the particular unit from a nominal or design specification resultant characteristic. The present invention preferably reduces or eliminates, simply and inexpensively, both types of variation.

The particular steps of the MEUI embodiment (preferred) of the present invention will now be described in detail. It should be understood that prior to performing the steps the present invention, a fuel injector **22**, will have been completely machined and assembled according to conventional manufacturing practices.

In step **132**, the timing and delivery characteristics, as these terms have been defined in the preceding discussion, for each injector are measured. Preferably, these characteristics are measured for at least two operating conditions: (1) a rated configuration being defined by high engine speed and high engine load or torque, and (2) a second, lower configuration being defined by a relatively lower engine speed and load. It should be understood that, in theory, measurements may be taken at an infinite number of operating conditions, limited practically only by memory and processing constraints. The start of injection characteristics of injector **22** is measured directly. That is, the time interval between the application of the fuel delivery command S_{11} and the time when fuel injection begins is measured and recorded. The start of injection characteristic is defined by the sum of time intervals A and B, depicted in FIG. **3**. The delivery or flow characteristics of injector **22** are measured as follows. The injector **22** is installed in a test bench which provides the fuel delivery command signal S_{11} and supplies a test fluid. The resulting quantity of flow versus time is measured and recorded.

In step **134**, each injector is categorized into one of a plurality of trim categories based on the measurements of the timing and delivery characteristics taken in step **132**. Each trim category is defined by a preselected range of delivery and timing variations. Thus, in the preferred embodiment, each trim category is defined as a function of both delivery and timing variations from nominal. Associated with each trim category is an offset value for both timing and delivery calculations to be used later in the method to "trim" or tailor each injector. It should be appreciated that the resolution of the preselected range of timing and delivery variation values used to define the boundaries of the trim categories, and the corresponding offset values, have a predefined relationship, depending on the particular control structure and methodologies employed (e.g., a relatively large delivery variation may require a correspondingly large offset value).

In step **136**, the trim category into which each injector has been categorized is recorded on the respective injector. This trim category designation may, for example, take the form of a four digit number stamped on injector **22**. Further, a bar code, indicative of the trim category, may also placed on injector **22**. It may be appreciated that these modes of recording the data are somewhat permanent in nature, however, other, more flexible forms of recording, for example, electrically-erasable programmable memory, which may be less permanent due to its capacity for being erased and changed, or a resistor having a selected resistance corresponding to data indicative of measured resultant characteristics, clearly fall within the scope of this invention.

At this point, each injector **22** has been fully assembled and characterized, and assigned a trim category indicative of the measured timing and delivery variation characteristics of that injector. The injector may now be shipped to a separate assembly operation to be assembled into an engine employing a plurality of such injectors, or, the injectors may be shipped to field service locations to replace worn or otherwise improperly operating units.

In step **138**, the trim category from each injector is read therefrom by means **30** for communicating information to controlling means **92** and is inputted into control module **92**, wherein the trim category or "trim" data signal is subsequently stored in memory means **96**. It should be appreciated that the above-described steps eliminate the costly sorting and maintenance of matched pairs associated with prior art manufacturing approaches. Whatever path the characterized and recorded injector takes in the manufacturing/maintenance process, the signature information remains easily accessible via the stamped trim category and bar code. The method of the present invention may employ a bar code reader or scanner **114** to scan the bar code affixed to each injector **22**, interpret the bar code to reconstruct the trim category, and transmit the reconstructed trim category via communications link **116** into control module **92**. In the alternative to the above-described bar code and scanning sequence, the data indicative of the measured timing and delivery may be electronically encoded on a respective injector or apparatus, for example, via an encoded electronic chip or via selection of an appropriately valued resistor, the resistance being indicative of the data being encoded and then read (or sensed) by the electronic control module **92** via means **30**, module **92** interpreting the read data or the sensed resistance value, respectively, to reconstruct the encoded data. This reading/sensing step may occur (i) following assembly of the injector into the fuel system or engine, or (ii) during initial startup of the fuel system or engine. It should be understood that the above-described resistor may be a resistor network. This methodology advantageously elminates the manual step of scanning the bar code.

The interface employed by control module **92** for the inputting of the "trim" categories designations may be of the type wherein the interface sequentially prompts means **30** for communicating information for the trim category of each injector number (i.e. control module **92** has been preprogrammed with the number of injectors employed in the particular configuration of fuel system **20**). For example, an operator may, in response, scan the bar code of the particular injector that is to be assembled into that injector position.

The remaining steps of the present invention occur during the operation or control of the injectors **22**. In step **140**, a base fuel delivery signal S_{11}, based on input data signals S_{1-8} and nominal timing and delivery characteristics for a MEIU injector is calculated for controlling each injector **22** according to any electronic fuel injection control strategy.

In step **142**, for each injector **22**, the base fuel delivery signal S_{11} is adjusted based on respective timing and delivery offset values associated particularly with the trim category in which the subject injector **22** was categorized in step **134**. It should be understood that although offset values are used in the preferred embodiment, more complex relationships and adjustment algorithms may be developed.

In step **144**, each injector **22** is controlled in accordance with the respective adjusted fuel delivery signal so that the resulting timing and delivery characteristics of that controlled injector, when operated, approach nominal timing and delivery values, and which also converge with the timing and delivery characteristics of the other controlled injectors **22** in fuel system **20**. It should be appreciated that fuel delivery signal S_{11} is supplied to each injector **22** at a time, relative to engine crank shaft position, in accordance with a preprogrammed fuel injection control strategy. The timing adjustment refers to offset adjustments made to the time when S_{11} is supplied to each injector so that the start of injection (SOI) occurs at the time desired by the fuel injection control strategy. Similarly, it should be appreciated that the delivery characteristic refers to the quantity of fuel injected for a calculated fuel delivery signal S_{11} pulsewidth or duration. Therefore, particular injectors may require a longer or a shorter period of fuel injection to satisfy the nominal delivered quantity desired at the operating condition. As a result, fuel delivery signal S_{11} may be elongated or foreshortened by control module **92** by using the trim category offset values so that delivery variations are reduced.

Referring now to FIG. **5**, a delivery versus timing trim category map is depicted, and shows in greater detail the categories into which an injector may be categorized in the preferred embodiment of the invention, as in step **134** of FIG. **7**. For example, seven trim categories are available into which a MEUI injector may be categorized. The box indicated by reference numeral **146** is designated trim category "0", and represents nominal timing and delivery values. Boxes **148**, **150**, **152**, **154**, **156**, and **158**, respectively represent trim categories **1–6**. Note that not all combinations of delivery and timing that are measured for a particular injector **22** have a corresponding trim category.

Referring now to FIG. **6**, the face of injector tappet or follower **34** is shown which corresponds to and shows in greater detail the results of performing the step of recording the trim category on each injector (step **136** of FIG. **7**). Box **162** may include a four digit trim code, box **164** may include a bar code readable by bar code scanner **114** and which is indicative of the trim category into which the subject injector **22** has been categorized, box **166** may include the injector serial number, and box **168** may include the injector part number. Other methods and manners of recording data indicative of the measured timing and delivery may be employed without departing from the spirit and scope of the present invention.

A second embodiment of the present invention is directed toward a hydraulically-actuated electronically controlled fuel injector. As shown in FIG. **8**, hydraulically-actuated electronically-controlled unit injector (HEUI) fuel system **200** includes at least one hydraulically-actuated electronically-controlled injector **202** for each combustion chamber cylinder of an engine (not illustrated), a means or circuit **204** for supplying hydraulically-actuating fluid to each injector **202**, means or a circuit **206** for supplying fuel to each injector **202**, and means or device **208** for electronically-controlling the fuel system **200**. In the embodiment shown, the injectors **202** are preferably unit injectors. Alternatively, the nozzle and pumping mechanism of each injector **202** may not be unitized. Further, fuel system **200** includes sensor means **210** for detecting at least one, and preferably a plurality of, operating parameters and generating a respective plurality of operating parameter signals indicative of the parameters detected, and means or device **212** for communicating information or data to electronically controlling means **208**.

As shown in FIG. **9**, each HEUI injector **202** includes an actuator and valve assembly **214**, a body assembly **216**, a barrel assembly **218**, and a nozzle and tip assembly **220**.

The actuator and valve assembly **214** is provided for selectively communicating relatively-high-pressure actuating fluid to each injector **202** in response to receiving fuel delivery signal S_{10}, as shown in FIG. **8**. It should be appreciated that fuel delivery signal S_{10} is functionally similar to fuel delivery S_{10}, as previously discussed in connection with a mechanically-actuated electronically-controlled fuel injector **22** (i.e., the signal S_{10} is used to command the beginning and duration of fuel injection; however, due to mechanical differences between the MEUI and HEUI injectors, the relative response times, among other things, may be different). The actuator and valve assembly **214** preferably includes poppet valve **222**, fixed stator **224**, and movable armature **226** connected to the poppet valve **222**. Popper valve **222** includes an upper annular peripheral groove **228**, an annular upper seat **230**, and an annular lower seat **232**.

As shown in FIG. **9**, the body assembly **216** includes a poppet adapter **234**, a poppet sleeve **236**, a poppet spring **238**, a poppet spring cavity **240**, a piston and valve body **242**, an actuating fluid intermediate passage **244**, and an intensifier piston **246**. The poppet adapter **234** has a main bore formed therethrough, and a counter bore formed on the lower end portion of the main bore. An annular drain passage **248** is defined between poppet sleeve **236** and the counter bore of poppet adapter **234**. The poppet adapter **234** also has a drain passage **250** defined therein. Preferably, the actuating fluid is chosen to be engine lubricating oil wherein drain passage **250** is adapted to communicate with an engine lubricating oil sump. Alternatively, the actuating fluid may be fuel wherein drain passage **250** is adapted to communicate with the fuel supply circuit **206**.

As shown in FIG. **9**, poppet sleeve **236** has at least one, and preferably two, laterally extending passages **252** formed therein. The poppet sleeve **236** has an annular shoulder formed on a lower end wherein an annular seat **254** is formed. The piston and valve body **242** has formed therein an actuating fluid inlet passage **256**.

As shown in FIG. **9**, the barrel assembly **218** includes barrel **258**, plunger **260**, plunger chamber **262**, and plunger spring **264**. The nozzle and tip assembly **220** includes an inlet flow check valve **266**, a needle check spring **268**, an axially movable needle check or valve **270**, a needle check tip **272**, a case **274**, a first discharge passage **276**, and a second discharge passage **278**.

The needle check tip **272** includes an annular seat **280**, a discharge passage **282**, and at least one, but preferably a plurality of, fuel injection spray orifices **284**. In the HEUI embodiment of FIG. **8**, the means or device **204** for supplying hydraulic actuating fluid comprises an actuating fluid sump **286** such as an engine oil pan, an actuating fluid transfer pump **288**, an actuating fluid cooler **290**, an actuating fluid filter **292**, a relatively-high-pressure actuating fluid pump **294**, a pressure regulator **296**, a high-pressure actuating fluid manifold **298**, a manifold supply passage **300**, and an actuating fluid return line **302**.

As shown in FIG. **8**, means or device **206** for supplying fuel to injectors **202** comprises a fuel tank **304**, a fuel transfer and priming pump **306**, a means or device **308** for conditioning fuel (filter, heater, etc.), a fuel manifold **310**, and a return line **312**.

The means or device **208** for electrically controlling the HEUI fuel system **200** preferably includes a programmable electronic control module **314**, memory means **316** coupled with control module **314**, and which may take the form of a non-volatile random access memory (NVRAM), and output means **318**.

The memory means **316** is provided for storing trim data signals for each injector **202** for use by an electronic fuel injection control strategy implemented on control module **314**. In addition, memory means **316** may further include a read-only memory (ROM) for storing a variety of predetermined operating data, as required by control module **314**.

Control module **314** via output means **318** generates two output command signals. One output control signal, S_9 is the actuating fluid manifold pressure command signal. The pressure command signal S_9 is provided as an input to pressure regulator **296** to adjust the output pressure of high pressure pump **294**. In order to accurately control the actuating fluid pressure, a sensor is provided for detecting the pressure of the hydraulically actuating fluid supplied to injectors **202** to generate a pressure indicative signal (S_6). Preferably the sensor detects the pressure of the actuating fluid in manifold **298**. The control module **314** compares the actual actuating fluid pressure with the desired pressure and makes any necessary correction to control signal S_9. The control signal S_9 determines the pressure of the actuating fluid in manifold **298** and consequently determines the pressure of the fuel injected (i.e., rate) during each injection phase or cycle independent of engine speed and load. Significant to the HEUI embodiment of the present invention, is that delivery signal S_{10} duration does not alone determine the quantity of fuel. Since the pressure or rate of injection can be controlled via adjustment of the actuating fluid pressure, a desired quantity of fuel may be injected via any one of a plurality of injection durations by varying the pressure. This aspect is different than for the MEUI embodiments where the duration, at a given operating condition, determines quantity, due to the fact that injection pressure is determined by mechanical actuation of plunger **46**, which is dependent on the camshaft/rocker arm **32** assembly. The ability to control fuel quantity independent of duration and engine speed provides another degree of freedom for implementing the present invention to reduce or eliminate timing and delivery variations.

The other output control signal, S_{10}, is the fuel delivery command signal which is supplied to each injector **202**. The fuel delivery command signal S_{10} determines the time for starting fuel injection and quantity of such fuel injection during each injection phase or cycle independent of engine speed and load.

Sensor means **210** is provided in fuel system **200** for detecting various operating parameters and generating a respective parameter indicative signal $S_{1\text{-}8}$, hereinafter referred to as an input data signal, the data signal being indicative of the parameter detected. Signals $S_{1\text{-}8}$ are indicative of the same parameters as described in the MEUI embodiment. The sensor means **210** preferably includes one or more conventional sensors or transducers which periodically detect one or more parameters and generate corresponding data signals that are provided as inputs to electronic control module **314**. Preferably, sensor means **210** includes engine speed sensor **320** adapted to detect engine speed and generate an engine speed signal S_1, an engine crank shaft position sensor **322** adapted to detect engine crank shaft position and generate an engine crank shaft position signal S_2, an engine coolant temperature sensor adapted to detect engine coolant temperature and generate an engine coolant temperature signal S_3, an engine exhaust back pressure sensor adapted to detect engine exhaust back pressure and generate an engine exhaust back pressure signal S_4, an air intake manifold pressure sensor adapted to detect air intake manifold pressure and generate an air intake manifold pressure signal S_5, an actuating fluid pressure sensor adapted to detect actuating fluid pressure and generate an actuating fluid pressure signal S_6, a throttle position setting sensor adapted to detect throttle position and generate a throttle position setting signal S_7, and a transmission gear setting sensor adapted to detect a gear setting and generate a gear setting signal S_8 (when so equipped).

Referring to FIG. **8**, means or device **212** for communicating information or data to electronic control module **14** preferably includes a bar code reader/scanner **336**. As described above in connection with the MEUI embodiment, the means **30** may take a plurality of forms.

INDUSTRIAL APPLICABILITY

Referring now to FIG. **9**, the operation of injector **202** will now be described. High-pressure actuating fluid is supplied by high-pressure pump **294** to inlet passage **256** of body **242**. When the actuator and valve assembly **214** of injector **202** is in a de-energized state, poppet valve **222** is in a first position wherein lower seat **232** abuts body **242**, thus blocking the communication of the high-pressure actuating fluid to the poppet spring cavity **240** and intensifier piston **246**. In the first position, since the fluid near the top of intensifier piston **246** is in communication with an actuating fluid sump by way of annular drain passage **248**, laterally extending passages **252**, and drain passage **250**, the force exerted by plunger spring **264** displaces intensifier piston **246** to a first or upper position abutting body **242**.

To begin injection, control module **314** applies a fuel delivery signal S_{10} which places a selected injector **202** in an electrically energized state wherein armature **226** is magnetically drawn toward stator **224**. Popper valve **222** moves with armature **226**, and is thus also drawn towards stator

224. The poppet valve **222** moves upwardly along the longitudinal axis of injector **202** until annular upper seats **230** abuts annular seat **254** of poppet sleeve **236** to define a second position. In the second position, annular lower seat **232** no longer abuts a body **242**, and high-pressure actuating fluid is admitted to the poppet spring cavity **240** and the passage **244** communicating with the intensifier piston **246**. The passage **244** to intensifier piston **246** no longer communicates with actuating fluid sump **286** since annular upper seat **230** blocks communication with drain passage **248**, and therefore the high-pressure actuating fluid supplied by manifold **298** hydraulically exerts a downward driving force on the top of intensifier piston **246**. As piston **246** and plunger **260** move downward in response to the above-mentioned force, the pressure of the fuel in plunger chamber **262** below plunger **260** increases. The intensification of the fuel pressure to a desired level is achieved through the selected ratio of effective working areas between the intensifier piston **246** and plunger **260**. This pressurized fuel flows through discharge passages **276**, **278**, and **282**, wherein the pressurized fuel acts on needle check **270** to lift needle check **270** from annular seat **280** once a selected valve opening pressure is reached. The pressurized fuel is then discharged through fuel injection spray orifices **284**.

To end injection, signal S_{10} is discontinued by control module **314** to electrically de-energize injector **202**. The absence of a magnetic force acting on armature **226** is effective to allow compressed poppet spring **238** to expand causing armature **226** and poppet valve **222** to move back to the first position. At the first position, high-pressuring actuating fluid is blocked from entering poppet spring cavity **240** and passage **244** to intensifier piston **246**. Since the passage **244** to the intensifier piston **246** again communicates with actuating fluid sump **286**, the fluid pressure therein decreased such that the force of the compressed plunger spring **264** overcomes the relatively smaller force applied by the actuating fluid to the top of intensifier piston **246**, wherein compressed plunger spring **264** expands to return plunger **260** and intensifier piston **246** to the upper position against body **242**. The pressure of the fuel and plunger chamber **262** below plunger **260** also decreases such that compressed needle check spring **268** moves needle check **270** downwardly against annular seat **280** of needle check tip **272** once a selected valve closing pressure is reached. The upwardly traveling plunger **260** allows inlet fuel to unseat flow check valve **266** to refill the plunger chamber **262**.

Limitations in the manufacturing and assembly process may introduce variations from design specification, which may cause variations in the timing, quantity and pressure of fuel delivered to an engine combustion chamber. As discussed above, to some extent, these variations may be compensated for or by changing the pressure of the actuating fluid via control signal S_9.

Referring to FIG. **10**, the method steps of the HEUI embodiment of the present invention are shown. In step **338**, the timing and delivery characteristics of each injector are measured at a plurality operating conditions, in a fashion identical to that described in the mechanically-actuated electronically-controlled fuel injector embodiment except that, an actuating fluid pressure is set to a selected value. It should be appreciated that the injectors **202** installed in fuel system **200** are not necessarily measured as a group during the method steps of the present invention (nor are the injectors **22** in system **20**). In fact, a key advantage of the present invention is that each categorized injector need not be identified with any particular fuel system or application.

In step **340**, each injector is categorized into one of a plurality of trim categories, in a manner similar to that described in the MEUI embodiment.

In step **342**, the trim category into which the subject injector **202** has been categorized is recorded permanently on the injector. The recording may take the form of a trim code stamped on each injector and/or affixing a bar code to the injector which is indicative of the selected trim category, in the same manner as described above (MEUI embodiment).

In step **344**, the trim category is read from each injector and is inputted, which may be scanned in via bar code reader/scanner **336**, to control module **314**, in a manner identical to that described in the mechanically-actuated electronically-controlled injector embodiment.

The remaining steps of the present invention **346–350** occur during operation of fuel system **200**. In step **346**, control module **314** calculates, for each injector **202** in fuel system **200**, a respective fuel delivery and actuating fluid pressure signals for controlling the injectors based on operating parameters including S_{1-8} and nominal timing and delivery characteristic values for hydraulically-actuated electronically-controlled fuel injectors.

In step **348**, a respective fuel delivery signal for each injector is adjusted based on respective timing and delivery offset values associated with a trim category into which the respective fuel injector has been categorized in step **340**. Use of offset values is identical to that described above in connection with the mechanically-actuated electronically-controlled embodiment of the present invention.

In step **350**, each injector is controlled in accordance with a respective adjusted fuel delivery signal and the actuating fluid pressure signal. Although current technology limits the practical extent to which changes in pressure may be made on an individual injector basis, it is expected that such technology will be available in the near future and thus such use of the pressure parameter clearly falls within the spirit and scope of this invention.

One of the many advantages of the present invention is the ability to eliminate the affects of variability introduced by the manufacturing and assembly process of an apparatus, such as a fuel injector or other fuel system component. This reduction or elimination of operating characteristic variability is obtained both simply, and inexpensively, and reduces to a large extent the end of the line rejection of assembled apparatus that would ordinarily not be of any value due to large variations in performance (i.e., would have to be scrapped).

Other aspects, objects, and advantages of this invention can be obtained from a study of the drawings, the disclosure and the appended claims.

We claim:

1. A method of operating an apparatus of the type having a nominal resultant characteristic at a plurality of operating conditions when controlled in accordance with a control signal, comprising the steps of:

measuring a resultant characteristic associated with the apparatus at a plurality of operating conditions;

adjusting the control signal as a function of the variation between the measured resultant characteristics and the nominal resultant characteristic and as a function of the operating condition of said apparatus; and

controlling the apparatus in accordance with the adjusted signal such that the resultant characteristics of the apparatus when operated approach the nominal resultant characteristics.

2. The method of claim 1, further comprising the step of: associating the resultant characteristics measured in said measuring step with the apparatus.

3. The method of claim 2, wherein the control signal is generated by a control means having a memory means, and wherein said associating step includes the substep of storing data indicative of the measured resultant characteristics of the apparatus in the memory means.

4. The method of claim 2 wherein said associating step includes the substep of permanently recording data indicative of the measured resultant characteristics of the apparatus on said apparatus.

5. The method of claim 4, wherein the control signal is generated by a control means, and wherein said associating step includes the substeps of reading the data recorded on the apparatus and inputting the read data into the control means.

6. The method of claim 1 wherein said adjusting step includes the substeps of categorizing the apparatus, based on the measured resultant characteristics, into one of a plurality of trim categories wherein each category has an associated offset value, and modifying the controls signal as a function of the offset value.

7. The method of claim 6 wherein said modifying step is further performed as a function of an actual operating condition.

8. The method of claim 1 wherein said adjusting step includes the substeps of determining the relationship between the nominal resultant characteristics as a function of the control signal and the measured resultant characteristics of the apparatus as a function of the control signal, and modifying the control signal based upon the determined relationship.

9. The method of claim 8 wherein said modifying step is further performed as a function of an actual operating condition.

10. A method of operating a plurality of electronically-controlled fuel injectors of the type having a nominal start of injection characteristic wherein fuel injection is controlled by a fuel delivery signal, comprising the steps of:

measuring, for each injector, a respective start of injection characteristic;

associating, for each injector, the measured start of injection characteristic with the respective injector;

adjusting, for each injector, the fuel delivery signal as a function of the variation of the respectively associated measured start of injection characteristic from the nominal start of injection characteristic;

controlling each injector in accordance with the respective adjusted fuel delivery signal to reduce start of injection variation.

11. The method of claim 10, wherein the fuel delivery signal is generated by a control means having a memory means, and wherein said associating step includes the substep of storing data indicative of the measured start of injection characteristic of each injector in the memory means.

12. The method of claim 10, wherein said associating step includes the substep of permanently recording data indicative of the measured start of injection characteristic of each injector on a respective injector.

13. The method of claim 12, wherein said associating step includes the substep of categorizing each injector, based on a respective measured start of injection characteristic, into one of a plurality of trim categories wherein the permanently recorded data is a trim category designation.

14. The method of claim 12, wherein the fuel delivery signal is generated by a control means, and wherein said associating step includes the substeps of reading the data recorded on the injector and inputting the read data into the control means.

15. The method of claim 14, wherein said permanently recording data substep is performed by bar coding the respective data indicative of the measured start of injection on each injector to generate a respective bar code, and wherein said reading and inputting substeps are performed by scanning the bar codes recorded on the injectors, interpreting each bar code to reconstruct the data indicative of the measured start of injection characteristic, and transmitting the reconstructed data into the control means.

16. The method of claim 14 wherein said permanently recording data substep is performed by affixing, for each injector, a resistor having a resistance value indicative of the measured start of injection of the respective injector, and wherein said reading and inputting sub-steps are performed by sensing, for each injector, the resistance value of the respectively affixed resistor, and interpreting, for each injector, the sensed resistance value to reconstruct the data indicative of the measured start of injection characteristic.

17. The method of claim 13 wherein each category has an associated offset value, and wherein said adjusting step includes the substep of modifying the fuel delivery signal for each injector as a function of a respective offset value.

18. A method of operating a plurality of electronically-controlled fuel injectors wherein fuel injection is controlled by a fuel delivery signal, the injectors being of the type having a nominal delivery characteristic as a function of operating conditions, comprising the steps of:

measuring, for each injector, a respective delivery characteristic at a plurality of operating conditions;

associating, for each injector, the measured delivery characteristic with the respective injector;

adjusting for each injector, the fuel delivery signal as a function of the variation of the respectively associated measured delivery characteristic from the nominal delivery characteristic at each operating condition of the injector;

controlling each injector in accordance with the respective adjusted fuel delivery signal to minimize injector to injector delivery variation.

19. The method of claim 18, wherein said associating step includes the substep of permanently recording data indicative of the measured delivery characteristic of each injector on a respective injector.

20. The method of claim 19, wherein the fuel delivery signal is generated by a control means and wherein said associating step includes the substeps of reading the data recorded on the injector and inputting the read data into the control means.

21. The method of claim 20 wherein said permanently recording data substep is performed by bar coding the respective data indicative of the measured delivery on each injector to generate a respective bar code, and wherein said reading and inputting substeps are performed by scanning the bar codes recorded on the injectors, interpreting each bar code to reconstruct the data indicative of the measured delivery characteristic, and transmitting the reconstructed data into the control means.

22. The method of claim 20 wherein said permanently recording data substep is performed by affixing to each injector a resistor having a resistance value indicative of the measured delivery characteristic of the respective injector, and wherein said reading and inputting substeps are performed by sensing, for each injector, the resistance value of the respective affixed resistor and interpreting, for each

injector, the sensed resistance value to reconstruct the data indicative of the measured delivery characteristic.

23. The method of claim **18**, wherein the fuel delivery signal is generated by a control means having a memory means, and wherein said associating step includes the substep step of storing data indicative of the measured delivery characteristic of each injector in the memory means.

24. The method of claim **19** wherein said associating step includes the substep of categorizing each injector, based on a respective measured delivery characteristic, into one of a plurality of trim categories wherein the permanently recorded data is a trim category designation.

25. The method of claim **24** wherein each category has an associated offset value, and wherein said adjusting step includes the substep of modifying the fuel delivery signal for each injector as a function of a respective offset value.

26. A method of operating a plurality of electronically-controlled fuel injectors wherein fuel injection is controlled by a fuel delivery signal generated by a control means having a memory means, the injectors being of the type having a nominal start of injection characteristic and nominal delivery characteristic, comprising the steps of:

measuring, for each injector, a respective start of injection characteristic and delivery characteristic;

categorizing each injector into one of a plurality of trim categories as a function of the variation of the measured start of injection and delivery characteristics from the respective nominal start of injection and delivery characteristics, each trim category having an associated start of injection and delivery offset value;

recording the category into which each injector was categorized in said categorizing step on a respective injector;

storing the respective category recorded on each injector in the memory means;

calculating the fuel delivery signal as a function of actual operating conditions based on nominal start of injection and delivery characteristics;

adjusting the fuel delivery signal for each injector as a function of the respective start of injection and delivery offset values;

controlling each injector in accordance with the respective adjusted fuel delivery signal to reduce start of injection and delivery variation.

27. The method of claim **26** wherein the injectors are hydraulically-actuated injectors which are further controlled by an actuating fluid pressure command signal, the method further comprising the step of adjusting the actuating fluid pressure command signal for each injector as a function of the respective start of injection and delivery offset values.

28. The method of claim **26** wherein said measuring step is performed at a plurality of operating conditions, and wherein said adjusting step includes the substep of further adjusting the fuel delivery command signal as a function of an actual operating condition.

29. The method of claim **26** wherein said recording step includes the substep of affixing, for each injector, a respective bar code that is indicative of the category into which the respective injector was categorized.

30. The method of claim **26** wherein said recording step includes the substep of affixing, for each injector, a respective resistor having a resistance value that is indicative of the category into which the respective injector was categorized.

31. A system for controlling the delivery of fuel through a plurality of fuel injectors to an engine, each injector being of the type characterized by at least one observed performance parameter, comprising:

sensor means for detecting a plurality of operating parameters and generating a respective plurality of operating parameter signals indicative of the parameter detected;

control means responsive to said operating parameter signals for generating a base fuel delivery signal for each injector; each fuel injector being coupled with said control means to receive a respective base fuel delivery signal for controlled fuel delivery to the engine;

memory means coupled with said control means for storing trim signals for each injector, said trim signals being derived from observed performance parameter values taken at a plurality of operating conditions;

means for communicating said trim signals to said memory means;

said control means being responsive to said trim signals for trimming said base fuel delivery signal for each injector as a function of said trim signals and as a function of said operating parameter signals for reducing performance parameter variation.

32. A method of preparing for shipment an apparatus of a type having measurable resultant characteristics at a plurality of operating conditions when controlled in accordance with a control signal, comprising the steps of:

measuring at least one resultant characteristic associated with the apparatus at a plurality of operating conditions;

determining a control signal adjustment as a function of a variation between the measured resultant characteristics and nominal resultant characteristics and as a function of an operating condition of the apparatus; and

recording data indicative of the control signal adjustment on the apparatus.

33. The method of claim 32 wherein the apparatus is a fuel injector; and

the plurality of operating conditions include different engine operating conditions.

34. The method of claim 33 wherein the control signal adjustment includes a fuel injection quantity adjustment that is a function of an operating condition of the fuel injector.

35. The method of claim 34 wherein said recording step includes a step of attaching a bar code to the fuel injector.

36. The method of claim 35 wherein the control signal adjustment includes a fuel injection timing adjustment.

37. The method of claim 36 wherein said attaching step includes a step of locating the bar code at a location that is readable after the fuel injector is installed in an engine.

38. A method of operating an apparatus of a type having measurable resultant characteristics at a plurality of operating conditions when controlled in accordance with a control signal, comprising the steps of:

reading data recorded on the apparatus that is indicative of a control signal adjustment;

inputting the control system adjustment data into an electronic control module;

establishing a control communication link between the apparatus and the electronic control module; and

controlling the apparatus in accordance with an adjusted control signal that is a function of a nominal control signal, an operating condition and the control signal adjustment data.

39. The method of claim 38 wherein the apparatus is a fuel injector; and the method includes a step of:

installing the fuel injector in an engine.

40. The method of claim 39 wherein said reading step includes a step of scanning a bar code attached to the fuel injector.

41. The method of claim 40 wherein the control signal adjustment data includes fuel injection quantity adjustment data that is a function of an operating condition of the fuel injector.

42. The method of claim 41 wherein the control signal adjustment data includes fuel injection timing adjustment data.

43. An actuatable mechanism that produces a measurable resultant characteristic in response to an electronic control signal, comprising:

a body;

an electrical actuator attached to said body;

a data recording attached to said body and including control signal adjustment data that is a function of a variation between measured resultant characteristics and nominal resultant characteristics and as a function of an operating condition of the mechanism.

44. The mechanism of claim 43 wherein the mechanism is a fuel injector.

45. The mechanism of claim 44 wherein said data recording includes a bar code.

46. The mechanism of claim 45 wherein the control signal adjustment data includes fuel injection quantity adjustment data that is a function of an operating condition of the fuel injector.

47. The method of claim 46 wherein the control signal adjustment data includes a fuel injection timing adjustment data.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : RE 37,807 C1
APPLICATION NO. : 90/008757
DATED : November 24, 2009
INVENTOR(S) : Shinogle et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page should be deleted and replace with the attached title page.

On the title page, item (10) Number: should read -- US RE37,807 C1 --

Signed and Sealed this

Twenty-ninth Day of June, 2010

David J. Kappos

David J. Kappos
Director of the United States Patent and Trademark Office

(12) **EX PARTE REEXAMINATION CERTIFICATE** (7177th)
United States Patent
Shinogle et al.
(10) **Number:** **US RE37,807 C1 --**
(45) **Certificate Issued:** **Nov. 24, 2009**

(54) **METHOD AND STRUCTURE FOR CONTROLLING AN APPARATUS, SUCH AS A FUEL INJECTOR, USING ELECTRONIC TRIMMING**

(75) Inventors: **Ronald D. Shinogle**, Peoria, IL (US); **Richard A. De Keyser**, Edelstein, IL (US); **Vernon R. Smith**, Peoria, IL (US); **Stephen F. Glassey**, Gulnare, CO (US); **Yasser A. Al Charif**, Farmington, MI (US)

(73) Assignee: **Caterpillar, Inc.**, Peoria, IL (US)

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Issued:	**Jul. 30, 2002**
Appl. No.:	**09/322,770**
Filed:	**May 28, 1999**

Related U.S. Patent Documents

Reissue of:

(64)	Patent No.:	**5,634,448**
	Issued:	**Jun. 3, 1997**
	Appl. No.:	**08/251,549**
	Filed:	**May 31, 1994**

(51) **Int. Cl.**

F02D 41/34	(2006.01)
F02D 41/40	(2006.01)
F02D 41/00	(2006.01)
F02D 41/24	(2006.01)

(52) **U.S. Cl.** **123/480**; 123/478; 73/114.45
(58) **Field of Classification Search** .... None
See application file for complete search history.

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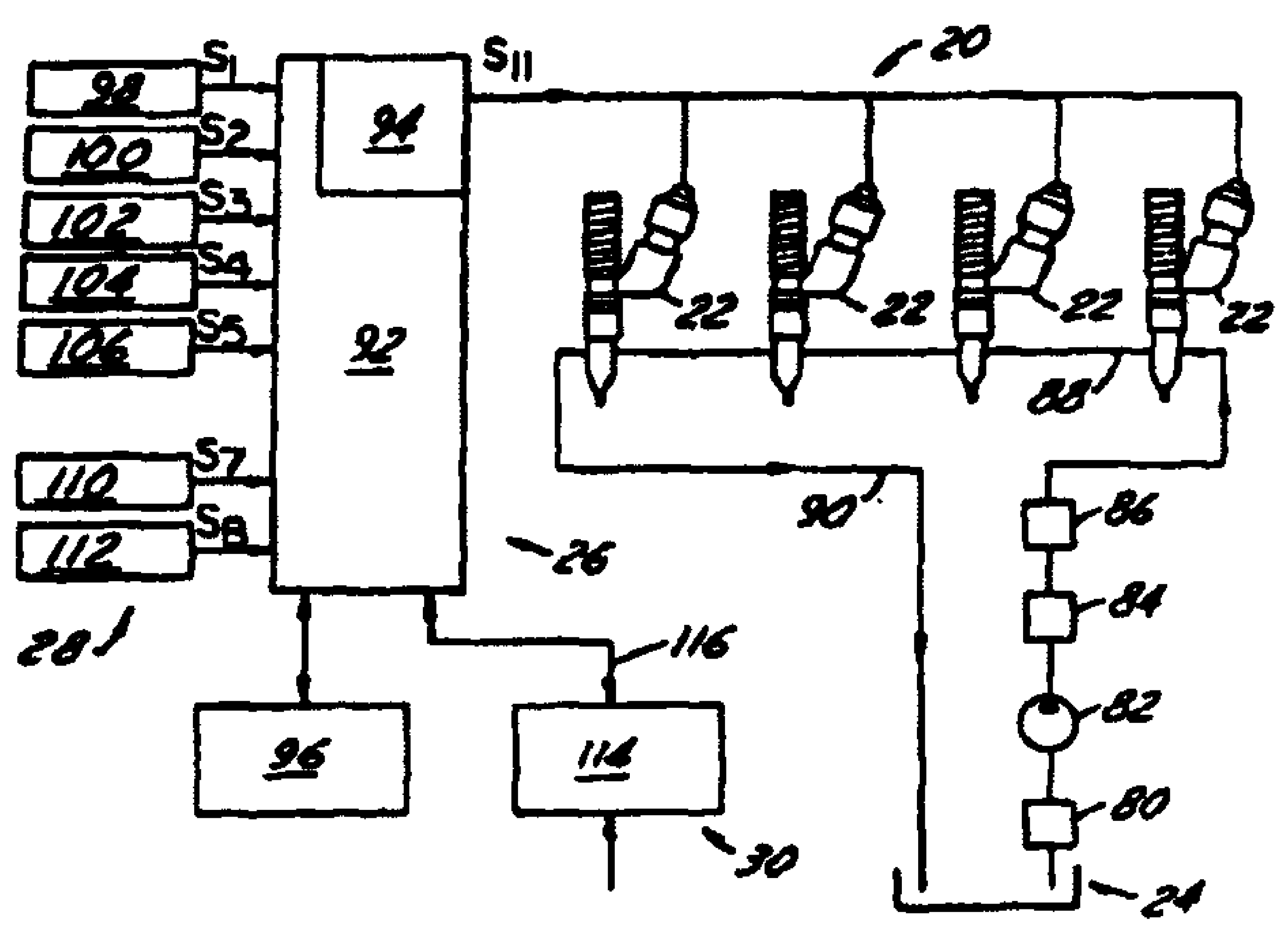
(Continued)

Primary Examiner—Catherine S. Williams

(57) **ABSTRACT**

A structure and method for electronically minimizing or eliminating performance variation of an apparatus controllable by a control signal, such as an electronically-controlled fuel injector, is disclosed. The method includes the steps of measuring the resultant characteristics of the apparatus at a plurality of operating conditions, such as timing and delivery characteristics of the fuel injector, adjusting the control signal as a function of the measured resultant characteristics, such as by adjusting a base timing and duration or pulse width of a fuel delivery command signal for a fuel injector, and controlling the apparatus in accordance with the adjusted control signal to reduce performance variation. A structure is disclosed to compensate or trim for individual injector variation, includes an electronic control module having a memory for storing trim signals for each injector, the trim signals being derived from observed performance parameter values taken at a plurality of operating conditions, a plurality of sensors for detecting at least one, and preferably a plurality of operating parameters and generating a respective one, and preferably a plurality of, operating parameter signals, and a means for communicating the trim signals to the memory. The electronic control module adjusts a base fuel delivery signal for each injector as a function of the trim data signals for each injector.



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(12) **EX PARTE REEXAMINATION CERTIFICATE** (7177th)

United States Patent

Shinogle et al.

(10) **Number:** **US RE37,807 F1**

(45) **Certificate Issued:** **Nov. 24, 2009**

(54) **METHOD AND STRUCTURE FOR CONTROLLING AN APPARATUS, SUCH AS A FUEL INJECTOR, USING ELECTRONIC TRIMMING**

(75) Inventors: **Ronald D. Shinogle**, Peoria, IL (US); **Richard A. De Keyser**, Edelstein, IL (US); **Vernon R. Smith**, Peoria, IL (US); **Stephen F. Glassey**, Gulnare, CO (US); **Yasser A. Al Charif**, Farmington, MI (US)

(73) Assignee: **Caterpillar, Inc.**, Peoria, IL (US)

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	Filed:	**May 31, 1994**

(51) **Int. Cl.**

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F02D 41/40	(2006.01)
F02D 41/00	(2006.01)
F02D 41/24	(2006.01)

(52) **U.S. Cl.** **123/480**; 123/478; 73/114.45

(58) **Field of Classification Search** .... None
See application file for complete search history.

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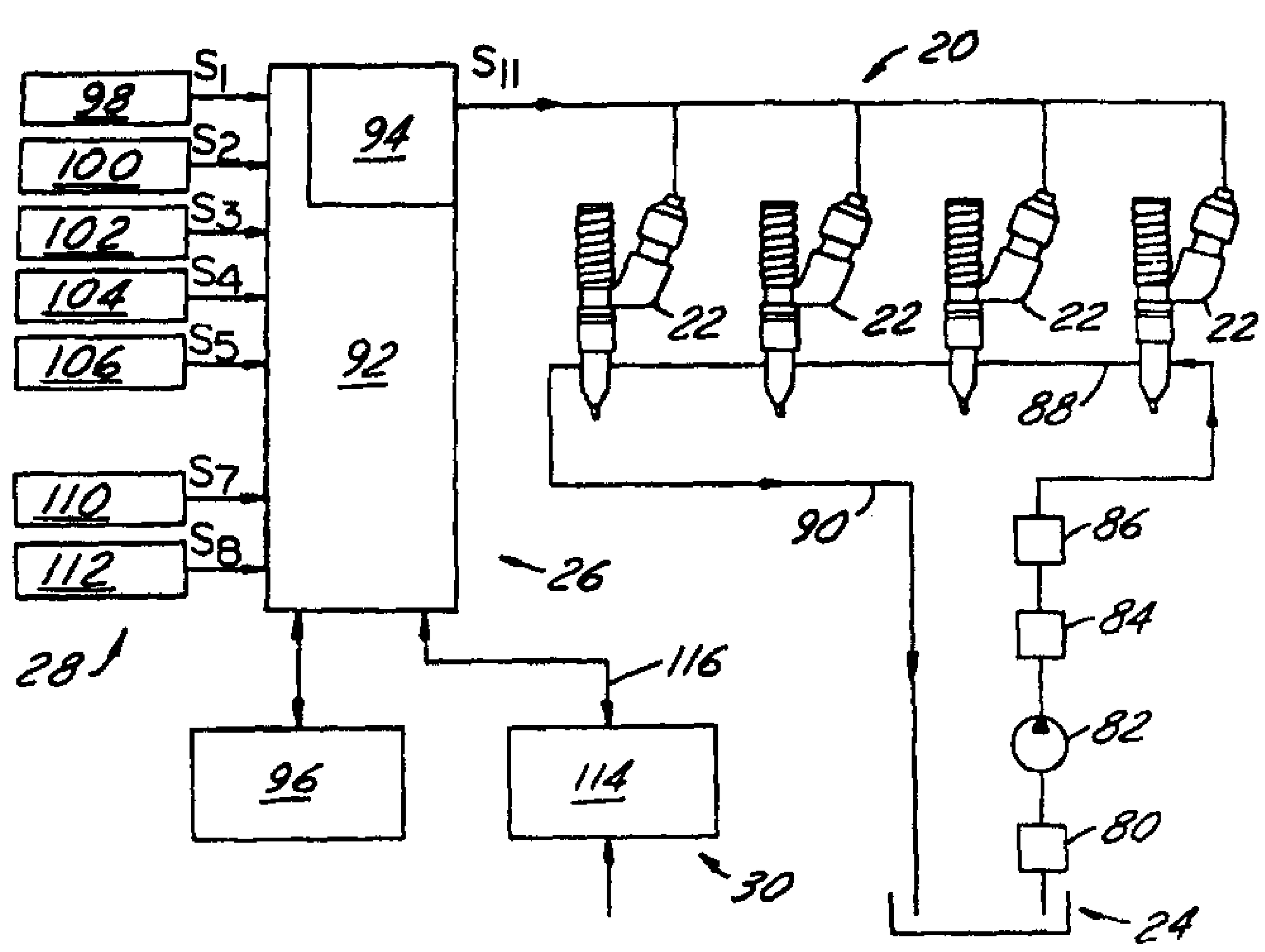
Lauvin et al., "Electronically Controlled High Pressure Unit Injector System for Diesel Engines," SAE Technical Paper Series 911819, Sep. 1991.

(Continued)

Primary Examiner—Catherine S. Williams

(57) **ABSTRACT**

A structure and method for electronically minimizing or eliminating performance variation of an apparatus controllable by a control signal, such as an electronically-controlled fuel injector, is disclosed. The method includes the steps of measuring the resultant characteristics of the apparatus at a plurality of operating conditions, such as timing and delivery characteristics of the fuel injector, adjusting the control signal as a function of the measured resultant characteristics, such as by adjusting a base timing and duration or pulse width of a fuel delivery command signal for a fuel injector, and controlling the apparatus in accordance with the adjusted control signal to reduce performance variation. A structure is disclosed to compensate or trim for individual injector variation, includes an electronic control module having a memory for storing trim signals for each injector, the trim signals being derived from observed performance parameter values taken at a plurality of operating conditions, a plurality of sensors for detecting at least one, and preferably a plurality of operating parameters and generating a respective one, and preferably a plurality of, operating parameter signals, and a means for communicating the trim signals to the memory. The electronic control module adjusts a base fuel delivery signal for each injector as a function of the trim data signals for each injector.



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EX PARTE REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the original patent but was deleted by the reissue patent; matter printed in italics was added by the reissue patent. Matter enclosed in heavy double brackets [[ ]] appeared in the reissue patent but is deleted by this reexamination certificate; matter printed in boldface is added by this reexamination certificate.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **10**–**17** and **26**–**30** is confirmed.

Claims **1**–**9**, **18**–**25**, **38**–**42**, **44** and **46** are cancelled.

Claims **31**–**32**, **43**, **45** and **47** are determined to be patentable as amended.

Claims **33**–**37**, dependent on an amended claim, are determined to be patentable.

New claims **48**–**72** are added and determined to be patentable.

31. A system for controlling the **[[**delivery**]]** **start of injection** of fuel through a plurality of fuel injectors to an engine, each injector being of the type characterized by at least one observed performance parameter, comprising:

sensor means for detecting a plurality of operating parameters and generating a respective plurality of operating parameter signals indicative of the parameter detected;

control means responsive to said operating parameter signals for generating a base fuel delivery signal for each injector; each fuel injector being coupled with said control means to receive a respective base fuel delivery signal for controlled fuel delivery to the engine;

memory means coupled with said control means for storing trim signals for each injector, said trim signals being derived from observed performance parameter values taken at a plurality of operating conditions;

means for communicating said trim signals to said memory means;

said control means being responsive to said trim signals for trimming said base fuel delivery signal for each injector as a function of said trim signals and as a function of said operating parameter signals for reducing **[[**performance parameter**]]** **start of injection** variation.

32. A method of preparing for shipment **[[**an**]]** **a fluid delivery** *apparatus of a type having measurable resultant characteristics at a plurality of operating conditions when controlled in accordance with a control signal, comprising the steps of:*

measuring at least one resultant characteristic associated with the apparatus at a plurality of operating conditions;

determining a control signal adjustment as a function of a variation between the measured resultant characteristics and nominal resultant characteristics and as a function of an operating condition of the apparatus;

categorizing the apparatus into one of a plurality of trim categories based on the control signal addjustment; and

recording data indicative of the control signal adjustment on the apparatus, **the data corresponding to the trim category of the apparatus**.

43. **[[**An actuatable mechanism**]]** **A fuel injector** that produces a measurable resultant characteristic in response to an electronic control signal, comprising:

a body;

an electrical actuator attached to said body **and configured to control timing of fluid injection from the body;**

a data recording attached to said body and including control signal adjustment data that is a function of a variation between measured resultant characterisitics and nominal resultant characteristics and **[[**as**]]** **is** a function of an operating condition of the **[[**mechanism**]]** **fuel injector, the control signal adjustment data including a start of injection adjustment to reduce start of injection variation**.

45. The mechanism of claim **[[44]]** **43** wherein said data recording includes a bar code.

47. The **[[**method**]]** **mechanism** of claim **[[46]]** **45** wherein the control signal adjustment data includes **[[**a fuel injection timing adjustment data**]]** **the timing of fluid delivery adjustment**.

48. The mechanism of claim 43 wherein the control signal adjustment data includes a total fluid output from the body adjustment.

49. A method of preparing for shipment a fuel injector of a type having measurable resultant characteristics at a plurality of operating conditions when controlled in accordance with a control signal, comprising the steps of:

measuring at least one resultant characteristic associated with the fuel injector at a plurality of operating conditions;

determining a control signal adjustment as a function of a variation between the measured resultant characteristics and nominal resultant characteristics and as a function of an operating condition of the fuel injector, the control signal adjustment including a start of injection adjustment to reduce start of injection variation; and

recording data indicative of the control signal adjustment on the fuel injector.

50. The method of claim 49 wherein the plurality of operating conditions include different engine operating conditions.

51. The method of claim 50 wherein the start of injection adjustment is a function of an operating conditon of the fuel injector.

52. The method of claim 51 wherein said recording step includes a step of applying a bar code to the fuel injector.

53. The method of claim 52 wherein said applying step includes a step of locating the bar code at a location that is readable after the fuel injector is installed in an engine.

54. A method of preparing for shipment a fuel injector of a type having measurable resultant characteristics at a plurality of operating conditions when controlled in accordance with a control signal, comprising the steps of:

measuring at least one resultant characteristic associated with the fuel injector at a plurality of operating conditions;

determining a control signal adjustment as a function of a variation between the measured resultant characteristics and nominal resultant characteristics and as a function of an operating condition of the fuel injector;

categorizing the fuel injector into one of a plurality of trim categories based on the control signal adjustment; and

recording data indicative of the control signal adjustment on the fuel injector, the data corresponding to the trim category of the fuel injector.

55. The method of claim 54 wherein the plurality of operating conditions include different engine operating conditions.

56. The method of claim 55 wherein the control signal duration adjustment is a function of an operating condition of the fuel injector.

57. The method of claim 56 wherein said recording step includes a step of applying a bar code to the fuel injector.

58. The method of claim 57 wherein said applying step includes a step of locating the bar code at a location that is readable after the fuel injector is installed in an engine.

59. A method of preparing for shipment a fluid delivery apparatus of a type having measurable resultant characteristics at a plurality of operating conditions when controlled in accordance with a control signal, comprising the steps of:

measuring at least one resultant characteristic associated with the fluid delivery apparatus at a plurality of operating conditions;

determining a control signal adjustment as a function of a variation between the measured resultant characteristics and nominal resultant characteristics and as a function of an operating condition of the fluid delivery apparatus, the control signal adjustment including a start of delivery from the fluid delivery apparatus adjustment to reduce start of delivery variation; and

recording data indicative of the control signal adjustment on the fluid delivery apparatus.

60. The method of claim 59 wherein the plurality of operating conditions include different engine operating conditions.

61. The method of claim 60 wherein the start of delivery from the fluid delivery apparatus adjustment is a function of an operating condition of the fluid delivery apparatus.

62. The method of claim 61 wherein said recording step includes a step of applying a bar code to the fluid delivery apparatus.

63. The method of claim 62 wherein the control signal adjustment includes a total delivery through the fluid delivery apparatus adjustment.

64. The method of claim 63 wherein said applying step includes a step of locating the bar code at a location that is readable after the fluid delivery apparatus is installed in an engine.

65. A fuel injector that produces a measurable resultant characteristic in response to an electronic control signal, comprising:

a body;

an electrical actuator attached to said body; and

a data recording applied to said body and including control signal adjustment data that is a function of a variation between measured resultant characteristics and nominal resultant characteristics and is a function of an operating condition of the fuel injector, the data recording including a bar code.

66. The fuel injector of claim 65 wherein the control signal adjustment data includes the timing of fluid delivery adjustment.

67. The fuel injector of claim 65 wherein the control signal adjustment data includes the total fluid output from the body adjustment.

68. A fuel injector that produces a measurable resultant characteristic in response to an electronic control signal, comprising:

a body;

an electrical actuator attached to said body;

a data recording attached to said body and including control signal adjustment data that is a function of a variation between measured resultant characteristics and nominal resultant characteristics and as a function of an operating conditon of the fuel injector, the control signal adjustment data including one of a plurality of trim categories based on the variation.

69. The mechanism of claim 68, wherein said data recording includes a bar code.

70. The mechanism of claim 69, wherein the trim category is associated with fuel injection quantity adjustment data that is a function of an operating condition of the fuel injector.

71. The mechanism of claim 69, wherein the trim category is associated with timing of fluid delivery adjustment data.

72. The mechanism of claim 69, wherein the trim category is associated with both total fluid output from the body adjustment data and timing of fluid delivery from the body adjustment data.

* * * * *