United States Patent [19]

Davis

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[54] **METHOD AND MEANS FOR REDUCING EXHAUST SMOKE IN I.C. ENGINES**

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[73] Assignee: **Ricardo & Co., Engineers (1927) Limited,** Sussex, England

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[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** ...... **123/32 EA,** 123/32 AE, 123/32 R, 123/140 MC

[51] **Int. Cl.** **F02b 3/00,** F02d 1/04

[58] **Field of Search** .... 123/32 AE, 32 EA, 123/140 MC, 119 E; 73/17

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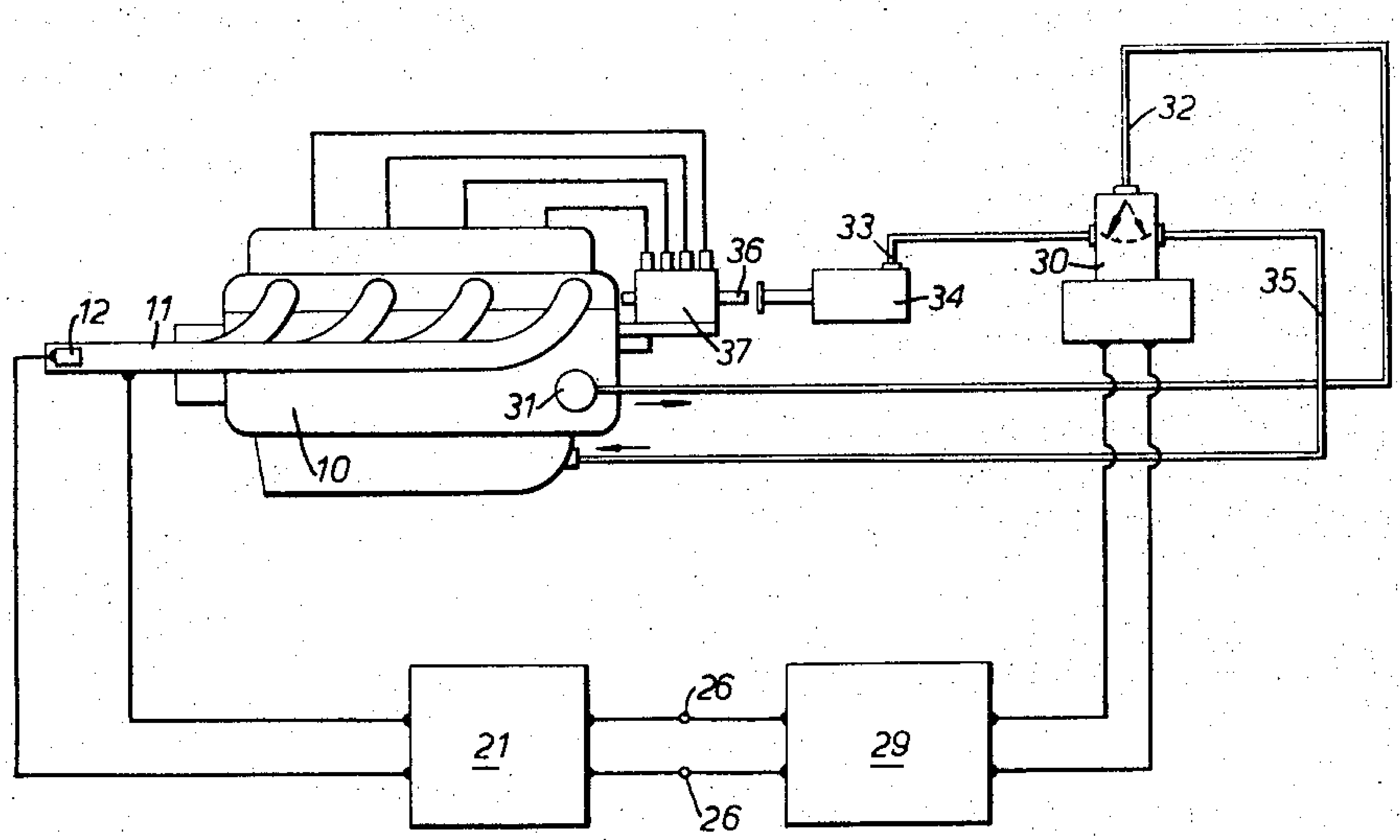
[57] **ABSTRACT**

An internal combustion engine having a fuel pump whose control rack is provided with an adjustable stop for limiting the maximum quantity of fuel delivered to the engine, is provided with an electrohydraulic control circuit coupled to the said stop for automatic reduction of the maximum fuel delivery in response to the occurrence of an increase in smoke density in the gaseous exhaust from the engine exhaust duct. An electrode assembly mounted in the exhaust duct and insulated therefrom receives an electrical charge from the charged carbon smoke particles impinging upon it, and the resultant potential developing on the electrode is continuously measured as a signal dependent upon exhaust smoke density, and is supplied as an input signal to the electrohydraulic control circuit. The output member of the control circuit is a hydraulic plunger whose movable member comprises the said adjustable stop.

7 Claims, 6 Drawing Figures



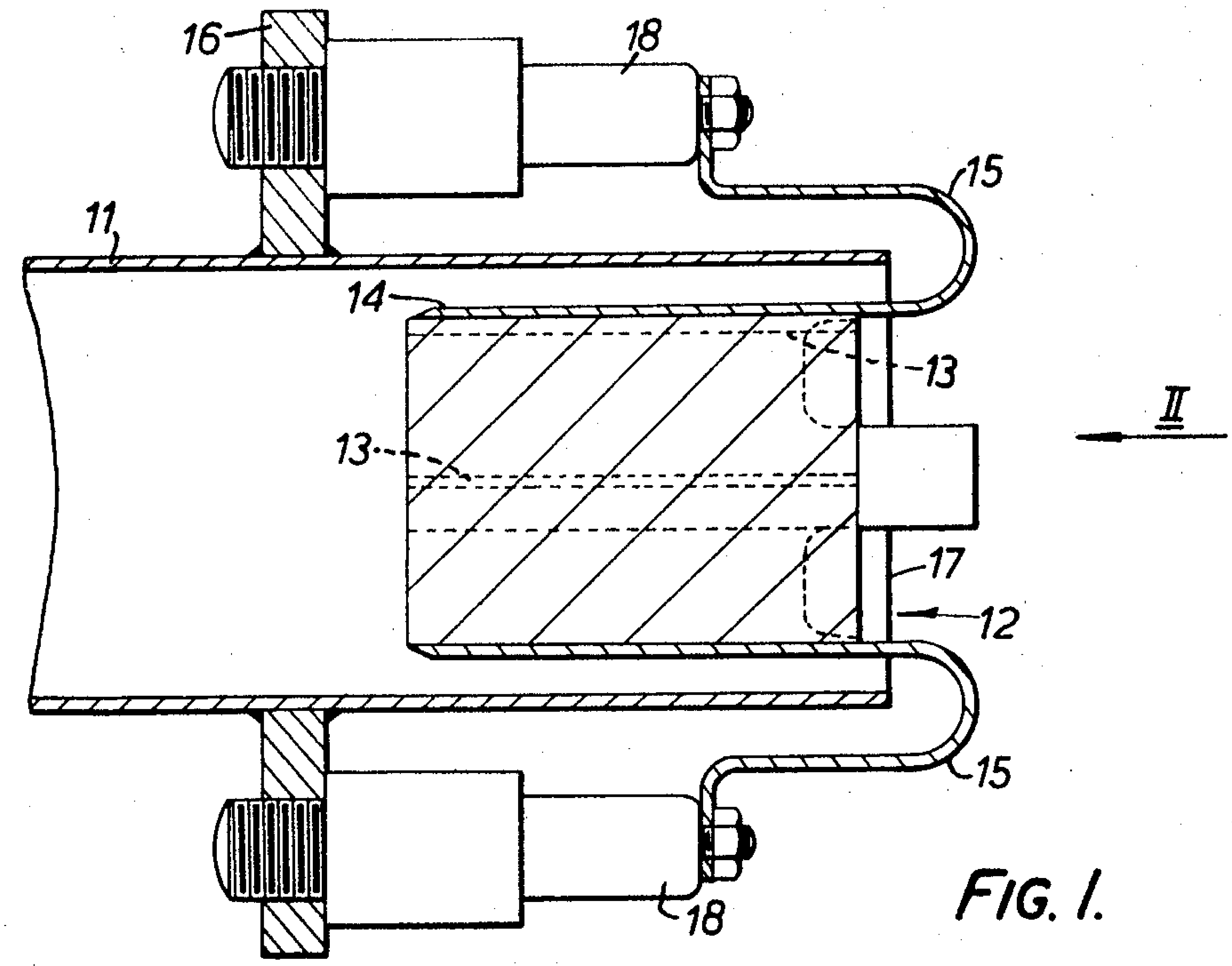


FIG. 1.

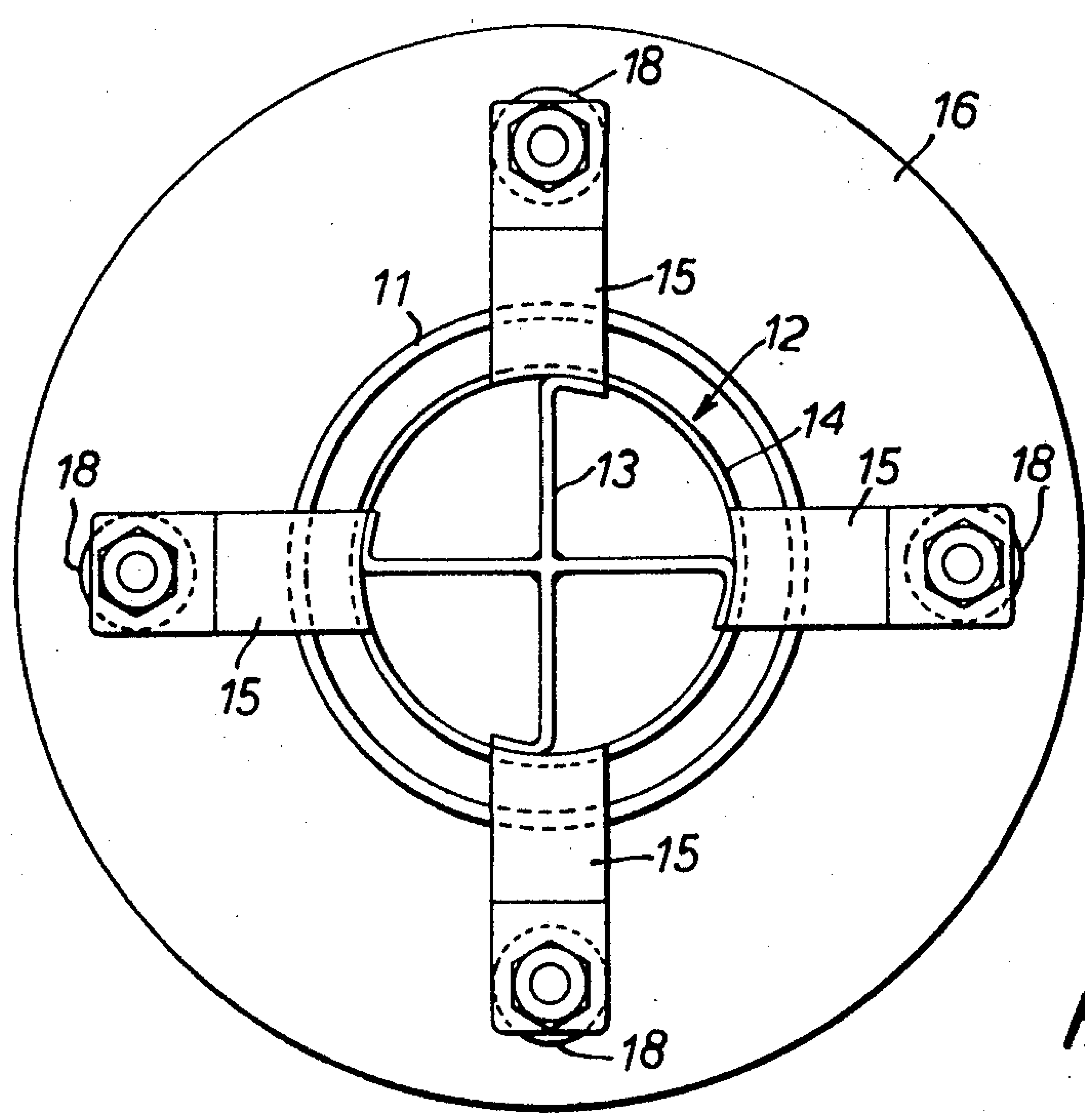


FIG. 2.

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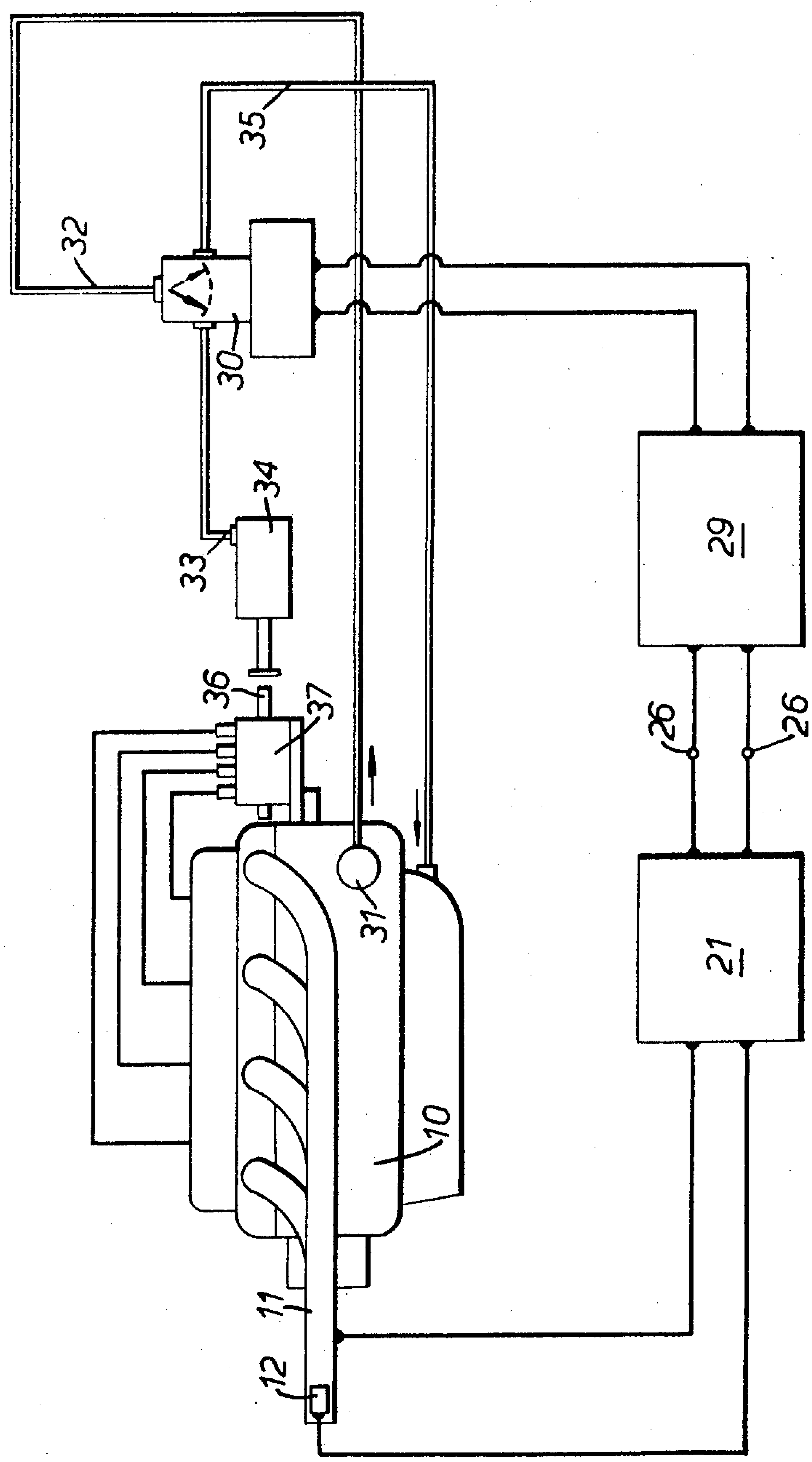

FIG. 3.

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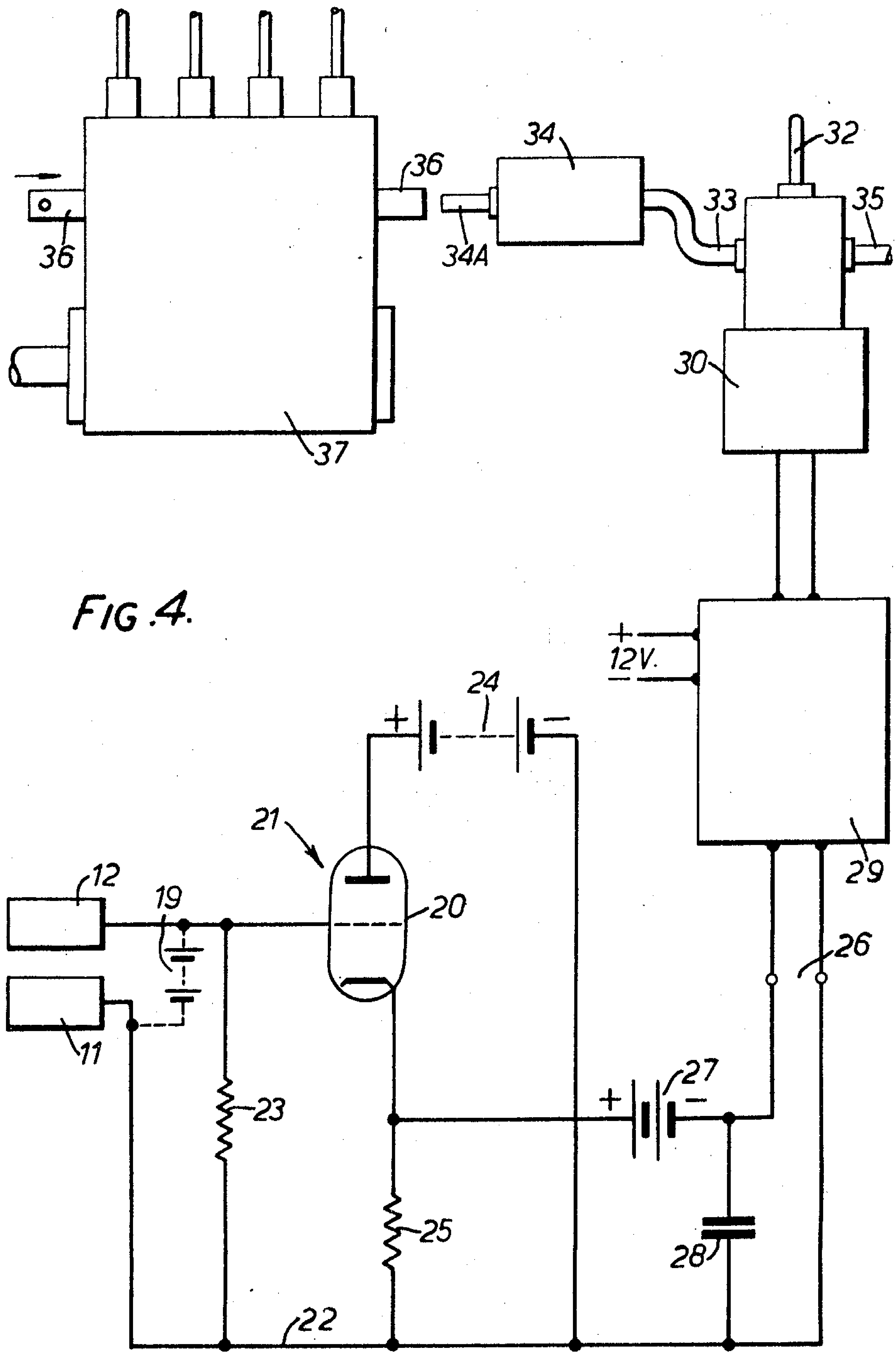

FIG. 4.

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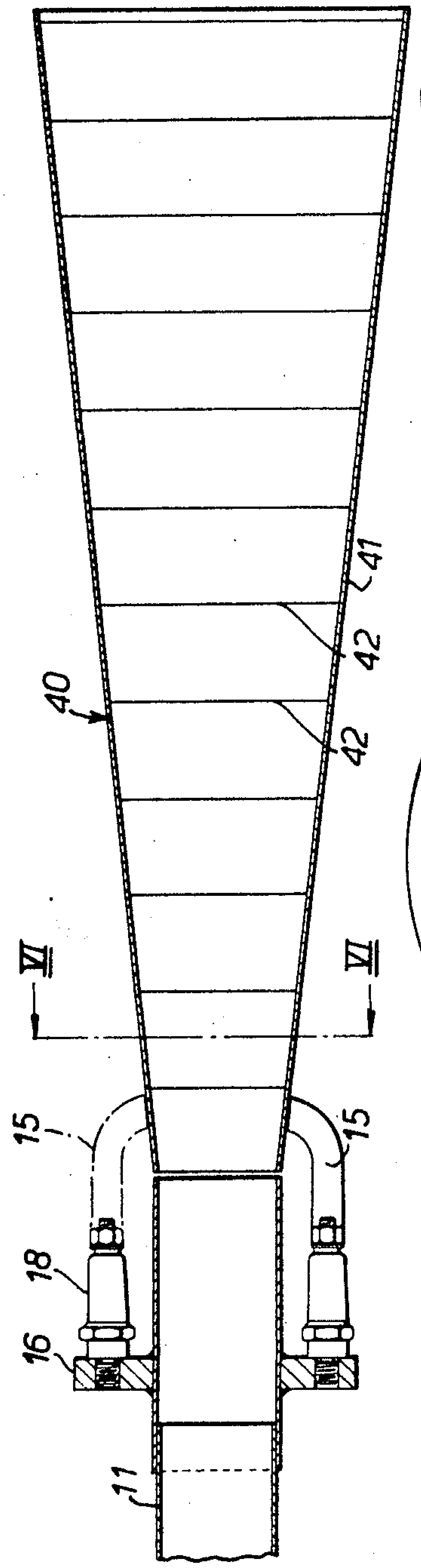

FIG. 5.

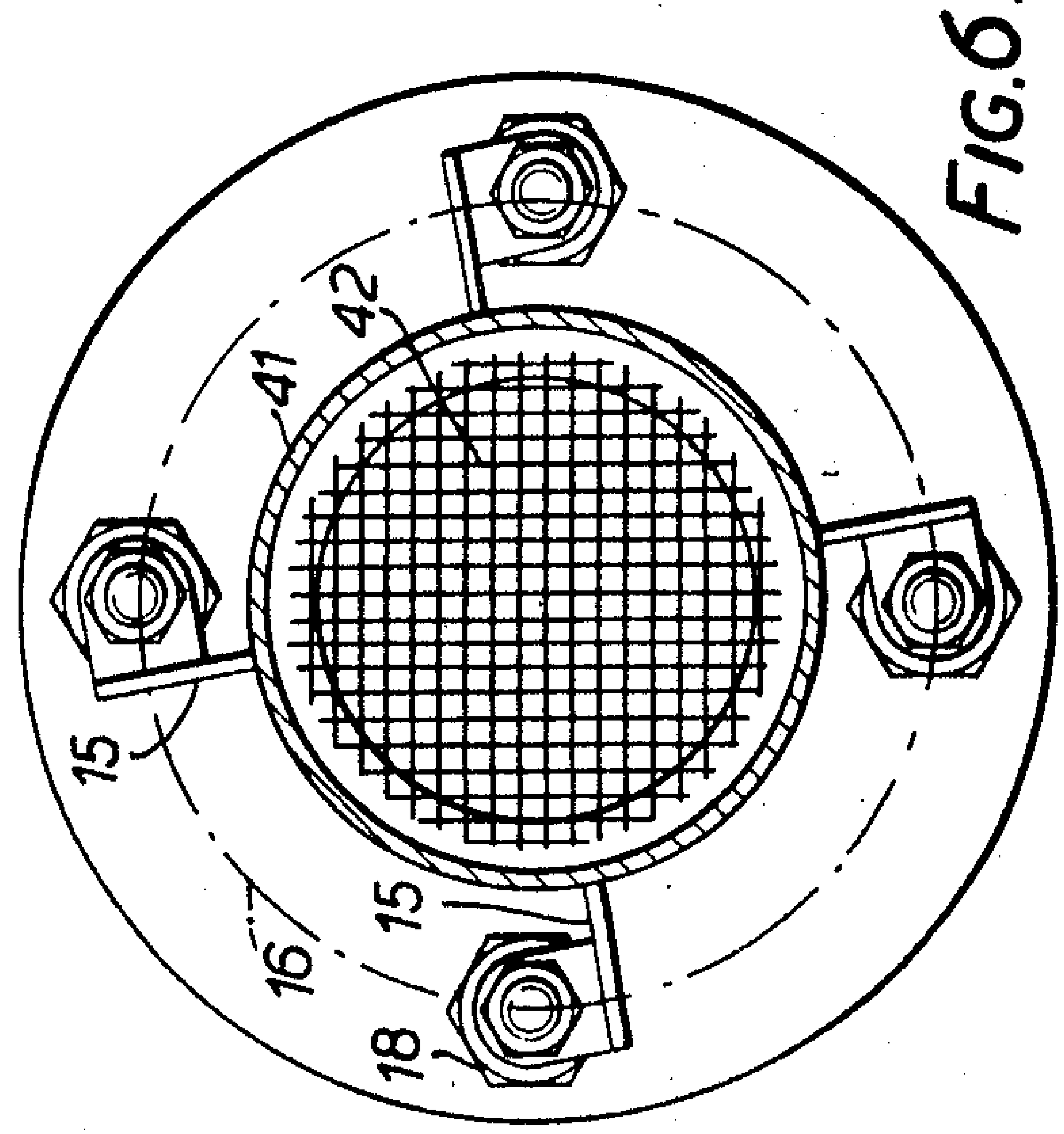

FIG. 6.

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METHOD AND MEANS FOR REDUCING EXHAUST SMOKE IN I.C. ENGINES

This invention relates to a method and means for reducing exhaust smoke emission from internal combustion engines, for example liquid-fuel-injection compression-ignition engines such as are loosely known as diesel engines.

There is a growing interest in the reduction of smoke emission from the exhaust of I.C. engines, for example in road vehicles, and an object of the present invention is to enable the exhaust smoke level to be restricted to a low value over a prolonged period of running of an engine under varying conditions, for example under different traffic conditions in the case of the engine of a road vehicle.

According to the present invention, means for reducing exhaust smoke emission from an internal combustion engine having a fuel control by which the quantity, of fuel delivered to the engine for combustion is controlled, comprises a device for measuring the density of smoke in the gaseous exhaust discharged from the exhaust duct of the engine, the device being constructed and arranged to provide an output signal dependent upon the exhaust smoke density, and control means responsive to the said output signal and constructed and arranged for coupling to the fuel control to adjust the latter automatically in response to the output signal in such a way as to reduce the fuel delivery in response to an increase in exhaust smoke density, and vice versa.

The smoke density measuring device may be of the construction forming the subject of the present applicants' co-pending unpublished British patent application No. 23802/68, namely having an electrode supported by an insulating mounting by which it can be mounted in the path of the exhaust gases, and an electrical circuit to whose input the electrode is connected for the purpose of deriving an electrical output signal corresponding to the potential developed between the electrode and the exhaust duct. This output signal may then be employed to drive or control a suitable motor means coupled to the fuel control stop of the engine.

As explained in our aforesaid specification No. 23802/68, this electrode device depends upon the principle that when carbon particles are emitted in an I.C. engine exhaust they are electrically charged, and a sample of this charge can be collected on the electrode, and the accumulated potential of the electrode can be measured and utilised as an output signal for controlling the maximum fuel delivery in inverse dependence on the concentration of carbon particles in the emission.

From another aspect, the invention comprises a method of operating an internal combustion engine with reduction in exhaust smoke density, which method comprises obtaining a continuous measurement of smoke density in the exhaust gasdischarged from the engine, deriving from the said measurement a control signal dependent upon the said smoke density, and utilising the control signal to adjust the quantity of fuel delivered to the engine for combustion, the fuel delivery being automatically adjusted in inverse dependence upon the measurement of smoke density.

The invention may be carried into practice in various ways, but one specific embodiment will now be described by way of example only and with reference to the accompanying drawings, in which:

FIG. 1 is a view in longitudinal section of an electrode arrangement attached to the exhaust duct of an I.C. engine;

FIG. 2 is an end view of the arrangement as seen in the direction of the arrow II in FIG. 1;

FIG. 3 is a diagram showing the engine, and the electrohydraulic control circuit which interconnects the electrode arrangement of its exhaust duct and the rack of its fuel pump;

FIG. 4 is a circuit diagram showing the details of the electrohydraulic control circuit of FIG. 3;

FIG. 5 is a longitudinal sectional view of a modified electrode arrangement; and

FIG. 6 is a cross-section on the line VI—VI of FIG. 5.

In the embodiment of FIGS. 1 to 4, a device for measuring the smoke intensity in the exhaust gases discharged from an I.C. engine **10** of the liquid-fuel-injection, compression-ignition kind, through its exhaust duct **11** includes an electrode assembly **12** comprising a cruciform spider **13** made of sheet metal and enclosed in a tubular sheet metal cylinder **14** which is provided with four supporting straps **15** of U shape. A circumferential flange **16** is welded to the exterior of the exhaust duct **11** near its open discharge end **17**, and carries four electrically insulating supporting posts **18** to which the outer ends of the four straps **15** are secured so that the electrode assembly **12** is positioned coaxially within the end portion of the exhaust duct **11** but is electrically insulated from the duct.

The electrode assembly **12** is connected electrically to an electrical measuring circuit, which as shown in FIGS. 3 and 4 comprises an electrometer valve **20** in an amplifier circuit **21** by which the potential of the change collecting on the electrode assembly **12** from the carbon particles in the exhaust emission can be measured continuously. The electrode assembly **12**, which may in some cases have a positive or a negative biassing potential applied between it and the exhaust duct **10**, as indicated diagrammatically at **19** in FIG. 4, is connected to the grid of the electrometer triode valve **20**, and the exhaust duct **11** is connected to the return line **22** of the cathode circuit. A grid resistor **23** is connected between the grid of the valve **20** and the cathode return line **22**. A suitable anode potential is applied to the anode of the valve **20** from a 10-volt battery **24**, and the potential developing across a series resistor **25** in the cathode circuit is applied to terminals **26**, in series with cells **27** providing a back-off potential of 2.7 volts. A smoothing capacitor **28** is connected in parallel across the terminals **26** to adjust the response time.

The terminals **26** are connected to an electrohydraulic control circuit comprising a power amplifier **29** which actuates a three-way electrohydraulic valve **30** controlling a hydraulic actuator **34**. The electrovalve **30** is supplied with engine oil under pressure by means of an oil pump **31** and supply pipe **32**, and the valve **30** has alternative delivery ports, one of which is connected by a pipe **33** to a hydraulic actuator **34**, and the other of which is connected back to the engine crankcase via a pipe **35**. The plunger **34A** of the hydraulic actuator **34** forms a variable stop for the fuel rack **36** of the fuel injection pump **37** of the engine **10**, such that an increase in the electrical signal from the amplifier **29** resulting from an increase in the level of smoke in the exhaust gases actuates the valve **30** to cause the actuator **34** to reduce the available travel of the fuel rack **36**, so controlling the maximum fuel delivery that the level of smoke is reduced. In this way a continuous monitoring of the exhaust smoke density is performed accompanied by a continuous and automatic adjustment of the maximum fuel delivery quantity to maintain a reduced smoke density.

The carbon particles in the exhaust gas are positively charged. Both the exhaust pipe **11** and the insulated electrode assembly **12** constitute collector electrodes on which these charges will accumulate, and they can be polarised either way, or not at all, depending on circumstances. Thus if a high potential difference **19** is applied between the exhaust duct **11** and the insulated electrode **12** this will give greater sensitivity, due to the greater attraction of the respective charges, but will lead to insulation problems which can be avoided if a low biassing potential difference **19** or none at all is used.

The carbon particles in the exhaust gases are collected on the collector electrode assembly **12** by an impaction process, and give up their charge to the electrode assembly **12**. The negative ions in the gas stream do not readily penetrate and pass through the stagnant boundary layer on the collector electrode **12**.

It will be understood that in all combustion charged ions are formed, even where no smoke is observed. However in smokeless combustion the effect of the charged ions is small and can be neutralised in the amplifier of the measuring circuit.

If desired the electrical measuring circuit to which the electrode assembly is connected may be one employing a semi-conductor device, for example a field-effect transistor, instead of the triode valve **21**. The field-effect transistor has the advantage of greater sensitivity and is less microphonic under vibration.

FIGS. **5** and **6** show another form of collector electrode **40** which may be used in the apparatus of FIGS. **1** to **4** in place of the electrode assembly **12**. The collector **40** comprises an open-ended frusto-conical sheet metal electrode **41** which is supported by means of the U-shaped supporting straps **15** close to the mouth of the exhaust duct **11** with its smaller end directed inwardly. The smaller end of the electrode **41** is of the same diameter as the mouth of the exhaust duct **11** and is positioned close to the mouth of the duct but without making contact therewith, so that the whole of the exhaust emission from the duct passes through the interior of the electrode **41**. A collector arrangement in the form of a series of axially-spaced transverse grids **42** of metal gauze is fitted in the interior of the electrode **41**. Each gauze sheet **42** extends across the whole of the internal cross-section of the electrode **41** and is connected electrically to the electrode at its perphery. The grids are formed with multiple square holes each three thirty-seconds inch in size.

It will be understood that whilst in the embodiment of FIGS. **1** to **4** an electrohydraulic control circuit is interconnected between the output of the exhaust smoke measuring circuit and the fuel control of the engine, other forms of electrically-responsive interconnection, for example operation electromechanically or electropneumatically, could be employed instead.

What we claim as our invention and desire to secure by Letter Patent is:

1. Means for reducing exhaust smoke emission from an internal-combustion engine having a fuel control by which the quantity of fuel delivered to the engine for combustion is controlled, which means comprises a device for measuring the density of smoke in the gaseous exhaust discharged from the exhaust duct of the engine, the said device providing an output signal dependent upon the exhaust smoke density, said device including an electrode supported by an electrically-insulating mounting adapted to locate the electrode in the path of the exhaust gases delivered through the exhaust duct, and an electrical measuring circuit to whose input the electrode is connected and which produces an electrical output signal corresponding to the electrical potential developed on the electrode by the impaction therewith of charged carbon particles in the exhaust gas, and control means responsive to the said output signal and arranged to adjust the fuel control automatically in response to the output signal in such a way as to adjust the fuel delivery in inverse dependence upon the measurement of exhaust smoke density.

2. Apparatus as claimed in claim **1** in which the control means responsive to the output signal comprises an electrohydraulic control circuit having a hydraulically-actuated output member coupled to the fuel control.

3. An internal combustion engine having a movable fuel control member, and having an exhaust duct and an electrode supported by an electrically-insulating mounting in the path of exhaust gas delivered through the said exhaust gas duct, as electrical measuring circuit to whose input the electrode is connected and which produces an electrical output signal corresponding to the electrical potential developed on the electrode by the impaction therewith of charged carbon particles in the exhaust gas, said output signal constituting a measurement of smoke density in the said exhaust gas, and control means responsive to the said output signal and operatively associated with the fuel control member, said control means automatically adjusting the travel of the fuel control member in the direction of increased delivery and thereby regulating the maximum fuel delivery in inverse dependence on the said measurement of smoke density.

4. An internal combustion engine of the liquid-fuel-injection type having a fuel injection pump with a movable fuel delivery control member, and having an exhaust duct, and an electrode supported by an electrically-insulating mounting in the path of exhaust gas delivered through the said exhaust gas duct, an electrical measuring circuit to whose input the electrode is connected and which produces an electrical output signal corresponding to the electrical potential developed on the electrode by the impaction therewith of charged carbon particles in the exhaust gas, said output signal constituting a measurement of smoke density in the said exhaust gas, and control means responsive to the said output signal and operatively associated with the fuel control delivery member, said control means including an electrohydraulic control valve responsive to the output signal of the measuring circuit, and a hydraulic actuator controlled by said valve, the hydraulic actuator being mounted adjacent to the fuel injection pump so that its movable member constitutes a movable stop which limits the travel of the fuel control member in the direction of increased delivery in an adjustable manner, and thereby regulates the maximum fuel delivery in inverse dependence upon said measurement of smoke density.

5. A method of operating an internal combustion engine with reduction of exhaust smoke emission, which comprises obtaining a continuous measurement of smoke density in the exhaust gas discharged from the engine by positioning an electrode in the path of the exhaust gas emission from the engine and measuring the electrical potential developing in the electrode as a result of the impaction of charged carbon particles thereon, deriving from the said measurement a control signal dependent upon the said smoke density, and utilising the control signal to adjust the quantity of fuel delivered to the engine for combustion, the fuel delivery being automatically adjusted in inverse dependence upon the measurement of smoke density.

6. A method as claimed in claim **5** in which the said control signal supplied to the input of an electrohydraulic control circuit whose output is operatively associated with a fuel control of the engine.

7. A method as claimed in claim **6** in which the engine is of the liquid-fuel-injection type having a fuel injection pump with a movable delivery control member, and in which the electrohydraulic control circuit includes as its output member a hydraulic actuator whose movable member is utilised as an adjustable stop to limit the travel of the delivery control member in the direction of increased fuel delivery.

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