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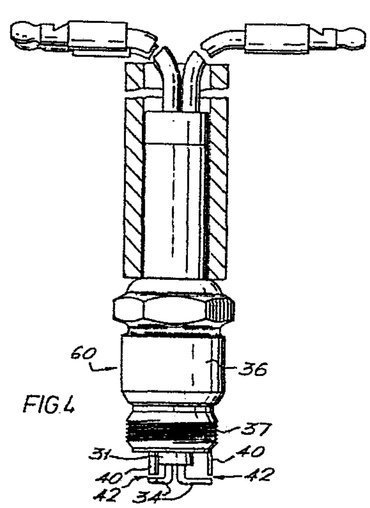
(54) **Spark plug for an internal combustion engine.**

(57) A spark plug (60, Fig. 4) for an internal combustion engine comprises a ceramic body (31) and a plurality (e.g. three) of spark electrodes (34) which receive high-tension electricity independently of each other via electrical conductors extending through the ceramic body. Each spark electrode (34) has a tip region which extends away from the plug axis in the vicinity of the end of the plug so as to define with a respective counter-electrode (40) of the plug a spark-gap (42) which is substantially parallel to the axis of the plug. Preferably the spark gaps (42) are substantially equiangularly spaced around the plug axis.

The spark plug of the invention enables an internal combustion engine to be operated with increased thermal efficiency compared to a conventional single-gap plug, and with an improved fuel economy which increases as the air-fuel ratio increases, whereby the engine may be operated on a fuel of reduced octane number (e.g. with low lead or lead-free gasoline) and/or with an increased compression ratio.

FIG.4



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Spark Plug for an Internal Combustion Engine

The present invention relates to a spark plug for an internal combustion engine, and to an ignition system and to an internal combustion engine comprising the spark plug.

The thermodynamic efficiency of a spark ignition internal combustion engine is dependent, inter alia, on the timing of the combustion and the rate at which it occurs. The best results are obtained when combustion is completed very close to the top dead centre position of the crank, but although rapid combustion is desirable, excessively fast combustion causing knocking, which can damage the engine, must be avoided.

Good combustion is favoured by a high degree of turbulence within the fuel-air charge prior to combustion. Turbulence is, however, dependent upon engine speed, and turbulence deteriorates at low speeds. At all speeds the power output from a given cylinder tends to fluctuate from cycle to cycle when the engine is operated under fixed conditions, and this fluctuation appears to be accentuated at lean fuel-air operating conditions. This effect, known as dispersion, is thought to depend on fluctuations in gas velocity in the vicinity of the spark plug and can reduce power output by as much as 10%.

It has now been discovered that the efficiency of an internal combustion engine can be influenced significantly by the design of the spark plug.

The present invention provides a spark plug for an internal combustion engine, the plug comprising a body having a central portion of electrically non-conductive material and a surrounding portion adapted for securing the plug relative to a spark plug hole of the engine, a plurality of spark electrodes at one axial end region of the plug intended to be disposed within a combustion chamber of the engine, a counter-electrode defining a spark gap with each spark electrode, and a respective electrical conductor for each spark electrode which conductor is disposed within the body and provides a respective electrically-conductive path through the body to the respective spark electrode from a respective electrical connection point or area at or near to the other axial end of the body for the application thereto of high-tension electricity, the electrical conductors being electrically insulated from each other within the body, wherein each spark electrode is offset from the central axis of the plug and has at least a projecting portion at or near to the end region of the body which extends away from the plug axis to a tip region of the spark electrode, and wherein the counter-electrode has an end part defining one side of a respective gap nearer to the said other axial end of the plug than the tip of the respective spark electrode defining the other side of the said spark gap so that the tip of each spark electrode defines with the counter-electrode a respective spark gap which is substantially parallel to the plug axis.

The spark plug of the invention enables multi-spark ignition from a plurality of high-tension sources to be effected in the or each cylinder of an engine from a single spark plug thereby at least partially improving the efficiency of operation of the engine.

The high-tension sources may be electrical conductors for conducting high-voltage electricity from a single originating source thereof or from a plurality of originating sources of high-voltage electricity whereby the sparks at each spark gap may appear either simultaneously together or separated in time. Moreover, the spark plug of the invention can be employed in place of a conventional spark plug having a single spark gap without the necessity of altering the cylinder head of the engine. The benefits of the new spark plug are therefore realisable on unmodified internal combustion engines.

Preferably, the spark plug comprises a discrete counter-electrode for each spark electrode.

The tip of the projecting portion of each spark electrode is preferably in a radial plane which is further from the said other axial end of the body than the radial plane of the said one axial end of the body.

Preferably, the or each counter-electrode defines one end of a respective spark gap in a radial plane which is between the radial plane of the tip of a corresponding spark electrode and the radial plane of the said one axial end of the body.

The spark plug of the invention is preferably devoid of any part which outwardly surrounds the spark gaps so that gases in the combustion chamber are substantially not physically inhibited or shielded from the sparks in the spark gaps by solid structures.

The plug may comprise three or more spark gaps defined between three or more spark electrodes and counter-electrodes.

The said surrounding part of the spark plug is preferably electrically conductive and may constitute at least part of, and/or may support, the counter-electrodes.

Preferably, the tip of each spark electrode is substantially flat or blunt or obtuse where it defines one end of a spark gap, so as to avoid or reduce erosion by the sparks passing across the spark gap 20.

Preferably, at least the tips of the spark electrodes are substantially equiangularly spaced around the axis of the plug so as to define spark gaps which are substantially equiangularly separated around the plug axis.

Preferably, the said surrounding portion of the plug does not extend as far away from the said other axial end of the body as the said one axial end of the said central portion, and preferably, the surrounding portion is externally screw-threaded for engagement with corresponding internal screw-threads of the spark plug hole of the engine.

This invention also provides an ignition system for an internal combustion engine comprising a spark plug as described above, and for each spark electrode of the spark plug, a respective source of high tension electricity.

The invention further provides an internal combustion engine comprising at least one cylinder having at least one spark plug as described above engaged with the cylinder, and for each electrode of the (or each) spark plug, a respective source of high-tension electricity. Any type of high-tension electricity source can be employed - e.g.an induction coil, or one based on piezo-electric effects or a solid state source.

The invention is now further described, by way of non-limitative, illustrative examples, and with reference to the accompanying diagrammatic drawings in which:

Fig. 1 shows a cross-sectional view through a spark plug of the invention and a perspective view of a high tension connector for conducting high tension electricity from a source thereof (not shown) to one of the spark electrodes;

Figure 2 is a side-elevation, partly in section, of a multi-gap test spark plug which is not in accordance with the invention;

Figure 3 is an underneath plan view of the plug of Fig.2;

Fig. 4 is a side elevation of a spark plug according to the invention; and

Fig. 5 is an underneath plan view of the plug of Fig.4.

In Fig. 1 of the diagrammatic drawings, the spark plug is generally indicated by 10 and comprises a body 11 in the form of a cylindrical rod of ceramic (or other suitable electrically-insulating material) in which are received three electrodes 12. In the illustrated cross-section, only one of the electrodes 12 is visible. The electrodes 12 extend within the body 11 parallel to the axis thereof and each electrode protrudes from one end of the body 11 which is intended to be within a cylinder of an internal combustion engine, and the protruding part is extended or bent radially outwardly into a spark electrode 13. The opposite end 14 of the electrode 12 protrudes from the other end of the body 11 and is also radially outwardly formed or bent. The end 14 is received in a rigid cap 15 of suitable high-melting, electrically-insulating material such as a suitable plastics material which serves to maintain in position the ends 14 of the electrodes 12 and thereby maintain the electrodes 12 in a substantially fixed disposition relative to the body 11.

The body is substantially fixedly received in a multi-part member 16 which has one part 17 provided with an external screw-thread 18 adjacent to the spark electrode for engagement of the spark plug 10 in the threaded bore (not shown) provided for the purpose in the cylinder head (not shown) of an internal combustion engine. On the part 17 and facing each spark electrode 13 is a respective counter-electrode 19 (of which only one can be seen in the drawing) which is of electrically conductive material and which defines a respective spark gap 20 with the respective spark electrode 13. The spark gas 20 is parallel to the longitudinal axis of the plug and radially off-set therefrom so as to be as exposed as possible on all sides to gas around the gap 20.

The multi-part member 16 is secured to the body 11 by any suitable fitting 21 which provides a substantially fluid-tight sealing relationship between the multi-part member 16 and the body 11, e.g. by compression between said one part 17 and another part 22 which is engaged therewith by screw threads. Other securing and sealing arrangements known in the art may be employed instead.

Each electrode 12 must be connectible independently of the electrodes to a source of high tension electricity. One way in which such independent connection may be achieved is shown in Figure 1 of the drawings by way of example. The body 11 of the spark plug has a radial bore 23 for each electrode for receiving radially an electrical connector in electrical contact with the respective electrode 12. A suitable electrical connector which can be radially received in the bore 23 in electrical contact with the electrode 12 is a radial projection 24 mounted on the inner face of a springy arcuate clip 25 of electrically conductive material at one end of a cable 26. The cable 26 is connected at its other end (not shown) to a respective source of high-tension electricity. Since, for the arrangement illustrated, there will be three radial bores 23 (one for each electrode) to receive respective radial projections 24 on three springy clips 25, the bores 23 will preferably be sufficiently separated along the axial length of the spark plug's body 11 to permit the clips 25 to be attached to the spark plug 10 with at least sufficient separation that high tension electricity passes to the corresponding electrode 12 without discharging to an adjacent clip and/or another electrode 12.

When the spark plug 10 is connected to the sources of high tension electricity, sparks may be produced across the spark gaps either substantially simultaneously or in a "rippled" or non-simultaneous fashion, depending upon the result desired in the cylinder of the internal combustion engine in which the sparks are to be employed. The spark plug of the invention enables combustion to be initiated and/or promoted at a plurality of points, thereby tending to improve the combustion of the fuel charge in the cylinder.

Reference is now made to Figures 2 and 3 of the diagrammatic drawings in which the spark plug 30 is seen to comprise a central ceramic insulator 31 in which are received three electrical conductors (not visible) which are connected near the top end (as shown) of the plug 30 to respective insulated cables 32 each having a push-fit electrical connector 33 at its free end for connection to a source of high-tension electricity. The electrical conductors are each connected to a respective spark electrode 34 which protrudes from the bottom end (as shown) of the central insulator 32 initially parallel to the axis of the plug and after a short distance thereafter, is turned substantially radially outwardly away from the axis of the plug 30.

The central ceramic insulator 31 is surrounded at its lower end, and sealed to, a mild steel sleeve member 36, the bottom end 37 of which has external screw threads for engagement with internal screw threads of a spark-plug hole of an internal combustion engine. An upper part 38 of the sleeve member 36 is formed with hexagonal flats around its circumference for engagement with a spanner or wrench. The sleeve member 36 may be formed from several parts. Three counter-electrodes 40 extend downwardly from the bottom end of the sleeve member 36 so as to define spark gaps 42 with the free end-faces of the spark electrodes 34. The three spark gaps 42 of the plug 30 are substantially radial with respect to the axis of the plug. It will be seen that the faces of the spark electrodes 34 and the opposed counter-electrodes at the ends of the spark gaps are flat, to reduce erosion during use. For comparative tests (described below) performed with a gasoline engine mounted on a test bed, the central insulator 31 has a ceramic sleeve immediately above the sleeve member 36 to reduce heat losses from the plug.

Reference is now made to Figures 4 and 5 which show views of a spark plug 60 which is identical to the spark plug of Figs 2 and 3 except in the arrangement of the electrodes to form the spark gaps. Like parts in Figures 2 to 5 are given the same reference numerals. As will be seen from Figs. 4 and 5, the spark electrodes protrude from the bottom (as shown) end of the plug 60 initially substantially parallel to the plug axis but are thereafter outwardly turned so as to extend beneath the counter-electrodes 40 (i.e. in a direction substantially perpendicular to the plug axis) to define with the counter-electrodes 40 respective spark-gaps 42 which are substantially parallel to the plug axis. The protrusion (known as the "reach") of the counter-electrodes beyond the end of the body of the plug 60 is approximately the same in the embodiment of Figs 4 and 5 as in the embodiment of Figs. 2 and 3 and is also approximately the same as the reach in a commercially-available single spark gap spark plug of the conventional type. It will be seen in Figs. 4 and 5 that the spark electrodes 42 present a substantially flat surface towards the counter-electrodes 40.

The spark plugs of Figs 2 and 4 were tested in a standard four cylinder 1593 cc gasoline engine of the type used in Ford Cortina ("Ford" is a registered trademark) car in the following manner:

The engine was installed on test-bed and modified so that one cylinder had its intake and exhaust systems segregated from the other three so that the fuel-air mixture strength, temperature, humidity, homogeneity, inter alia, could be precisely controlled to the one segregated cylinder while the engine was operated using all four cylinders. In addition the segregated cylinder was provided with a piezo-electric transducer flush-mounted in the cylinder head, and by the use of suitable electronic equipment and software programmes, a large number of pressure cycles from the segregated cylinder were captured and analysed by an on-line computer system which supplied the information to a 'floppy disc' recorder for off-line data analysis. A software programme was employed to calculate the indicated thermal efficiency of an individual cycle or the mean thermal efficiency of a population of cycles. The testing procedure had been evaluated thoroughly beforehand to confirm that it would give very precise test results.

All the tests were carried out with fully opened throttle at 3000 RPM at a fixed spark advance (31° BTDC) and precisely controlled test-bed engine conditions. Tests on the triple spark plugs of Figs. 2 and 4 were preceded and succeeded by tests with a conventional single electrode spark plug to ensure that no fall-off in engine performance had occurred to influence the test results.

The results summarised in Table 1 are for the configuration of the spark gaps at right angles to the axis of the plug (as in Figures 2 and 3 of the drawings). Surprisingly, these results conclusively demonstrate a reduction in fuel economy using the triple electrode spark plug of Fig 2 in comparison to performance when using the conventional single spark plug. The results given in Table 2 are for the spark plug of Figs. 4 and 5 of the drawings and surprisingly, it is conclusively demonstrated that there are positive improvements in fuel economy which progressively increase as the engine is run under leaner conditions (i.e. smaller equivalence ratios, wherein the equivalence ratio is defined as the stoichiometric air to fuel ratio for complete combustion of the fuel divided by the actual weight ratio of air to fuel used in the tests). It should be noted that the test results in Table 1 cannot be compared in absolute terms with those of Table 2 since they were obtained under slightly different running conditions. All the results within each Table are, however, comparable on an absolute level.

TABLE 1

Comparison of Thermal Efficiencies and Fuel Economy (.F.E) Benefits

of Triple Gap Spark Plug of Figures 2 and 3 versus Conventional Single Spark Plug

(wide-open throttle)

Ignition Mode	Equivalence Ratio	% Thermal Efficiency	% Improvement in F.E. FOR TRIPLE SPARK GAP OVER SINGLE
SINGLE SPARK GAP	0.84	32.75	-
TRIPLE SPARK GAP	0.84	32.0	-2.3
SINGLE SPARK GAP	0.81	31.75	
TRIPLE SPARK GAP	0.81	30.75	-3.2

TABLE 2

Comparison of Thermal Efficiencies and Fuel Economy (F.E.) Benefits of Triple Gap Spark Plug of Figs. 4 and 5 versus Conventional Single Spark Plug

(wide open throttle)

Ignition Mode	Equivalence Ratio	% Thermal Efficiency	% Improvements in F.E. FOR TRIPLE SPARK GAP OVER SINGLE GAP
SINGLE SPARK GAP	0.94	29.5	-
TRIPLE " "	0.94	30.0	+1.7
SINGLE " "	0.90	30.2	-
TRIPLE " "	0.90	30.8	+2.0
SINGLE " "	0.78	29.25	-
TRIPLE " "	0.78	32.4	+10.8
SINGLE " "	0.74	28.0	
TRIPLE " "	0.74	31.0	+10.7
SINGLE " "	0.70	23.5	
TRIPLE " "	0.70	28.0	+19.2

The test results dramatically illustrate that a spark plug providing a plurality of sparks for ignition of the fuel-air charge in the cylinders of a gasoline engine reduces engine efficiency (in relation to the efficiency for a conventional single spark-gap plug) when the sparks traverse gaps which are radial with respect to the plug axis at the end region of the plug, and that the reduction in engine efficiency is increased as the engine is run with a fuel-air mixture which is leaner (i.e. containing less fuel). The thermal efficiency of the engine is similarly impaired. However, a spark plug which provides a plurality of ignition sparks which are substantially parallel to the plug axis at the end region of the plug improves both the thermal efficiency and fuel economy of the engine compared to a conventional single spark-gap plug, and the thermal efficiency continues to be higher for the multi-gap spark plug than a conventional single-gap plug as the fuel-air mixture is weakened, and moreover, the fuel economy becomes progressively greater as the fuel-air mixture is weakened.

The improved engine performance demonstrated using the spark plug of the invention may be further improved by arranging for the spark gaps to be slightly displaced relative to each other in the axial sense, and still further improvements can be realised by initiating the sparks at the gaps at slightly different times during each cycle of the engine.

The improvements in engine efficiency and fuel economy are of particular interest and importance at the present time in view of the present need to economise on the use of fuels for internal combustion engines, and there are a number of ways in which the improvements can be exploited, of which the following are of great significance:

(1) an existing engine or engine design can be operated with a weaker fuel-air mixture without any detriment, or any significant detriment, to its power output (e.g. % thermal efficiency), thereby economizing on the use of fuel.

(2) with a weakened fuel-air mixture, the octane number requirement of the fuel can be reduced. Many fuels include components which are added to the fuel to raise the octane number, and such components may be partially or completely eliminated. The usual octane-boosting additives are organo-metal compounds (usually organo-lead compounds) and it is believed that the reduced emissions of used organo-metal compounds, and additives (such as scavengers) used therewith in automotive exhaust gas would be welcomed by those who consider that such emissions might pose hazards to health and well-being. Fuels often contain organic compound octane-boosting components which add to the cost of the fuel either during the refining stage or thereafter when additives are incorporated in the fuels. A reduction in the need for such organic compound octane-boosting components would contribute to a reduction in the cost of the fuel.

(3) At a given power output, the fact that the engine can be run with a leaner fuel-air mixture using the spark plug of the invention than with a conventional spark plug provides the additional benefit that at part-throttle operating conditions, the engine's pumping losses (i.e. the work lost in raising the pressure of gas/vapour from the engine intake manifold pressure to the exhaust manifold pressure) are reduced thereby further improving the fuel economy of the engine. Since most operation of a gasoline engine used in an automobile is at part-load with the engine partially throttled, the use of the spark plug of the invention with lean fuel-air mixtures (obtained by appropriate adjustment of the carburettor) is very significant in terms of improved fuel consumption.

(4) For new designs of engine, wherein the compression ratio which influences thermodynamic efficiency but which is limited in practice (inter alia) by the increasing octane requirement of engines of increased compression ratio, the spark plugs of the invention will enable higher compression ratio engines to be manufactured without resorting to modifications in engine design which while desirable, add to the complication and cost of the engine.

Of course, the foregoing modes of exploitation of the improvements may be exploited in any combination in addition.

It is to be understood with reference to Figs. 2 to 5 that the spark plugs illustrated are designed merely for testing purposes and that spark plugs according to the invention would preferably have anti-tracking ribbed ceramic insulators 31 without the surrounding heat-insulating sleeve. Moreover, the connection of the high tension leads to the plug terminals 33 would preferably be via a single cap having the requisite number of terminals at the top of the plug. The engagement would preferably be by means of 'push-fit' connectors, and the single cap may have male-type connectors which are adapted to be received and engaged by female sockets in the top of the plug.

Claims

1. A spark plug for an internal combustion engine, the plug (10) comprising a body having a central portion (11) of electrically non-conductive material and a surrounding portion (16, 17) around at least part of the central portion (11), the surrounding portion being adapted (18) for securing the plug (10) relative to a spark plug hole of the engine, a plurality of spark electrodes (13) at one axial end region of the plug intended to be disposed within a combustion chamber of the engine, a counter-electrode (19) defining a spark gap (20) with each spark electrode (13), and a respective electrical conductor (12) for each spark electrode (13) which conductor is disposed within the body and provides a respective electrically-conductive path through the body to the respective spark electrode (13) from a respective electrical connection point or area (23) at or near to the other axial end of the body for the application thereto of high-tension electricity, the electrical conductors (12) being electrically insulated from each other within the body, characterized in that each spark electrode (13) is offset from the central axis of the plug (10) and has at least a projecting portion (13) at or near to the end region of the body which extends away from the plug axis to a tip region of the spark electrode (13), and in that the counter-electrode (19) has an end part defining one side of a respective gap (20) nearer to the said other axial end of the plug than the tip of the respective spark electrode (13) defining the other side of the said spark gap (20) so that the tip of each spark electrode (13) defines with the counter-electrode (19) a respective spark gap (20) which is substantially parallel to the plug axis.

2. A spark plug as in claim 1 comprising a discrete counter-electrode (19) for each spark electrode (13).

3. A spark plug as in claim 1 or claim 2 in which the tip of the projecting portion of each spark electrode (13) is in a radial plane which is further from the said other axial end of the body than the radial plane of the said one axial end of the body.

4. A spark plug as in claim 3 in which the or each counter-electrode (19) defines one end of a respective spark gap (20) in a radial plane which is between the radial plane of the tip of a corresponding spark electrode (13) and the radial plane of the said one axial end of the body.

5. A spark plug as in any one of claims 1 to 4 which is devoid of any part which outwardly surrounds the spark gaps (20).

6. A spark plug as in any one of claims 1 to 5 comprising three or more spark gaps (20) defined between three or more spark electrodes (13) and counter-electrodes (19).

7. A spark plug as in any one of claims 1 to 6 in which the said surrounding part (16, 17) is electrically conductive and constitutes at least part of, and/or supports, the counter-electrodes (19).

8. A spark plug as in any one of claims 1 to 7 in which the tip of each spark electrode (13) is substantially flat or blunt or obtuse where it defines one end of a spark gap (20).

9. A spark plug as in any one of claims 1 to 8 in which at least the tips of the spark electrodes (13) are substantially equiangularly spaced around the axis of the plug so as to define spark gaps which are substantially equiangularly separated around the plug axis.

10. A spark plug as in any one of claims 1 to 9 in which the said surrounding portion (16, 17) does not extend as far away from the said other axial end of the body as the said one axial end of the said central portion (11), and preferably in which the surrounding portion is externally screw-threaded (18) for engagement with corresponding screw-threads of the spark plug hole of the engine.

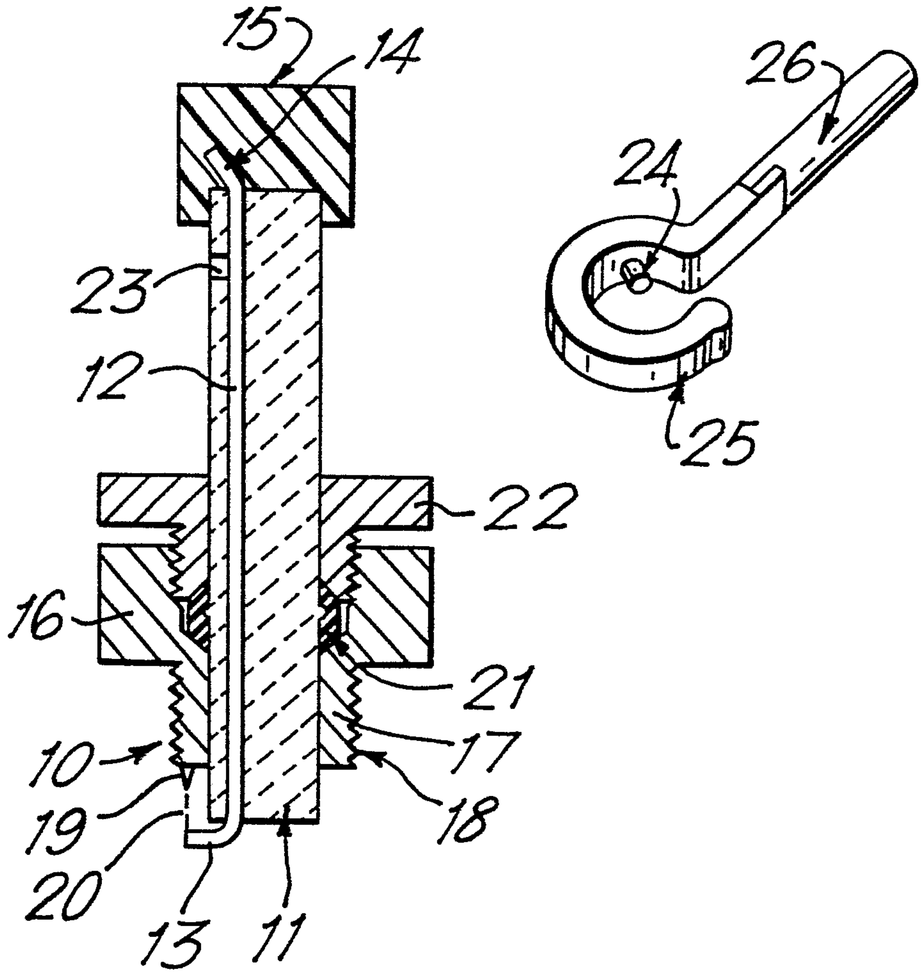

FIG.1.

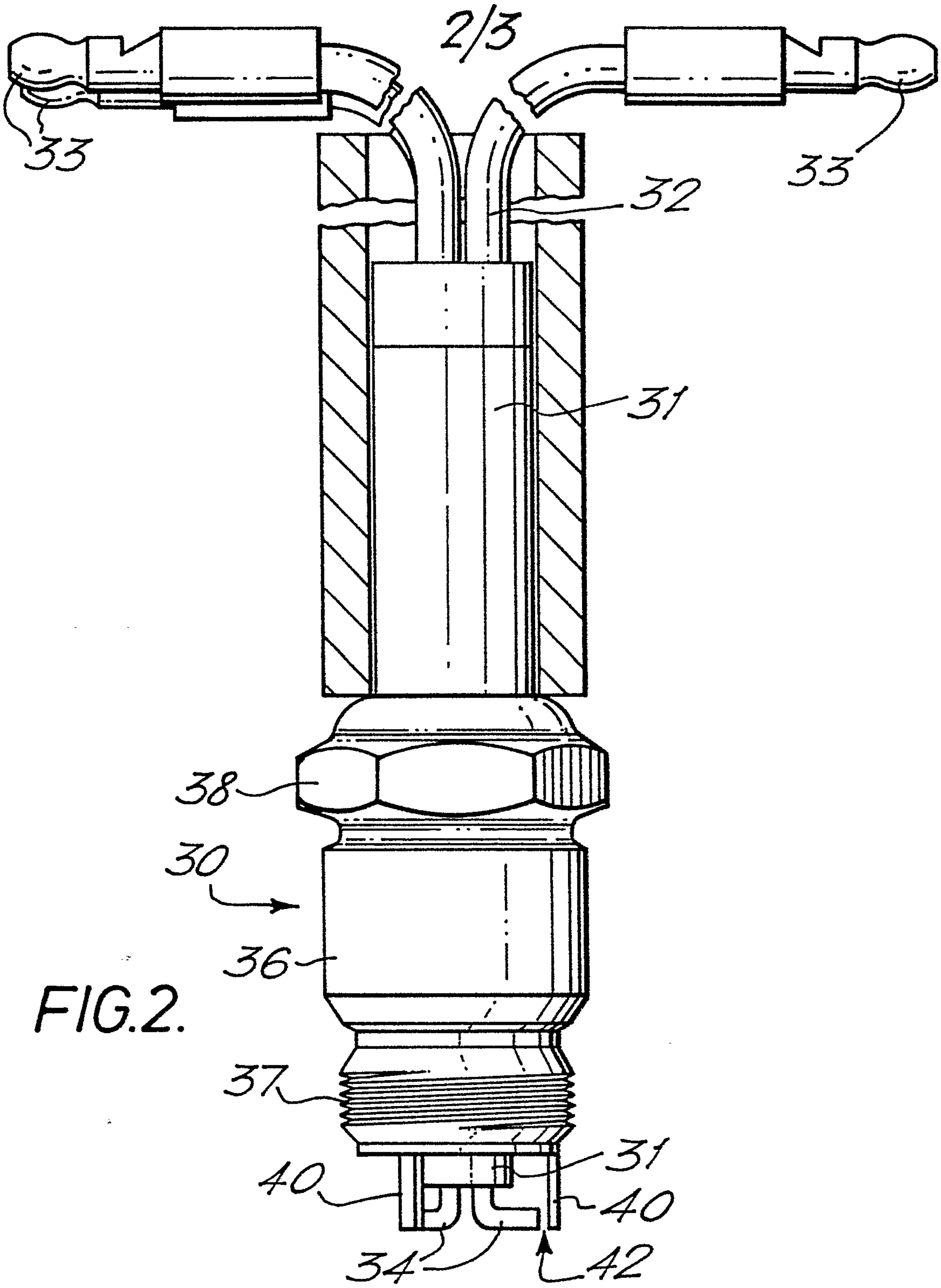

FIG.2.

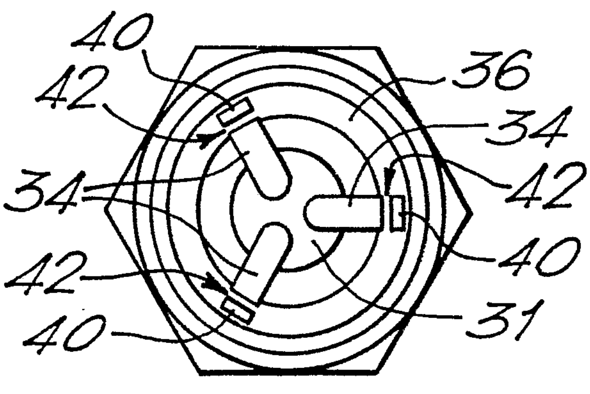

FIG.3.

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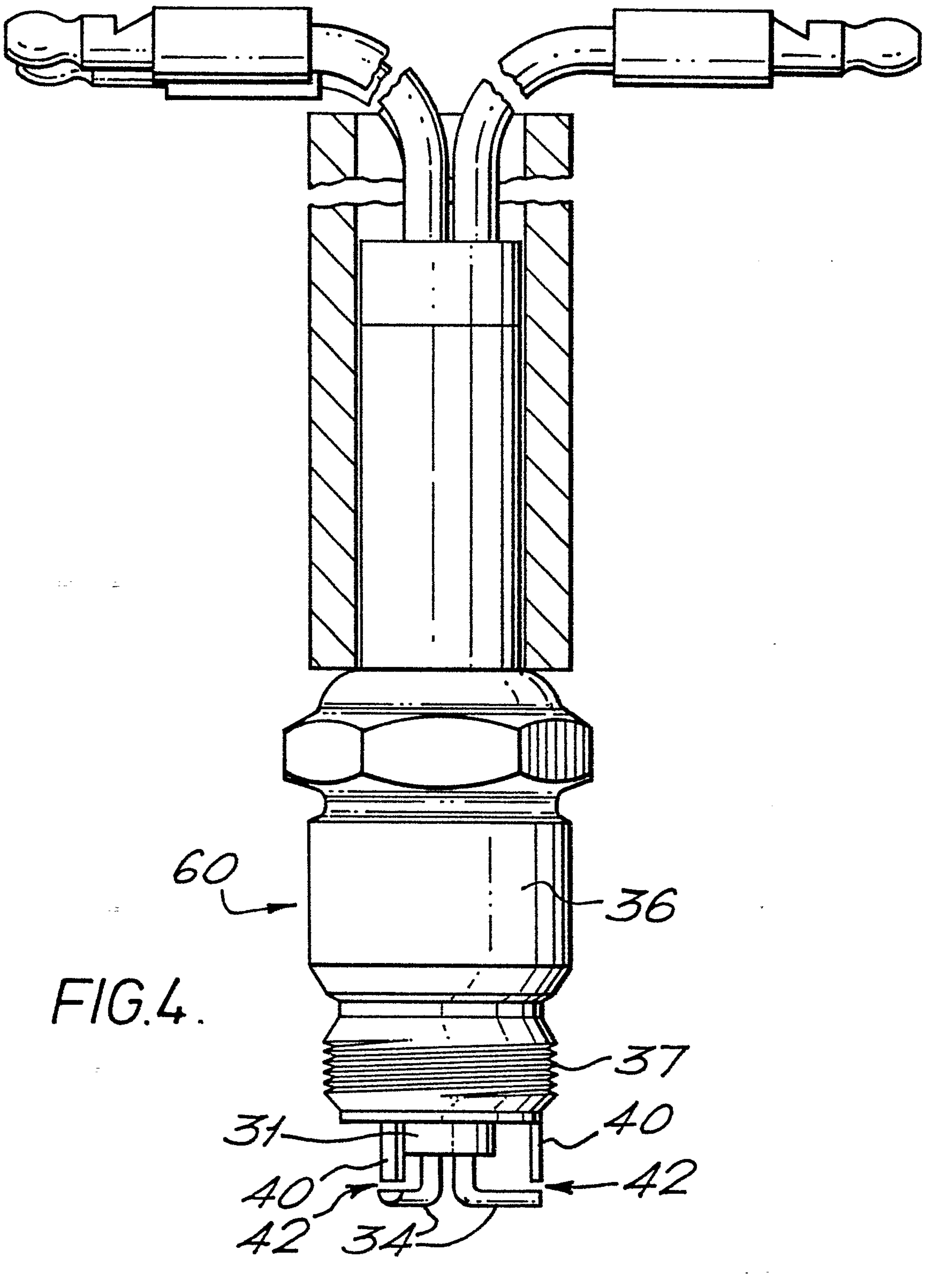

FIG.4.

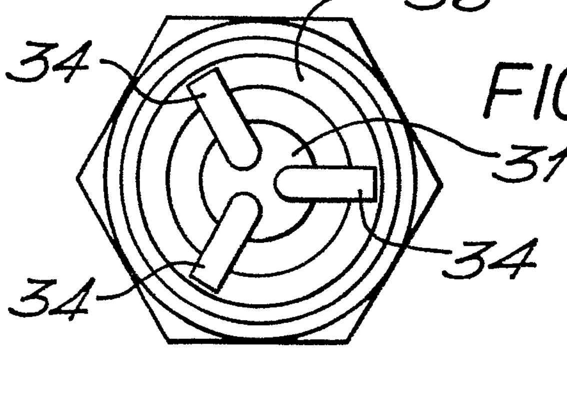

FIG.5.

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EUROPEAN SEARCH REPORT

0089429
Application number

EP 82 30 1507

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. ³)
Y	FR-A- 519 077 (MEI) * Page 1, lines 25-31, 45-60; figure 3 *	1,3,5, 7,9	H 01 T 13/46 H 01 T 13/22
Y	FR-A-1 039 839 (CITROEN) * Page 1, right-hand column, lines 21-30; figure 2 *	1,2,4-7,9,10	
A	US-A-1 335 797 (ROHDE) * Page 1, lines 100-106; figure 2 *	1-3,5, 7-10	
A	US-A-3 974 412 (PRATT)		TECHNICAL FIELDS SEARCHED (Int. Cl. ³)
A	DE-C- 595 340 (LANGER)		H 01 T
A	FR-A- 459 263 (DE MEY)		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	25-11-1982	BIJN E.A.

CATEGORY OF CITED DOCUMENTS

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