(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 097 211**
A2

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: **82306191.6**

(22) Date of filing: **22.11.82**

(51) Int. Cl.³: **F 02 D 5/02**
F 02 D 35/02

(30) Priority: **21.06.82 GB 8217928**

(43) Date of publication of application:
04.01.84 Bulletin 84/1

(84) Designated Contracting States:
AT DE FR IT NL SE

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(54) **Stroboscopic engine fuel-injection timing.**

(57) Fuel injection is detected by listening for pulses of sound at or near 40 KHz from the region of the fuel injection and used to produce a first series of pulses representing the instants of fuel injection. A second series of pulses is derived from the first series and used to control a strobe lamp flashing on a rotating timing marker of the engine. The timing of the second series of pulses is adjusted until the strobe lamp flashes at the instants that the timing marker passes a stationary reference marker. The timing relationship between the first and second series of pulses then indicates the timing of the fuel injection.

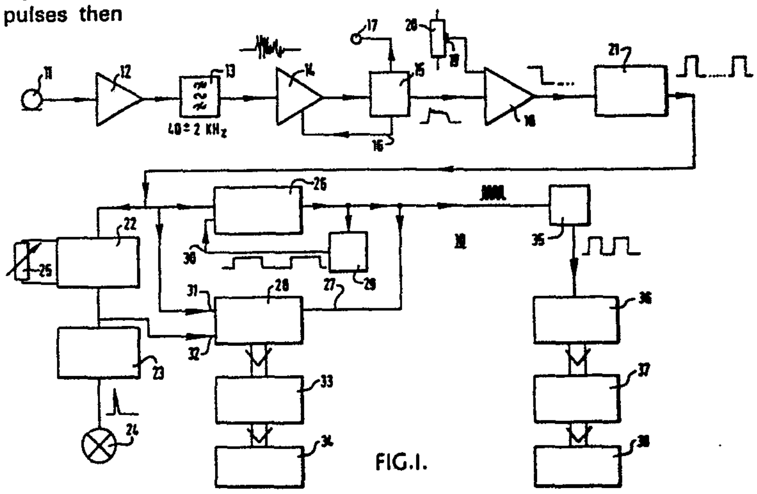

FIG.1.

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"STROBOSCOPIC ENGINE FUEL-INJECTION TIMING"

This invention relates to a method of and apparatus for determining the timing of fuel-injection by a fuel-injector of a fuel-injected internal combustion engine provided with a timing marker on a rotating fly wheel or other rotating part of the engine by means of a strobe lamp, that is to say, a lamp which is adapted to produce repeated flashes of light at precisely timed instants, hereinafter referred to as "stroboscopic engine fuel-injection timing".

A fuel-injected internal combustion engine is commonly provided with a timing marker on a rotating flywheel of the engine and with a stationary reference marker positioned closely adjacent the rotational path of the timing marker, so that the timing marker passes the reference marker at some specific instant during the engine cycle, for example, the so-called "top-dead-centre" ("TDC") position - when the piston or one of the pistons of the engine is at the "highest" position, that is, the position of maximum compression - or for example a fuel-injection position, being a position of the piston where it is desired for fuel-injection to occur at some specified speed of the engine, somewhat in advance of the TDC position, that is to say, before the piston reaches the TDC position. The relationship of the fuel-injection position to the TDC position is often expressed in terms of the angle, in degrees, through which the crankshaft rotates from the fuel-injection position to the TDC position.

It is known to use a strobe lamp for timing ignition of a spark-ignited (that is, electrical spark-ignited) internal combustion engine, obtaining a signal for the strobe lamp from a spark plug lead of the engine. Such a signal is of no use for timing fuel injection, nor is such a signal even available in a compression-ignition fuel-injected internal combustion engine, that is, a diesel engine.

It is known, or has been proposed, to detect lift of a needle of a fuel-injector of an internal combustion engine, by having the needle specially adapted to operate an electrical sensor upon being lifted, but a disadvantage of this is the requirement for the needle to be specially adapted.

It is also known, or has been proposed, to detect lift of a needle of a fuel-injector of an internal combustion engine, by using an acousto-electrical transducer or microphone to listen for an impact of the needle against a stop limiting the lift of the needle. However, a disadvantage is that the needle does not always impact against the stop, and the noise of the impact (if it occurs) is difficult to distinguish from other noises of the engine.

Furthermore, both above-mentioned ways of detecting lift of a needle provide no way of checking that the lift of the needle results in the actual injection of fuel.

It is also known, or has been proposed, to detect fuel-injection of an internal combustion engine by using a piezo-electric transducer to detect minute expansions and contractions of a fuel-line of the fuel injector of the engine due to pressure pulsations in the fuel in the fuel-line. However, there may be considerable error, due to the differences in timing between the pressure pulsations and the actual injection of fuel.

The present invention is based upon a discovery that an acousto-electric transducer, external to the engine, in combination with an electrical amplifier circuit, may be reliably used to detect actual injection of fuel into a fuel-injected internal combustion engine, provided that the transducer is arranged to detect ultrasonic frequency sound waves emanating from the region of the injection of the fuel into the engine, even though the transducer is external to the engine, and provided that the combination of the transducer and the amplifier circuit is tuned to a particular ultrasonic frequency which is substantially the same frequency regardless of the engine.

According to one aspect of the present invention there is provided a method of determining the timing of fuel-injection by a fuel-injector of a fuel-injected internal combustion engine provided with a timing marker on a rotating part of the engine, comprising:- detecting the instants of fuel-injection; producing a first series of electrical pulses representing said instants of fuel-injection; deriving a second series of electrical pulses from said first series of pulses; controlling a strobe lamp by means of said second series of pulses; illuminating the said rotating part of the engine by means of the strobe lamp; adjusting the timing of said second series of pulses relative to said first series of pulses as necessary, so that each flash of the lamp occurs as the timing marker passes a reference position; and determining the timing relationship between said first and second series of pulses; characterised in that the detection of the instants of fuel injection is achieved by applying an acousto-electric transducer in combination with an electrical amplifier circuit to the engine, externally thereof, and detecting ultrasonic frequency sound waves emanating from the region of the injection of the fuel into the engine; the combination of the transducer and the electrical amplifier circuit being turned to an ultrasonic frequency at or near to forty kilohertz.

According to another aspect of the present invention there is provided apparatus for determining the timing of fuel-injection by a fuel-injector of a fuel-injected internal combustion engine provided with a timing marker on a rotating part of the engine, the apparatus comprising a strobe lamp for illumination of the said rotating part of the engine, and means:- for detecting the instants of fuel injection; for producing a first series of electrical pulses representing said instants of fuel injection; for deriving a second series of electrical pulses from said first series of pulses; for controlling the strobe lamp by means of said second series of pulses; for adjusting the timing of said second series of pulses relative to said first series of pulses as necessary, so that each flash of the lamp can be made to occur as the timing marker passes a reference position; and for determining the timing relationship between said first and second series of pulses; characterised in that the means for detection of the instants of fuel injection comprises an acoustic-electric transducer in combination with an electrical amplifier circuit, adapted to be applied to the engine externally thereof for detection of ultrasonic frequency sound waves emanating from the region of the injection of the fuel into the engine; the combination of the transducer and the electrical amplifier circuit being tuned to an ultrasonic frequency at or near to forty kilohertz.

The above two statements about "the combination of the transducer and the electrical amplifier circuit being tuned to an ultrasonic frequency at or near to forty kilohertz" are meant to be broadly construed as to just how the aforesaid combination is "tuned", in the sense that it is the presence of, or a substantial increase in, sound at an ultrasonic frequency at or near to forty kilohertz (40 KHz) that signals the injection of the fuel, so that the aforesaid combination of transducer and amplifier circuit is required to process signals preferentially at this frequency.

The invention will be described by way of example with reference to the accompanying drawings, wherein:-

Fig. 1 is a block schematic diagram of preferred apparatus embodying the invention;

Fig. 2 illustrates one possible form of the ultrasonic (frequency) microphone of Fig. 1;

Fig. 3 illustrates another possible form of the microphone of Fig. 1; and

Fig. 4 illustrates a typical oscilloscope trace of the output of the microphone of Fig. 3.

Referring to the drawings and particularly Fig. 1, the preferred apparatus 10 embodying the invention comprises an acousto-electric transducer 11, in the form of an ultrasonic frequency microphone, connected to the input of an amplifier 12, the output of which is connected to a bandpass filter 13 having a centre frequency of approximately forty KHz and a bandwidth of ± two KHz, although the centre frequency and the bandwith need not necessarily be exactly these values. The output of the filter 13 is connected to the input of a second amplifier 14, the output of which is connected to the input of a demodulator 15. An automatic gain control ("AGC") feedback loop 16 is provided from the demodulator 15 to the amplifier 14. One output 17 of the demodulator 15 is provided for connection to an oscilloscope (not shown). A second output from demodulator 15 forms one input to a comparator 18. A second input to comparator 18 is from a manually adjustable tapping 19 of a potentiometer 20, such that the output from comparator 18 switches between two levels according to whether the output from demodulator 15 is below or above the output on tapping 19 of potentiometer 20. The output from comparator 18 is supplied to a pulse-shaping and retrigger-inhibiting circuit 21.

The part of the apparatus 10 thus far described, from transducer 11 to pulse-shaping and retrigger-inhibiting circuit 21, provides a first series of electrical pulses representing instants of fuel-injection. More particularly, the transducer 11 picks up ultrasonic frequency sound signals from the region of the injection of the fuel into the engine, including in particular sound signals having a frequency at or near to 40 KHz, which are amplified by amplifier 12 and supplied to filter 13, which passes substantially only signals having a frequency of 40 ± 2 KHz to the second amplifier 14 and demodulator 15 with the AGC feedback loop 16. So long as no fuel is being injected, the output from demodulator 15 to comparator 18 is low relative to the level at tapping 19 of potentiometer 20, so that comparator 18 delivers an output at a corresponding level to the pulse-shaping and retrigger-inhibiting circuit 21. When fuel is being injected into the engine, producing sound at a frequency at or near to 40 KHz, the output from demodulator 15 rises above the level at tapping 19 of potentiometer 20, so that the output from comparator 18 switches to the other of its two levels for the duration of the fuel injection. Hence, for each pulse delivered by comparator 18 to the pulse-shaping and retrigger-inhibiting circuit 21, the leading and trailing edges of the pulse correspond substantially to commencement and termination of the injection of the fuel. Depending upon the design of the pulse-shaping and retrigger-inhibiting circuit 21, the output pulses therefrom may either be pulses the duration of which corresponds substantially to the duration of the pulses from the comparator 18, or may be fixed duration pulses triggered by the leading edges of the pulses from the comparator 18.

The pulses from pulse-shaping and retrigger-inhibiting circuit 21, being the first series of pulses, are delivered to a circuit 22 which is adapted to derive a second series of pulses therefrom and supply this second series of pulses to a trigger and high tension voltage generator circuit 23 for controlling a strobe lamp 24. The timing relationship between the second series of pulses and the first series of pulses is selectively adjustable by manual adjustment means 25 forming part of circuit 22. By this means, the second series of pulses may either be coincident in time with the first series of pulses or delayed relative to the first series of pulses with an adjustable delay, depending on whether the strobe lamp is to flash at the same time as pulse-shaping and retrigger-inhibiting circuit 21 delivers a pulse or whether the flash of the strobe lamp 24 is to be delayed.

The output from pulse-shaping and retrigger-inhibiting circuit 21 is also supplied to a phase-locked loop circuit 26, which generates clock pulses for delivery at input 27 to a counter 28 by virtue of the output of the phase-locked loop circuit 26 being supplied to a "divide-by-7200" circuit 29 in a feedback loop 30 to the phase-locked loop circuit 26, so that each single pulse from the pulse-shaping and retrigger-inhibiting circuit 21 produces a whole series of clock pulses at input 27 to counter 28. The counter 28 starts counting upon detecting the leading edge of a pulse from the pulse-shaping and retrigger-inhibiting circuit 21 at input 31, and stops counting upon detecting the leading edge of the second series pulse from circuit 22 at input 32, so that the count registered by counter 28 for each pulse from pulse-shaping and retrigger-inhibiting circuit 21 is a measure of the delay, if any, between the first and second series of pulses at the input and output respectively of circuit 22, depending on the setting of adjustment means 25. The output from counter 28 controls a display drive 33 which controls a display device 34 for displaying the angle of advance directly of fuel injection relative to top-dead-centre.

In use, the transducer 11 is applied to the fuel-injector (not shown) of a fuel-injected internal combustion engine (not shown) provided with a timing marker (not shown) on a rotating part (not shown) of the engine. The strobe lamp 24 is used to illuminate the said rotating part of the engine, and adjustment means 25 is adjusted until the strobe lamp is flashing on the rotating part of the engine just as the timing marker passes a reference position, usually indicated by a stationary reference marker of the engine. That adjustment (of adjustment means 25) having been made, the timing of the second series of pulses corresponds to the reference position of the engine crankshaft (which may be either the TDC position or a desired fuel-injection position) whilst the first series of pulses (from circuit 21) correspond to the timing of fuel injection. If the reference marker of the invention corresponds to top-dead-centre, there should be a predetermined angle of advance of the fuel injection relative to top-dead-centre. On some engines, top-dead-centre is not marked, but instead the reference marker shows the desired position of the timing marker at the instant of fuel-injection. In this case, if the fuel injection timing is correct, the second series of pulses will be coincident in time with the first series of pulses, with zero delay between them.

The output pulses from phase-locked loop circuit 26 are also supplied to a divider 35 and hence to a frequency counter 36 with a one-second timebase, the output of which controls a speed display drive 37 driving an engine speed display device 38.

Referring to Figure 2, the ultrasonic frequency microphone transducer 11 may be housed in a transducer housing 39 attached to one jaw 40 of a transducer clamp assembly 41. The jaw 40 and a second jaw 42 are respectively integral with two handles 43 and 44 which are pivoted at 45 and are biased apart (so that jaws 40 and 42 are biased together) by a spring 46. A foam rubber mounting 47 is used to seat the transducer 11 in the transducer housing 39. Inside the jaw 40 is a foam rubber seal 48 with an aperture 49 for ultrasonic frequency sound waves from a region between the two jaws 40, 42 to reach the transducer 11. Figure 2 also shows part of a lead 50 for connecting the transducer 11 to amplifier 12 of Fig. 1.

By means of the assembly 41, the jaws 40, 42 can be clamped about a fuel-delivery pipe (not shown) of the fuel-injector with the foam rubber seal 48 pressed against the fuel-delivery pipe by the force of the spring 46, so that the transducer 11 picks up the forty KHz frequency sound waves produced by the injection of the fuel. Alternatively the jaws 40, 42 may be clamped to the body of the fuel-injector, not shown.

Figure 3 shows an alternative arrangement in which the transducer 11 takes the form of a non-contact directional microphone 51 aimed at a fuel-delivery nozzle 52 of the fuel-injector (not otherwise shown) to pick up the forty KHz frequency sound waves produced by the injection of the fuel at 53 into the combustion chamber 54 of a cylinder of the engine 55. Other items shown in Fig. 3 are an air inlet valve 56 and piston 57 with four piston rings 58 and gudgeon pin 59.

Fig. 4 illustrates the oscilloscope trace (obtained at output 17 in Fig. 1) from using microphone 51 as the transducer 11, showing the timing advance of the fuel injection relative to the TDC position.

Reference is directed to our British Patent Application No. 81 38392 and European Patent Application No. 81 305960.7, both entitled "Improvements in or relating to methods of and apparatuses for determining opening of injectors".

Claims:-

1. A method of determining the timing of fuel-injection by a fuel-injector (52) of a fuel-injected internal combustion engine (55) provided with a timing marker on a rotating part of the engine, comprising:- detecting the instants of fuel-injection; producing a first series of electrical pulses representing said instants of fuel-injection; deriving a second series of electrical pulses from said first series of pulses; controlling a strobe lamp (24) by means of said second series of pulses; illuminating the said rotating part of the engine by means of the strobe lamp (24); adjusting the timing of said second series of pulses relative to said first series of pulses as necessary, so that each flash of the lamp (24) occurs as the timing marker passes a reference position; and determining the timing relationship between said first and second series of pulses; characterised in that the detection of the instants of fuel injection is achieved by applying an acousto-electric transducer (11) in combination with an electrical amplifier circuit (12, 13) to the engine (55), externally thereof, and detecting ultrasonic frequency sound waves emanating from the region (52) of the injection of the fuel into the engine (55); the combination of the transducer (11) and the electrical amplifier circuit (12, 13) being tuned to an ultrasonic frequency at or near to forty kilohertz.

2. A method as claimed in claim 1, in which said transducer (11) is a contact transducer which is placed in contact with the fuel-injector (52).

3. A method as claimed in claim 2, in which the contact transducer (11) is a contact microphone.

4. A method as claimed in claim 3, in which the contact microphone is of piezo-electric type.

5. A method as claimed in claim 1, in which the transducer is a directional microphone (51) which is directed at the fuel-injector (52).

6. Apparatus (10) for determining the timing of fuel-injection by a fuel-injector (52) of a fuel-injected internal combustion engine (55) provided with a timing marker on a rotating part of the engine, the apparatus (10) comprising a strobe lamp (24) for illumination of the said rotating part of the engine, and means (11-28):- (11-21) for detecting the instants of fuel injection and producing a first series of electrical pulses representing said instants of fuel injection; (22) for deriving a second series of electrical pulses from said first series of pulses; (23) for controlling the strobe lamp by means of said second series of pulses; (25) for adjusting the timing of said second series of pulses relative to said first series of pulses as necessary, so that each flash of the lamp (24) can be made to occur as the timing marker passes a reference position; and (26-32) for determining the timing relationship

between said first and second series of pulses; characterised in that the means (11-21) for detection of the instants of fuel injection and producing said first series of pulses comprises an acousto-electric transducer (11) in combination with an electrical amplifier circuit (12, 13), adapted to be applied to the engine (55) externally thereof for detection of ultrasonic frequency sound waves emanating from the region (52) of the injection of the fuel into the engine (55); the combination of the transducer (11) and the electrical amplifier circuit (12, 13) being tuned to an ultrasonic frequency at or near to forty kilohertz.

7. An apparatus as claimed in claim 6, in which the transducer (11) is a contact transducer.

8. An apparatus as claimed in claim 7, in which the contact transducer is a contact microphone (51).

9. An apparatus as claimed in claim 8, in which the contact microphone (51) is of piezo-electric type.

10. An apparatus as claimed in any one of claims 7 to 9, in which the contact transducer (11) is provided with a spring clip or clamp (41) for attachment to the injector (52).

11. An apparatus as claimed in claim 6, in which the transducer (11) is a directional microphone (51).

12. An apparatus as claimed in any one of claims 6 tc 11, in which the electrical amplifier circuit (12, 13) includes a filter (13) arranged to pass a

component of the output of the transducer (11) having a frequency at or near to forty kilohertz.

13. An apparatus as claimed in claim 12, in which the filter is a bandpass filter having a centre frequency at or near to forty kilohertz.

14. An apparatus as claimed in any one of claims 6 to 13 and comprising means to determine the engine speed from pulse frequency.

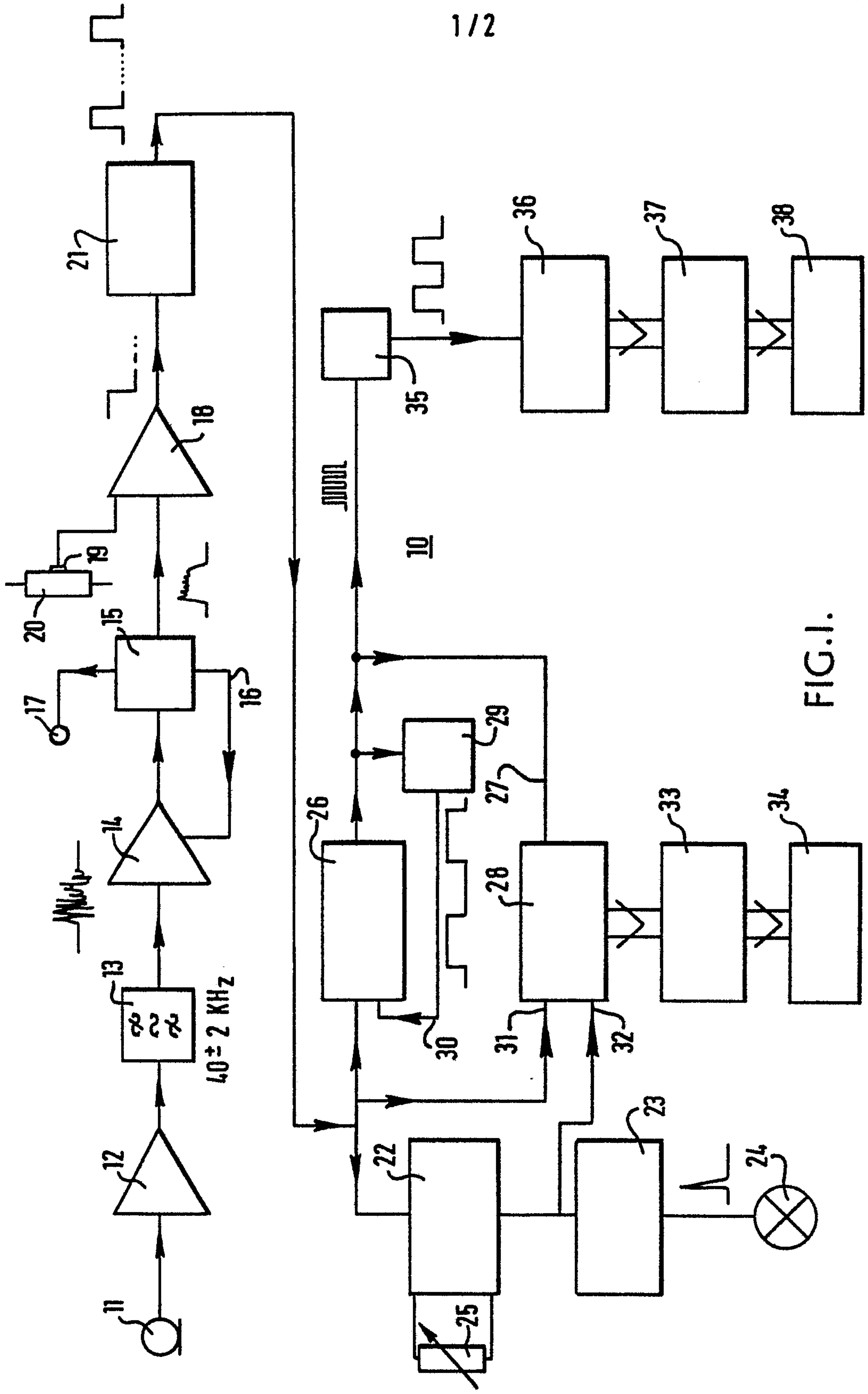
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FIG.1.

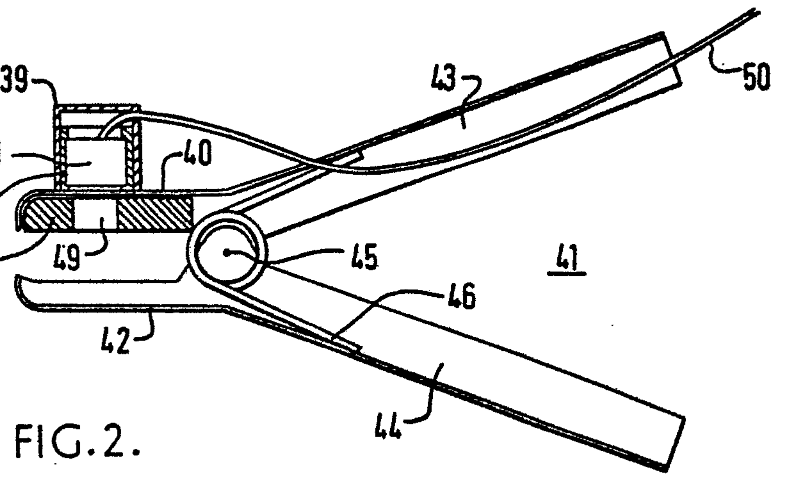

FIG. 2.

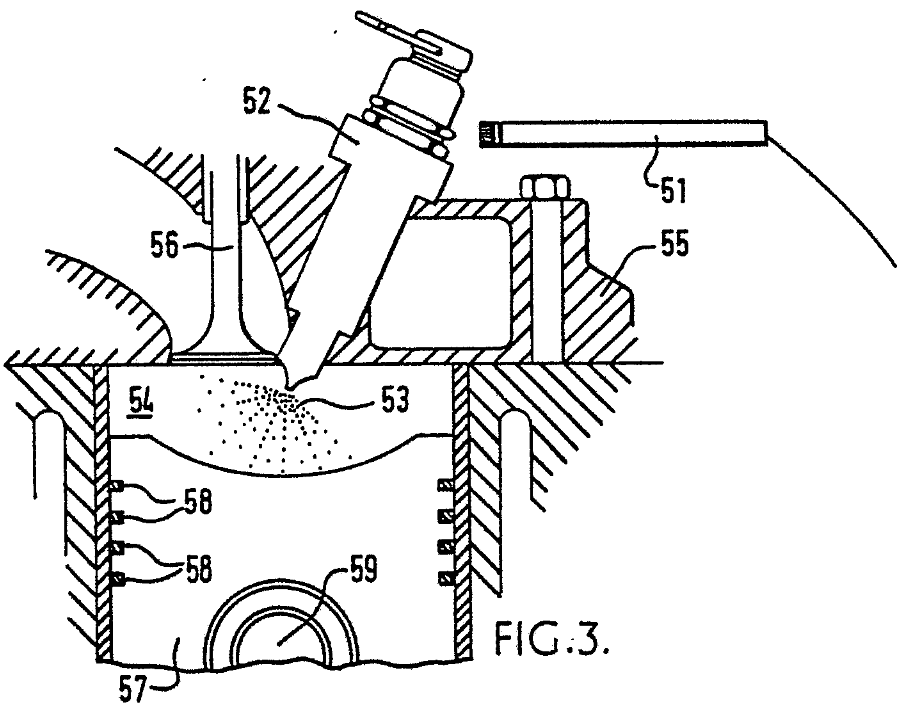

FIG. 3.

FIG. 4.