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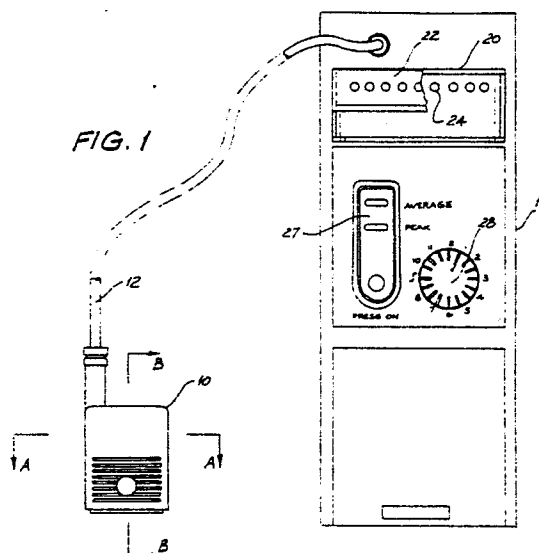
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54 **Injector tester.**

57 A device for testing fuel injectors in situ. The device comprises a detector (10) having a piezo-electric crystal (50) which converts mechanical impulses caused by the fuel injector valve needle snapping back onto its seat into electrical signals. The signals are fed to electronic processing means (15) which detects the signal amplitude and displays it on an LED bar graph display (20) as an indication of the operating efficiency of the fuel injector. A timing system using the detector (10) as a generator of timing signals is also disclosed.

A novel detector assembly (60) is also described. The detector assembly is an encapsulated sealed unit housing at least one piezo-electric element (64), two magnets (63, 65) and a pair of pole pieces (66, 67) in fixed spatial relationship during assembly and in use. The detector components are protected during encapsulation by a two piece carrier (62, 68).



INJECTOR TESTER

The present invention relates to a device for testing fuel injectors such as those used in diesel engines. A novel detector assembly for such injector testers is also provided. The invention also relates to a timing system for fuel injected engines.

BACKGROUND ART

Fuel injectors with atomiser nozzles have between 4 and 7 small holes in the nozzle, approximately 0.2mm in diameter. In use, these holes are frequently reduced in size, or blocked entirely, causing an imbalance in the spray pattern of atomised fuel into the cylinder and consequent imbalance in the air-fuel ratio, resulting in incomplete combustion.

This incomplete combustion manifests itself in power loss and black smoke emission from the exhaust. Continued operation of an engine under such conditions results in irreparable damage to the injector, the piston and the cylinder head, in that sequence.

A faulty injector still in the engine can only be detected when it has failed completely. The engine is run at idle and each injector fuel supply connection is eased, in turn, until fuel leaks out. Under this condition, the injector will fail to operate. If, when the nut is eased, the idle speed is markedly affected than that injector is operating properly. Conversely, easing the nut on a faulty injector has no effect on the idle speed. This known method of testing fuel injectors is a time consuming and inefficient method.

The most widely practiced method of detecting faulty injectors before failure thereof is to remove and replace all injectors at specified service intervals. Another common detection method for a faulty injector is the "black smoke" test (a vehicle expelling 10 seconds or more of black smoke detected against the sky line). A loss of power under load is also an indication of fuel injection problems. However, these methods are either inefficient or unreliable.

It is also difficult to determine the moment of fuel injection/combustion in a diesel engine for the purpose of establishing an engine timing system. U.S. Patents Nos. 4,130,013; 4,231,251; 4,088,916; 3,978,721; 4,261,209 and 4,187,720 disclose devices having transducers for sensing pulsating fluid flow in the fuel line. However these devices sense fuel pressure waves in the fuel line rather than vibrations in the detector head itself caused by the snap action of the valve needle at fuel injection.

U.S. Patent No. 4,102,181 discloses a process for determining the point of fuel injection by sensing the vibrations caused by abutments of the needle in the valve against a stroke limiter using, as a sensing element, a vibration acceleration indicator or microphone. In U.S. Patent No. 4,228,680 a piezo-electric crystal is used in a transducer for producing an electrical signal related to the position of the valve needle. As much vibration is produced during normal operation of a diesel combustion engine, the vibrations of the engine are sensed by the piezo-electric sensor along with the vibrations caused by the valve needle. It is then necessary to use sophisticated and expensive frequency discriminators to distinguish the desired vibration from background noise.

DISCLOSURE OF INVENTION

It is an object of the present invention to overcome or substantially ameliorate the above described problem by providing an improved injector tester which enables fuel injectors to be tested in situ for faulty operation.

It is a further object to provide a novel detector assembly for use with such injector testers.

It is another object of the present invention to provide a timing system for a fuel injected engine using a frequency selective transducer to detect the injection of fuel into the engine.

According to one aspect of the present invention, there is provided apparatus for testing a fuel injector, said apparatus comprising a detector adapted to be placed on said fuel injector and housing a transducer for converting mechanical impulses to electrical signals; electronic processing means connected to the output of said transducer and comprising an amplitude detecting circuit for detecting the amplitude of the received electrical signals; and display means connected to the output of said amplitude detecting circuit for providing a display proportional to the detected amplitude; wherein the detector is an encapsulated sealed unit and said transducer comprises at least one piezo-electric element positioned between two magnets, said element and magnets being held in fixed spatial relationship within said sealed unit.

A particularly advantageous feature of the present invention is the robust sealed detector assembly which houses the components of the transducer in fixed spatial relationship and protects them from the industrial environment in which the injector tester is used.

Due to the configuration of the transducer (i.e. the piezo-electric element between two magnets), its frequency response is limited to a "window" which includes the frequencies of interest but excludes other unwanted vibrations, i.e. it is frequency selective.

The piezo-electric element is a piezo-resistive device or other piezo crystal, preferably in bilaminar or trilaminar form.

Preferably, the display means comprises a series of light emitting diodes.

According to another aspect of the present invention, there is provided a timing system for a fuel injected engine, said timing system comprising: a detector adapted to be placed on a fuel injector or fuel line in said engine; the detector housing a transducer for converting mechanical impulses to electrical signals; and timing signal generating means connected to the output of said transducer for generating timing signals in response to the output signal from the transducer; wherein the detector is an encapsulated sealed unit and the transducer comprises at least one piezo-electric element positioned between two magnets, said element(s) and magnets being held in fixed spatial relationship within said sealed unit.

The transducer used in the fuel injector tester can also be used as part of the timing system. The mechanical impulse generated when the fuel injector valve needle snaps back onto its seat is detected by the transducer and an electrical signal is generated. The electrical signals received from the transducer indicate when the injector injects fuel into the combustion chamber, and the output signals can be used to operate a timing system such as an engine speed tachometer or a strobe light for checking timing or other diagnostic functions. Consequently, a fuel injected engine, such as a diesel engine, can be strobe light timed onto the fly wheel timing marks in the same fashion and with the same ease as an electric ignition engine. Accurate and dynamic tuning of the diesel engine can thereby be obtained.

BRIEF DESCRIPTION OF DRAWINGS

Preferred embodiments of the present invention will now be described with reference to the drawings in which:

Fig. 1 is an elevational view of the injector tester of a first embodiment;

Fig. 2 is a cross-sectional elevational view taken along C-C (Fig. 3) of the detector of Fig. 1;

Fig. 3 is a cross-sectional end elevational view taken along B-B of the detector of Fig. 1;

Fig. 4 is a cross-sectional plan view taken along A-A of the detector of Fig. 1;

Fig. 5 is an enlarged cross-sectional elevational view of the piezo-electric crystal of the detector of Fig. 1;

Fig. 6 is an enlarged cross-sectional end elevational view of the piezo-electric crystal of the detector of Fig. 1;

Fig. 7 is a schematic block diagram of the circuitry of the injector tester of Fig. 1;

Fig. 8 is a partial cut-away perspective view of a detector for the injector tester according to a second embodiment;

Fig. 9 is an exploded perspective view of the detector of Fig. 8;

Fig. 10 is a plan view of the carrier top shown in Fig. 9;

Fig. 11 is an inverse plan view of the carrier top shown in Fig. 9;

Fig. 12 is a sectional view along V-V of Fig. 11;

Fig. 13 is a side elevational view of the carrier top shown in Fig. 9;

Fig. 14 is a front elevational view of the carrier top;

Fig. 15 is a rear elevational view of the carrier top;

Fig. 16 is a sectional view along X-X of Fig. 11;

Fig. 17 is a sectional view along IX-IX of Fig. 11;

Fig. 18 is a plan view of the carrier bottom shown in Fig. 9;

Fig. 19 is an inverse plan view of the carrier bottom;

Fig. 20 is a sectional view along XIII-XIII of Fig. 18;

Fig. 21 is a side elevational view of the carrier bottom;

Fig. 22 is a front elevational view of the carrier bottom; and

Fig. 23 is a sectional view along XVI-XVI of Fig. 18.

BEST MODE OF CARRYING OUT THE INVENTION

As illustrated in Figs. 1 to 7, the injector tester of a first preferred embodiment comprises a detector 10 which incorporates a ferro-magnetic clamp for attaching the detector 10 directly to the injector body with sufficient strength to sustain the attachment whilst the engine is running.

The detector 10 houses a transducer which comprises at least one bilaminar piezo-electric element 50 positioned between two magnets 30, 40. The piezo-electric (or piezo-resistive) element (Fig. 5) actually comprises two piezo substrates 52, 54

with a metal layer 55 sandwiched therebetween. Wires connected to the two substrates 52, 54 lead to the electronic processing means 15 for processing the signals received from the detector.

As illustrated in Fig. 6, the magnets 30, 40 are provided with end plates or pole pieces 32, 34 and 42, 44. The piezo-electric element 50 is held between the pole pieces 32, 34 and 42, 44 so that mechanical vibrations of the pole pieces are transmitted directly to the crystal where they are converted to electrical signals. However, there are air gaps between the magnets and the piezo-electric element. A rivet 35 is inserted through the bottom magnet 40 into the detector body to prevent the piezo-electric element from being crushed between the pole pieces or magnets by excessive shock. In this manner, vibrations are sensed by the piezo-electric element, yet it is protected from excessive shock. The crystal/magnet assembly is coated with epoxy to form a sealed unit and housed in a plastic jacket.

Due to the above described mounting arrangement, the transducer is frequency selective. For example, the low frequency component of the engine vibrating in its mounts falls below the transducer's range, and other unwanted noises and vibrations generated by the engine and its components are filtered by the mounting arrangement so that the transducer is primarily responsive only to the particular band of frequencies within which the vibrations of the injector needle/nozzle assembly fall.

The electronic processing means 15 of the injector tester is a pulse height analyser circuit and is schematically shown in Fig. 7. The output of the detector 10 is fed to an amplitude range selector 16 which can be a multiple resistance switch which is adjusted to a desired setting so that the detected amplitude falls within the range of the display means 20. The output from the amplitude range selector 16 is amplified in pre-amplifier 17 and then fed to a peak detector 18. A "clamp and hold" circuit can also be incorporated to extend the duration of the recorded pulse so that the peak value can be analysed by an analogue level detector, if desired. If average, rather than peak, value is desired, an average select switch 19 can be enabled to provide an average reading of the detected pulse.

The peak or average value of the detected pulse is fed via buffer amplifier 14 to a display 20 which comprises a display driver (not shown) which drives a series of light emitting diodes 24. Thus, the instantaneous vibration level caused by the reseating injector needle is translated into a scaled visual display. The short firing time of the injector is extended so that the operator can see and interpret the information being displayed.

In operation, the detector is placed on an injector which is known to be operating properly, or if no injector is known to be operating properly, it is placed on the injector giving the highest reading on the visual display 20. The amplitude range select switch 16 is set so that the pulses received from the chosen injector light up substantially all of the diodes in the bar graph display 20. With the amplitude range selector on the same setting, the detector is then placed on an injector suspected of malfunctioning and the number of light emitting diodes which are illuminated by the suspected injector will provide an indication of its condition. A properly operating injector will light up substantially all of the diodes, whereas a faulty injector will illuminate few diodes.

The pulse height analyser circuit is fabricated in CMOS integrated circuits and a high input impedance ensures limited protection against electrical interference. Power is supplied from a standard 9 volt dry cell battery contained within the processor package, and the processor will function accurately so long as there is sufficient power to operate the LED display.

Other than the on/off switch, there are only two controls required to be operated; the amplitude range select switch 28 and the peak/average switch 27. The amplitude select switch adjusts the amplitude of the received pulse so that the displayed value falls within the range of the bar graph display. This switch is incorporated to compensate for different pulse heights from different engines since the pulse height is affected by the speed of the engine, the engine block mass/injector body mass ratio, injector needle valve/nozzle mass ratio, the number of nozzle holes or the shape of the pintle nozzle, and the damping response of the needle return spring. These factors do not have to be considered separately since the optimum range setting can be quickly determined simply by adjusting the peak level in the display to just below full scale.

The peak/average selects a fast or slow decaying display, in order to visually highlight any fault. The "average" position reveals constant, injector faults over a number of engine cycles and exposes the most common injector faults such as clogged or carbonized tips, defective valve seating, stuck valve stem, eroded valve stem and incorrect spring tension. Other intermittent faults are detected with a display which shows the "peak" level on each injector stroke. Thus, the "peak" position allows the display to reveal any fluctuations due to partly sticking valve stem, contaminated fuel, loose debris within the injector body or cracked or sticking valve spring.

Not only will the device test injectors, but it can also be used to detect bearing knock in motors.

A detector assembly according to a second preferred embodiment is illustrated in Figs. 8 to 23. In practice, the injector tester will be used on diesel engines operating in heavy vehicles, power plants and other industrial situations where there is excess heat and dust. The detector assembly must therefore be very robust and protect the sensitive piezo-electric element(s) from heat, shock and dirt. To provide this protection, the detector assembly is encapsulated by injection moulding. Injection moulding techniques are well known. However, devices which are encapsulated by injection moulding are usually passive components able to withstand the high temperatures and pressures involved in injection moulding. On the other hand, the piezo-electric element of the present invention is an active sensitive device which could not be encapsulated by ordinary injection moulding techniques. It was therefore necessary to provide a novel detector assembly which enabled the detector to be encapsulated by injection moulding yet protected the sensitive piezo-electric element from the high pressures and temperatures involved.

The detector assembly, as shown in Fig. 9, comprises a two piece plastic "boot" or carrier unit (carrier top 62 and carrier bottom 68) which house the detector components, namely two piezo-electric elements 64 positioned between magnets 63, 65, the bottom magnet 65 being located between two rigid plate members or pole pieces 66, 67. The insides of the carrier top and bottom, shown in Figs. 11 - 12, 18 - 20, are designed to hold the components in fixed spatial relationship.

The carrier top 62 is a structurally engineered vessel with structural ribs 69 between which is positioned a ceramic magnet 63. In assembly, the carrier top 62 is inverted on an assembly rig with specific electromagnetic field generators to align and hold the ceramic magnet in place. The piezo-electric elements 64 are then placed on top of the ribs 69 and the ceramic magnet 63. A pin 72 maintains a desired minimum spacing between the piezo-electric elements which are connected by electrical wires. The wires from the piezo-electric elements 64 lead to an electric cable which is held in place in a tortoise track formed by stacked pin locking and separate isolating cavities 70, 71.

The carrier top 62 also comprises a pair of locking jaws 73 which engage undercut segments 74 on the carrier bottom to provide positive locking and sealing of the two carrier components. When the carrier top and bottom are locked together, the cable is held securely in the tortoise track formed by the mating cavities 70, 71. These cavities are designed and calculated to contain, restrain and clamp the outer shield and inner conductor of the cable and to remove all strain from the fine wires interconnecting the piezo-electric elements. The

accurate positioning of these cavities provides a jugged track to guide the piezo-electric element interconnecting wires between and around the ceramic magnets and metal pole pieces to preclude electrical short-circuits and electric white noise from disturbing the precise electromagnetic induction field required for accurate readings. The other ribs, pins, walls and ledges in the carrier top 62 position and clamp the components in the carrier bottom when the top and bottom are held together by the clamping jaws. This technique stacks the integral components in a manner providing the essential electromagnetic acoustical resonating air cavities.

The carrier bottom 68 comprises two slots 75, 76 engineered to precisely position the two pole pieces 66, 67 within a tolerance of ± 0.001 inches, and to provide a cavity in which to locate the base ceramic magnet 65. The carrier base dimension is designed to provide a magnetic clamp system of specific magnet gauss force. The wall dimensions and flashing lips are engineered to tolerances of ± 0.0005 inches to ensure sealing between the pole pieces and the carrier top. This precludes any foreign material from entering the carrier air pocket during encapsulation. The carrier bottom also incorporates four strategically positioned pins 77 to elevate the carrier bottom during final injection moulding of the outer covering to control melt and to temper warp factors.

The assembly rig (not shown) also incorporates magnetic field control to reposition the top magnet 63 in relation to the piezo-electric elements 64, metal pole pieces 66, 67 and lower ceramic magnet 65. This final positioning is required to complete this stage of manufacture prior to encapsulation.

The audio cable 78 consists of a single core and external shield wire, and terminates in an audio plug (not shown) which in turn is plugged into the tester unit containing the electronic processing circuit.

As a result of the precision design of the ribs, pins and walls inside the carrier top and bottom, the piezo-electric elements 64 are held in electromagnetic acoustical resonating air cavity between the top and bottom magnets 63, 65. Moreover, the piezo-electric elements 64 have direct contact with the pole pieces 66, 67 so that vibrations in the injector are transmitted through the pole pieces to the piezo-electric elements.

The carrier top and bottom are formed from material designed to withstand the very high pressures and temperatures during the injection moulding encapsulating phase. The preferred material is poly carbonate, G.E. grade "LEXAN". This material

is able to withstand temperatures up to 25,000 psi and temperatures as high as 300°C. Plastics such as polypropylene, nylon 6 and acrylonitrile butadiene styrene can also be used.

After the carrier top and bottom have been locked together to seal the components within the cavities defined therein, the final external injection moulding process is carried out to provide a 1mm outer skin cover 61 of petroleum resistant PVC. This PVC skin cover not only provides the final aesthetic appearance but also provides strain relief for the integrally moulded cable while enclosing the cable securely within an extended grommet 79 in the finished detector head assembly. The skin cover 61 also provides a sealant to totally preclude the entry of any foreign fluids or material in use, particularly diesel fuel, oils, gasoline etc. The magnetic acoustic cavities within the detector assembly are thereby maintained free from contamination.

The outer PVC skin cover 61 is designed to provide pressure distribution surfaces to facilitate constant material flow during the injection moulding process. This results in constant density of material to all sides of the carrier and obviates distortion of the magnetic field and electronics therein. The skin cover 61 also damps the carrier's outer walls so that the vibrations are picked up from the pole pieces and piezo-electric elements and unwanted vibrations are not induced through the external walls of the detector 60. The encapsulating material is preferably petrol resistant PVC such as that sold under the trade name ICI WELVIC. Typically, encapsulation takes place at pressures of 38 - 48 KGS/CU M and temperatures of 150 - 165°C.

The finished product is a detector assembly which is robust and protects the sensitive piezo-electric elements from the shock, temperatures and contamination encountered in industrial environments. The detector components are also held in fixed spatial relationship during assembly, encapsulation and thereafter in use.

A further use of the present invention is in a timing system for a fuel injected engine. In this further application of the invention, the detector 10 or 60 is suitably clamped to an injector body or a high pressure fuel line. The piezo-electric transducer in the detector 10 or 60 senses the vibration caused by the injector needle snap-action or the pressure wave which causes the injector to fire. Again, the detector is frequency selective so that the engine's background noise is blanked out, and the output will be proportional to the frequency of firing of the particular injector unit. The output can be used to actuate a strobe light unit, a tachometer or an engine diagnostic system.

The foregoing describes only some embodiments of the present invention, and modifications which are obvious to those skilled in the art may be made thereto without departing from the scope of the invention as defined in the following claims.

Claims

1. Apparatus for testing a fuel injector, said apparatus comprising a detector adapted to be placed on said fuel injector and housing a transducer for converting mechanical impulses to electrical signals; electronic processing means connected to the output of said transducer and comprising an amplitude detecting circuit for detecting the amplitude of the received electrical signals; and display means connected to the output of said amplitude detecting circuit for providing a display proportional to the detected amplitude; wherein the detector is an encapsulated sealed unit and said transducer comprises at least one piezo-electric element positioned between two magnets, said element and magnets being held in fixed spatial relationship within said sealed unit.

2. Apparatus as claimed in claim 1 wherein one of said magnetic members is located between a pair of rigid plate members bearing on said piezo-electric element(s), one end of at least one plate member protruding from said sealed unit and adapted to be in physical contact with said injector whereby vibrations in said injector are transmitted by said at least one plate member to said element(s).

3. Apparatus as claimed in claim 2, wherein said detector comprises a pair of interlocking cup members having internal flanges, pins and ridges for holding the piezo-electric element(s), magnets and plate members in fixed spatial relationship, the interlocked cup members being encapsulated by injection moulding.

4. Apparatus as claimed in claim 3 wherein said cup members are made from heat-resistant and pressure-resistant plastics material.

5. Apparatus as claimed in claim 1, wherein the display means comprises a bar graph display having a series of light emitting diodes.

6. Apparatus as claimed in claim 1, wherein said electronic processing means comprises an amplitude range selector for varying the amplitude of the signal received from the detector.

7. Apparatus as claimed in claim 1, comprising two piezo-electric elements connected in parallel.

8. A timing system for a fuel injected engine, said timing system comprising: a detector adapted to be placed on a fuel injector or fuel line in said engine; the detector housing a transducer for converting mechanical impulses to electrical signals;

and timing signal generating means connected to the output of said transducer for generating timing signals in response to the output signal from the transducer; wherein the detector is an encapsulated sealed unit and the transducer comprises at least one piezo-electric element positioned between two magnets, said element(s) and magnets being held in fixed spatial relationship within said sealed unit.

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9. A timing system as claimed in claim 8, wherein one of said magnetic members is located between a pair of rigid plate members bearing on said piezo-electric element(s), one end of at least one plate member protruding from said sealed unit and adapted to be in physical contact with said injector or fuel line, whereby vibrations in said injector or fuel line are transmitted by said at least one plate member to said element(s).

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10. A timing system as claimed in claim 9, further comprising a tachometer connected to said timing signal generating means.

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11. A timing system as claimed in claim 9, further comprising a stroboscopic light connected to said timing signal generating means.

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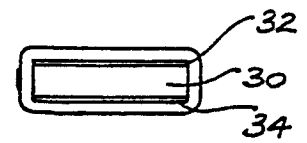
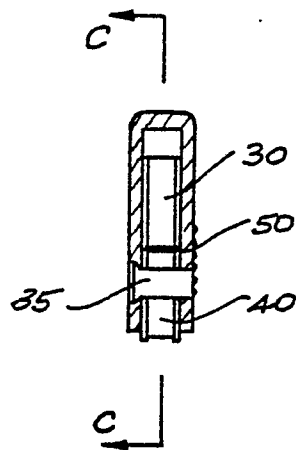
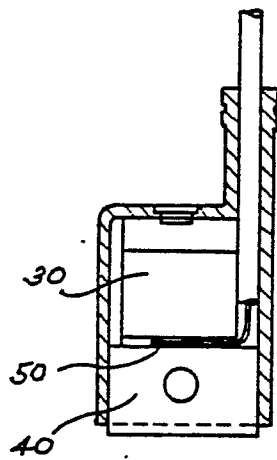
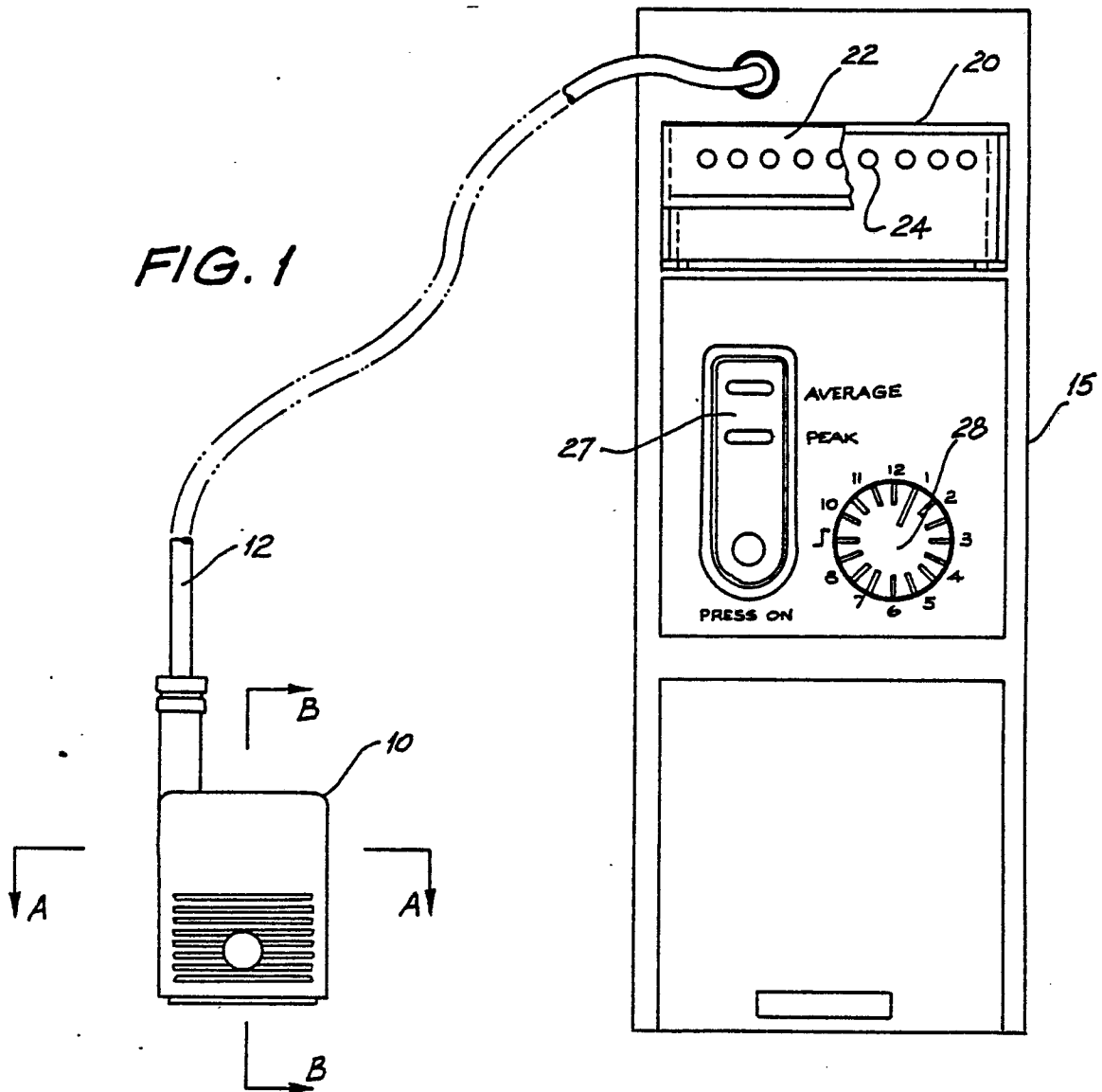
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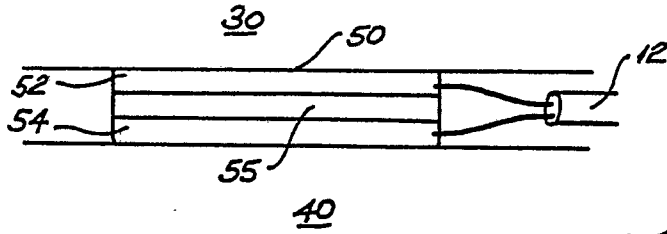


FIG. 5

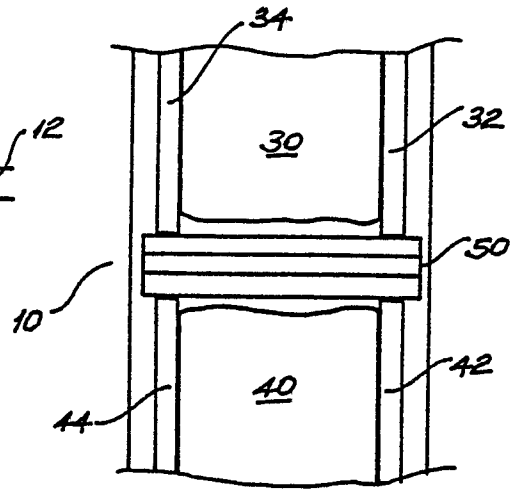


FIG. 6

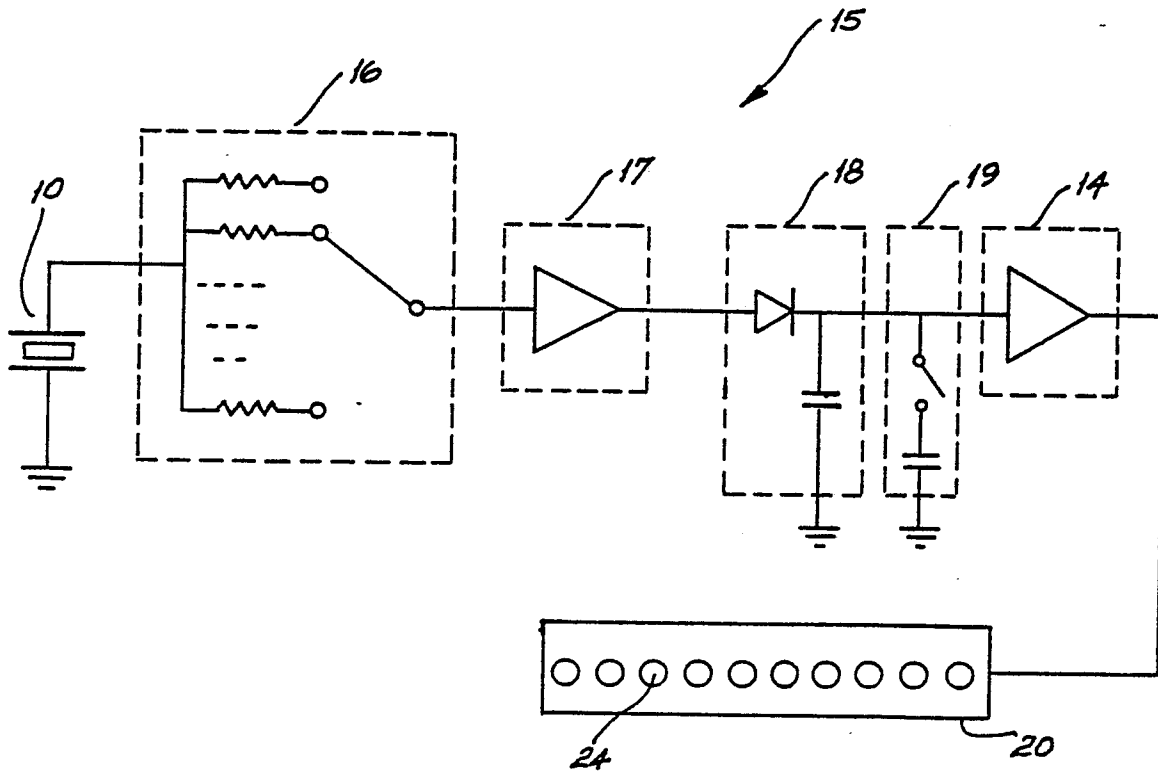
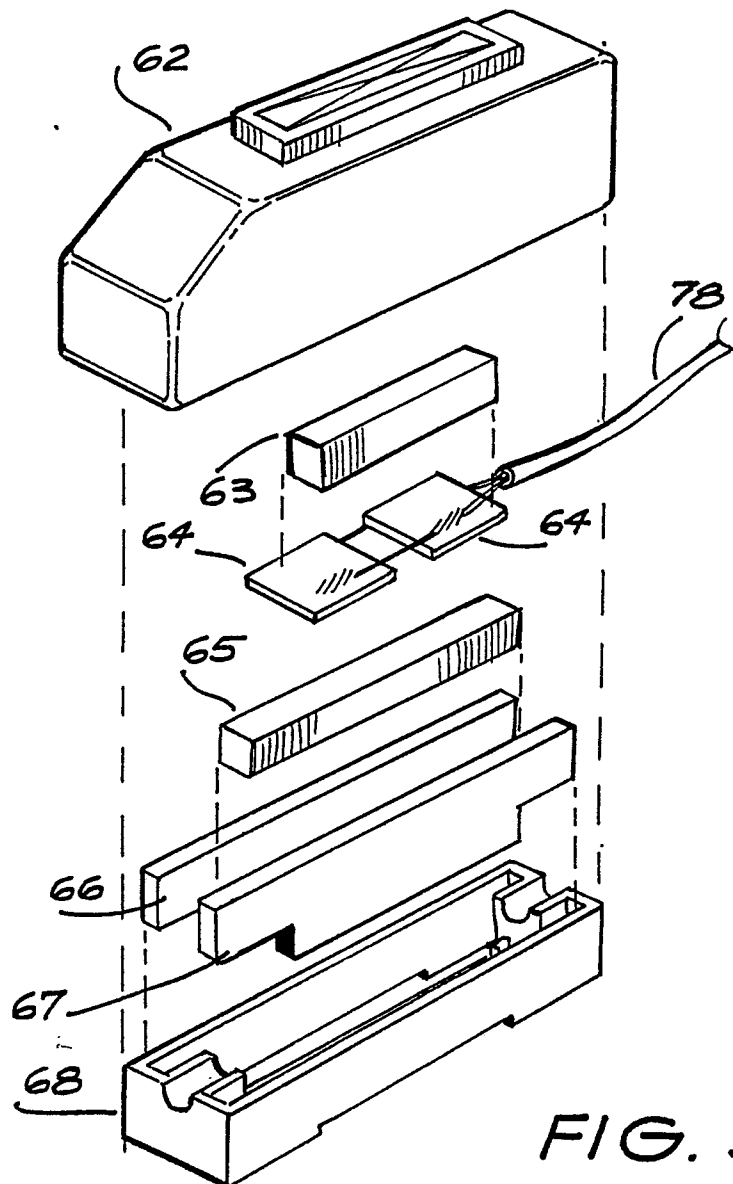
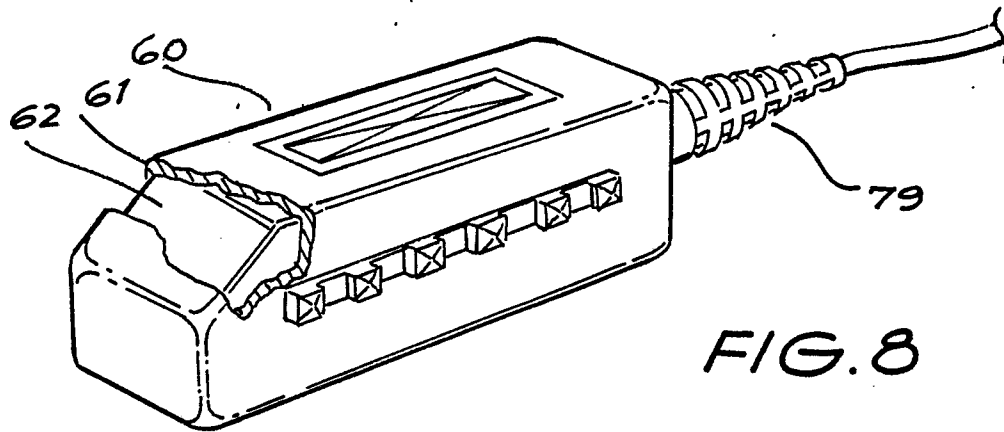


FIG. 7



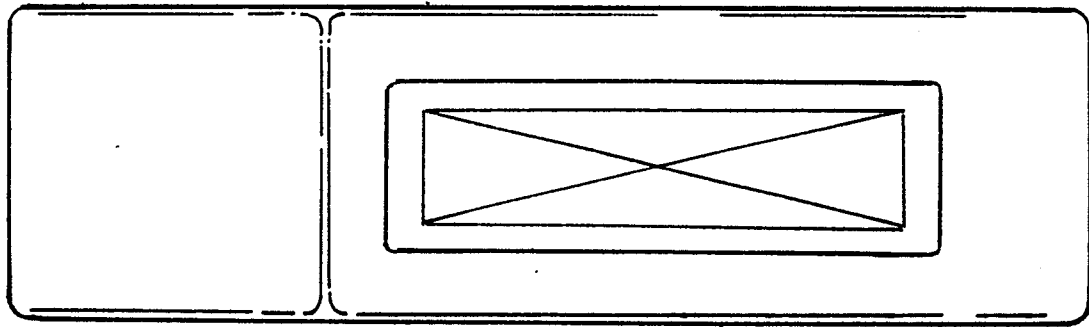


FIG. 10

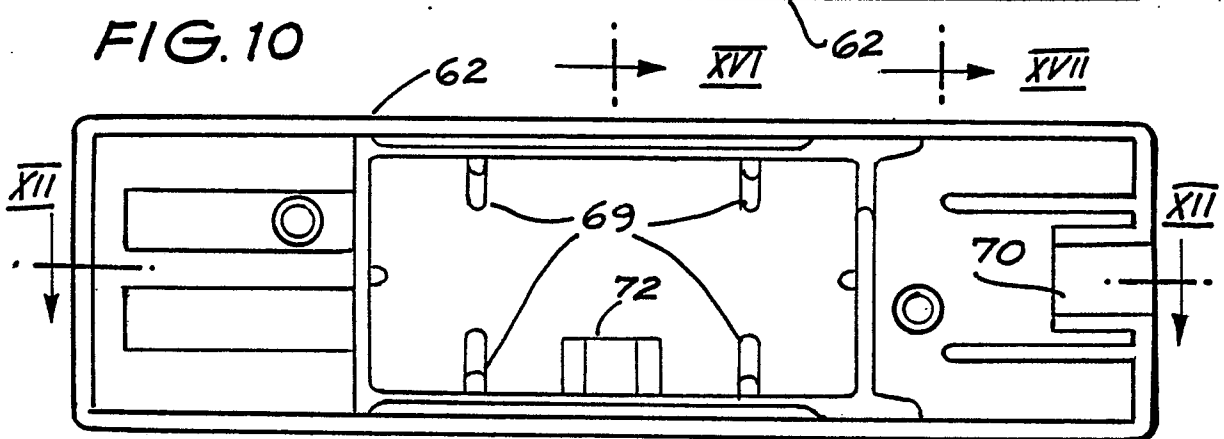


FIG. 11

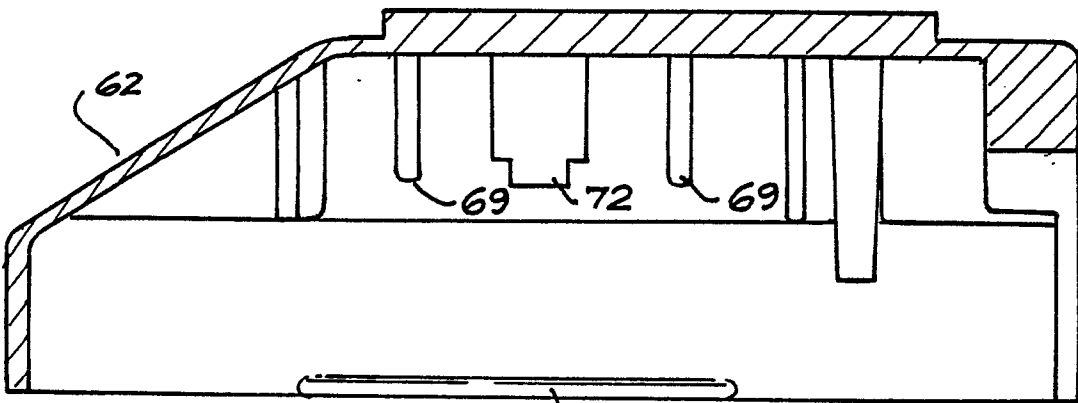


FIG. 12

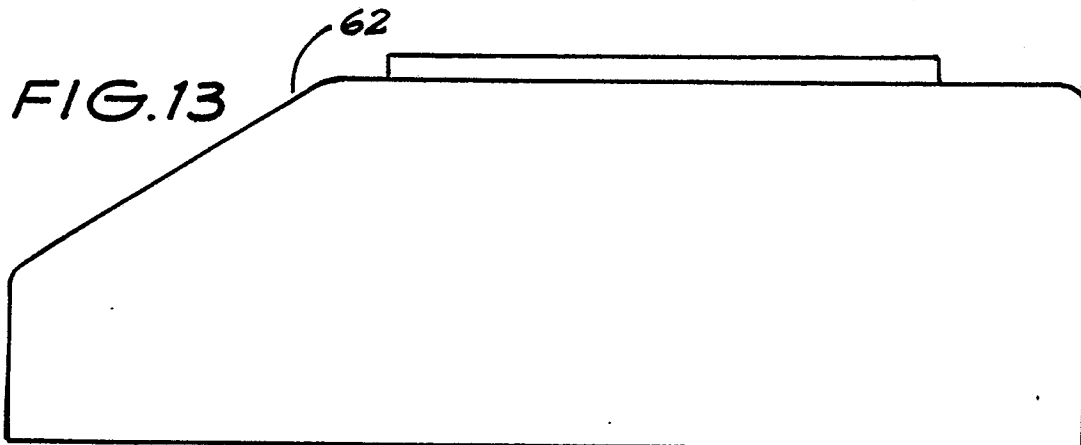


FIG. 13

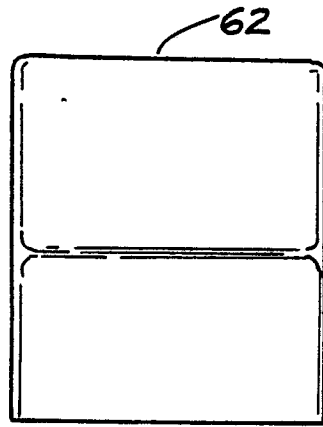


FIG. 14

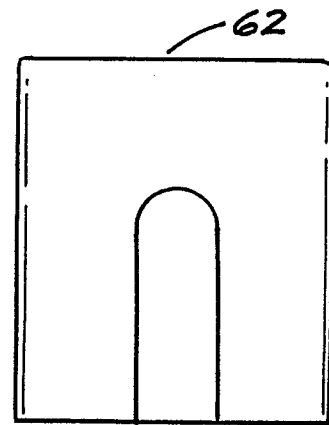


FIG. 15

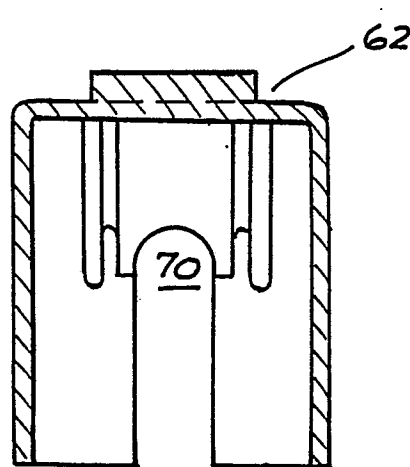


FIG. 16

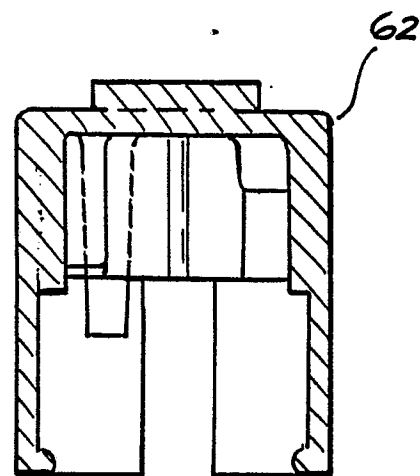
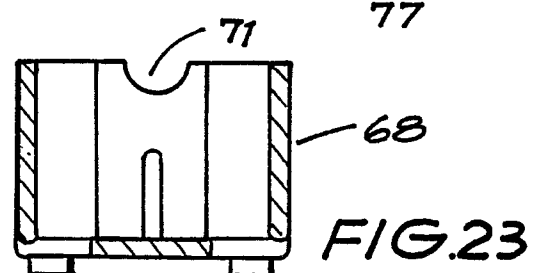
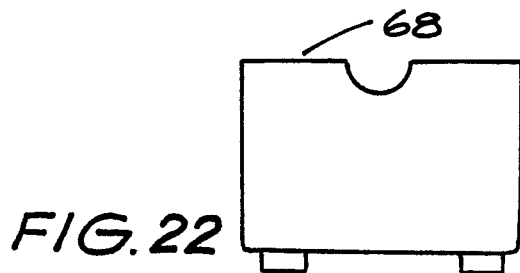
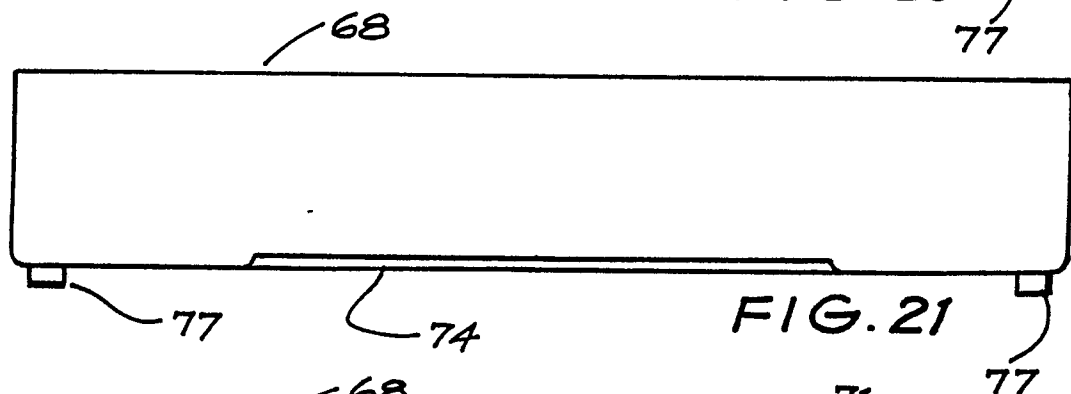
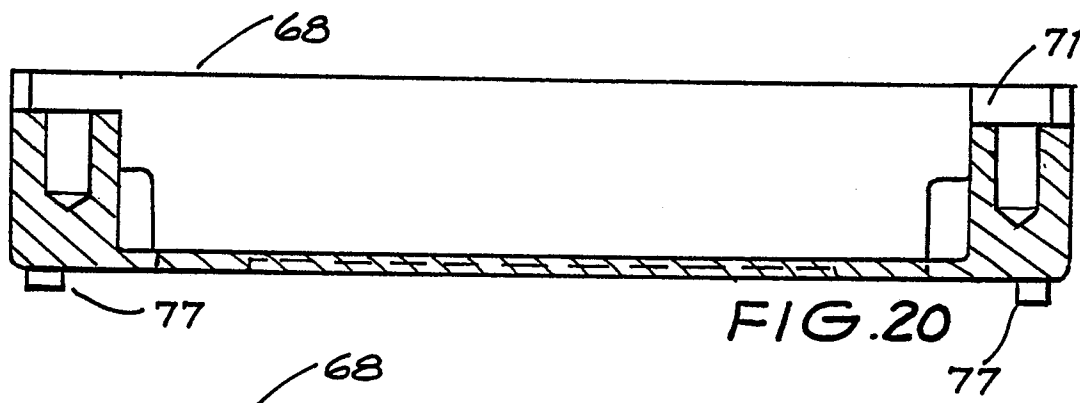
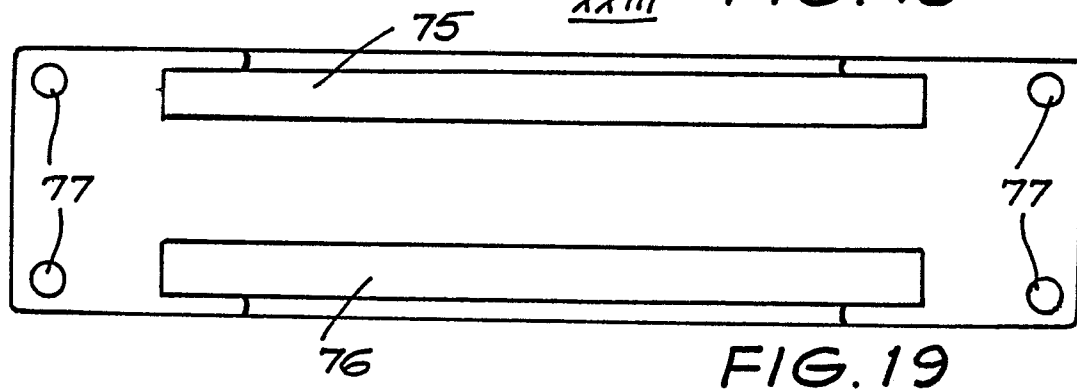
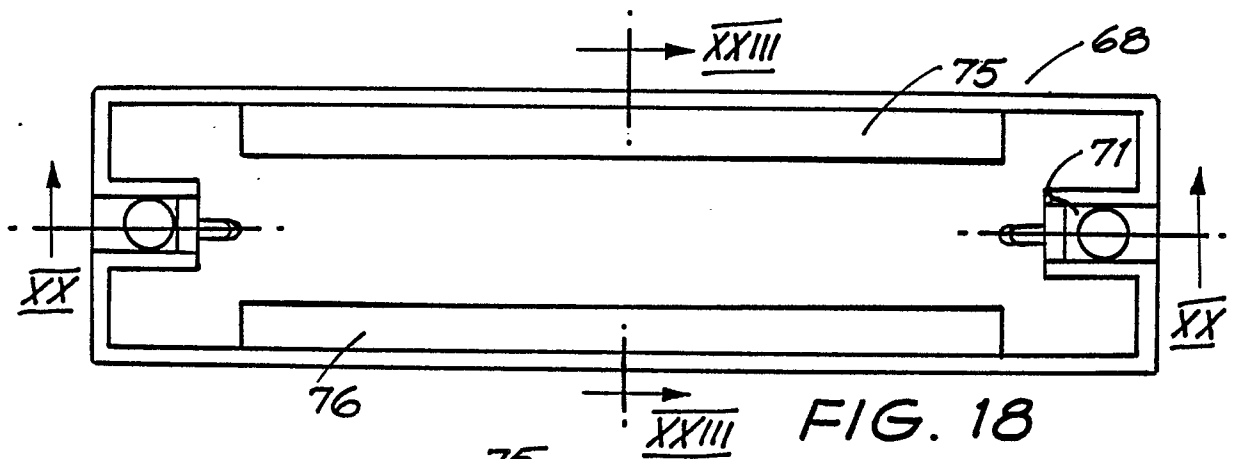


FIG. 17





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.4)
X	WO-A-8 301 814 (K.J. DANIEL) * Whole document *	1,3,5, 6,8-11	F 02 M 65/00
A	US-A-4 319 481 (E. YELKE) -----		
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			F 02 M
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 27-10-1986	Examiner THIBO F.
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding - document	