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<p>(54) Title: ULTRASONIC MONITORING TECHNIQUE FOR CONTAINERS AND APPARATUS TO CARRY IT OUT</p>		
<p>(57) Abstract</p>		
<p>The invention provides an apparatus and method for fill level monitoring in which the height of contents in a container (10) is monitored. The apparatus comprises an ultrasound receiver (30) and signal processing means (50-56) adapted to receive signals from the receiver, the arrangement being such that the signal processing means (50-56) identifies a first signal (32), in use, which is representative of a wavefront (26) transmitted through the contents of the container (10) independently of the height of the contents in the container (10), and a second signal (34) that is representative of a wavefront (24) that is reflected from the interface (22) between the surface of the contents in the container (10) and the environment above the contents, and in which the signal processing means (50-56) uses the difference in travel time for the two wavefronts (24, 26) to provide a measurement of the level of the contents in the container (10). A plasma generation system comprising a pulsed laser (99) and a target (101) in front of the container (102) is also disclosed, the plasma (103) creating ultrasound in the container (102).</p>		

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**ULTRASONIC MONITORING TECHNIQUE FOR CONTAINERS
AND APPARATUS TO CARRY IT OUT**

This invention relates to an ultrasonic monitoring technique for
5 containers, and to apparatus to carry it out. It especially (but not
exclusively) relates to apparatus for, and a method of , measuring the fill
level of a substance in a container, preferably of a liquid in a container
that is moving on a production line.

10 The invention arose out of a consideration of the process of filling
beverage cans with beverage and will be discussed in that context, but it
will be apparent that it is applicable more widely than that.

In conventional beverage can filling lines the amount of beverage
15 that is put in the can before it is sealed is determined by a number of
variables. These include (but are not restricted to) a) container variables
(line speed/can size etc.) b) filler variables (including filler valve physical
characteristics and control techniques) and c) product variables. Any
changes in these variables may affect the fill level within the container
20 and so the amount of beverage in a container can vary. Fill level
detectors are used to measure the level of beverage in a can, usually a
sealed can. At present suitable fill level detectors use X-rays, or gamma
rays. Both of these are health hazards and their use is carefully
controlled.

25 According to a first aspect of the invention we provide fill level
monitoring apparatus adapted to monitor the height of contents in a
container, the apparatus comprising an ultrasound receiver, and signal
processing means adapted to receive signals from the receiver; the
30 arrangement being such that the signal processing means identifies a first

signal, in use, which is representative of a first ultrasonic wave which has been transmitted through the contents of the container independently of the height of the contents in the container, and a second signal that is representative of a second ultrasonic wave that has been reflected from the
5 interface between the surface of the contents in the container and the environment above the contents, and in which the signal processing means uses the difference in transit times for the two waves to provide an indication of the level of the contents in the container.

10 Preferably the dimensions of the container are known and these are used in conjunction with the transit times for the two waves to provide an indication of the level of the contents in the container. Preferably an indication of the level of the contents is provided which is independent of the temperature or composition of the contents.

15 Preferably the apparatus includes ultrasound generation means, but in some cases that may be additional to the detection part of the apparatus.

20 The container may be moving during the transmission of the first and/or second ultrasonic waves.

Preferably the ultrasonic waves which are detected as the first and second signals are generated simultaneously by the ultrasound generation
25 means. The ultrasonic waves that are detected as the first and second signals may be different parts of the same wavefront.

The apparatus is preferably capable of generating and/or detecting a second set of first and second waves shortly after the first set (e.g. 5ms
30 after). The apparatus is preferably capable of performing a second

measurement on the same container shortly after the first measurement (e.g. 5ms after).

The ultrasound generation means preferably is a laser, or includes a laser, especially, but not exclusively a CO₂ laser. TEA CO₂ lasers have the output characteristics and repetition rate that we desire for an embodiment of the invention (about 40 or 50 cycles per second).

The ultrasound receiver and/or ultrasound generation means is preferably couplant free, (by couplant free we mean no solid or liquid couplant exists between the ultrasound receiver and the container, and/or between the ultrasound generation means and the container). However, in principle liquid coupled, and even mechanical contact detectors/ultrasound producers are envisaged, but they cannot work in fast running canning lines as well as do couplant free detectors/emitters.

The apparatus is preferably arranged such that the ultrasound receiver is disposed to the side of a container. Preferably the ultrasound generation means is, in use, to the side of the container, most preferably "radial" to the container. The receiver and generation means may be on opposite sides of the container, or when viewed from above the container they may be at an angle away from the 180° straight-through configuration.

The receiver and the generation means may be at substantially the same height relative to the container. Alternatively, we may prefer to have the receiver at a different height to that of the generation means. This may be used to improve the resolution of the first and second signals.

Preferably the receiver is not more than about 10 mm from the container when the ultrasound waves that generate the first and second signals are detected, most preferably not more than 5 mm, 2 mm or 1 mm away.

5

Preferably the generation means produces a divergent ultrasound wavefront.

The first and second signals may be derived from one or more ultrasonic wavefronts, preferably a single wavefront, generated at the same location on the container or at a geometrically small area of the container (e.g. about 4mm²). Preferably the receiver detects ultrasound from only a localised height of the container, most preferably over a height of 4 mm or less, or 3 mm or less, or 2mm or less.

15

The apparatus preferably includes a broadband ultrasound receiver. Most preferably the receiver can detect from low frequency to at least 1MHz, and preferably above 1MHz. The receiver may be able to receive from DC to above 1MHz.

20

The ultrasound generation means preferably is capable of producing a broadband signal, in the same range of frequencies as mentioned above for the receiver.

25

The apparatus preferably has an electronic signal filter, such as a band pass filter. It preferably has a signal amplifier, which may be tuned to the same band of frequencies as the receiver.

The receiver may be an EMAT (electromagnetic acoustic transducer). An EMAT may be the receiver of choice if the container is

30

to be a metal can. The EMAT may be polarised preferably to give maximum sensitivity to top surface reflections of ultrasound from the upper surface of the contents of the container.

5 Preferably the container is a metal can.

There is preferably a feedback mechanism whereby the apparatus can feed back signals, derived from the first and second signals, to control apparatus for subsequent use in controlling the filling operation or
10 filling apparatus.

According to a second aspect of the invention we provide a fill level monitoring apparatus adapted to monitor the height of contents in a container, comprising an ultrasound receiver and signal processing means
15 adapted to receive signals from the receiver, the arrangement being such that the signal processing means identifies a signal which is representative of an ultrasonic wave which has been reflected from the interface between the surface of the contents of the container and the environment above the contents, and in which the signal processing means uses the transit time of
20 the ultrasound wave to provide an indication of the level of the contents in the container.

We can get an indication of the fill level of the contents in the container from just the "top surface" reflection. If we know the diameter
25 of the container and the velocity of sound in the contents of the container we can calculate the height of the surface above the datum point. The container diameter and the velocity of sound for a medium can be, in some embodiments, pre-programmed into the signal processing means.

The velocity of sound in a medium varies as a function of the temperature of that medium. The temperature of the contents of a container on a production line as it passes a point on the line may vary from one container to another.

5

We could measure the temperature of the contents of the container and use that in an algorithm or in an appropriate look up table. We prefer, however, to measure the arrival times of the two detection signals indicative of two different waves that have travelled different paths, using
10 that (together with a knowledge of the dimensions of the container and geometry of the paths taken by the waves that generated the signals) to eliminate the need to know the temperature of the contents of the container.

15 In one preferred embodiment the path geometry for two different paths is known, and the time difference between arrival of the two signals at the detector is known, and hence the height of the surface of the contents above a datum point can be evaluated by taking the time difference and applying an appropriate algorithm, or inspecting an
20 appropriate look up table.

According to another aspect of the invention we provide a container filling line comprising container filling means adapted to deliver contents to a container, control means controlling the operation of the container
25 filling means, and fill-level monitoring apparatus in accordance with the first or second aspect of the invention.

The filling line preferably includes container rejection means adapted to remove a container from the line. Tracking means may be

provided to track a container from the point where it is identified as being a reject to the point at which it is actually rejected.

According to another aspect of the invention we provide a method
5 of monitoring the fill level of contents in a container comprising
generating ultrasound waves in the container, detecting a straight through
ultrasound wave, detecting a top surface reflected wave from the top
surface of the contents of the container, and determining the time
difference between the two waves in order to obtain an indication of the
10 level of the contents in the container.

According to another aspect of the invention we provide a method
of monitoring the height of contents in a container comprising generating
an ultrasonic wave; reflecting it from the interface between the contents of
15 the container and the environment above the contents; determining the
transit time of the reflected wave; and using a knowledge of the geometry
of the container and of the transit time to determine the height of the
contents.

20 Preferably the dimensions of the container are known and are used
in conjunction with the arrival times of the two waves to obtain an
indication of the level of the contents in the container. The method then
compensates for variations in the temperature or composition of the
contents.

25
According to a further aspect of the present invention, a non-
contact apparatus for monitoring contents of a container is provided
comprising non-contact ultrasonic wave generation means adapted to
produce in use an ultrasonic wave in a container being monitored, non-
30 contact ultrasonic wave detector means adapted to detect an ultrasonic

wave and to generate a detection signal dependent upon the ultrasonic wave which is detected, and signal processing means adapted to process the detection signal generated by the ultrasonic wave detector means in order to detect a particular characteristic of the contents of the container, and in which the wave generation means comprises plasma producing means adapted to produce a plasma at or near the surface of the container.

Having detector means and processing means may be optional. We may provide just the ultrasound producing system.

10

The plasma producing means may comprise a laser. Alternatively it could be an electrical source (e.g. high voltage discharge).

The plasma producing means may produce plasma, e.g. by a high energy strike, at the container surface, for example by having a laser beam or electrical spark hit the container. However, we prefer to have the plasma generated at a region close to the container, but not actually at the wall of the container. Spaced plasma generation means are preferably provided to achieve this. The spaced plasma generation means may comprise a target that is not the container (e.g. a member between the energy source that produces the energy strike and the container). We may simply have a target plate next to the container, the laser beam (or other energy source) striking the target plate instead of the container directly.

One advantage of the plasma target system is that we have found that by using plasma to generate ultrasound no mark, or much less of a mark, can be made on the container (direct impact with a laser beam of sufficient intensity to generate ultrasound can mark the surface of a container).

30

The laser is preferably adapted to operate in pulsed mode. Pulsed lasers can fire many times per second. This enables us to monitor many containers per second, possibly 30, 40 or 50 per second.

5 According to a still further aspect, the present invention provides a couplant-free method of monitoring the contents of a container comprising, firstly, generating an ultrasonic wave within the contents of the container, secondly, detecting an ultrasonic wave at a localised region of the container and producing a detection signal dependent upon the
10 detected ultrasonic wave, and thirdly processing the detection signal in order to determine a particular characteristic of the contents of the container, the ultrasonic wave being generated by the impact of a laser beam or by a plasma generating device adapted to generate plasma at or slightly spaced from the container.

15

 Preferably the ultrasonic wave is detected at a localised region at the outer surface of the container.

 According to another aspect of the invention we provide an
20 ultrasound source comprising an energy source adapted to produce a pulse of energy and a target at which plasma is generated, the arrangement being such that in use the target is interposed between the energy source and an article that is to have ultrasound generated in it, and the energy source produces in use an energy strike that impinges on the target, as
25 opposed to impinging directly on the article, generating a plasma at the target, which plasma generates ultrasound in the article.

 The target is preferably spaced from the article. The spacing may be of the order of 1mm, 2mm, 3mm, 4mm, 5mm, or above.

30

The target may be moveable. It may be replaceable.

Focusing means may be provided to focus the energy strike onto the target. The energy source may be a laser.

5

According to another aspect of the invention we provide a non-contact method of inspecting an article comprising, firstly, generating an ultrasonic wave within a portion of the article, secondly, detecting an ultrasonic wave in a portion of the article and producing a detection signal
10 dependent upon the detected ultrasonic signal, and thirdly processing the detection signal in order to detect a particular characteristic of the article, the ultrasonic wave being generated by the impact of a laser beam, or electric discharge, or by a plasma generating means adapted to generate plasma spaced from the article.

15

Thus we may inspect things that are not containers, for example castings. Using plasma-generated ultrasound helps to avoid marking the article during ultrasound inspection.

20

The title of this patent application is not to be taken as restricting this last aspect of the invention just to inspecting containers.

The invention will now be illustrated by way of example only with reference to the accompanying drawings of which:-

25

Figure 1 shows schematically the principle of using ultrasound wave transit time differences to determine fill height in a moving can;

Figures 2 and 2' show the difference in time between peaks for signals representative of straight through and Top Surface Reflection (TSR) waves in a can filled to two different levels;

5 **Figure 3** illustrates a simplified divergent ultrasound wavefront in a can;

Figure 4 shows schematically a directional ultrasound fill level system which preferentially emits ultrasound in the straight-through and expected Top Surface Reflection directions;

10

Figure 5 schematically illustrates one embodiment of the invention;

15 **Figure 6** illustrates the signal detected in trials from the embodiment of Figure 5;

Figure 7 illustrates test results showing how, for the particular geometry of the embodiment of Figure 5, the signal separation is a linear function of the additional volume of content in a container;

20

Figure 8 schematically illustrates a can filling line fitted with the embodiment of Figure 5;

25 **Figure 9** shows schematically another way of generating ultrasound;

Figures 10 to 12 show schematically further ways of generating a plasma near the surface of a container.

The invention can be thought of as using a couplant free ultrasonic technique for measuring the fill-level in containers on a moving production line.

5 The system, according to one embodiment consists of a couplant free means of generating an ultrasonic wave in a moving container and a couplant free means of detecting the ultrasonic waves propagating via a plurality of ultrasonic paths through the contents of the container. The general technique is to measure the time difference between two ultrasonic
10 arrivals, one travelling to the detector directly, the other having been reflected from the gas-liquid interface at the liquid level (Top Surface Reflection, TSR). As the liquid level changes, the temporal separation of the two ultrasonic pulses will change correspondingly. The displacement components normal to the container surface for the direct ultrasonic wave
15 and TSR ultrasonic wave are preferentially measured.

It will be appreciated that although primarily used for liquids the technique can be used for any medium that permits the propagation of longitudinal ultrasonic waves through the bulk of that medium. "Liquid"
20 should be interpreted with that in mind. The liquid need not (indeed usually will not) completely fill the container: there may be a gas in a space above the liquid surface in a sealed container.

One particular geometry that is suitable for such a liquid level
25 measurement is shown in Figure 1. An open can body 10, having liquid 20 e.g. beer and gas 21 therein, is shown. The can end has not yet been fixed to the can (of course it will be appreciated that the technique will work whether or not the can is sealed). An ultrasonic source 28 provides ultrasonic waves 24, 26 in the liquid 20, and these are received
30 by an ultrasonic detector 30, which in turn generates electrical signals

representative of the waves. The "transit time" of the TSR wave 24 reflected from the gas-liquid interface 22 is longer than that of the direct wave 26. This can be used to indicate the level to which the can 10 is filled.

5

Figures 2 and 2' illustrate how the time separation between the TSR 24 and direct 26 ultrasonic waves may change with changes in liquid level. The time difference t_A between the electrical signal 32 representative of the direct wave 26 and the electrical signal 34 representative of the TSR wave 24 is greater than the corresponding time difference t_B which relates to a container with less liquid above the datum point 36 of the detector.

In order to obtain high accuracy in the temporal separation measurement it is desirable to have one ultrasonic source simultaneously generate the two ultrasonic waves from the same localised position on the surface of the container. The ultrasonic field produced by such a source must have some component that travels to the detector via a path independent of liquid level, and some component that has an ultrasonic path dependent upon the liquid level. This could be achieved by using one localised ultrasonic source that generates a divergent ultrasonic wavefront in the container contents (see Figure 3) from which both detected ultrasonic waves are derived, and detecting the waves at the same localised detection position at the surface of the container. This could also be achieved by an ultrasonic source that has strong guided components off-axis to the container surface normal, and along the direction of the surface normal (see Figure 4). It is possible to use an array of ultrasonic generators to achieve such a field. An array of detectors may be used, but we prefer to have a single detector with a small active area.

The divergent field will have a range of TSR path lengths from the gas-liquid interface over the entire range of possible angles. The reason that a distinct signal can be detected when using a divergent ultrasonic field is due to the geometry of the system and the scattering of the ultrasonic wave from the liquid-gas interface. A simplified explanation is that the ultrasonic wave incident on the liquid-gas interface will reflect at an angle to the normal of the interface that is equal to the incident angle of the propagation direction of the wave to the interface normal. As the active ultrasonic detector area is finite, then a finite range of these reflections will be detected. Detecting over a range of incident angles increases the signal amplitude but also leads to signal broadening. We may prefer to detect over only a narrow range of incident angles.

It is preferred to have geometrically small (e.g. about 2-4 mm high and about 10-20 mm wide) active areas at the generation point and detection point of the ultrasonic waves. This reduces broadening of the electrical signals representative of the ultrasonic waves and hence can make the measurement of temporal separation easier and more accurate. It will be appreciated that different detectors may have different optimum sites relative to a container. The size of the generation point and detection point in the direction of the height of the container is more important than their width.

The velocity of ultrasound in liquids is over one thousand times greater than the typical velocity of a container on a high speed production line. This essentially makes the ultrasonic measurement an instantaneous technique compared to the distance that a container will have moved on the production line during the time taken to measure and analyse the

ultrasonic waves. The measurement can of course also be performed statically.

It is preferred that the ultrasonic system be broadband, containing
5 significant frequency content from DC to above 1MHz. The frequency
content of the broadband ultrasonic source varies from DC to over 1MHz.
The broadband ultrasonic receiver has a frequency response from DC to
above 1MHz but may be limited by a band pass filter to remove signals
from unwanted mechanical vibrations and electrical noise. The definition
10 of broadband in this patent is that the frequency content has measurable
and significant frequency components from DC to above 1MHz. This
improves the accuracy of the temporal separation measurement between
the two different ultrasonic path lengths of the direct path and TSR path.

15 Figure 5 illustrates one embodiment of the invention in which the
ultrasonic source is a TEA CO₂ laser beam 40 focused by a lens 41 to
form a localised broadband longitudinal ultrasonic source on a beverage
can 42 moving on a canning line and containing liquid 44 and gas 46.
The couplant free detector in this embodiment is a broadband
20 electromagnetic acoustic transducer (EMAT) 48 at the opposite side of the
can 42, which is designed to detect longitudinal waves in this particular
geometry. A preamplifier 50 amplifies the signals from the EMAT and is
also broadband in frequency response. Digitisation and signal processing
means 52, a rejection system 54 and feedback and data output means 56
25 are also provided. The laser beam impact site is positioned on the
opposite side of the can 42 to the EMAT 48 such that both detector and
laser beam pulse site are below the gas-liquid interface 58.

The ultrasound detector and source need not be at the same level
30 and indeed in this embodiment are not at the same level. Quite often it is

advantageous to have the detector and source at different levels to alter the observed relative amplitudes and separations of the signals representative of the direct ultrasonic wave and the TSR wave that arises from the reflection at the gas-liquid interface. The EMAT 48 is polarised to give maximum sensitivity to the signal representative of the TSR wave 5 64 and minimise signals arising from other ultrasound paths such as guided waves in the can skin itself. A waveform containing an electrical signal 60 representative of the direct ultrasonic wave 66 and an electrical signal 62 representative of the TSR ultrasonic wave 64 is shown in 10 Figure 6.

A plot of measured time separation (between the electrical signals representing the TSR and the direct ultrasonic waves), versus volume of water added to a can of constant cross-sectional area already containing 15 water is shown in Figure 7. The characteristics of the plot will change as the relative positions of liquid level, EMAT and laser beam impact point are varied, and as the composition of the liquid changes. This type of measurement could be used as a calibration for all successive measurements made on cans containing the same liquid.

20

While the apparatus described will also generate ultrasonic waves in glass, plastic or paper containers the EMAT transducer can only operate on metal containers. Other types of detectors that could be employed for these cases include a modified wheel probe (used as an 25 ultrasonic generator and/or detector), and an air coupled transducer (ACT). An ACT can today be used only as a detector due to its currently low efficiency.

As ultrasonic generation sources can operate at high repetition 30 rates, the technique described above lends itself to the rapid automated

inspection of containers on production lines. The data from the signal processing of the ultrasonic waves can be used in feedback to control other processes on a production line.

- 5 Other ultrasound generation sources could be used (e.g. electric spark strike).

Figure 8 shows, schematically, a beer (or other beverage) can filling line. A conveyor 100 moves cans (or other containers) 102 past a
10 filling station 104 (normally a rotary carousel but shown as a single station for clarity) provided with a beer delivery pipe 106. Containers can be presented this way in a continuous process at speeds of up to 3000 per minute. They are then conveyed to a seamer station 108 where a can end is fitted and sealed to the body of the can. A reject removal
15 system 105 is provided downstream for removing cans that do not contain sufficient beer.

The filling station 104 has a fill level detection system 110 which comprises a TEA CO₂ laser 112, and EMAT 114, and signal processing
20 means 116. An output signal from the signal processing means is fed to a controller 118 which controls the operation of the beer delivery pipe 106 (and also the conveyor 100, the seamer station 108, and the reject system 105).

25 The controller 118 operates the beer delivery pipe 106 until the fill-level detection sends a signal to the controller indicating that the beer has reached the desired level, at which point the beer supply is shut off for that can. This enables us to fill each can to a desired level and variations in beer supply pressure/other can-filling factors are automatically

compensated since we use feedback from the actual level of beer in the can.

We would envisage supplying the laser, EMAT and signal
5 processing means 116 as a kit for original equipment, and for retro fitting to existing canning/container filling lines.

In order to generate ultrasound in a material, the material must be 'shocked' or stressed. The frequency content of the ultrasound generated
10 will be governed by the rate at which such a stressed state is achieved. For example a periodic mechanical shock of time period one microsecond would generate an ultrasonic wave predominantly of frequency one megahertz. The frequency content of a temporally spike-like ultrasonic generation mechanism contains a range of frequencies and is termed
15 broadband. Making the generating spike sharper in time domain increases the magnitude of the higher frequency ultrasonic components in the resulting ultrasonic wave.

Pulsed lasers can be used to generate ultrasonic waves by rapidly
20 stressing the surface or surface layer of a sample when directed onto that sample. If the laser beam is of sufficient energy density at the sample surface it can generate a plasma, which may comprise particles that have derived from the sample surface and the surrounding atmosphere at that point. This plasma has a net resultant force normal to the surface of the
25 sample and thus predominantly generates a longitudinal wave in the sample. This mode of laser generated ultrasound is said to be in the ablative regime. At low laser energy densities the illuminated area of the sample undergoes a rapid heating, and the ultrasound mode generated is predominantly a shear wave mode in a rigid medium.

The high energy density required to form a plasma on a sample surface usually requires the incident pulsed laser beam to be focused. One problem with this type of ultrasonic generation of longitudinal waves is that the surface of the sample may absorb significant amounts of the incident energy and be in some way damaged. This would be the case for instance when a TEA CO₂ laser is focused onto a painted metal surface, where the paint would be damaged or removed from the surface.

A technique of using a plasma to generate ultrasound without damaging the sample surface has been developed. The technique exploits the fact that a plasma is a hot expanding volume of particles, and directs the plasma onto the sample surface without exposing that surface to the laser beam. This is achieved by generating the plasma on a target in front of or close to the sample in which the ultrasound is to be generated. This can help to avoid marking the sample.

Figure 9 shows a laser beam 99 focused by a lens 100 onto a target 101 in front of the sample 102 (or article) being tested. The laser beam 99 is thus totally blocked from the sample 102. The laser beam 99 generates a plasma 103 at the target 101. The plasma 103 is free to expand away from the point of impact on the target 101 and impacts on the sample 102. Thus only the plasma 103 is incident on the surface of the sample 102 where ultrasound is to be generated. This technique will predominantly generate longitudinal ultrasonic waves. A metal (e.g. stainless steel) target 5mm thick, spaced a few mm from the sample is preferred.

We believe that satisfactory results can be achieved with a target - sample spacing in the range >0 mm to 10 mm, most preferably in the range 1 mm to 5 mm.

The thickness of the target is in part determined by the laser, but a thickness of about 0.1 to 5 mm is preferred.

5 The target may be damaged by the laser beam (or a hole made in it). This may mean that the target has to be moved between laser pulses to interpose a different part of the target, or different target. The target may be capable of obstructing direct impact from the laser beam for a large number of pulses, producing an acceptable plasma. If so it may not
10 need moving between every pulse.

It will be appreciated that the transit time measurement that we perform does not measure the absolute height of liquid in a container, but rather the height of the surface above the ultrasound receiver. However,
15 because we know the height of the receiver relative to the base of the container we can know the height of the surface of the liquid relative to the base of the container. It is necessary to have both the emitter and receiver of ultrasound below the level of the liquid in the container (because ultrasound of the required frequency content does not propagate
20 well in air).

The ultrasound wave that is generated by the plasma has a spherical wavefront, and this is reflected by the gas-liquid interface as a reflection of the spherical wavefront.
25

We prefer to derive the first signal from the ultrasonic wave which has propagated from the generation location directly to the detection location in a known pathlength. We may in some circumstances prefer to use the signal derived from a reflected ultrasonic wave off the sides or

bottom of the container which again has propagated via a known pathlength.

5 As the velocity of sound in a medium is dependent upon the temperature and composition of the medium a measurement of the actual transit time for a path of known length through the contents of the container will allow us to determine the height of the medium independent of the temperature and composition of the medium.

10 It will also be appreciated that if we use an EMAT as a receiver it cannot detect ultrasound unless the region of the container at which it detects is metallic, or has a metallic content. Foil-lined cardboard or plastic containers can be accommodated. Indeed, we may deliberately arrange for the containers to have a metal or metallic area or member at
15 or in its wall at a region where, in use, the EMAT will be used as a detector. Because of the difficulty in orientating containers on a moving filling line we prefer to have the metal or metallic area or member extend completely around the periphery of the container.

20 The metal or metallic area or member may be provided on a label or sleeve of the container, possibly on the inner surface of the label or sleeve, possibly by having a metallic backing or band on the label or sleeve.

25 Other variations will now be described by way of further example.

Figure 10 shows a pair of electrical discharge plates 203 and 204 adjacent a side wall of a can (again referenced 201). A discharge from one plate to the other creates a plasma, referenced 200, which generates
30 ultrasound.

Figure 11 shows a container 201 having ultrasound generated in it by momentum transfer from a plasma 200 generated by a laser beam 205 striking a plate-like target 206 extending radially to the container. The plasma 200 expands laterally off the target 206, in a direction generally parallel to the plane of the plate member 206 (of course without collimating means the plasma expands generally spherically, but is constrained by the plate 206). Collimating means, mechanical (e.g. plate(s) with holes in them) or magnetic guiding, or both may be provided.

Figure 12 shows a container surface 201 having ultrasound generated in it by plasma 200 generated by the impact of a laser beam 207 onto a plate 208. The plate 208 extends generally parallel to the central axis of the container and has a hole 209 in it. Plasma escapes through the hole 209 on to the container.

We may have a target-container separation of 30mm or more. It is preferably less than 10mm. However, it is desirable to have a minimum target-container separation in excess of 1mm in order to ensure that the plasma has attained sufficient momentum normal to the surface of the container to generate ultrasound in the container contents with sufficient energy to perform the measurement.

We have appreciated that it is beneficial to generate plasma close to the edge of a target that also acts as a mask preventing the laser beam from directly striking the container. We prefer to confine the impact of the plasma to a localised region on the container; this produces the desired ultrasound source. In the arrangements of Figures 9 and 12 we prefer to have the laser beam strike the target as close to the edge of the

target (or hole in the case of the arrangement of Figure 12) as possible, consistent with ensuring that no portion of the laser beam directly impinges on the container. A distance of about 1mm from the edge is preferred.

5

The laser pulses used to generate ultrasound preferably have a rise time of about 100ns or less, and have a pulse energy between 0.1 and 10J.

The laser beam may be focused to a spot of about 5mm diameter.

10

It should be made clear that although in many embodiments of the invention we have referred to "plasma" striking the container to generate ultrasound in the container (and hence in its contents) the plasma itself (as high energy ionised particles) need not reach the container still as a true plasma. The ions could reform as atoms - it is the momentum transfer that is important. Indeed after generating a plasma it may be that by the time the energy reaches the container there is only a supersonic (or possibly fast subsonic) shock wave in the air (or other gaseous medium surrounding the can) and little or no true plasma left. The invention does not therefore necessarily require ionised true plasma to strike the container. We may therefore wish "plasma generation means" to be read as "shock wave generation means" (non-mechanical contact, non-liquid contact).

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It will be appreciated that we may choose to use the detection of the first "straight-through" wave to serve as an accurate reference point so that the transit time of the second "top-surface reflection" wave is accurately known (variation in delays in laser actuation, and ultrasound generation at the container are eliminated from the processing of the

signals by using the time difference). We may then use that time difference to evaluate the height of the contents.

We may know the absolute transit time of the first wave through
5 the contents of the container and the absolute transit time of the second
wave through the contents of the container and subtract one from the other
to determine the time difference between detection of the waves.
Alternatively, we may use detection of the first wave as a reference point
and measure the time between detection of the first wave and detection of
10 the second wave.

The time difference between detection of the straight-through wave
and detection of its reflection back from the opposite side of the container
(two traverses of the diameter of the container) can be used, effectively,
15 to determine the velocity of sound in the contents of the container (if the
diameter of the container is known), thereby enabling the apparatus to
work with containers with different contents, or with contents at different
temperatures. We may use a knowledge of the time difference between
detection of the straight-through wave and detection of the top surface
20 reflection wave, and between the first detection of the straight-through
wave and the detection of the reflection of that wave, in an appropriate
algorithm.

CLAIMS

1. A fill level monitoring apparatus adapted to monitor the height of contents in a container, comprising an ultrasound receiver and signal
5 processing means adapted to receive signals from the receiver, the arrangement being such that the signal processing means identifies a first signal which is representative of a first ultrasonic wave which has been transmitted through the contents of the container independently of the height of the contents in the container, and a second signal that is
10 representative of a second ultrasonic wave that has been reflected from the interface between the surface of the contents in the container and the environment above the contents, and in which the signal processing means uses the difference in transit times for the two waves to provide an indication of the level of the contents in the container.
- 15
2. A fill level monitoring apparatus according to Claim 1 in which the first and second waves are parts of the same ultrasonic wavefront in three dimensions.
- 20
3. A fill level monitoring apparatus according to Claim 1 or Claim 2 in which the first signal is representative of a wave that has travelled directly to the receiver without reflection.
4. A fill level monitoring apparatus according to any preceding claim,
25 in which the ultrasound receiver is couplant free.
5. A fill level monitoring apparatus according to any preceding claim, in which the apparatus includes a broadband ultrasound receiver.

6. A fill level monitoring apparatus according to Claim 5, in which the broadband ultrasound receiver can detect from low frequency to above 1MHz.
- 5 7. A fill level monitoring apparatus according to any preceding claim, in which the receiver is an EMAT.
8. A fill level monitoring apparatus according to Claim 7, in which the EMAT is polarised, to give maximum sensitivity to top surface
10 reflections of ultrasound from the upper surface of the contents of the container.
9. A fill level monitoring apparatus according to any preceding claim, in which the receiver detects ultrasound from only a localised region in
15 height of the container.
10. A fill level monitoring apparatus according to Claim 9 in which the receiver detects ultrasound over a localised region of generally vertical dimension height of 4mm or less.
20
11. A fill level monitoring apparatus according to any preceding claim, in which the apparatus is arranged such that the ultrasound receiver is disposed to a side of a container.
- 25 12. A fill level monitoring apparatus according to any preceding claim, in which the receiver is not more than 10mm from the surface of the container when the ultrasound waves that generate the first and second signals are detected.

13. A fill level monitoring apparatus according to any preceding claim, which includes ultrasound generation means.
14. A fill level monitoring apparatus according to Claim 13 in which
5 the ultrasound generation means is adapted to generate simultaneously the ultrasound wave(s) which give rise to the first and second signals.
15. A fill level monitoring apparatus according to Claim 13 or
Claim 14 in which the ultrasound generation means is adapted to generate
10 at the same location on the container the ultrasound wave(s) which when detected generate the first and second signals.
16. A fill level monitoring apparatus according to any one of
Claims 13 to 15 in which the ultrasound generation means is adapted to
15 generate the ultrasound waves in a localised region in height of the container.
17. A fill level monitoring apparatus according to any of
Claims 13 to 16 in which the ultrasound generation means includes a
20 laser.
18. A fill level monitoring apparatus according to any of
Claims 13 to 17, in which the ultrasound generation means is couplant
free.
25
19. A fill level monitoring apparatus according to any of
Claims 13 to 18, in which the ultrasound generation means is capable of
generating a broadband ultrasonic wave.

20. A fill level monitoring apparatus according to any of Claims 13 to 19, in which the apparatus is arranged such that the ultrasound generation means is disposed to the side of the container.
- 5 21. A fill level monitoring apparatus according to any one of Claims 13 to 20, in which the receiver and generation means are on opposite sides of the container.
22. A fill level monitoring apparatus according to any of
10 Claims 13 to 20, in which when viewed from above the container the receiver and the generation means are at an angle away from the 180° straight-through configuration.
23. A fill level monitoring apparatus according to any one of
15 Claims 13 to 20, in which the receiver and the generation means are at substantially the same height relative to the container.
24. A fill level monitoring apparatus according to any of
20 Claims 13 to 22, in which the receiver is at a different height to that of the generation means relative to the container.
25. A fill level monitoring apparatus according to any one of
25 Claims 13 to 24, in which the apparatus is capable of generating a second set of first and second waves shortly after the first set.
26. A fill level monitoring apparatus according to any preceding claim in which the receiver is adapted to detect ultrasonic waves which generate a second set of first and second signals, and in which the signal processing means is adapted to verify the difference in transit time of the

first set of first and second waves using the second set of first and second signals.

27. A fill level monitoring apparatus according to any preceding claim,
5 in which the container is moving during the transmission of the ultrasonic wave that creates the first signal and/or reflection of the ultrasonic wave that creates the second signal.

28. A fill level monitoring apparatus according to any preceding claim
10 which is used with a container that is metallic or has a metal region.

29. A fill level monitoring apparatus according to any preceding claim,
in which there is a feedback mechanism whereby the apparatus can feed
back signals, derived from the first and second signals, to control
15 apparatus for subsequent use in controlling the filling operation or filling apparatus.

30. A fill level monitoring apparatus according to any preceding claim,
in which the apparatus has an electronic signal filter, such as a band pass
20 filter.

31. A fill level monitoring apparatus according to any preceding claim,
in which the apparatus has a signal amplifier, which is tuned to the same
band of frequencies as the receiver.
25

32. A fill level monitoring apparatus adapted to monitor the height of
contents in a container, comprising an ultrasound receiver and signal
processing means adapted to receive signals from the receiver, the
arrangement being such that the signal processing means identifies a
30 signal which is representative of an ultrasonic wave which has been

reflected from the interface between the surface of the contents of the container and the environment above the contents, and in which the signal processing means uses the transit time of the ultrasonic wave to provide an indication of the level of the contents in the container.

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33. A container filling line comprising container filling means adapted to deliver contents to a container, control means controlling the operation of the container filling means, and fill-level monitoring apparatus in accordance with the apparatus of any of Claims 1 to 32.

10

34. A method of monitoring the fill level of contents in a container comprising generating ultrasound waves in the container, detecting a straight through ultrasound wave, detecting a top surface reflected wave from the top surface of the contents of the container, and measuring the time difference between the detection of the two waves in order to obtain an indication of the level of the contents in the container.

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35. A method of monitoring the height of contents in a container comprising generating an ultrasonic wave; reflecting it from the interface between the contents of the container and the environment above the contents; determining the transit time of the reflected wave; and using a knowledge of the geometry of the container and of the transit time to determine the height of the contents.

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36. A non-contact apparatus for monitoring contents of a container comprising non-contact ultrasonic wave generation means adapted to produce in use an ultrasonic wave in a container being monitored, non-contact ultrasonic wave detector means adapted to detect an ultrasonic wave and to generate a detection signal dependent upon the ultrasonic wave which is detected, and signal processing means adapted to process

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the detection signal generated by the ultrasonic wave detector means in order to detect or monitor a particular characteristic of the contents of the container, and in which the wave generation means comprises plasma producing means adapted to produce a plasma at or near the surface of the
5 container.

37. A non-contact apparatus according to Claim 36, in which the plasma producing means comprises a laser.

10 38. A non-contact apparatus according to Claim 37, in which the laser is adapted to operate in pulsed mode.

39. A non-contact apparatus according to Claim 34, in which the plasma producing means is an electrical source for example an electrical
15 discharge.

40. A non-contact apparatus according to any of Claims 36 to 39, in which the plasma producing means produces plasma at the container surface.
20

41. A non-contact apparatus according to Claim 40 in which a laser beam or an electrical spark is adapted to strike the container.

42. A non-contact apparatus according to any of Claims 36 to 39, in which spaced-plasma generation means is provided adapted to generate the
25 plasma at a region close to the container, but not actually at the wall of the container.

43. A non-contact apparatus according to Claim 42, in which the spaced plasma generation means includes a target that is not the container.
30

44. A non-contact apparatus according to Claim 43 in which the plasma producing means comprises an energy source having an energy emitting region, and the target comprises a member disposed between the energy emitting region and the container.
5

45. A couplant-free method of monitoring the contents of a container comprising, firstly, generating an ultrasonic wave within the contents of the container, secondly detecting an ultrasonic wave at a localised region of the container and producing a detection signal dependent upon the detected ultrasonic wave, and thirdly processing the detection signal in order to determine a particular characteristic of the contents of the container, the ultrasonic wave being generated by the impact of a laser beam or by a plasma generating device adapted to generate plasma at or slightly spaced from the container.
10
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46. Ultrasound generating means for generating ultrasound in an article by means of a shockwave, the means comprising an energy source adapted to create a plasma shockwave spaced from an article, the energy source being arranged such that the energy it emits does not impinge directly upon the article but such that the shockwave does impinge upon the article.
20

47. Ultrasound generating means according to Claim 46, in which there is a target spaced from the article, and in which energy from the energy source impinges upon the target.
25

48. Ultrasound generating means according to Claim 47 in which the target is spaced from the article by a distance of the order of 1mm, 2mm, 3mm, 4mm, 5mm, or above.
30

49. Ultrasound generating means according to Claim 47 or Claim 48, in which the target is moveable.

5 50. Ultrasound generating means according to any of Claims 47 to 49, in which the target is replaceable.

51. Ultrasound generating means according to Claim 46, in which focusing means is provided to focus, at least to a degree, the energy from
10 the energy source onto the target.

52. Ultrasound generating means according to any of Claims 46 to 51, in which the energy source is a pulsed CO₂ laser.

15 53. A method of monitoring the fill level of contents in a container comprising generating a first ultrasonic wave in the container and measuring its transit time to travel a first path through the contents of the container that is independent of the level of contents in the container; generating a second ultrasonic wave in the container and measuring its
20 transit time to travel a second path through the contents of the container that has a reflection from the surface of the contents of the container; and using the difference in transit time to evaluate the height to which the container is filled.

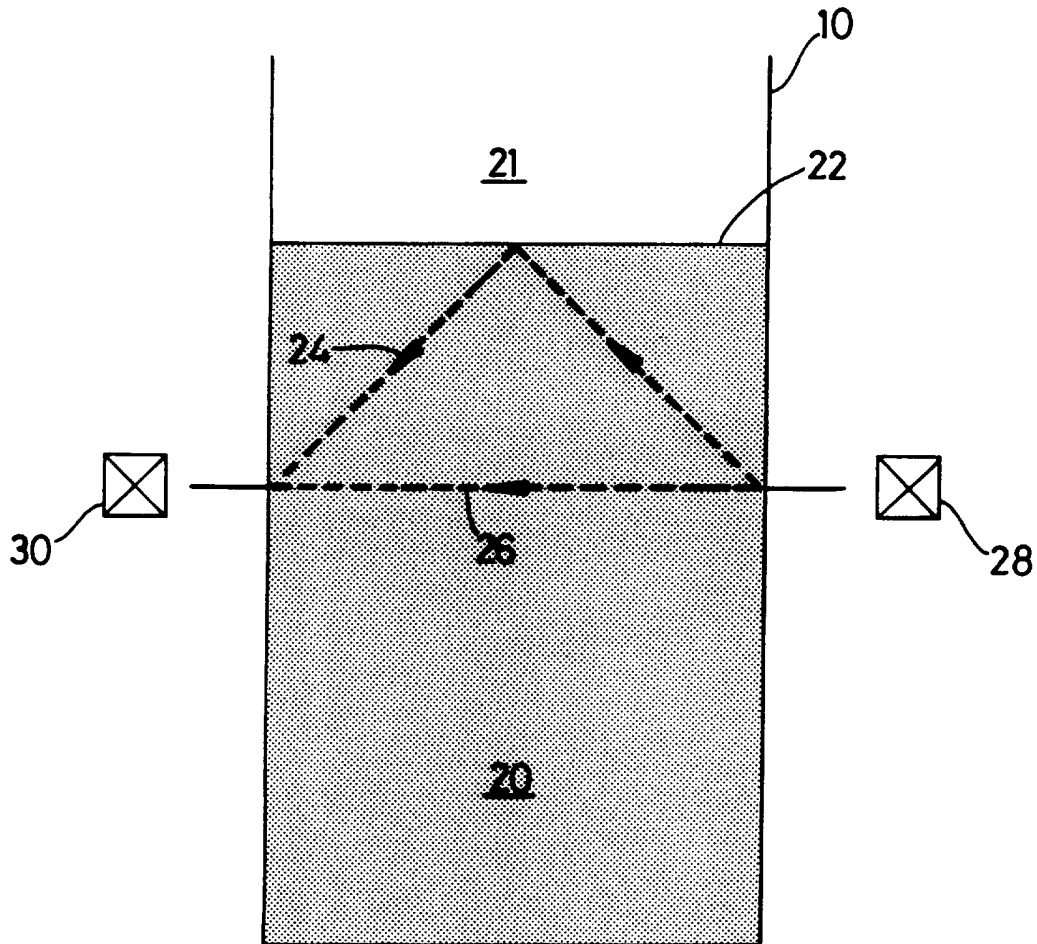


Fig.1

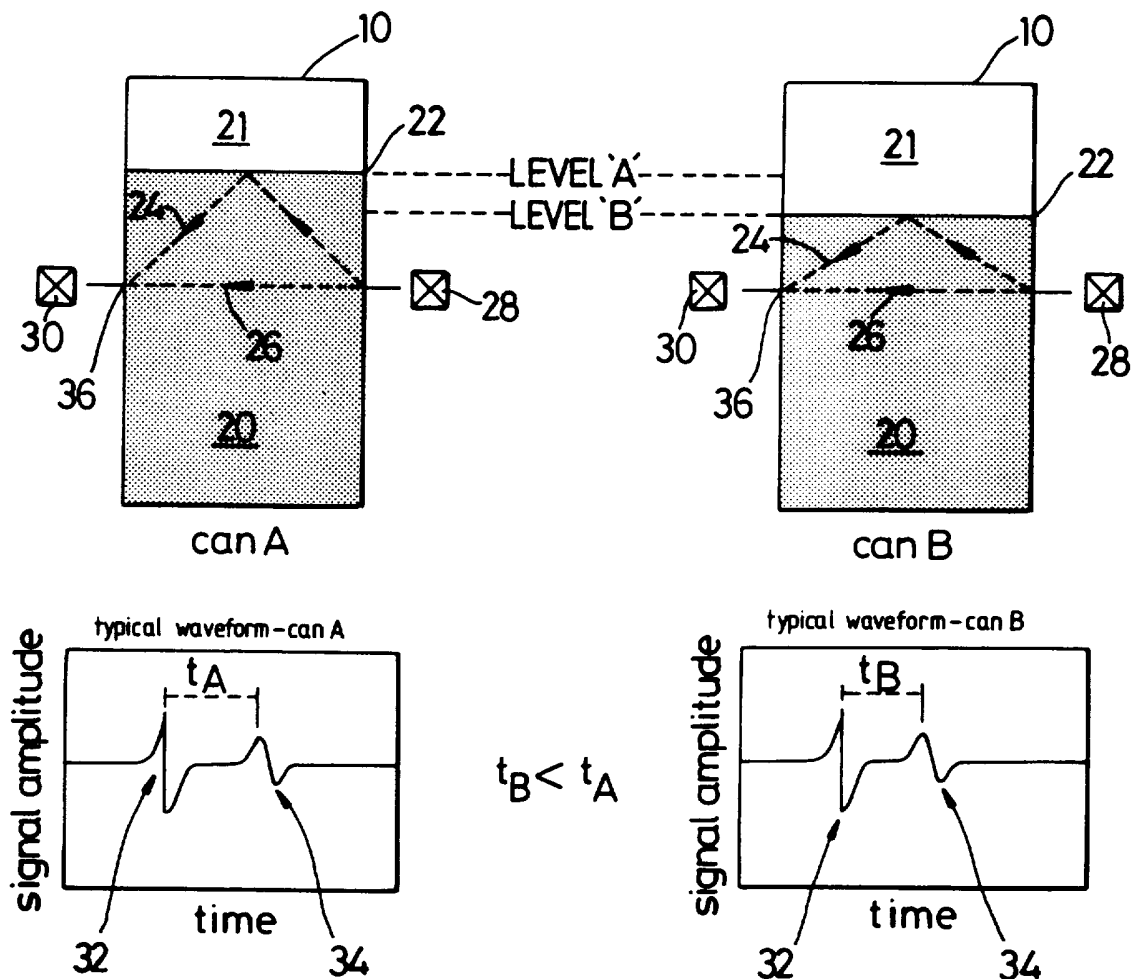


Fig. 2

Fig. 2'

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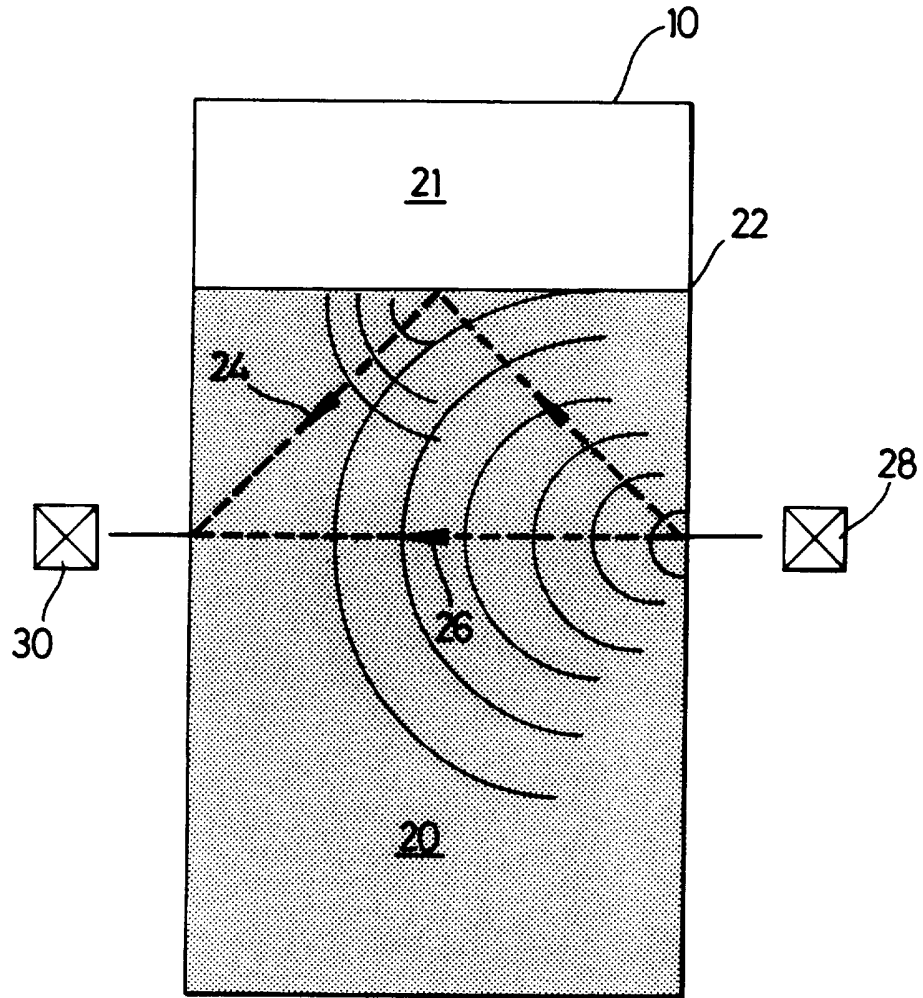


Fig. 3

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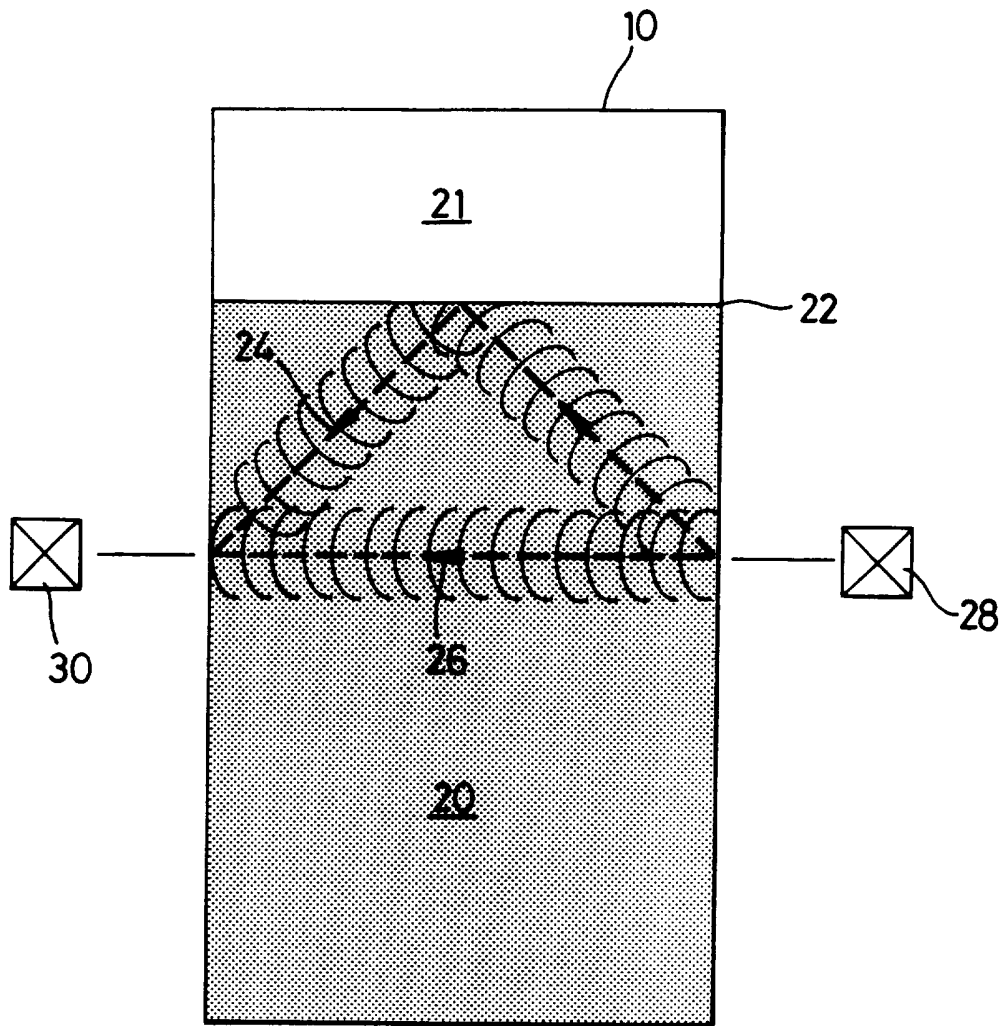


Fig. 4

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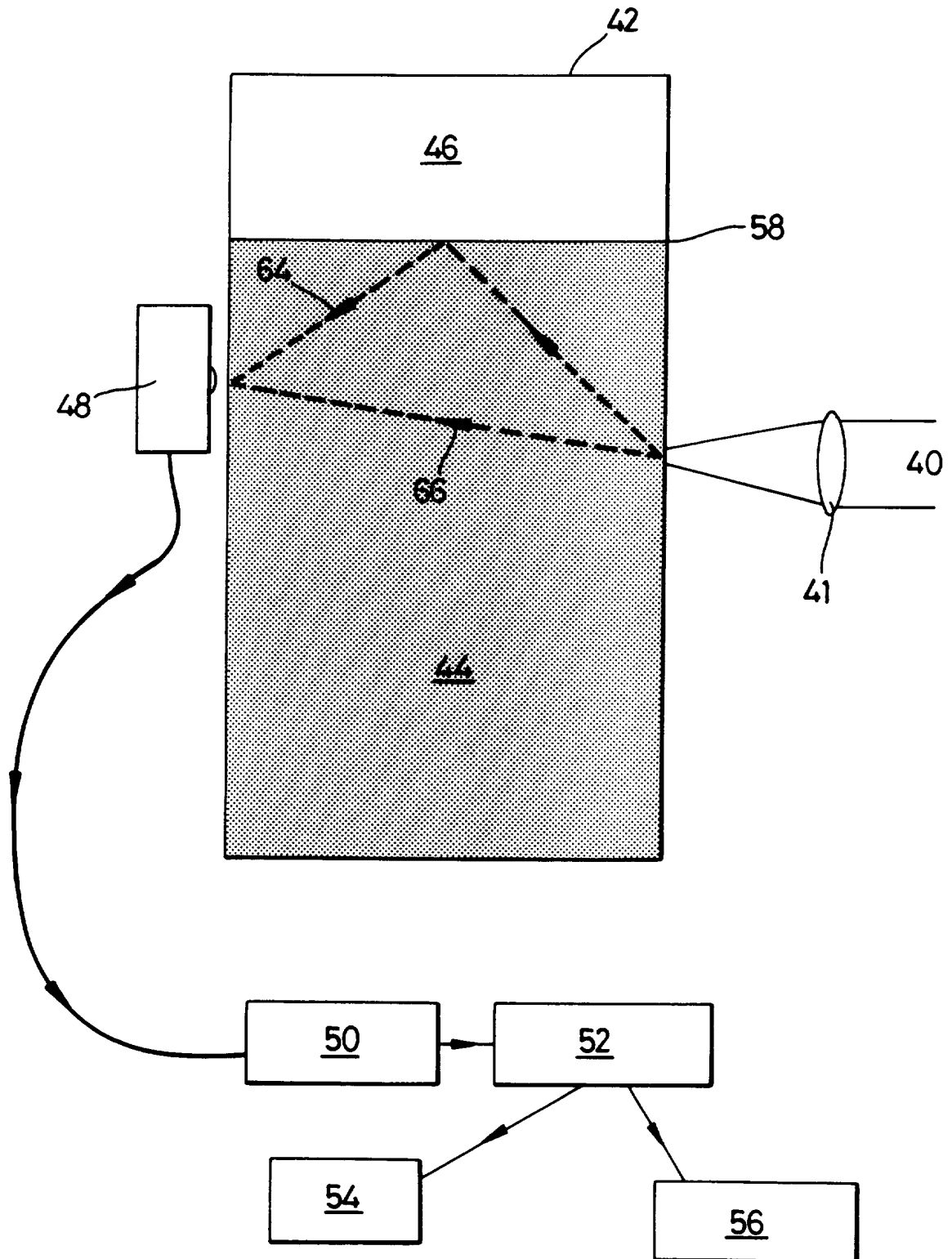


Fig. 5

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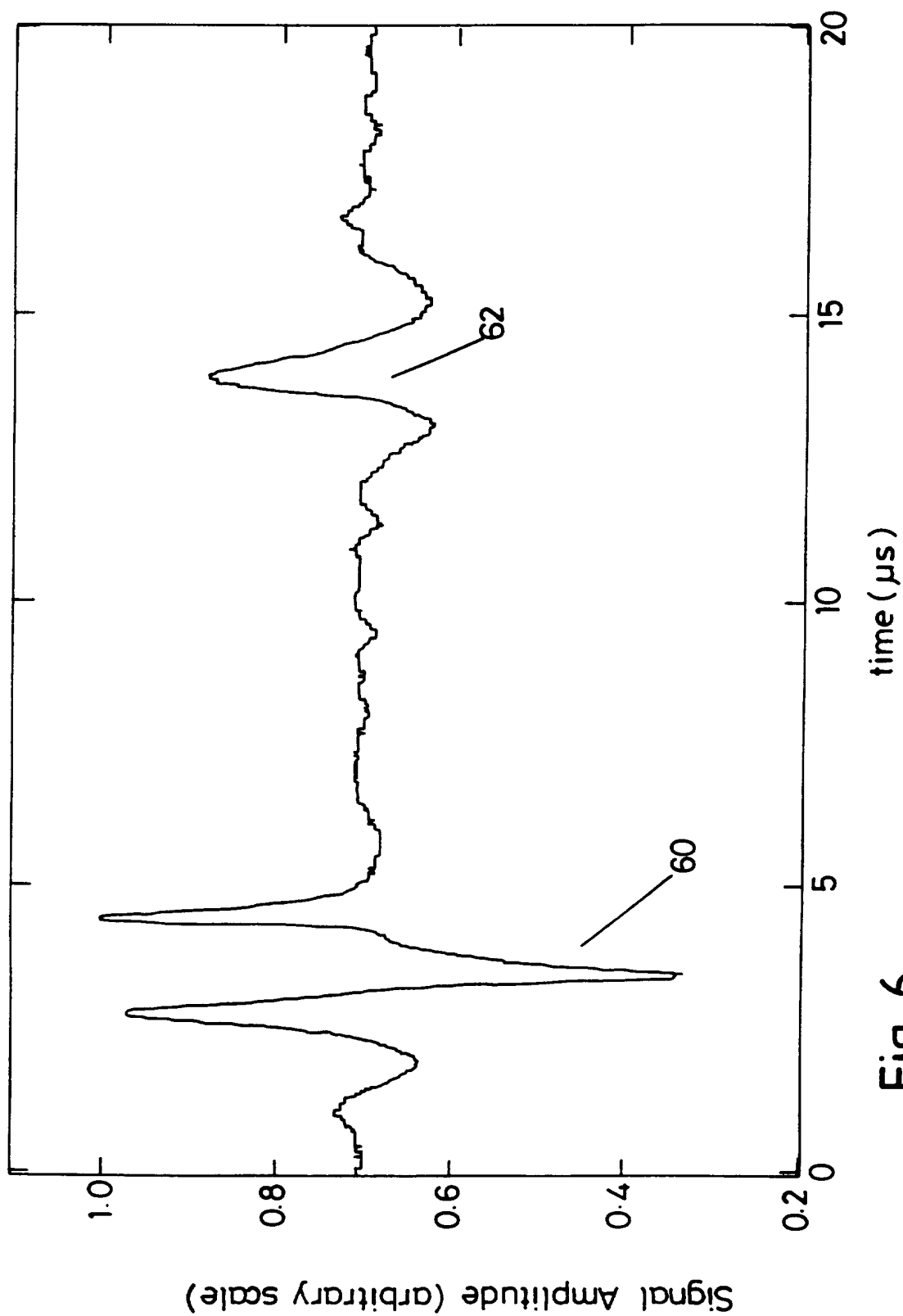


Fig. 6

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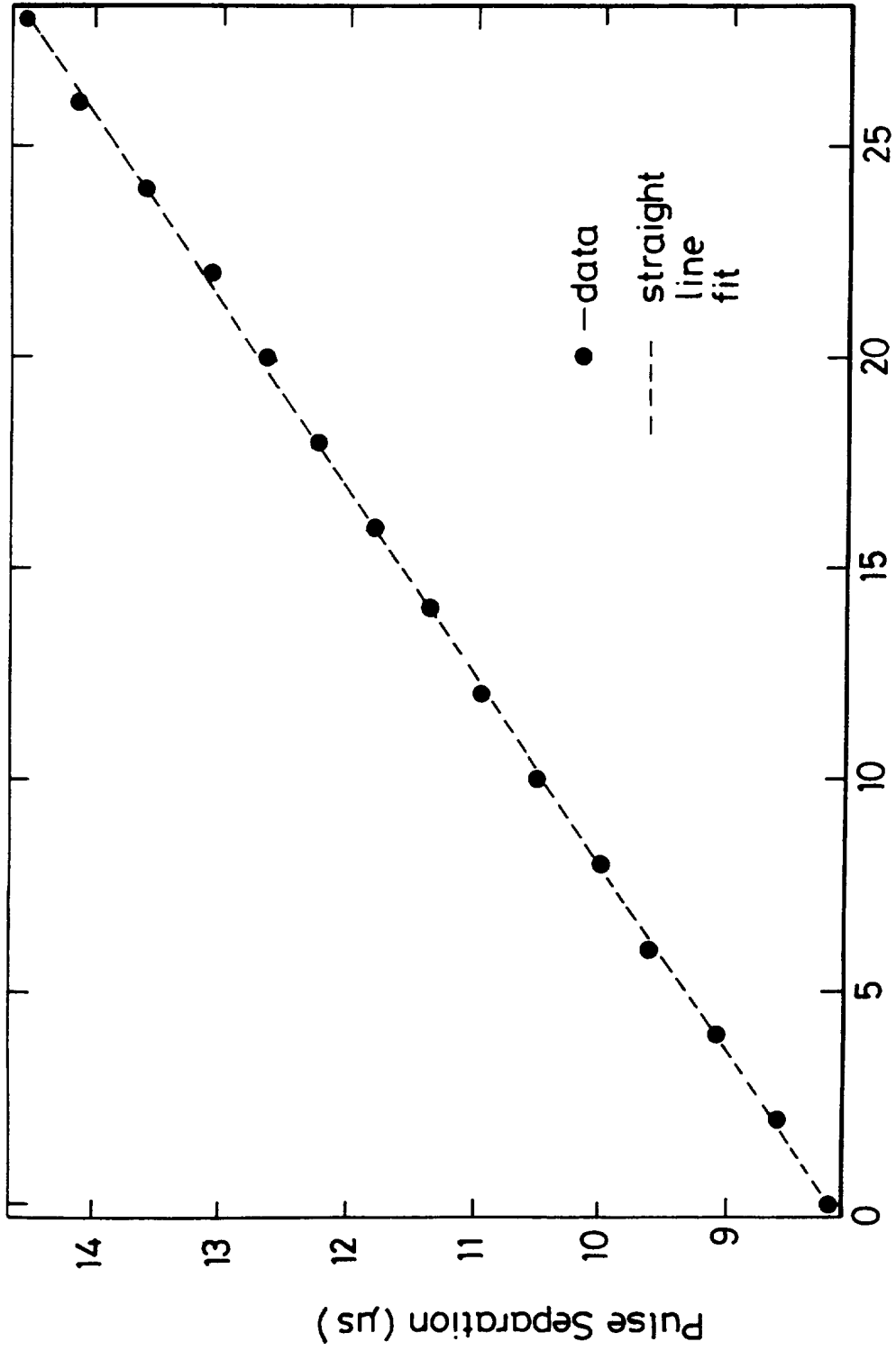


Fig.7 added volume (ml)

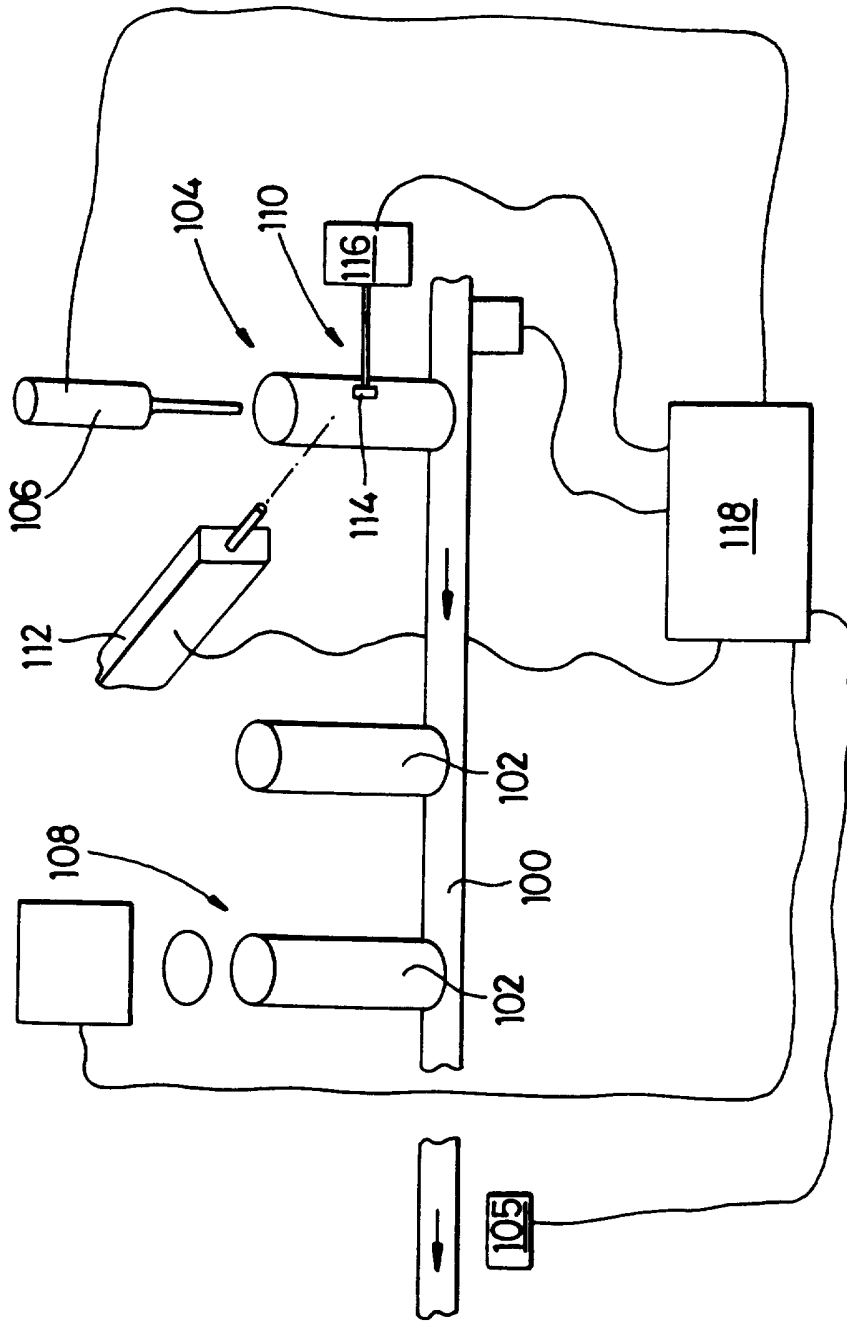


Fig. 8

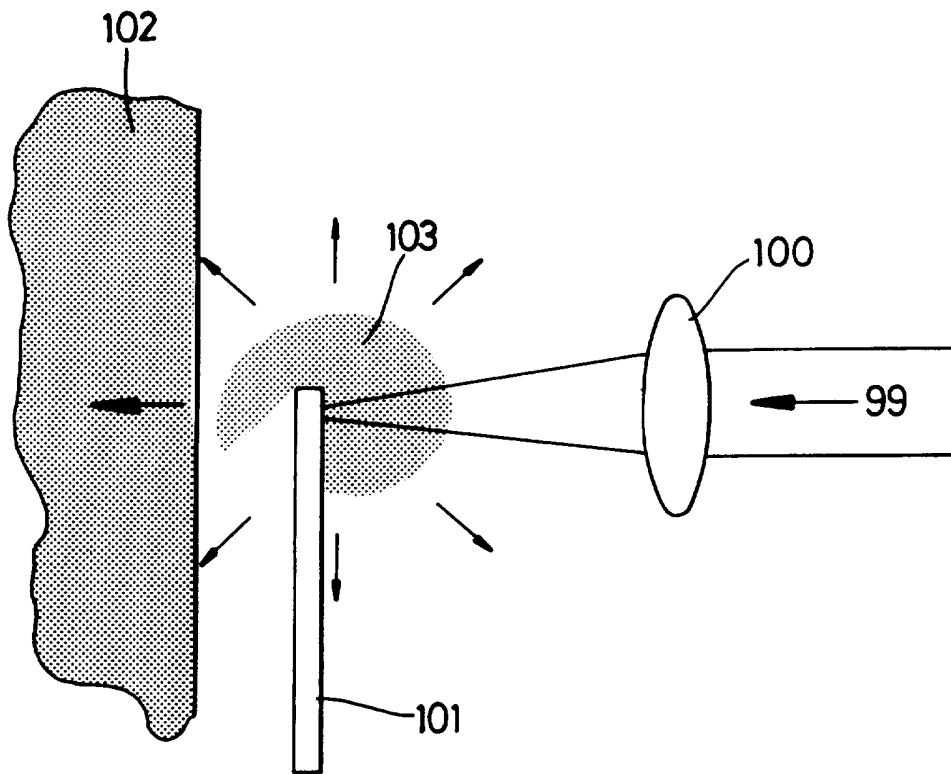


Fig. 9

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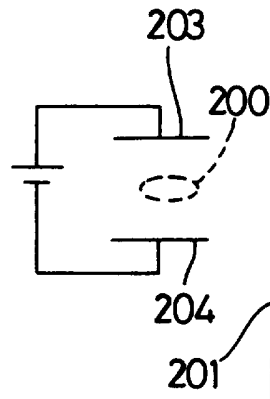


Fig.10

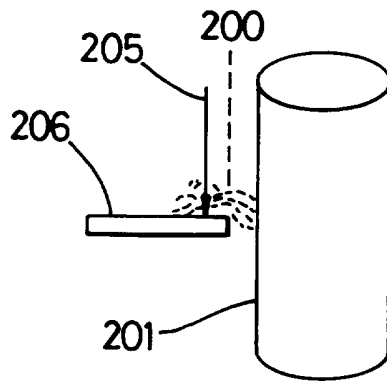


Fig.11

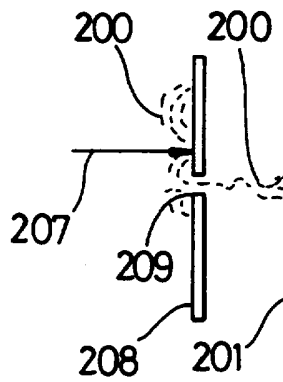


Fig.12