

(CONVENTION: By one or more persons and/or a Company.)

620488

Form 4.

COMMONWEALTH OF AUSTRALIA

Patents Act 1952-1969

CONVENTION APPLICATION FOR A PATENT

(1) Here insert (in full) Name or Names of Applicant or Applicants, followed by Address(es).

I (1) ING. ARMIN W. HRDLICKA of Anzengruberstrasse 34, A-9020 Klagenfurt, Austria

(2) Here insert Title of Invention.

hereby apply for the grant of a Patent for an invention entitled: A. METHOD. FOR. MEASURING. LENGTH. AND. APPARATUS. FOR. IMPLEMENTING. THE. METHOD

(3) Here insert number(s) of basic application(s).

which is described in the accompanying complete specification. This applications is a Covention application and is based on the application numbered: A. 68/89. and A. 2375/89.

(4) Here insert Name of basic Country or Countries, and basic date or dates.

for a patent or similar protection made in: Austria on 16th January 1989 and 16th October 1989

My address for service is WATERMARK PATENT & TRADEMARK ATTORNEYS 290 Burwood Road, Hawthorn, Victoria, Australia.

DATED this 3rd day of January 1990

F013534

04/01/90

(5) Signature(s) of Applicant(s) or Seal of Company and Signatures of its Officers as prescribed by its Articles of Association.

ING. ARMIN W. HRDLICKA by L. J. Dyson

Registered Patent Attorney

To: THE COMMISSIONER OF PATENTS.

WATERMARK PATENT & TRADEMARK ATTORNEYS

DECLARATION IN SUPPORT OF A CONVENTION APPLICATION FOR A PATENT OR PATENT OF ADDITION

(1) Here insert (in full) Name of Company.

In support of the Convention Application made by⁽¹⁾.....

ING. ARMIN W. HRDLICKA

(hereinafter referred to as the applicant) for a Patent

(2) Here insert title of Invention.

for an invention entitled:⁽²⁾.....

A METHOD OF MEASURING LENGTH, AND APPARATUS FOR

IMPLEMENTING THE METHOD

(3) Here insert full Name and Address, of Company official authorized to make declaration.

I,⁽³⁾ ING. ARMIN W. HRDLICKA

of Anzengruberstrasse 34, A-9020, Klagenfurt, AUSTRIA

do solemnly and sincerely declare as follows:

~~1. I am authorised by the applicant for the patent to make this declaration on its behalf.~~

2. The basic applications as defined by Section 141 of the Act ~~was~~ were each made in⁽⁴⁾ AUSTRIA

on the 16th day of January, 1989, by me and

on the 16th day of October, 1989, by me

(4) Here insert basic Country or Countries followed by date or dates and basic Applicant or Applicants.

3.⁽⁵⁾ Names of Inventors on reverse sidethereof.

~~is/~~are the actual inventors of the invention and the facts upon which the applicant is entitled to make the application are as follow:

The applicant is the assignee of the said actual Inventors.

(5) Here insert (in full) Name and Address of Actual Inventor or Inventors.

4. The basic applications referred to in paragraph 2 of this Declaration ~~was~~ were the first applications made in a Convention country in respect of the invention the subject of the application.

DECLARED at Klagenfurt, AUSTRIA

this 7th day of December, 19 89.

(6) Signature.

(6)

Ing. Armin W. Hrdlicka

To: THE COMMISSIONER OF PATENTS.

(12) PATENT ABRIDGMENT (11) Document No. AU-B-47672/90
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A METHOD FOR MEASURING LENGTH, AND APPARATUS FOR IMPLEMENTING THE METHOD
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- (56) Prior Art Documents
US 3737770
US 3237445
FR 1467228
- (57) Claim

1. A method for determining in contactless manner the length of a column of liquid or gas contained in a tubular cavity sealed unilaterally or open on both sides, or the length of a solid bar, in which method a standing wave of ~~known~~^{determinable} speed of propagation and ~~known~~^{determinable} frequency or wavelength is generated in said column or bar, a node of said standing wave being present at one end of the column or bar, in particular at the closed end opposite the open end of the cavity, or an antinode being located at one of the two open ends of the cavity, and in which method the frequency of the standing wave is varied,

characterized in that

the amplitude of the standing wave is detected at that end of the column or bar where the wave is fed-in, in that the wave frequency is varied until at least two consecutive maxima (anti-nodes) or an amplitude minimum (node) following a maximum have been detected, and in that the length of the column or bar is computed at ~~known~~ frequency f of the standing wave using the relation

$$L = \sigma c / [2(f_u - f_n)] \quad \text{---(3)}$$

where L is the length of the bar or column, c is the speed of propagation of the wave, f_n is the wave frequency of the standing wave at the first determined maximum or minimum, f_u is the wave frequency of the standing wave at the last determined maximum or minimum from the nth to the uth maximum or minimum

($\sigma = u - n$), or at known wavelength λ using the relation

$$L = \sigma \lambda_u \lambda_n / [2(\lambda_n - \lambda_u)] \quad \text{---(5)}$$

where L is the length of the bar or column,

λ_n is the wavelength of the standing wave at the first ascertained maximum or minimum, λ_u is the wavelength of the standing wave at the last ascertained maximum or minimum and σ is the number of ascertained maxima or minima from the nth to the uth maximum or minimum ($\sigma = u - n$).

COMPLETE SPECIFICATION
(ORIGINAL)

Class

Int. Class

Application Number:
Lodged:

Complete Specification Lodged:
Accepted:
Published:

Priority :

Related Art :

Name of Applicant : ING. ARMIN W. HRDLICKA

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Complete Specification for the invention entitled:

A METHOD FOR MEASURING LENGTH, AND APPARATUS FOR IMPLEMENTING THE METHOD

The following statement is a full description of this invention, including the best method of performing it known to :-

US

A METHOD FOR MEASURING LENGTH, AND APPARATUS FOR IMPLEMENTING THE METHOD.

Description

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The invention concerns a method for determining in contact-less manner the length of a column of liquid or gaseous substance contained in a tubular cavity closed on one side or open at both, or of a solid bar, a standing wave of known frequency or wavelength and with known speed of propagation being generated in the column or the bar, one node of said standing wave being located at one end of the bar or column, in particular at the closed end opposite the cavity's open end, or an antinode being located at one of the two open ends of the cavity and the frequency of the standing wave being varied.

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Heretofore known methods for measuring levels, be it in hydrology, in the zones of surface or of ground waters, in research on computing waste water channels or measuring the level to which reservoirs are filled, all rest predominantly on traditional or costly measurement techniques illustratively employing pressure pickups or floats, or being based on measurements of transit times (echoing).

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Aside the floats used for many years and of which the height function of the level to be measured is sensed by gears, pressure pickups are used which by means of a sensor at their tip measure liquid columns between the pickup tip and the surface of the medium.

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Furthermore measurement procedures are used in hydrology that employ stationary systems which by means of pressure-balance at a weighing apparatus determine the height of a water column using a so-called bubble mouthpiece (for instance the compressed air level Ω made by SEBA Hydrometrie, Kaufbeuren). Again cable-lights sondes and depth probes are being used. As regards the cable-lights sondes, the dipping of a sonde tip into ground water of which the level must be ascertained is being displayed. A length-graduation on the cable allows reading off the height to the water surface. In depth plumbing apparatus,

a counter is made to stop when the probe impacts the water surface, and here too the height to the water surface may be determined.

In the known transit-time measurements using echoing, a pulse transmitted by a pulse generator is reflected from the water surface or other object and the time between pulse emission and return for the reflected pulse is taken as the measure of the path covered. Such pulse-echo measurements are hardly used in hydrology because of the expense.

One of the drawbacks of the known mechanical measuring means is that the test values come from inaccurate devices. Besides the inaccuracies due to temperature fluctuations, there are also other difficulties, for instance when inserting floats in plumbing pipes used for ground-water measurements, in particular when these frequently long plumbing pipes are bent.

Temperature-caused inaccuracies also occur in cable-lights sondes and depth-plumbing apparatus. These test devices additionally incur the defect of the elongation of the cable by its own weight. Probes which hang for a long time in water in stationary equipment may become permeable. Again, the probes may tear when being pulled out and hence be lost.

The French patent 2,185,095 describes a procedure to determine the dimensions of test bodies. For that purpose the test bodies are moved into a high-frequency (hf) chamber and two frequencies are ascertained, which are resonant frequencies of the test body of which the dimensions are being sought. On the basis of the equations stated in the French patent 2,185,095 the dimensions of the test body thereupon can be ascertained. An illustrative application provided by the French patent 2,185,095 is the determination of the thermal expansion coefficients of the material making up the test body.

No inference at all can be drawn from the French patent 2,195,085 on how to determine the length of a cavity filled with a gas or liquid or of a bar by generating a standing wave and ascertaining consecutive maxima (or two minima and one maximum followed by a minimum).

The US patent 3,237,445 is based on the conventional thickness determination from the equation $t = c/f$ using the resonant frequency of the body's fundamental, where this body's thickness must be ascertained. The US patent 3,237,445 further states about that known procedure that the resonance frequency is determined by continuously varying the ultrasonic frequency by assuming that the resonant frequency of the fundamental will provide a maximum signal after the ultrasound has passed through the body being measured (the body is especially transparent to the resonant frequency or the harmonics of same). To avert changing the frequency until the resonance frequency has been reached, the US patent 3,237,445 proposes pointing simultaneously ultra-sound with a plurality of frequencies at the test body and to determine the frequencies again after the sound has passed through it. Because the test body is especially transparent to the resonance frequency, the ultra-sound with the resonance frequency will be especially emphasized because that frequency was least damped as it passed through the body.

The British patent 842,241 relates to ultrasonic thickness determination from the equation $f = V/2T$, with the frequency of an oscillator being varied over a predetermined range of the frequency spectrum. At those frequencies where the oscillator responds (harmonic frequency), the half wavelength of the harmonic oscillation is determined and the thickness of the test body is directly read off mutually rotatable scales. The British patent 842,241 cites the presence of standing waves when determining thickness by ultra-sonics.

The German Auslegeschrift 23 12 062 discloses a wall-thickness test means operating on the principle of ultrasonic immersion resonance, an ultrasonic generator being acoustically coupled by a coupling liquid to the object of which it is desired to ascertain the wall thickness. The frequency of the ultrasonic generator is constantly modulated by an hf oscillator whereby transient standing waves are formed in rapid succession in the coupling liquid in many consecutive harmonics (in particular see column 7, lines 46 through column 8, line 6 of the German Auslegeschrift 23 12 062.

The German Auslegeschrift 31 17 236 makes use of a standing wave to ascertain the presence of an object within a monitored space, and whether such an object is moving. The frequency is not changed. No range determination of any kind is performed, rather it must be assumed that the piezo-ceramic generator of the wave motion is mounted a specific distance from the test body.

As regards the procedure disclosed in the German Auslegeschrift 21 44 472 for measuring the thickness of metal parts, a standing wave is generated between two antennas and the test body is placed between them. The frequency remains constant, and no attempt is made to use the standing waves of which the wavelength changes inside the body to measure this body's thickness.

The object of the present invention is to provide a simple and accurate method for measuring the length of or spacings between the end points of a path to be determined.

This problem is solved in the invention in that the amplitude of the standing wave is determined at that end of the column or bar where the wave is feed in, in that the frequency of the wave is so varied until at least two consecutive maxima (oscillation antinodes), two consecutive minima (nodes) or a minimum following a maximum of the standing wave have been detected, and in that the length of the bar or column is computed using the equation

$$L = \sigma c / [2(f_u - f_n)] \quad (3),$$

where L is the length of the bar or column, c is the speed of propagation of the wave, f_n the frequency of the standing wave at the first determined maximum or minimum, f_u the frequency of the standing wave at the last determined maximum or minimum and σ is the number of determined maximum or minimum from the nth to the uth maximum or minimum ($\sigma = u - n$), or, if the wavelength λ is known, from the equation

$$L = \sigma(\lambda_u \lambda_n) / [2(\lambda_n - \lambda_u)] \quad (5)$$

where L is the length of the bar or column, λ_n the wavelength of the standing wave at the first determined maximum or minimum, λ_u the wavelength of the last

determined maximum or minimum and σ the number of determined maxima or minima from the n th to the u th maximum or minimum ($\sigma = u - n$).

Preferably longitudinal waves are used in the invention.

Preferably a standing acoustic wave shall be generated in the invention in the column or bar.

The invention furthermore applies to the case of generating a standing sound wave in the column, especially for a gaseous substances, or in the bar.

In one practical embodiment of the invention, the standing wave in the column or bar is generated from that end where the amplitude of the standing wave is being detected.

Advantageously in practice and for the case of a column containing a tubular cavity sealed at one end, the standing wave shall be generated from the open end of the cavity, or that to generate the standing wave a sound generator, illustratively an audio-frequency generator shall be used.

The invention further extends to computing the length of the column of medium at known frequency and wave velocity of the standing wave generated in the column of medium from the formula

$$L = c/[2(f_n - f_{n-1})] \quad (1)$$

where L is the length of the column of medium, c the wave velocity, f_n the frequency of the n th maximum and f_{n-1} the frequency of the $(n-1)$ th maximum. This is a special case of the computation by formula (3), where $\sigma = 1$.

The method of the invention is superior in accuracy and as regards implementing costs to the known test procedures and is easily digitized.

Another object of the invention is apparatus with which to carry out its method for determining the length of a column of liquid or gas in a cavity sealed at one end or open at both, and to provide such apparatus of simple design to implement the method of the invention.

This problem is solved by the invention by apparatus characterized by a loudspeaker connected to a spacer of which the other end can be placed against

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one or the open end of the especially tubular cavity containing the column of gaseous or liquid substance, and by a receiving microphone as an acoustic pickup.

In the case of the column open at both sides, advantageously acoustically absorbing material may be mounted at that end of the column where the standing wave is generated, so that interfering reflection shall be averted.

Further preferred designs of the apparatus of the invention form the objects of claims 10 through 18.

The apparatus of the invention is used to couple the sound source required for the sound waves for the measurement of the length of an especially tubular cavity to that cavity. The energization of the gas or liquid column is achieved in such a way that the formation of unambiguous resonances shall be assured so that measurement by the method of the invention can be carried out simply and accurately. The coupling of the transmitted wave is performed by the apparatus of the invention in such manner that the reflected wave can freely exit the entry aperture. Therefore superpositions of the incoming wave with the reflected, standing wave cannot take place. Accordingly any differences in maxima or minima at the receiving microphone that might lead to spurious interpretation are averted.

Further a constant sound volume (acoustic pressure) of the waves generated by the audio generator is assured even when changing the frequency/wavelength in the operation of the apparatus of the invention, if additionally the acoustic pressure shall be measured in the resonance space of the loudspeaker and is fed back through a control circuit and kept constant.

Applications of the method and of the apparatus of the invention are the measurement of levels in hydrology and further the fill-condition of reservoirs. Moreover the invention may be used to measure manometric pressure fluctuations and to monitor consumption. The apparatus of the invention operates substantially without mechanical parts and the test values so obtained are at once processable further because already present in digital form. Liquid levels of reservoirs of any

liquid, for instance of oil and of liquid gas can be accurately measured and displayed.

Further applications of the invention are in aerodynamics, in meteorology and in vacuum technology, that is, wherever the measurement of manometric liquid columns (for instance mercury columns) is performed.

Because the method and the apparatus of the invention are very accurate, it is possible to determine the quantity of liquid removed from a reservoir by measuring the old and the new levels. In this application the known and complex, mechanical or inductive flow meters can be eliminated.

Illustratively a measurement of the invention is carried out by mounting a sound (audio) generator at the open or at one open end of the pipe and next to it an acoustic receiver (microphone). The sound generator emits sound for instance of known frequency and hence of known wavelength into the pipe. The acoustic receiver continuously senses the acoustic intensity at the open or at one open end of the pipe.

The known frequency (or wavelength) of the sound emitted by the acoustic generator is changed continuously (or stepwise), for instance being increased. As a result, fluctuations of sound intensity arise near the acoustic receiver (microphone). The acoustic intensity is a measure of the standing-wave amplitude. The acoustic intensity always reaches a maximum where there is an antinode of the sound wave produced by the acoustic generator in the pipe near the acoustic receiver (microphone). This is the case if the constant pipe length is one-fourths, three-fourths, five-fourths or seven-fourths etc. for the unilaterally closed pipe two-fourths, four-fourths, six-fourths or eight-fourths etc for the bilaterally open pipe of the wavelength generated each time by the acoustic generator. As a rule, antinodes (amplitude maxima) occur at the open or at one open pipe end if the pipe length (length of the gas or liquid column or of the bar) is an odd fraction of the four-fold pipe length for the unilaterally closed pipe, or an even fraction for the bilaterally open pipe, of the four-fold pipe length, or, in other words, when the pipe length is an odd four-fold of the quarter-wavelength for the laterally open pipe.

In the measurement method of the invention, the (known) frequency of the acoustic generator is changed and the resonance intensity is ascertained, whereby two consecutive wave amplitudes (antinodes) are then determined. There is no need to know what the number of the maximum is. The sought length of the column of medium at known frequency and wave velocity in the column of medium of the generated standing wave is computed from the equation below

$$L = c/[2(f_n - f_{n-1})] \quad (1)$$

where L is the length of the column of medium (in the stated example, the level in the well shaft), c the wave velocity (in the example the sound velocity), f_n the frequency of the nth maximum and f_{n-1} the frequency of the (n-1)th maximum.

Taking into account the speed of sound in air of $c = 331.3 + 0.6t$ m/s, equation (1) may be changed as follows

$$L = [331.3 + 0.6t]/[2(f_n - f_{n-1})] \quad (2)$$

where t is the temperature in °C of the medium being measured.

Eq. (1) is derived from the two relations, namely

$$(a) \quad L = (2n - 1)\lambda_n/4 = (2n - 1)c/4f_n$$

for the unilaterally closed pipe, or

$$L = [2n - 1] \frac{\lambda_n}{4} = \frac{2n - 1}{2} \cdot \frac{c}{f_n}$$

for the bilaterally open pipe,

for the nth maximum, and

$$(b) \quad L = [2(n-1) - 1]\lambda_{n-1}/4 = (2n-3)c/[4f_{n-1}]$$

for the unilaterally closed pipe, or

$$L = [2(n-1) - 1] \frac{\lambda_{n-1}}{4} = \frac{2n - 3}{2} \cdot \frac{c}{f_{n-1}}$$

for the bilaterally open pipe,

for the (n-1)th maximum, and where λ_n is the wavelength of the nth maximum; f_n is the frequency of the nth maximum; λ_{n-1} is the wavelength of the (n-1)th maximum; f_{n-1} the frequency of the (n-1)th maximum; n = serial number of the maximum dropping out of the equation and therefore need not be known; c = speed of propagation of the wave in the medium, and L = sought length.

The implementation of the method does not mandatorily require two directly consecutive maxima or minima. Instead maxima or minima also may be used between which there is an arbitrary but known number of maxima or minima.

If the two maxima are not directly consecutive, the length L is computed from

$$L = \sigma c / [2(f_u - f_n)] \quad (3)$$

where σ is the number of antinodes passed through (neglecting first); f_u is the frequency of the u th maximum; f_n is the frequency of the n th maximum; λ_u is the wavelength of the u th maximum; λ_n is the wavelength of the n th maximum; $u =$ the serial number of the last recorded maximum and $n =$ the serial number of the first recorded maximum.

Neither n nor u need be known, however the difference $\sigma = u - n$ must be, that is, it must be counted during measurement, where u should be larger than n , ie, when gradually increasing the frequency, first the n th frequency, then the $(n+1)$ th, then the $(n+2)$ th frequency shall be passed through, etc., and lastly the u th frequency.

If the speed of propagation of the acoustic wave shall be set for air, ie $C = 331.3 + 0.6t$, then

$$L = \sigma [331.3 + 0.6t] / [2(f_u - f_n)] \quad (4).$$

Eq. (3) is computed from the two following conditions:

last recorded maximum, $L = (2u - 1)\lambda_u / 4 = (2u - 1)c / 4f_u$ or

$$L = (2u - 1)(2\lambda_u) / 4 = (2u - 1)c / 2f_u,$$

first recorded maximum, $L = (2n - 1)\lambda_n / 4 = (2n - 1)c / 4f_n$ or

$$L = (2n - 1)(2\lambda_n) / 4 = (2n - 1)c / 2f_n$$

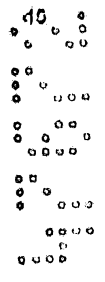
If the wavelength and the wave velocity are known, the length can be computed from

$$L = \sigma \lambda_u \lambda_n / [2(\lambda_n - \lambda_u)] \quad (5).$$

In eq. (5), L is the length of the bar or column, c the speed of propagation of the wave, λ_n the wavelength of the standing at the first ascertained maximum or mini-

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mum, λ_u the wavelength of the standing wave at the last-determined maximum or minimum and σ is the number of ascertained maxima or minima between the u th and the n th maximum or minimum.

The method and /or the apparatus of the invention may also be used to monitor and control the filling of a reservoir. First the level is ascertained in the manner described above. Then the reservoir is filled with the wave emitted into the reservoir, this time at constant frequency. The number of antinodes is ascertained and after the number of antinodes (or of minima) corresponding to the difference between the level determined earlier and that to be reached has been recorded, the filling of the reservoir is stopped.

It was discovered moreover that the receiving microphone of the method and apparatus of the invention need not be mounted precisely at the end of the column. As long as the microphone is mounted within one-eighth of the wavelength outside or inside the column, adequate length measurement shall be possible.

If, in eqs. (3) and (5) f_n is larger than f_u or λ_u is larger than λ_n , then the length shall correspond to the absolute value of the computational result.

When the length of a solid bar must be determined using the method and apparatus of the invention, preferably an oscillation node shall be formed at the end of bar opposite the acoustic generator and receiver, then, by means of its end at which there shall be the node of the wave generated in it, the bar must rest against a body of an acoustically harder material, whereby the wave shall be predominantly reflected in the bar at its end.

Further details of the invention are stated in the description below in relation to the attached drawings.

Figs. 1a and 1b schematically shows various standing waves in a column,

Fig. 2 is a functional diagram of the apparatus of the invention,

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Fig. 3 is an embodiment mode of the apparatus of the invention set upon a pipe partly filled with liquid,

Fig. 4 is a detail of the apparatus of Fig.3, shown on an enlarged scale,

Fig. 5 is a block-circuit diagram of a regulation unit for the apparatus of the invention,

Figs. 6a and 6b shows plots of the amplitude A as a function of the frequency f in two different cases, and

Fig. 7 is a plot showing the distance between the frequency measurement points.

Fig. 1a illustratively shows standing waves in a pipe of length L, an acoustic (audio) generator 1 and an acoustic receiver (microphone) 7 being associated to the open pipe end. As regards the first example of Fig. 1a, the wavelength $\lambda = 4L$, in the second example, the wavelength $\lambda = 4/3L$, in the third example $\lambda = 4/5L$ and in the fourth $\lambda = 4/7L$.

In general, $\lambda_n = 4L/(2n-1)$, whence $L = (2n-1)\lambda_n/4$.

The examples shown in Fig. 1a each display an antinode at the acoustic generator 1 and a node at the stationary (closed) pipe end.

Fig. 1b shows several examples of standing waves in a bilaterally open pipe of length L, an acoustic generator (audio generator 1), and a sound receiver (microphone 7) being associated with one open pipe end. In the first illustration shown in Fig. 1b, the wavelength $\lambda = 4/2L$, in the second illustration, $\lambda = 4/4L$, in the third illustration $\lambda = 4/6L$ and in the fourth illustration, $\lambda = 4/8L$.

In general, $\lambda_n = 2L/(2n - 1)$, and accordingly

$$L = (2n-1)\lambda_n/2.$$

Fig. 1b shows that in the examples provided, there is always an antinode both at the sound generator and at the opposite open pipe end.

The amplitude and hence the acoustic intensity at the microphone shall always be a maximum when the wavelength emitted by the acoustic generator shall be an odd fraction of the four-fold length L, namely $4/1, 4/3, 4/5, 4/7 \dots$ etc

of the pipe length L , ie when the pipe length is $1/4, 3/4, 5/4, 7/4 \dots$ etc of the emitted wavelength, that is, an odd multiple of one fourth the wavelength (Fig. 1a).

Similar considerations apply to Fig. 1b.

The apparatus shown in Fig. 2 is equipped with an acoustic generator in the form of a loudspeaker 1 mounted in a resonance chamber 2 with constricted, tubular acoustic output aperture 3.

The housing of the resonance chamber 2 is provided with a spacer 4 located at the open end 5 of the pipe 6 of which the length L is sought.

An acoustic receiver which in the embodiment is a microphone 7 is also mounted at the open end 5 of the pipe 6. The receiving microphone 7 may be mounted at the part 8 of the spacer 4 resting against the end of the pipe 6.

The design of the spacer 4 is such that the radiation 9 from the reflected wave shall be as unhampered as possible. For that reason the parts of the spacer transverse to the radiation 9 are made narrow. Where called for, the radiated waves may be attenuated further by using damping material.

A control-microphone 10 is mounted in the resonance chamber 2, for instance at its housing. This control microphone 10 is coupled through a regulator 11 to the loudspeaker 1 of which it controls the acoustic output whereby the same acoustic pressure shall be present in the resonance chamber 2 at every frequency (wavelength).

The apparatus employed to implement the method of the invention may be programmed in such manner that it shall operate in part or in whole fully automatically so that the operator need only read off the result, ie the sought length.

The apparatus of Fig. 3 consists of a housing 21, a spacer 22 (comprising a spacing stub 40, support rods 41 and fastener ring 42), a loudspeaker 23, a receiving microphone 24, a control microphone 25, a regulator unit 26 and a sinewave generator 27.

The shape of the housing 21 at the acoustic exit is selected in such a way that the reflected wavefront 9 no longer can be reflected back into the pipe 29. Here again additional damping material may be provided to prevent reflections.

The purpose of the spacer 22 is to keep the loudspeaker 23 away from the open end of the pipe 29 and to hold the receiver microphone 24 at the pipe aperture. The components of the spacer 22, in particular its support rods 41, are designed in such a way that as little as possible of interfering radiation (indicated by arrows in Fig. 4) is generated in the transmitted and reflected wavefront 9. Advantageous geometries are round rods and rings with round end surfaces, as shown in detail also in Fig. 4.

The regulator unit 26 consists of the control microphone 25, a pre-amplifier 30, a digital filter 31 of which the pass frequency is within the transmitted frequency, a rectifier 32, an amplitude modulator 33, an output amplifier 36, a quartz oscillator 34, a frequency multiplier 35 which also clocks the filter 31, and a square-pulse/sine-wave converter 27. The block-circuit diagram of the regulator unit is shown in Fig. 5.

Fig. 6a shows the amplitude A of the standing wave at one or at the open end of the pipe 6 or 29 as a function of the frequency f . The measurement accuracy depends on the precision with which the maxima or minima can be spotted. The maxima shown in Fig. 6a are unambiguously measurable and therefore provide an accurate result. The accuracy furthermore depends directly on the number of maxima or minima in the measurement range. The more maxima or minima are being measured, the smaller the significance of the percentage error involved in spotting maxima or minima.

Fig. 6b shows a case wherein the amplitude A is degraded by additional reflections. The maximum following Δf_1 occurs when reflections take place causing an increase in sound volume. The drop in sound volume following Δf may occur on account of reflection at the housing or through inappropriate coupling.

The apparatus of the invention offers high accuracy and reliability of measurement. The following are among the advantageous factors:

(X)

(a) The design of the housing and of the spacer is such that no additional reflections occur (Figs. 3, 4); where called for, damping materials may be applied when using bilaterally open pipes,

(b) The coupling level of the transmitted waves is kept constant over the entire range of frequencies,

(c) The highest sensitivity of the control and of the receiving microphone is at the transmission frequency to eliminate environmental noise.

Fig. 7 shows the amplitude A of the standing wave at the or one open end of the pipe 6 and 29 resp. as function of the frequency f . The sampling of the measurement frequency is much tighter in the initial and final ranges $B1$ and $B3$ than in the center range $B2$. Thereby the distance f_1 between the first and second maxima and also the sixth maximum can be ascertained more accurately and the measurement as a whole is thus more accurate.

The method of the invention can be optimized as follows regarding accuracy and measurement time. The problem is to reliably determine under all conditions the mean distance Δf (Fig. 6a) between consecutive maxima and minima.

Regarding Fig. 7, the method of the invention can be carried out as follows:

(a) DETERMINING THE MAXIMUM MEASUREMENT FREQUENCY

The wavelength at the maximum frequency must be large compared to the pipe diameter because otherwise no standing wave shall form in the pipe.

(b) DETERMINING THE SAMPLING DISTANCE dF OF THE MEASUREMENT FREQUENCY

It is determined by the largest of the lengths to be measured. the minimum frequency difference occurs between the beat maxima or minima. For good analysis, at least 12 frequency points shall be measured between two maxima or minima.

$$dF \leq c/[12(2L_{\max})] \quad (= \text{minimum frequency difference}).$$

(c) AWAITING ONSET OF OSCILLATION

A waiting period is mandatory between setting the frequency and scanning the sound volume at least until the wave reflected at the pipe end has come back to the input, in other words the waiting time is

$$dt \geq 2L_{\max}/c.$$

5 (d) LOWEST FREQUENCY AT BEGINNING OF MEASUREMENT

The minimum frequency at which an extremum may yet occur is given by

$$f_{\min} = c/(4L_{\min}).$$

10 Accordingly there is little point in starting to measure at much below that frequency.

(e) PROCEEDING WITH THE MEASUREMENT

-- Start with lowest frequency at minimum sampling distance dF and longest waiting time dt ,

-- Increase the frequency in increments of dF until the first and second minimum or maximum occurs,

15 -- A first estimate of pipe length can be obtained from the frequency difference between the two minima/maxima and accordingly the waiting time and frequency distance can be matched to the expected pipe length, in other words, henceforth:

20 I. On the basis of the initially coarsely predicted pipe length, the waiting time can be set to the particular shortest predictable value, and

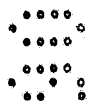
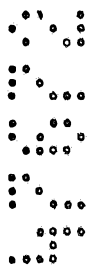
II. dF is so enlarged that the fewest measurements ≥ 12 will be located between two consecutive maxima or minima.

25 III. The required number of maxima or minima which must be ascertained depends on one hand on the required accuracy and on the other on the available time for measurement. The largest possible number of maxima or minima (within the admissible measurement range of I and II) must be ascertained to achieve highest accuracy. If the measurement times are limited or if the accuracy requirement is not so high, the number of maxima or minima to be ascertained

can be lowered down to the theoretical limit value of two consecutive maxima or minima.

IV. Because the measurement accuracy depends directly on how accurately Δf is determined, advantageously at the end of the measurement interval the least frequency difference of the frequency distance dF shall be reverted to (Fig. 7).

V. Measurement also may begin at the highest frequency and be carried out with step-wise lowering of the frequency. all implementations then must be adapted correspondingly.



~~Claims~~ THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method for determining in contactless manner the length of a column of liquid or gas contained in a tubular cavity sealed unilaterally or open on both sides, or the length of a solid bar, in which method a standing wave of ~~known~~^{determinable} speed of propagation and ~~known~~^{determinable} frequency or wavelength is generated in said column or bar, a node of said standing wave being present at one end of the column or bar, in particular at the closed end opposite the open end of the cavity, or an antinode being located at one of the two open ends of the cavity, and in which method the frequency of the standing wave is varied,

characterized in that

the amplitude of the standing wave is detected at that end of the column or bar where the wave is fed-in, in that the wave frequency is varied until at least two consecutive maxima (anti-nodes) or an amplitude minimum (node) following a maximum have been detected, and in that the length of the column or bar is computed at ~~known~~ frequency f of the standing wave using the relation

$$L = \sigma c / [2(f_u - f_n)] \quad (3)$$

where L is the length of the bar or column, c is the speed of propagation of the wave, f_n is the wave frequency of the standing wave at the first determined maximum or minimum, f_u is the wave frequency of the standing wave at the last determined maximum or minimum from the n th to the u th maximum or minimum

($\sigma = u - n$), or at known wavelength λ using the relation

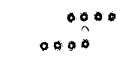
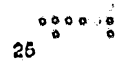
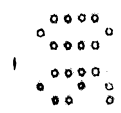
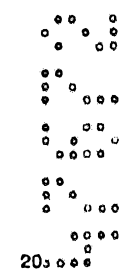
$$L = \sigma \lambda_u \lambda_n / [2(\lambda_n - \lambda_u)] \quad (5)$$

where L is the length of the bar or column,

λ_n is the wavelength of the standing wave at the first ascertained maximum or minimum, λ_u is the wavelength of the standing wave at the last ascertained maximum or minimum and σ is the number of ascertained maxima or minima from the n th to the u th maximum or minimum ($\sigma = u - n$).

2. Method defined in claim 1, characterized in that a standing, electromagnetic wave is generated in the column or bar.

(X)



3. Method defined in claim 1, characterized in that a standing acoustic wave is generated in the column, in particular in the case of a gaseous substance.

4. Method defined in one of claims 1 through 3, characterized in that the standing wave in the column or bar is generated from that end at which the standing-wave amplitude is detected.

5. Method defined in claim 4, characterized in that in the case of a column containing a tubular cavity closed at one end the standing wave is generated from the open end of the cavity or that in the case of a column within a bilaterally open tubular cavity the standing wave is generated from the open end of the cavity.

6. Method defined in one of claims 3 through 5, characterized in that illustratively an audio generator is used as the acoustic generator for producing the standing wave.

7. Method defined in one of claims 3 through 6, characterized in that an acoustic receiver, for instance a microphone, is used to determine the amplitude of the standing wave generated in the medium.

8. Method defined in one of claims 1 through 7, characterized in that the length of the column of medium is computed at known frequency and wave velocity of the standing wave generated in the column of medium by means of the formula

$$L = c/[2(f_n - f_{n-1})] \quad (1)$$



where L is the length of the column of medium, c is the wave velocity, f_n is the frequency of the n th maximum and f_{n-1} is the frequency of the $(n-1)$ th maximum.

9. Method defined in one of claims 1 through 8, characterized in that the wavelength λ of the acoustic waves of the maximum used frequency f_{\max} is larger than the transverse dimension of the cavity to be measured,

10. Method defined in one of claims 1 through 9, characterized in that the minimum frequency distance dF of the measurement frequency is determined by the relation

$$dF \leq c/[k(2L_{\max})],$$

where c is the wave velocity of propagation, k is the number of measurement points between two maxima or minima and preferably larger or equal to 12, and L_{\max} is the maximum length of the column of medium to be measured.

11. Method defined in one of claims 1 through 10, characterized in that the minimum waiting period dt between emitting and measuring the acoustic wave is determined from the relation

$$dt \geq 2L_{\max}/c$$

where L_{\max} is the maximum length of column of medium to be measured and c is the wave propagation velocity.

12. Method defined in one of claims 1 through 11, characterized in that the minimum frequency f_{\min} at which an extremum may yet occur is determined from the relation

$$f_{\min} = c/[4L_{\min}]$$

where c is the wave propagation velocity and L_{\min} is the smallest length of column of medium to be measured.

13. Method defined in claim 12, characterized by the

steps:

(a) The measurement begins at the lowest frequency f_{min} and with the least frequency distance df and longest waiting period dt ,

(b) The frequency f is raised in increments of dF until the first and second minima or maxima occur,

(c) The pipe length is estimated from the frequency difference between the two minima or maxima and adaptation of the waiting period dt and frequency differential dF , the waiting period dt being set for the lowest possible value and the frequency differential dF for the largest possible value,

(d) Measuring as many maxima or minima as required by the desired measurement accuracy.

14. Method defined in claim 13, characterized in that near the end of the measurement interval, the system is switched back to the minimum frequency differential in the manner of the beginning of the measurement,

15. Method defined in either of claims 13 and 14, characterized in that the measurement starts at the ^{lowest}~~highest~~ frequency f_{min} and that the measurement frequency f is lowered stepwise.

16. Apparatus ^{when used in}~~for~~ implementing the method of one of claims 1 through 15,

characterized

by a loudspeaker (1) connected to a spacer (4, 22) of which the other end (8) can be placed against one open or the open end (5) of the especially tubular cavity (6, 29) containing the gaseous or liquid substance, and by a receiving microphone (7, 24) acting as an acoustic receiver.



17. Apparatus defined in claim 16, characterized in that the loudspeaker (1, 23) is mounted in a resonance chamber (2) bounded by a housing (21).

6 18. Apparatus defined in claim 17, characterized in that the housing (21) of the resonance chamber (2) comprises a constricted, tubular acoustic exit aperture (3) pointing to one open or to the open end (5) of the cavity (6, 29).

10 19. Apparatus defined in one of claims 16 through 18, characterized in that a control-microphone (10, 25) detecting the acoustic pressure in the resonance chamber (2) is associated through a regulator unit (11; 26, 27) to the loudspeaker (1, 23) which thereby is so controlled that the acoustic pressure in the resonance chamber (2) shall be kept constant with varying frequency.

15 20. Apparatus defined in one of claims 16 through 19, characterized in that the highest sensitivity of the receiving microphone (7, 24) is variable and in that a device is provided whereby the highest sensitivity of the receiving microphone (7, 24) can be matched to the frequency of the transmitted wave produced by the loudspeaker (1, 23).

20 21. Apparatus defined in one claims 16 through 20, characterized in that the spacer (22) comprises a ring (42) with support rods (41) and connected by rods (40) to the housing (21) of the resonance chamber (2).

25 22. Apparatus defined in claim 21, characterized in that the support rods (41) extend inside the ring (42) and project beyond the ring (42) to the outside.

23. Apparatus defined in claim 21, characterized in that the tubular acoustic exit aperture (3) conically tapers toward ^{the exit end of the resonance chamber} ~~its free end~~.

5 24. Apparatus defined in one of claims 16 through 23, characterized in that the surfaces of the spacer (4, 22) facing the open end of the cavity (6, 29) and in particular the surfaces of its rods (41) and of its ring (42) are convex.

10 25. Apparatus defined in one of claims 16 through 24, characterized in that in the case of a standing column contained in a bilaterally open cavity, acoustically damping material is mounted to that end where the standing wave is generated.

DATED this 3rd day of January 1990.

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"THE ATRIUM"
290 BURWOOD ROAD
HAWTHORN, VIC. 3122.



(X)

Fig. 1a

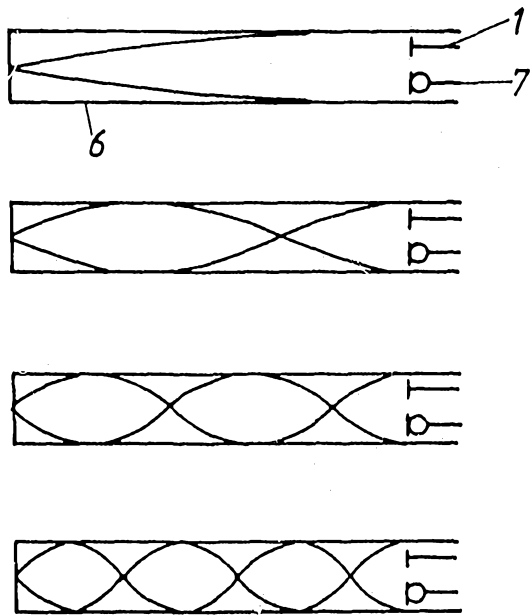


Fig. 1b

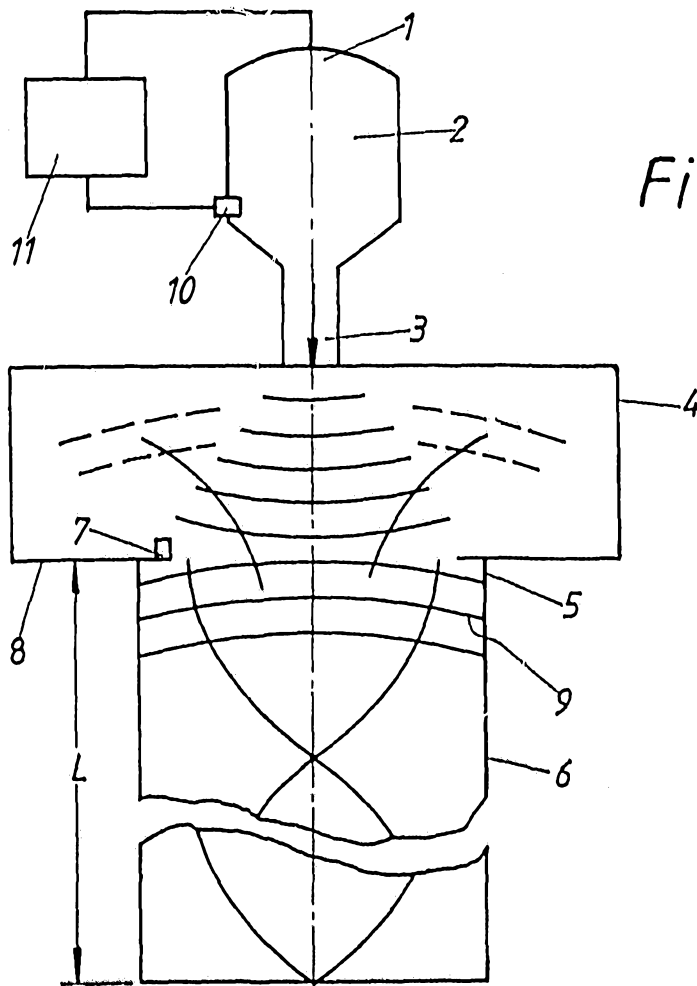
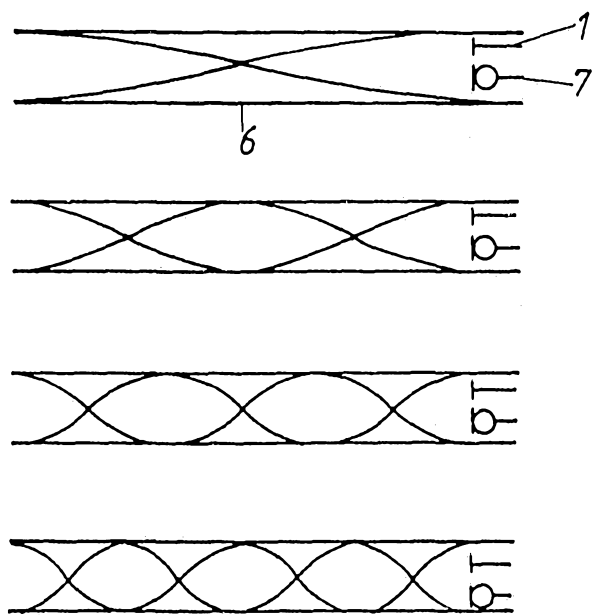


Fig. 2



Fig.3

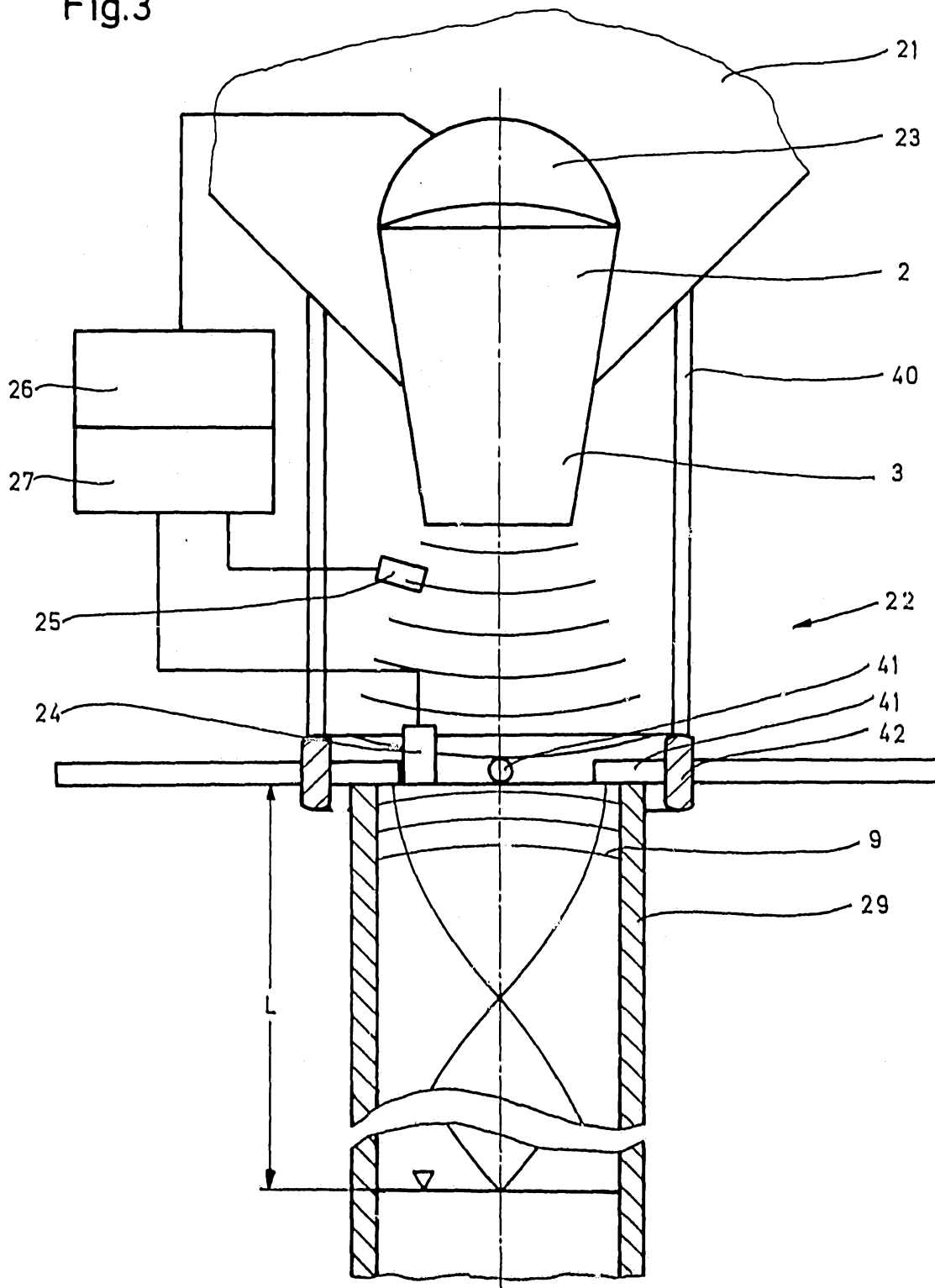


Fig.4

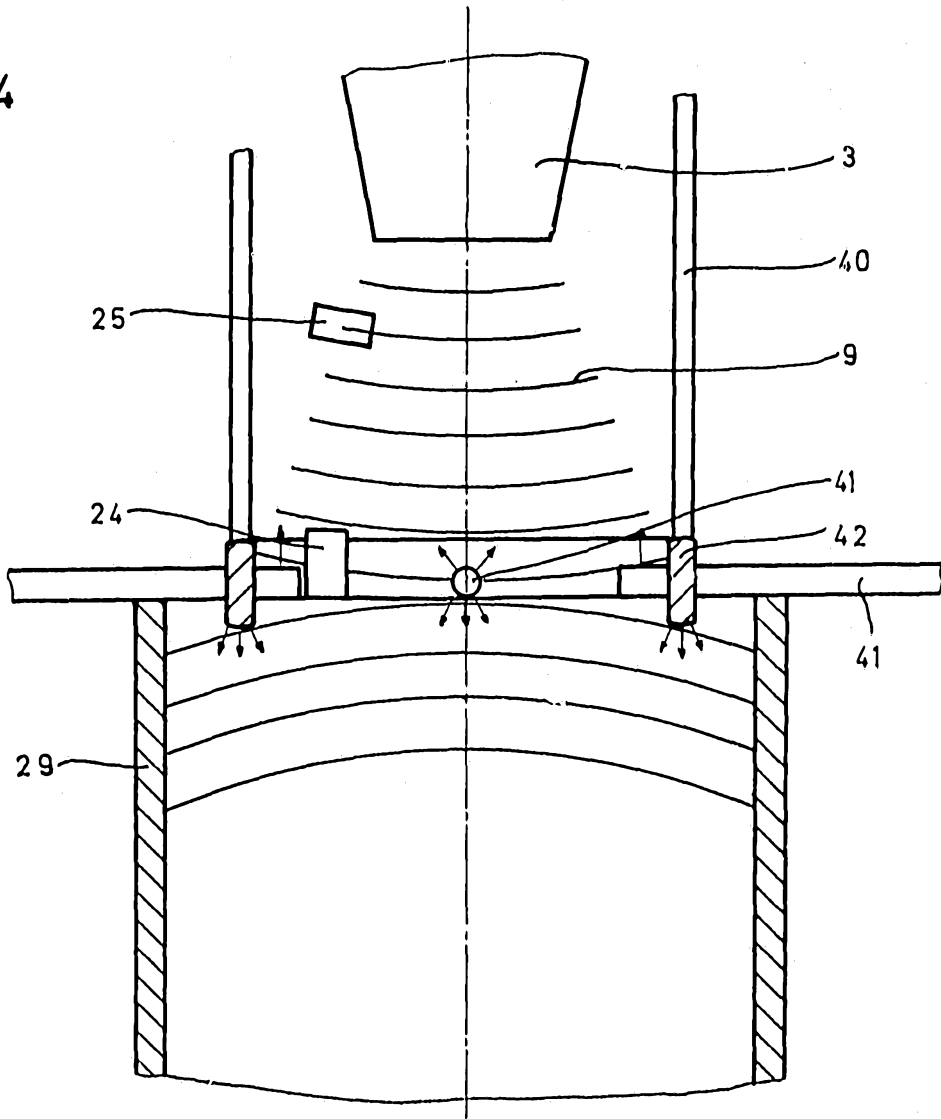


Fig.5

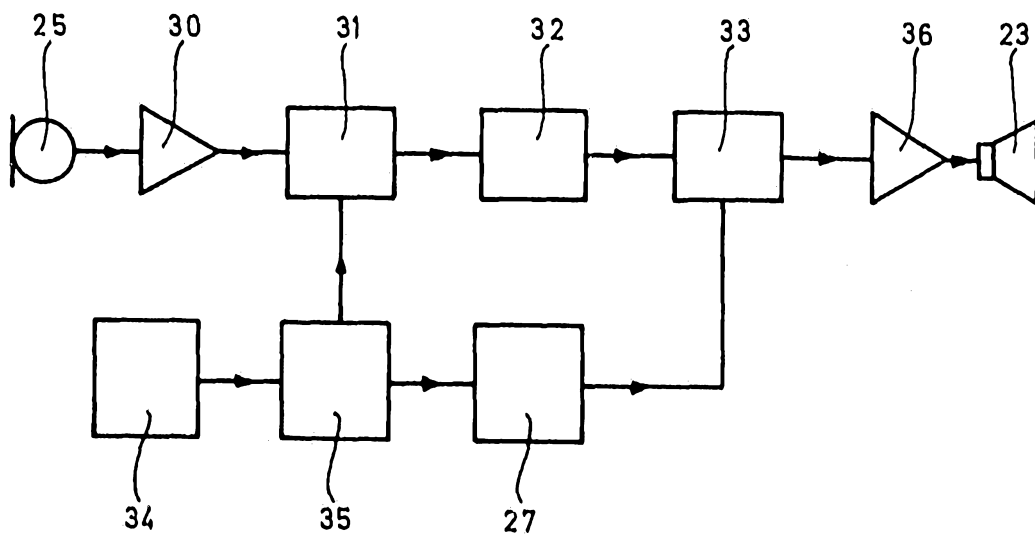


Fig.6a

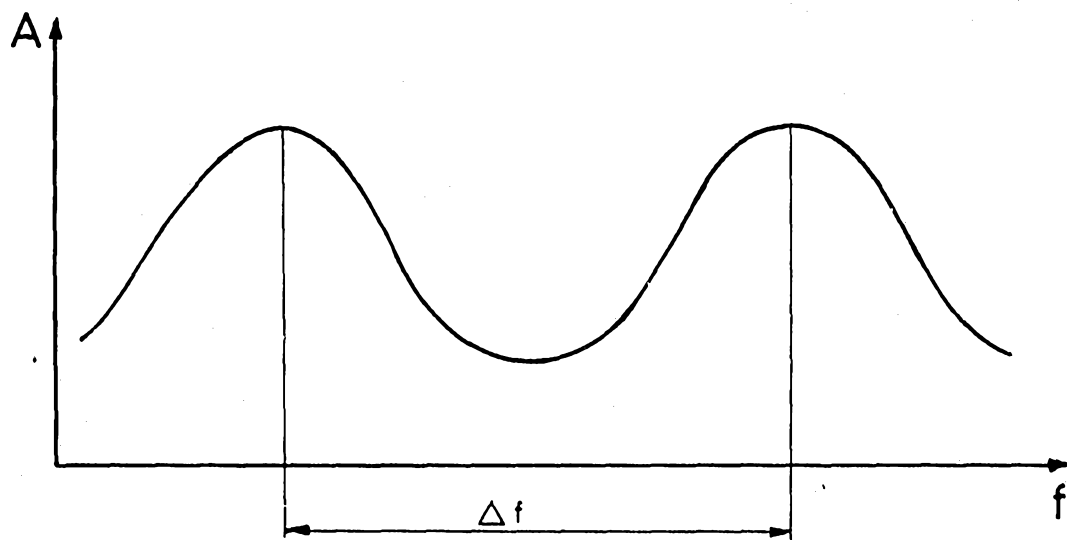


Fig.6b

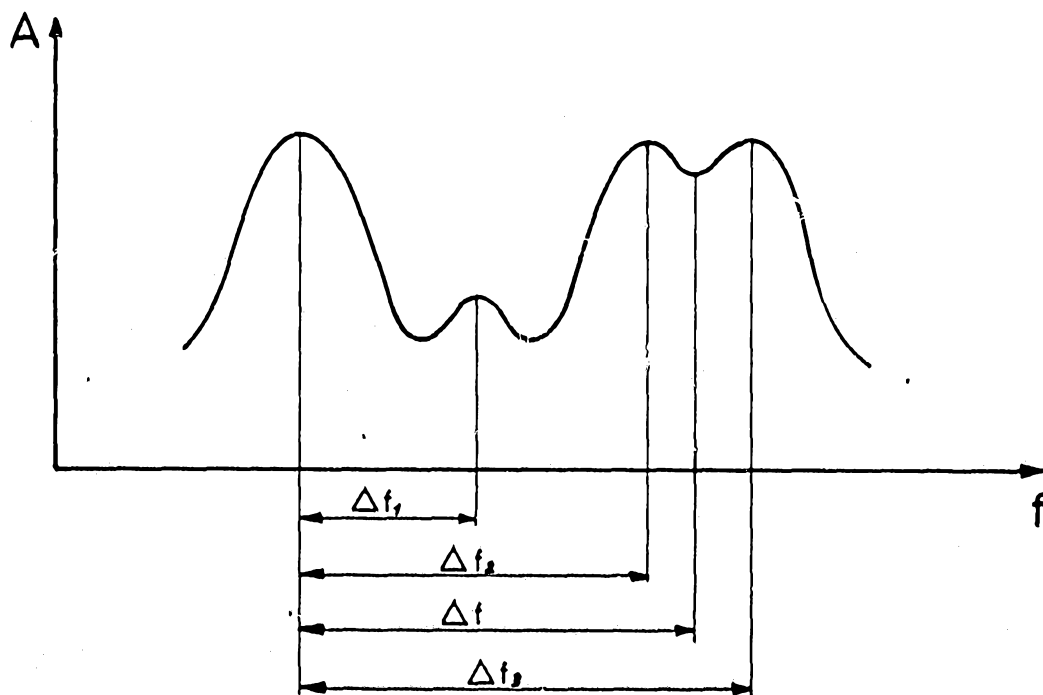


Fig.7

