Jan. 20, 1970 C. G. LOMAS ET AL 3,491,332

SONIC DETECTOR

Filed June 28, 1968

FIG. 1

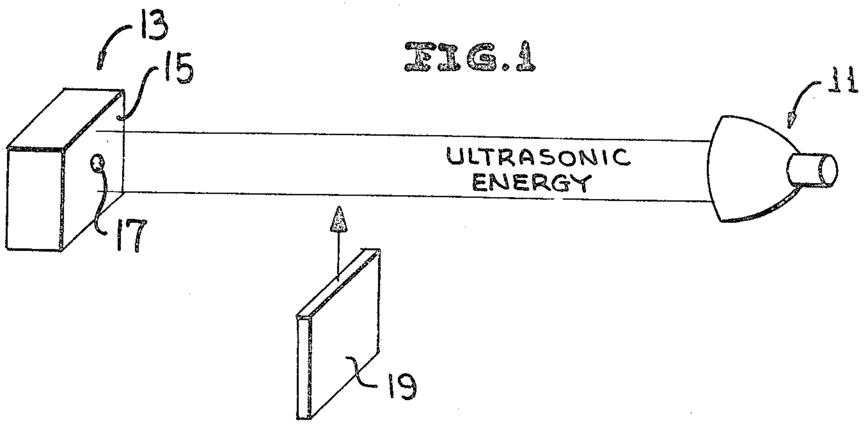


FIG. 2

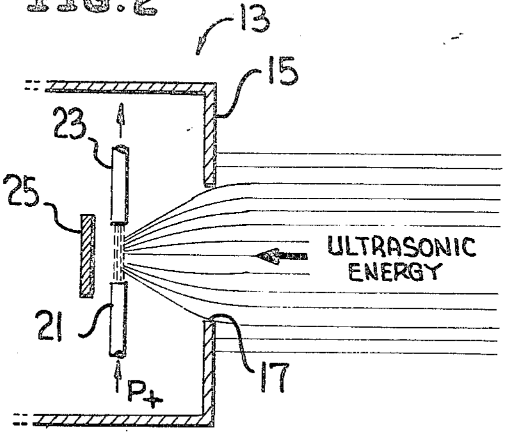


FIG. 3

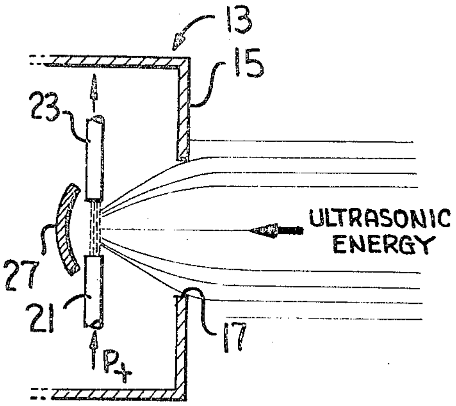
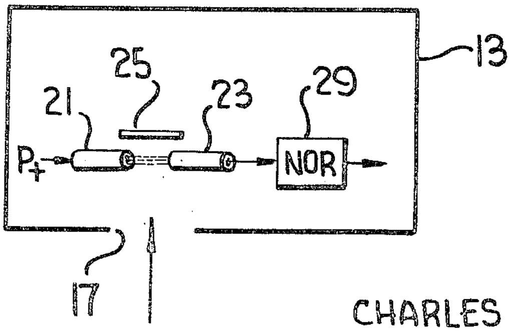


FIG. 4



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SONIC DETECTOR

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ABSTRACT OF THE DISCLOSURE

A sonic detector responds to interruption of an acoustic energy beam directed thereat. The beam is transmitted through an aperture in an enclosure wall behind which is a flowing fluid stream oriented to be impinged upon by portions of the beam transmitted through the aperture. The stream is sensitive to at least one frequency component of the beam whereby the stream remains laminar unless impinged upon by the beam in which case it is rendered turbulent. Means for discerning the laminar and turbulent states of the stream are provided. The edges of the aperture diffract the beam energy such that the predetermined frequency components of the beam converge at a focal point through which the fluid stream flows. In addition, a reflector plate may be positioned behind the stream, with or without an apertured enclosure, to reflect energy at said predetermined frequency back into impinging relation with the stream.

BACKGROUND OF THE INVENTION

The present invention relates to object detection based on interruptions of a beam of acoustic energy, and more particularly, to fluidic sonic detectors utilizing the phenomenon of laminar-to-turbulent transition of a fluid stream in response to acoustic energy at a specified frequency impinging thereagainst.

It is known that laminar fluid streams may be rendered turbulent in response to impingement thereagainst of acoustic energy at a specified frequency. Such fluid streams may be sensitive to one or more discrete frequencies or band of frequencies as determined by the distance between the nozzle and receiving aperture, and the stream Reynolds number. Thus, for a given set of parameters, a stream can have a greater sensitivity to one frequency or group of frequencies than to other frequencies. This phenomenon would appear to be readily applicable to object-detection applications whereby a stream would normally be rendered turbulent by a beam of acoustic energy impinging thereagainst and rendered laminar in response to the presence of an object appearing between the energy source and the fluid stream. However, there are a number of practical problems involved in utilizing the above described phenomenon for object-detection purposes. More particularly, due to the sensitivity of the fluid stream to various acoustic signals, the detector would have to be employed in an environment substantially devoid of acoustic noise. In addition, in order for the acoustic beam to have a sufficient intensity at the point of impingement against the fluid stream to cause the stream to become turbulent, the acoustic energy source must either operate at extremely high power levels or must be located so close to the sensing stream as to render object detection impractical.

Further, it is desirable that the signal received by the sensing stream receiver tube be capable of utilization in driving a fluidic switching circuit such as a fluidic NOR gate which assumes a NOR state in response to a low pressure input signal below some threshold level, and an OR state in response to an input pressure signal above

the threshold level. Since the fluid receiver tube for the sensing stream receives a pressure signal during both the turbulent and laminar states of the sensing stream, it is important that the low pressure level, received when the sensing stream is in its turbulent state, is sufficiently low to permit the NOR gate to revert to its NOR state. This requires a highly turbulent state for the sensing stream when impinged upon by the acoustic beam, and this in turn requires a relatively high-intensity acoustic signal in order to produce the required degree of turbulence. Again, this would appear to require either providing a high power acoustic energy source or, in the alternative, placing the source too close to the sensing stream to permit detection of objects of any practical size.

Still another consideration limiting the practicability of utilizing the acoustic sensitivty of a laminar stream for object-detecton applications is the sensitivity of the sensing stream to randomly occurring air drafts which may tend to either deflect the sensing stream from its receiver tube or, in some cases, induce turbulence in the stream.

It is therefore an object of the present invention to provide an acoustic-sensitive object-detection apparatus utilizing the laminar to turbulent transition of a fluid stream in response to impingement thereagainst of acoustic energy at a specified frequenry, wherein the above-described problems are eliminated.

It is another object of the present invention to utilize the laminar to turbulent transition of a fluid stream in response to acoustic signals impinging thereagainst to provide a practical and reliable device for detecting the passage of an object between a source of acoustic energy and the fluid stream.

It is another object of the present invention to utilize a fluid stream for detecting interruption of a beam of acoustic energy impinging thereagainst by sensing whether the fluid stream is in its laminar or turbulent state.

SUMMARY OF THE INVENTION

In accordance with the principles of the present invention a flowing fluid stream is located behind a wall of an enclosure toward which a beam of acoustic energy is directed. An aperture is defined in the wall for transmitting portions of the beam therethrough so as to impinge against the fluid stream. The fluid stream is laminar when undisturbed and becomes turbulent when impinged upon by acoustic energy at a predetermined frequency, a component of which frequency is present in the beam. The edges of the aperture diffract acoustic energy transmitted therethrough so that energy at the predetermined frequency converges toward a focal point behind the apertured wall. The fluid stream flows through the focal point and therefore the acoustic energy intensity at the point of impingement against the fluid stream is amplified.

Located behind the fluid stream is a reflector plate which may be either flat or concave (the concave surface facing the fluid stream) for reflecting acoustic energy back toward the fluid stream. The reflector plate may be utilized with or without the apertured enclosure, depending upon the required degree of amplification of the acoustic beam intensity.

The size of the aperture, the spacing of the fluid stream therefrom, and the spacing of the reflector plate from the fluid stream are all chosen for maximum amplification of the intensity of the acoustic beam at the point of impingement against the fluid stream. These dimensions depend upon a particular frequency to which the fluid stream is sensitive, which in turn depends upon the distance between the supply tube issuing the stream and the stream receiver tube, and the stream Reynolds number.

The resulting configuration permits relatively large spacing between the acoustic beam source and the sensing stream without requiring a high power source because of the beam intensity amplification produced by the beam diffraction at the aperture edge and by the acoustic energy reflection from the reflector plate. In addition, external acoustic disturbances have minimal effect on the sensing stream due to the apertured enclosure, which also minimizes the effects of the random air drafts and other environmental disturbances. Further the reflector plate, when employed with the apertured wall configuration, produces a sufficient amplification of the acoustic energy beam intensity to render the pressure level of the turbulent stream received by the receiver tube substantially below the threshold of a conventional fluidic NOR gate.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a diagrammatic representation of an object detection system in accordance with the principles of the present invention;

FIGURE 2 is a diagrammatic sketch illustrating the configuration of the sensor portion of the system of FIGURE 1;

FIGURE 3 is a diagrammatic sketch illustrating a modification of the sensor illustrated in FIGURE 2; and

FIGURE 4 is a schematic illustration of the sensor circuitry of the system illustrated in FIGURE 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now specifically to FIGURE 1 of the accompanying drawings, there is diagrammatically illustrated a system for detecting objects in accordance with the principles of the present invention. A source of acoustic energy **11** may take the form of a whistle mounted in a reflector, the latter beaming the acoustic energy across an open space. Preferably, the acoustic beam is at an ultrasonic frequency (that is, at a frequency above the range of frequencies which are normally audible to the human ear) in order to avoid annoyance of people in the surrounding area. The acoustic beam is directed generally toward an enclosure **13** within which is housed an acoustic-sensitive detector in accordance with the principles of the present invention. A front wall **15** (that is, the wall facing source **11**) of enclosure **13** has a circular aperture **17** defined therein. Aperture **17** is in substantial alignment with the beam of energy transmitted from source **11** and of itself comprises part of the acoustic-sensitive detector of the present invention. An object **19** to be detected, when passed between source **11** and enclosure **13**, intercepts the acoustic beam so that no more than a negligible level of acoustic energy is received at aperture **17**. It is the function of the sensor unit within enclosure **13** to provide a fluid output signal indicative of the passage of an object, such as object **19**, between source **11** and enclosure **13**.

Referring now to FIGURE 2 of the accompanying drawings, there is illustrated a sketch in partial section of the interior of enclosure **13** of FIGURE 1. Disposed behind wall **15** is a nozzle or supply tube **21** which is responsive to application of pressurized fluid thereto for issuing a laminar stream of fluid. A receiver tube **23** is disposed in coaxial alignment with supply tube **21** so as to receive the stream issued thereby, when undisturbed, in its laminar state. Supply tube **21** is disposed so that the fluid stream is directed generally perpendicular to the acoustic beam and so that acoustic energy transmitted through aperture **17** impinges against the stream. The perpendicular relationship between the stream and the beam is not critical; however, in order to achieve the maximum effect of the acoustic energy in converting the laminar stream to its turbulent state, it is desirable that the stream be directed as nearly perpendicular to the direction of the acoustic energy beam as possible.

Acoustic energy transmitted through aperture **17** is diffracted by the edges of the aperture so that the transmitted acoustic energy converges toward a focal point some distance behind wall **15**, the focal point position changing with the frequency of the acoustic energy transmitted through the aperture. In addition, for any given frequency, variation in size of the aperture **17** produces concomitant variations in focal point location. The supply tube **21** and receiver tube **23** are disposed so that the fluid stream flowing therebetween passes through the focal point for the frequency component of the acoustic energy to which the stream is highly sensitive. The frequency component to which the stream is highly sensitive, as discussed above, depends upon the stream Reynolds number (more specifically, the fluid supply pressure P+, the diameter of supply tube **21** and the kinematic viscosity of the stream) and the distance between the supply tube **21** and the receiver tube **23**. These parameters are, of course, chosen so that the specified frequency to which the stream is sensitive is the same as the frequency of the acoustic energy beam, or at least the same as one frequency component of the acoustic energy beam. Since acoustic energy at the specified frequency is focused to impinge against the stream, the intensity of the acoustic energy at that point of impingement is relatively high and therefore a relatively high degree of turbulence is induced in the stream thereby.

In addition to focusing the acoustic energy to provide intensity amplification, aperture **17** in wall **15** minimizes the effects of acoustic signals which are not axially directed with respect to aperture **17**. Such signals may, in fact, be focused somewhat by the aperture but at focal points other than that for which the axially directed acoustic beam is focused. Generally these signals will have too low an intensity after passage through aperture **17** to significantly affect the fluid stream.

The amplification of the acoustic beam intensity at the point of impingement against the fluid stream permits greater spacing between source **11** and enclosure **13** (of FIGURE 1) for a given power level of source **11**. Practical object detection is therefore realizable by virtue of the arrangement thus far described.

Another means of amplifying the intensity of the acoustic signal impinging against the stream is to provide a reflector plate **25** behind the stream; that is, the plate is disposed on the side of the stream opposite aperture **17**. Reflector plate **25** acts to reflect acoustic energy back toward the stream and thereby increase the turbulence of the stream in response to a given acoustic signal level. We have found that the optimum distance between plate **25** and the stream flowing between tubes **21** and **23** for inducing maximum stream turbulence varies with specified frequency component in the acoustic energy beam to which the stream responds by becoming turbulent. Further, it has been found that the provision of plate **25**, spaced for maximum turbulence at the specified frequency, has the effect of rendering the stream sufficiently turbulent to lower the average pressure level in receiver tube **23** below that which is the threshold pressure in conventional fluidic NOR gates. That is to say, when a conventional fluidic NOR gate, such as the type illustrated and described in U.S. Patent No. 3,286,086 has its control port connected to receive the pressure signal procided by receiver tube **23**, the NOR gate does, in fact, assume different states corresponding to the laminar and turbulent states of the fluid stream flowing between supply tube **21** and receiver tube **23**.

It has been found that, in addition to utilizing acoustic beam frequencies above the range of audibility to humans, it is desirable to utilize ultrasonic frequencies above 30 kHz. This is because acoustic disturbances generated by frictional engagements between surfaces, such as might occur in machine shop environments, etc., are primarily below 30 kHz. If the detector is tuned to a higher frequency, the effect of such noises upon detector operation is substantially minimized.

By way of example, and in no sense intending to limit the scope of the present invention, the following system dimensions and parameters have been found suitable for object detection for distances as great as three feet between source **11** and enclosure **13** with a 42 kHz. ultrasonic source frequency:

Diameter of aperture **17**	inch	1
Distance between wall **15** and sensing stream flowing between tubes **21** and **23**	inch	⅝
Diameter of sensing stream	do	.023
Distance between supply tube **21** and receiver tube **23**	inch	.385
Supply pressure (P+)	p.s.i.g.	2.91
Distance between sensing plate **25** and sensing stream	inch	.22

Referring now to FIGURE 3 of the accompanying drawings, there is illustrated an alternative embodiment to the sensor illustrated in FIGURE 2 wherein the flat reflector plate **25** of FIGURE 2 has been replaced by a concave reflector plate **27** in FIGURE 3. In all other respects, the apparatus illustrated in FIGURE 2 is identical to that illustrated in FIGURE 3 and like numerals are employed in both figures to designate like components. Concave reflector plate **27** is disposed with its concave surface facing the sensing stream flowing between tubes **21** and **23**. The apex of the concave surface is optimally spaced from the sensing stream to induce maximum turbulence therein in response to acoustic signals at the frequency to which the sensing stream is rendered turbulent.

Referring now to FIGURE 4 of the accompanying drawings, there is illustrated in schematic form a complete fluidic sensing circuit constructed in accordance with the principles of the present invention. The entire circuit is shown enclosed in enclosure **13** and the acoustic beam from source **11** is illustrated as entering enclosure **13** via aperture **17**. In all respects, the circuit illustrated in FIGURE 4 comprises elements which are the same as those illustrated in FIGURE 2 with the exception that NOR gate **29** is illustrated in FIGURE 4 as receiving the output pressure signal from receiver tube **23**. NOR gate **29**, as described above, may take the form of the NOR gate illustrated and described in U.S. Patent No. 3,286,086 and functions to provide an output signal only in the absence of an input signal applied thereto and likewise provides no output signal when an input signal is applied thereto. When the beam of acoustic energy is received by aperture **17** and focused on the sensing stream from supply tube **21**, the combined amplification effects of aperture **17** and the reflector plate **25** renders the sensing stream sufficiently turbulent so that fluid pressure below the switching threshold of NOR gate **29** is provided by receiver tube **23** and NOR gate **29** provides a NOR output signal. Upon interruption of the acoustic beam, such as by interposition of object **19** of FIGURE 1 between source **11** and enclosure **13**, the fluid stream issuing from tube **21** becomes laminar and the receiver tube **23** receives a relatively large pressure. This relatively large pressure is sufficient to change the operational mode of NOR gate **29** to inhibit the NOR output signal therefrom.

Additional fluidic logic circuitry may be included within enclosure **13** to provide any one or a number of logic functions desired in response to object detection by the sensing stream.

While we have described and illustrated one specific embodiment of our invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention.

We claim:

1. A fluidic detector comprising:

a wall member;

a source of acoustic energy disposed in front of said wall member for providing an acoustic energy beam directed generally toward said wall member and having at least one predetermined frequency component;

an aperture defined in said wall member and disposed for transmitting at least a portion of the acoustic energy in said beam when otherwise unimpeded through said aperture;

supply means disposed behind said wall member for issuing a fluid stream which remains laminar when undisturbed and which becomes turbulent in response to impingement thereagainst by acoustic energy at said predetermined frequency;

wherein said aperture is configured such that acoustic energy at said predetermined frequency transmitted through said aperture is diffracted and converges toward a focal point through which said fluid stream flows;

means for sensing whether said fluid stream is laminar or turbulent.

2. The combination according to claim **1** wherein said aperture has edges which diffract acoustic energy transmitted through said aperture, the size of said aperture being such that acoustic energy transmitted therethrough at said predetermined frequency converges toward a specified focal point behind said wall member, and wherein said supply means is positioned such that said fluid stream passes through said specified focal point.

3. The combination according to claim **2** wherein said wall member comprises one wall of an enclosure within which said supply means and said means for sensing are disposed.

4. The combination according to claim **3** wherein said supply means includes a supply tube responsive to application of fluid at a specified pressure thereto for issuing said fluid stream, and wherein said means for sensing includes a fluid receiver tube disposed substantially coaxial with said supply tube and spaced therefrom to receive substantially all of said fluid stream in a laminar state when said fluid stream is undisturbed and to receive portions of said fluid stream in a turbulent state when acoustic energy at said predetermined frequency impinges against said fluid stream, and wherein the inside diameter of the supply tube, said specified pressure, and the distance between the supply tube and said receiver tube are interrelated such that the fluid stream is rendered turbulent in response to impingement thereagainst of acoustic energy at said predetermined frequency.

5. The combination according to claim **4** further comprising reflector means disposed within said enclosure on the opposite side of said fluid stream from said aperture for reflecting acoustic energy impinging against said reflector means into impingement against said fluid stream.

6. The combination according to claim **5** wherein the distance between said reflector means and said fluid stream is that which induces maximum turbulence in said fluid stream in response to reflection of acoustic energy at said predetermined frequency.

7. The combination according to claim **6** further comprising a fluidic NOR gate responsive to the fluid flow in said receiver tube for providing a fluid signal only when said fluid stream is turbulent.

8. The combination according to claim **6** where said reflector means comprises a flat plate having a reflecting surface disposed substantially perpendicular to said acoustic energy beam.

9. The combination according to claim **6** wherein said reflector means comprises a concave plate having its concave surface facing said fluid stream and wherein the apex of the concave surface is located a distance from said fluid stream such that maximum turbulence is induced in said fluid stream in response to reflection of acoustic energy at said predetermined frequency.

10. The combination according to claim **2** further comprising reflector means disposed on the opposite side of the fluid stream from said aperture for reflecting acoustic energy impinging against said reflector means into impingement against said fluid stream.

11. The combination according to claim **10** wherein the distance between said reflector means and said fluid stream provides maximum turbulence in said fluid stream in response to reflection of said predetermined frequency component of said acoustic energy beam.

12. The combination according to claim **11** wherein said predetermined frequency is ultrasonic and above 30 kHz.

13. The combination according to claim **11** wherein said source comprises a whistle for generating an ultrasonic signal and a reflector for beaming said signal toward said aperture in said wall member.

14. A fluidic detector comprising:

source means for providing a beam of acoustic energy having at least one predetermined frequency component;

means for issuing a fluid stream which is laminar when undisturbed and turbulent when impinged upon by acoustic energy at said predetermined frequency, said supply means being disposed such that said beam when otherwise unimpeded impinges against said fluid stream;

reflector means disposed on the opposite side of said stream from said source for reflecting energy from said beam at said predetermined frequency into impinging relationship with said fluid stream; and

means for sensing whether said fluid stream is laminar or turbulent.

15. The combination according to claim **14** wherein said reflector means comprises a flat plate located at a distance from said stream for providing maximum reflection of said predetermined frequency component of said beam to induce maximum turbulence in said stream.

16. The combination according to claim **14** wherein said reflector means comprises a concave plate having a concave surface facing the fluid stream with the apex of said concave surface located at a distance from said fluid stream for providing maximum reflection of the predetermined frequency component of said beam into impinging relation with said stream.

17. The combination according to claim **14** wherein the supply means includes a supply tube responsive to application of fluid at a specified pressure for issuing said fluid stream, and wherein said means for sensing includes a receiver tube disposed substantially coaxial with said supply tube and spaced therefrom to receive substantially all of said fluid stream when laminar and to receive portions of said fluid stream when rendered turbulent in response to impingement against said fluid stream by acoustic energy, and wherein the inside diameter of said supply tube, said specified pressure, and the distance between said supply and receiver tubes are related such that said fluid stream is rendered turbulent in response to impingement thereagainst by acoustic energy at a predetermined frequency.

18. A fluidic detector responsive to interruption of a beam of acoustic energy directed thereat, said beam including at least one predetermined frequency component to which said detector is sensitive, said detector comprising;

an enclosure including a wall member toward which said beam is directed from exteriorly of said enclosure, said wall member having an aperture defined therein for transmitting at least a portion of the said beam through said aperture;

supply means disposed within said enclosure for issuing a fluid stream which is laminar when undisturbed and turbulent when impinged upon by acoustic energy at said predetermined frequency, said supply means being disposed in alignment with said aperture such that acoustic energy transmitted through said aperture impinges upon said fluid stream; and

means for sensing whether said fluid stream is laminar or turbulent.

19. The combination according to claim **18** further comprising reflector means disposed within said enclosure and in alignment with said aperture and said stream in the order stated for reflecting acoustic energy at said predetermined frequency back toward the fluid stream in impinging relationship thereto.

20. The combination according to claim **19** wherein the edges of said aperture diffract acoustic energy transmitted through said aperture such that acoustic energy at said predetermined frequency converges toward a specified focal point within said enclosure, wherein the supply means is located so that said fluid stream passes through said specified focal point and wherein the reflector means is spaced from said fluid stream by a distance equal to one-quarter wavelength of said predetermined frequency component.

21. The combination according to claim **20** further comprising a fluidic NOR gate responsive to said means for sensing for providing a fluid signal at one level when said stream is laminar and at a second level when said stream is turbulent, said fluidic NOR gate being disposed within said enclosure.

References Cited

UNITED STATES PATENTS

3,271,755 9/1966 Bagno ------------ 340—16 X

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U.S. Cl. X.R.

181—.5; 340—16, 258