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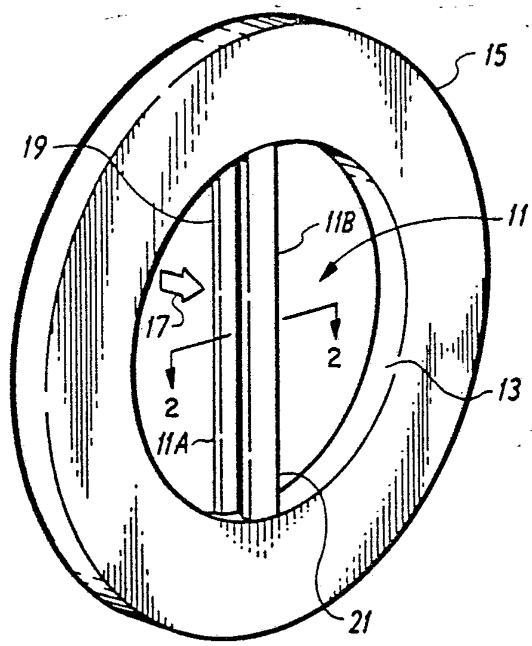

(57) Abstract

A body (11) for improved shedding of vortices has a short downstream length, e.g. 0.3 cm, yet is capable of excellent flow metering performance. The body includes an upstream elongate thin plate (19) spanning the inner diameter of a conduit, and one or more downstream sections (21). Generally, these sections are in the form of cylindrical rods of various cross-sections, with their longitudinal axes parallel to that of the plate. These sections may be separated from the plate, or rigidly attached to the downstream side thereof. By simultaneously maintaining the ratio of the width (H_F) of the thin plate to the overall width (H_T) of the downstream sections within the range from 1.0 to 2.2, and the ratio of the width of the thin plate to the diameter of the conduit within the range from 0.1 to 0.3, enhanced linearity of signal is achieved. This results in a narrow profile flowmeter assembly which occupies the same amount of space as a conventional orifice plate.

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Narrow profile vortex shedding body

The present invention relates generally to a vortex-shedding bluff body, and more particularly to such a body having a minimal downstream extension, usable in a narrow profile flowmeter configuration.

It is well known that the presence of a bluff, or non-streamlined, body within a moving fluid stream causes vortices to be shed alternately from opposite sides of the body, the frequency of production of the vortices being related to the flow rate of the fluid. The dynamics of the so-called Von Karman vortex street which emanates from the bluff body have been extensively studied, and the principles have been effectively applied in numerous commercial flow-rate measuring devices.

Although a single thin, flat plate is recognized as being capable of shedding vortices (see, for example U.S. Patent No. 3,116,639), this shape has seen limited commercial use. Bluff bodies typically used in commercial flow meters have a more complex structure, and a downstream length which is a substantial fraction of the transverse width, generally resulting in a flowmeter of considerable length. For example, U.S. Patent No. 3,572,117 shows a bluff body which extends downstream for a distance of one to two times its width. Similarly, in U.S. Patent No. 3,948,097 the bluff body has a downstream length between 0.5 and 0.9 times its width, while U.S. Patent No. 3,810,388 teaches that a width-to-length ratio of 1.5 (i.e., the length is 2/3 the width) yields maximum energy for vortex formation.

U.S. Pat. No. 4,297,898 discloses the use of "plate-like" upstream and downstream obstacles but the thickness of the respective obstacles and the gap therebetween yields a configuration whose overall downstream length is on the order of 1.2 times its width.

The use of a bluff body of appreciable downstream length has restricted the utility of a vortex flowmeter in certain applications. For example, a user of a narrow-profile flowmeter, such as an orifice plate, generally cannot replace his existing installation with the higher-performance vortex flowmeter without extensive modification to the piping system to accommodate the considerably longer vortex flowmeter housing. Although in U.S. Patents Nos. 4,171,643 and 4,186,599 a narrow-profile vortex shedding configuration is formed from a thin plate, multiple vortex-shedding members are employed, spaced transversely across the diameter of the pipe.

In view of the above, it is an object of the present invention to generate strong, linear vortex streets from a bluff body without the need for a minimum downstream length. It is a further object of the invention to provide a narrow-profile vortex flowmeter using such a bluff body which is suitable for replacement of an orifice plate flow measuring system.

An embodiment of a body for shedding vortices within a fluid flowing through a conduit of inside diameter D, in accordance with the present invention, includes an upstream elongate member spanning the interior of the conduit, having an upstream-facing surface aligned normal to the flow direction. The surface has a width H_F as measured perpendicular to the direction of span of the upstream member. The body further includes a downstream member, which also spans the interior of the conduit, its direction of span being parallel to that of the upstream member. This downstream member has a width H_T in the direction normal to the flow direction, as measured perpendicular to its direction of span, and an extension L along the direction of flow, as measured from the upstream-facing surface. The ratio H_F/H_T is within the range from 1.0 to 2.2, while the ratio H_F/D is in the range from 0.1 to 0.3, and the ratio L/H_F is less than 0.4.

In a particular embodiment of the present invention, the downstream member consists of elongate convex projections integrally formed with the back surface of the upstream member. These projections, in addition to being individually parallel to the direction of span of the upstream member, are also parallel to one another. There are one or more such projections. In the case of multiple projections, the dimension H_T represents the overall width of the combination of projections, i.e., the transverse distance between the outermost edges of the two outermost projections. These projections can have various cross-sectional shapes, including rectangular, semi-circular and U-shaped.

In an alternate embodiment, the downstream portions are elongate plates or rods which are separated by a narrow gap from the back surface of the upstream plate. As in the previous embodiment, the rods or plates are parallel to each other as well as being parallel to the direction of span of the upstream member, and similarly they can have square, rectangular, circular, oval, etc. cross-sections. The overall width H_T of such a configuration is the same as defined above for the convex projections.

The limitation of the overall downstream extension L of the bluff body structure to a maximum of 0.4 times the width H_F, allows the overall length of a flowmeter utilizing such a body to be no greater than the typical thicknesses of orifice plate installations, for an appreciable range of conduit inner diameters. This constraint makes the narrow profile flowmeter suitable for replacement of orifice plates.

The novel features and advantages of the present invention will become apparent to those skilled in the art from the following description of the preferred embodiments in conjunction with the accompanying drawings in which:

FIG. 1 is a perspective view of a bluff body in accordance with the present invention;

FIG. 2 is a cross-sectional view of the bluff body of FIG. 1, taken along the line 2-2;

FIG. 3 is a schematic of a flowmeter apparatus utilizing the bluff body of FIG. 1;

FIG. 4 is a graph depicting the variation in vortex linearity with variations in the ratio H_F/H_T; and

FIG. 5A, 5B through 10A, 10B are, respectively, perspective and sectional views of several alternate embodiments of the bluff body, the sectional views being taken along the lines 5B-5B through 10B-10B respectively.

Referring now to FIG. 1, an elongate bluff body 11 spans a circular opening 13 within a thin housing 15. The body is rigidly attached to the housing at both ends. The opening is equal in size and shape to the bore of a conduit (not shown) within which the bluff body is placed for the purpose of shedding vortices within a stream of fluid. The direction of fluid flow, once the bluff body is placed within the conduit, is in the direction toward the viewer, as indicated by an arrow 17.

The bluff body 11 is made up of two components, an upstream portion 11A and a downstream portion 11B. The upstream portion is an elongate thin plate 19, with a flat upstream-facing surface 19A (see FIG. 2) aligned normally to the direction of fluid flow. The non-streamlined contours of the body cause vortices to be shed alternately from its opposite sides, in a manner well known to the art. The thickness, or downstream-extending dimension, of the plate is minimal, being determined primarily by the structural requirements necessary to withstand the forces generated by the fluid flowing past the plate. Preferably, the thinner the plate the better, since according to the present invention, desired stability and linearity characteristics of the vortex street can be maintained without the added downstream length taught by the prior art. Thus, extra downstream length means wasted volume and material.

The downstream portion 11B comprises a second elongate thin plate 21 parallel to the upstream plate 19 and stretching across the inner opening 13 of the housing in the same direction as the upstream plate. As with the first plate, the second plate is rigidly attached to the housing.

Referring now to FIG. 2, there is shown a cross-sectional view of the bluff body 11 of FIG. 1 as viewed perpendicular to its longitudinal axis (longitudinal axis being the same as direction of span across the opening 13). This view shows quite clearly the parallel arrangement of the upstream and downstream portions. The width of the upstream plate 19, that is, the dimension which is normal both to the flow direction and to the longitudinal axis of the bluff body, is labeled as H_F. The width of the downstream plate 21 is similarly defined and is given the label H_T.

Experiments have shown that strong vortices having a frequency which is linearly proportional to the velocity of flow are achieved by maintaining the ratio H_F/H_T within specified limits (hereinafter described), while simultaneously keeping the ratio of H_F to the diameter D of the opening 13 within the range 0.1 to 0.3, a range of values already known to the prior art. (It should be remembered that the diameter D is equal to the diameter of the conduit through which the fluid flows.) This linearity is sustained over a range of velocities from approximately 0.15 to 3.0 meters per second (i.e., a 20:1 rangeability). These results are achievable even if the total downstream length L of the bluff body, as measured from the upstream-facing surface 19A, is allowed to fluctuate over a range of values, namely the range in which L/H_F 0.4.

FIG. 3 is a schematic representation of a flowmeter apparatus on which these experimental results were obtained. The bluff body 11 and its attached housing 15 are installed in a conduit 23 carrying fluid in the direction indicated by an arrow 25. The presence of the body within the stream generates a periodic vortex street, indicated generally by reference numeral 27, which progresses downstream with the moving fluid. At a downstream location, a pair of ultrasonic transducers, a transmitting transducer 29 and a receiving transducer 31, are disposed on opposite sides of the conduit. An oscillator 33, typically operating at a frequency of 1 MHZ, drives the transmitting transducer so as to project an acoustic signal through the conduit and the fluid, toward the receiving transducer. The interaction of the acoustic signal with the vortex-carrying fluid stream causes a modulation of the acoustic signal, at the repetitive frequency of the vortices. The receiving transducer detects the modulated signal and transfers it to an amplifier 35. The detected signal is passed through a demodulator 37 to yield a measurement signal having a frequency equal to that of the vortex street. Finally the measurement signal passes through a filter 41 to an electronic counter 43, producing an output indicative of the vortex generation frequency. Since acoustic or ultrasonic detection of vortices and vortex frequencies are well known in the prior art, no detailed description of the detection circuitry need be given. However it should be noted that any of a variety of well known vortex detection schemes, including non-acoustic systems, may be adaptable to the measurement of vortices produced by the bluff body of the present invention.

Visualizations of the flow around bluff bodies built in accordance with the present invention have shown that, due in part to the abbreviated downstream length, vortex formation occurs downstream of the entire body. The fully formed vortex is not shed from the upstream portion alone, but from the upstream and downstream portions acting in concert. Although the upstream and downstream portions, if viewed separately, each have vortex-shedding shapes, when coupled together as described herein they define a unitary vortex-shedding structure. Thus, it has been found that attempts to detect the vortices alongside, or at a point too near, the body may yield signals having unsatisfactory characteristics, e.g., poor stability and linearity. Optimum results are obtained by locating the ultrasonic transducers sufficiently downstream of the bluff body that the vortices have broken away from the separation streamline produced by the body, and have become fully defined. Typically, this is a distance of approximately two-thirds of the pipe diameter downstream from the body.

By externally setting the flow velocity of the stream to a predetermined, calibrated value and measuring the corresponding vortex frequency, a proportionality between the flow velocity and the frequency can be determined. Varying the flow velocity, while maintaining the dimensions of the bluff body constant, yields a series of proportionality values, and the percent deviation in the proportionality over a range of velocities equals the percent non-linearity of the vortex generating scheme. The generally accepted unit for expressing proportionality is the Strouhal number S, which is generally defined as the ratio of the vortex frequency F times the face width H_F of the bluff body divided by the flow velocity V. Because of the unique geometry of the bluff body of the present invention, it is more appropriate to use the corrected Strouhal number S_∞ as the indicator of proportionality, S_∞ being given by the equation:

$$S_\infty = \frac{FH_F}{V}\left[\frac{\frac{\pi D^2}{4} - H_F D}{\frac{\pi D^2}{4}}\right]\left[1 - \frac{H_F}{D}\right] \qquad 1.35$$

The curve shown in FIG. 4 represents a general summary of the experimentally observed variations in linearity occurring with changes in H_F/H_T, for a variety of bluff body configurations built in accordance with the present invention. These data were generated with L constant, and $0.1 \leq H_F/D \leq 0.3$. It can readily be seen that a particularly desirable degree of linearity, i.e., non-linearity limited to within $\pm 0.75\%$, can be expected when H_F/H_T is in the range from approximately 1.0 to 2.2.

Although the downstream portion of the embodiment of FIG. 1 is a single, thin plate of rectangular cross-section, this is not the only type of downstream arrangement which performs adequately in the context of the present invention. For example, consider the bluff body shown in FIGS. 5A and 5B, in which the downstream portion is a rod, or cylinder, 44 of circular crosssection. Although experimentation was not performed on downstream bodies of every conceivable shape, it is generally expected that bodies having square, triangular or even irregularly shaped cross-sections will perform in accordance with the teachings of the present invention as long as the constraints on the ratio of H_F/H_T and H_F/D are observed.

It should be noted that isolated deviations from the desirable ±0.75% non-linearity shown in FIG. 4 may occur for a particular H_F/H_T for a body configuration of the type shown in FIGS. 1 and 5A, i.e., a single downstream body separated from the upstream portion. Even in such a case, however, the body configuration continues to function as an effective vortex shedder. However, these deviations can be eliminated by altering slightly one of the dimensions, while keeping the ratios within the prescribed limits.

Multiple downstream bodies also are functional, as in the case of the structures shown in FIGS. 6A, 6B and 7A, 7B. It should be pointed out, however, that in the case of multiple downstream bodies, H_T does not merely refer to the combined widths of the two individual bodies, but rather is a measurement of the overall width of the bodies, as measured between their outermost edges, as shown in FIGS. 6B and 7B.

Although in each of the previously discussed embodiments there is a separation between the back surface of the upstream portion and the downstream portions, the principles underlying the present invention are found not to be restricted to such a configuration. Indeed, as long as the dimensional ratios are maintained as previously discussed, the downstream portions can be attached to, or integrally formed with, the upstream portion, and the same vortex-generating characteristics are maintained. Referring now to FIGS. 8A and 8B, the downstream portions are in the form of discrete elongate protuberances or projections 45, having a convex outer surface, which depend from the back of the upstream portion. As in the case of the earlier embodiments, the longitudinal axes of these projections are parallel to the longitudinal axis of the upstream plate, as well as being parallel to each other. Although these projections are shown to be generally rectangular in cross-section, semi-circular projections 47 (FIGS. 9A and 9B), and U-shaped projections 49 (FIGS. 10A and 10B), also have proven acceptable. Again, although no more than two downstream portions are shown in any of the embodiments, it is to be understood that multiple such bodies can be used, subject to the dimensional limitations.

The present invention establishes that appreciable downstream length L (i.e., $L/H_F > 0.4$) of the bluff body is not necessary for producing commercially acceptable vortex streets, a notion which is contrary to that espoused by the prior art. Thus, the myriad bluff bodies described or suggested herein are particularly useful in a flowmeter having a narrow profile. In other words, the total length L can be made small enough to allow the bluff body and its surrounding housing 15 (see FIG. 1) to be no thicker than the spacing typically associated with orifice plates. For pipe sizes up to 8 inch diameter, a standard orifice plate generally is 1/8 inch thick; for larger pipe diameters, the orifice plates may range from 0.6 to 1.3 cm thick. By inserting such a narrow profile flowmeter between two sections of pipe in the place of an orifice plate, and utilizing downstream ultrasonic transducers functioning in the manner of transducers 29, 31 (see FIG. 3), a traditional orifice plate installation can be converted to a more accurate, reliable and more linear vortex flowmeter installation with little if any modification to the piping system.

In lieu of the electronic counter 43, appropriate electronic circuitry for converting the measurement frequency into a volumetric flow rate, or other appropriate units, can be substituted. Again such circuitry is well known to those skilled in the electronics art, and will not be elaborated upon in the present application.

Of all the embodiments described herein, the preferred embodiment is as shown in FIGS. 8A and 8B, with the attached rectangular projections. Experimentation has shown this embodiment to shed vortices effectively in both liquid and gaseous flows. When combined with a vortex detecting device, particularly an ultrasonic type, it provides an accurate and sensitive flowmetering capability. An embodiment which is particularly amenable to a vortex detecting scheme which depends on a physical interaction with the vortices, such as a piezoelectric detector, is the embodiment of FIGS. 5A and 5B. Sufficient energy is transferred between the vortices and the downstream circular rod to permit measurement of the vortex frequency through observation of the rod's movements. This bluff body configuration can be adapted readily to the external vortex sensing scheme disclosed in co-pending U.S. application serial number 236,416, which has a common assignee as the present application.

Clearly, certain modifications and substitutions to the disclosed embodiments may become apparent to those skilled in the art, but which do not depart from the spirit of the present invention. For example, different cross-sectional shapes for the downstream portions of the bluff body, or alternate vortex detection schemes may be proposed. It is intended, however, that such modifications be included within the scope of the following claims.

Claims:

1. A body for shedding vortices within a fluid flowing through a conduit of inside diameter D, of the type having both upstream and downstream members, characterized by:

said upstream member (19) being elongate and spanning the interior of said conduit, having an upstream-facing surface (19A) aligned normal to the flow direction, said surface having a width H_F as measured perpendicular to its direction of span; and

said downstream member (21) being elongate and spanning the interior of said conduit, its direction of span being parallel to the direction of span of said upstream member, having a width H_T, as measured perpendicular to its direction of span, and an extension L along the flow direction, as measured from said upstream-facing surface, the ratio H_F/H_T being within the range from 1.0 to 2.2, the ratio H_F/D being in the range from 0.1 to 0.3, and the ratio L/H_F being less than 0.4.

2. The body as set forth in claim 1, further characterized by said downstream member being integral with said upstream member.

3. The body as set forth in claim 1, further characterized by said downstream member being separate from said upstream member.

4. The body as set forth in claim 2, further characterized by said downstream member being an elongate convex projection (45), aligned parallel to the direction of span of said upstream member and fixed to the downstream side of said upstream member.

5. The body as set forth in claim 2, further characterized by said downstream member comprising a plurality of elongate convex projections, each aligned parallel to the direction of span of said upstream member and fixed to the downstream side of said upstream member.

6. The body as set forth in claim 4, further characterized by said convex projection having a generally rectangular cross-section along its length.

7. The body as set forth in claim 4, further characterized by said convex projection having a generally semicircular cross-section along its length.

8. The body as set forth in claim 4, further characterized by said convex projection having a U-shaped cross-section along its length.

9. The body as set forth in claim 3, further characterized by each of said convex projections having a generally rectangular cross-section along its length.

10. The body as set forth in claim 5, further characterized by each of said convex projections having a generally semi-circular cross-section along its length.

11. The body as set forth in claim 5, further characterized by each of said convex projections having a U-shaped cross-section along its length.

12. The body as set forth in claim 3, further characterized by said downstream member comprising an elongate rod having a generally rectangular cross-section along its length.

13. The body as set forth in claim 3, further characterized by said downstream member comprising an elongate rod (44) having a generally circular cross-section along its length.

14. The body as set forth in claim 3, further characterized by said downstream member comprising an elongate rod having a generally oval cross-section along its length.

15. The body as set forth in claim 3, further characterized by said downstream member comprising a plurality of elongate rods, each rod being aligned parallel both to the direction of span of said upstream member and to each other, and lying in a plane transverse to the flow direction.

16. The body as set forth in claim 15, further characterized by each of said rods having a generally rectangular cross-section along its length.

17. The body as set forth in claim 15, further characterized by each of said rods having a generally circular cross-section along its length.

18. The body as set forth in claim 15, further characterized by each of said rods having a generally oval cross-section along its length.

19. A narrow profile vortex-shedding assembly, of the type suitable for insertion between two sections of conduit, characterized by:

a thin, annular housing (15) having an inner opening which matches the bore of said sections of conduit;

a first elongate member (19) spanning said inner opening and being rigidly attached to said housing, said first member having a width H_F as measured perpendicular to its direction of span; and

a second elongate member (21) spanning said inner opening downstream of said first member, its direction of span being parallel to the direction of span of said first member, and being rigidly attached to said housing, said second member having a width H_T as measured perpendicular to its direction of span, the performance characteristics of the vortices shed by said assembly being dependent on the magnitude of the ratio H_F/H_T.

20. A narrow profile vortex-shedding assembly, of the type suitable for insertion between two sections of conduit, characterized by:

a thin, annular housing (15) having an inner opening which matches the bore of said sections of conduit;

a first elongate member (19) spanning said inner opening and being rigidly attached to said housing, said first member having a width H_F as measured perpendicular to its direction of span; and

a second elongate member (21) spanning said inner opening downstream of said first member, its direction of span being parallel to the direction of span of said first member, and being rigidly attached to said housing, said second member having a width H_T as measured perpendicular to its direction of span, the ratio H_F/H_T

being within the range from 1.0 to 2.2, the total thickness of said assembly being not greater than that of a standard size orifice plate for said conduit.

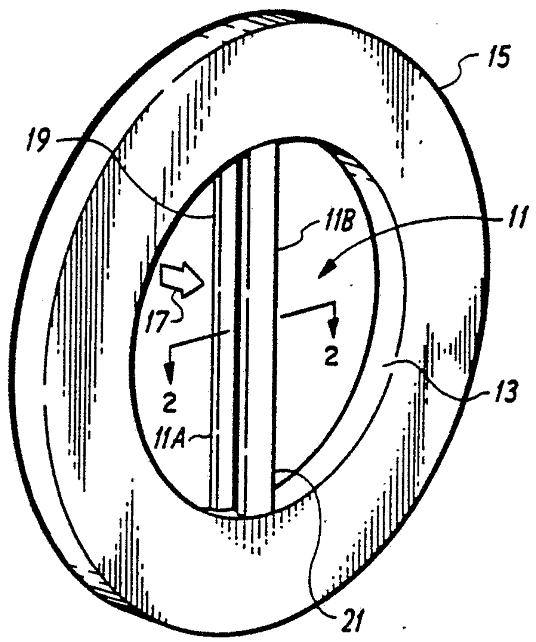

FIG. 1

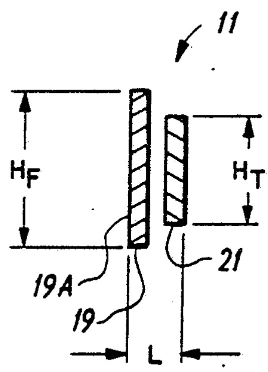

FIG. 2

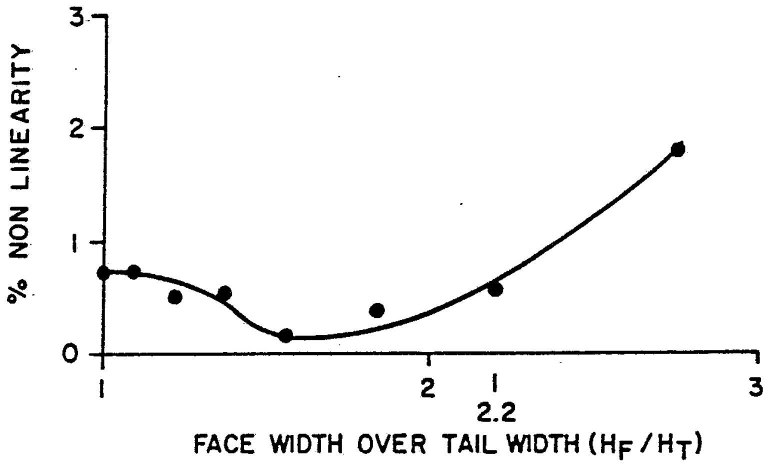

FIG. 4

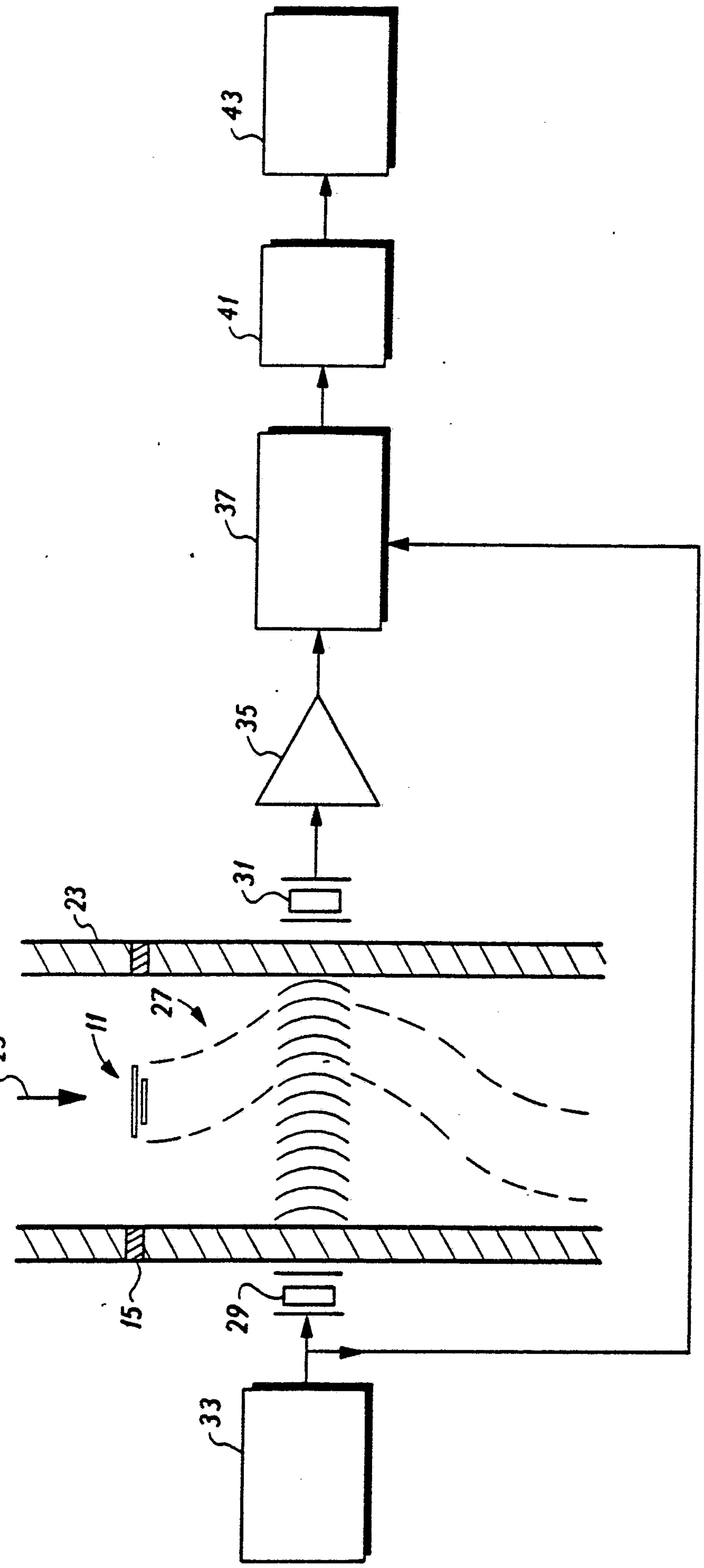

FIG. 3

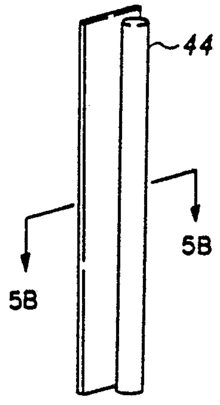

FIG. 5A

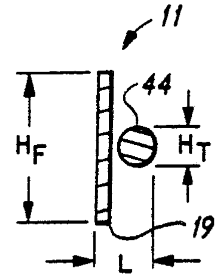

FIG. 5B

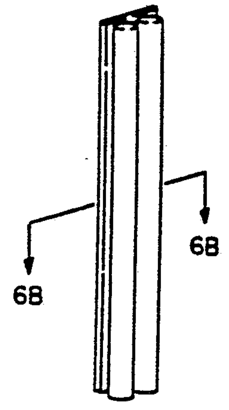

FIG. 6A

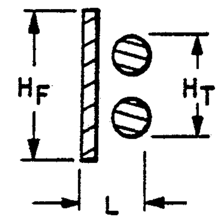

FIG. 6B

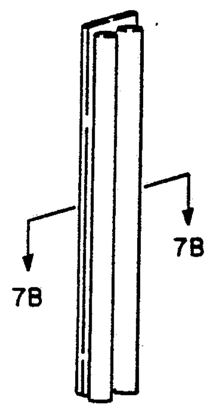

FIG. 7A

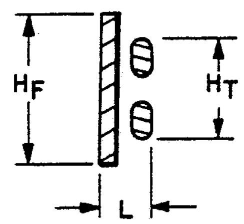

FIG. 7B

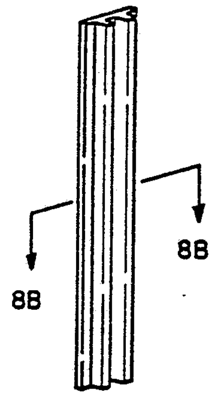

FIG. 8A

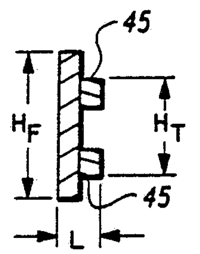

FIG. 8B

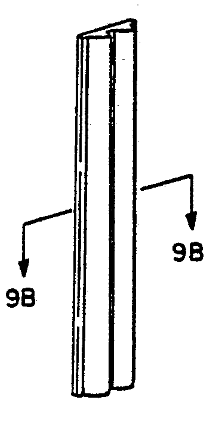

FIG. 9A

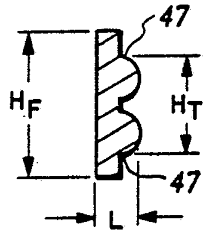

FIG. 9B

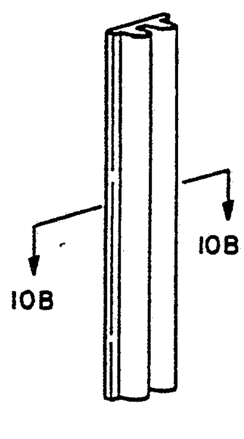

FIG. 10A

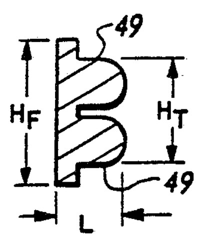

FIG. 10B

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 83/00469

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^3: G 01 F 1/32

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
IPC^3	G 01 F

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	GB, A, 1500704 (G. KENT LTD.) 8 February 1978, see figures 1A, 1B, 2,3,4, 6A-6D; page 1, line 85 - page 2, line 50 --	1,3,9,12, 13,19,20
Y	GB, A, 1489870 (EMI LTD.) 26 October 1977, see figures; page 1, lines 34-53; page 2, lines 18-58 --	1,3,9,12, 19,20
X	US, A, 4171643 (R.L. FRICK) 23 October 1979, see abstract; figures 1,2,6,7; column 3, lines 5-46; column 6, line 63 - column 7, line 21 --	1,2,6,8, 9,11,19,20
Y	FR, A, 2376400 (ROSEMOUNT INC.) 28 July 1978, see figures; page 2, lines 17-20; page 2, line 37 - page 3, line 3; page 4, lines 22-24; page 10, line 15 - page 11, line 17 --	1,19,20
Y	FR, A, 2088461 (YOKOGAWA ELECTRIC WORKS LTD.) 7 January 1972, see figures 6,9,10; page 7, line 15 - page 8, line 34	1,3

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
30th June 1983	01 SEP. 1983
International Searching Authority [1]	**Signature of Authorized Officer** [20]
EUROPEAN PATENT OFFICE	G.L.M. Kruydenberg

International Application No. PCT/US 83/00469

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No [18]
Y	DE, A, 2517533 (YOKOGAWA ELECTRIC WORKS LTD.) 20 November 1975, see figures --	1,3,9,10, 12,13
A	US, A, 4030355 (P.J. HERZL) 21 June 1977, see figures; abstract --------	1-3

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO. PCT/US 83/00469 (SA 5113)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 14/07/83

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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
GB-A- 1500704	08/02/78	None		
GB-A- 1489870	26/10/77	None		
US-A- 4171643	23/10/79	FR-A-	2376400	28/07/78
		DE-A-	2757384	06/07/78
		JP-A-	53084760	26/07/78
		US-A-	4186599	05/02/80
		GB-A-	1589690	20/05/81
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82