PATENT SPECIFICATION

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(54) DIRECTIONAL HOT FILM ANEMOMETER TRANSDUCER

(71) We. ENVIRONMENTAL INSTRUMENTS, INC., a corporation of the Commonwealth of Massachusetts, having its principal place of business at 4, Merver Road, Natick, Massachusetts, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates generally to anemometer sensing apparatus for ascertaining motion of a fluid relative to the apparatus, and more particularly to a transducer apparatus employing electrically self-heated conductors for determining speed, mass flow and direction of motion of the fluid in which the transducer is immersed.

Heretofore, thermal anemometer sensors of various types have been developed for measuring classical fluid flow parameters. Examples of these sensors are described, and circuits therefor, are shown in United States Patents, Nos. 3,138,025, 3,333,470, 3,352,154, 3,604,261, and most particularly, by U.S. Patent No. 3,900,819. The described embodiment of the present invention overcomes several inherent deficiencies and disadvantages found in the transducer disclosed in the last mentioned United States patent.

Although dual element transducers built in accordance with the teachings of U.S. patent No. 3,900,819 represent a significant improvement over the use of hot wire and other sensing elements. It has been observed that the measured cosine response of the transducers are by no means near the ideal. It appears that maximum errors in angular measurement by pairs of conjugate transducers occur at or near the 45 degree points between the cardinal points of 0, 90, 180, 270 and 360 degrees.

The described embodiment of the present invention provides a directional hot film anemometer sensor which overcomes the aforementioned disadvantage of the prior art fluid flow sensors. The anemometer transducer has no moving parts, provides a broad dynamic range of operation, and may be exposed to an exteremely wide range of environmental extremes with sustained exposure to frozen precipitation, as in the case of mountain or northern weather stations, without the need for extensive protection mechanical basket-like enclosure structure, or auxiliary de-icing heating of a protective structure.

According to the present invention, there is provided a directional hot film anemometer for measuring fluid flow comprising:

(a) a transducer having a central element closely spaced from and disposed between two outer elements, the three elements being elongate and extending side by side in the direction of elongation,

(b) electrically non-conductive thermal insulating means forming barriers closing the gaps between the central element and the adjacent outer elements,

(c) each of the elements having an elongate electrically insulative body carrying on its outer surface an adherent fiilm of a substance whose electrical resistance varies with temperature, and

(d) each of the elements having means providing electrical connections to its adherent film whereby the film can be heated by the passage of an electrical current. The central element can be used to thermally bias the pair of anemometer sensing elements so as to improve their cosine law agreement when used as direction sensing devices whereby the resistance distribution and the temperature distribution, can be altered selectively so as to modify the spatial response of the primary sensing element pair to incident wind flow or fluid flow.

Two forms of directional hot film anemometer constructed in accordance with the invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 is a perspective view of one form of a directional hot film anemometer transducer made in accordance with the present invention, wherein three parallel supported electrical resistive sensing elements are used to form the transducer,

Fig. 2 is an elevational sectional view of the directional hot film anemometer transducer illustrated in Fig. 1, taken along the line 8—8 thereof, and looking in the direction of the arrows,

Fig. 3 is a perspective view of the second form of the directional hot film anemometer transducer of Fig. 1, wherein the resistive conductor of the central support element is disposed in a limited area of the central element,

Fig. 4 is a graphical representation of the distribution of temperature axially along the directional hot film transducer of Fig. 3,

Fig. 5 is a schematic circuit diagram of an illustrative circuit which may be used to excite the directional hot film anemometer transducers shown in Fig. 1 and Fig. 3, and

Fig. 6 illustrates the angular response which may be realized from a directional hot film anemometer transducer of the present invention when the output signals derived from the excitation circuit of Fig. 5 are appropriately processed, linearized and combined.

Referring now to the drawings, and initially to Fig. 1, the transducer 10d includes a pair of cylindrical elements or members 11a and 11b which are resistive sensing elementts whose lengths "L" are greater than their diameters "D". Both sensing elements 11a and 11b are symmetrically disposed alongside a central active hot film sensing element 15b to which they are mechanicallly attached by an electrically non-conductive thermal insulating means in the form of adhesive or bridging means 12a and 12b. The bodies of the sensing elements 11a, 11b, and 15b have connection means at each end formed by the end connection means 13a, 13b and 13c and electrical connecting wires 17a, 17b and 17c at one end, and the end connection means 14a, 14b and 14c and connecting wires 16a, 16b and 16c at the other end. The bodies of the sensing elements 11a, 11b and 15b are uniformly resistive, and the connction means 13a, 13b, 13c, 14a, 14b and 14c are made of similar material in order to maintain the highest possible signal to noise performance of the total transducer. The connecting lead wires, 16a, 16b, 16c, 17a, 17b and 17c are also constructed of a material which is similar to that used by the end connection means 13a, 13b, 13c, 14a, 14b and 14c in order to avoid unwanted spurious electrical noise. It is the lead wires 16a, 16b, 16c, 17a, 17b and 17c that provide the mechanical support of the transducer 10d. The material usually used is annealed platinum which is extremely malleable. Alternatively materials which may be used for the sensing elements 11a and 11b and their associated electrical connections are described in U.S. Patent No. 3,352,154 and in U.S. Patent No. 3,900,819.

The central sensing element 15b provides biasing heating at the central portion of the axial transducer array. It has been found that an increase in sensitivity of dual element sensors of the type disclosed in U.S. Patent No. 3,900,819 can be realized by such heating augmentation, with little additional power, since the tertiary element 15b lies in the thermal lee of sensing elements 11a and 11b. In other words, the leeward sensing element, away from incident wind does not now absorb power from the leading edge sensor which is cooled by incident wind.

Bridging means 12a and 12b can be a semiflexible, thermally isolating adhesive material, such as room temperature vulcanizing silicone rubber, which serves to rigidly support and attach sensing elements 11a and 11b to the central element 15b. Other materials can be used but should not be permitted to cover more than 180 degrees of the circumference of either sensing element 11a or 11b, so as not to interfere with the spatial response of the transducer to the impinging flow. On the other hand a near infinitesimal amount of adhesive material 12a and 12b can be used so as to just close the aerodynamic gap between the sensing elements 11a and 11b and the support element 15.

As a practical matter, the central element 15b should not be much larger in diameter than the sensing elements 11a and 11b in order to avoid the generation of a large stagnation region ahead of the sensing elements 11a and 11b, which region is determined or generated by the geometry of the central element 15b, rather than by the geometry of the sensing elements themselves. In order to function as an effective directional anemometer transducer, the element geometry must predominantly determine the local flow field past the transducer array.

Fig. 2 illustrates the cross section structure of the transducer 10d of Fig. 1, elements 11a, 11b and 15b are all similar to each other. Each element 11a, 11b and 15b has an electrically insulative body in the form of a hollow, tubular aluminium oxide refractory substrate cylinder 18a, 18b and 18c upon the surface of each of which is uniformly deposited by firing, sintering, sputtering or other deposition means, a thin coating or film of platinum metal 19a, 19b and 19c which has a further layer 20a, 20b and 20c of fused silica, aluminium oxide or other protective coating material which provides abrasion and wear protection for the platinum film 19a, 19b and 19c. Typical dimensions of substrates 18a, 18b and 18c are a cylinder diameter of 0.024 inches with a bore diameter of 0.012 inches and a length of one inch.

Typical thickness of the platinum film 19a, 19b and 19c is in the range of 2500 to 5000 Angstroms, and a one inch long sensing element 11a, 11b or 11c with substrate 18a, 18b, 18c diameter of 0.24 inches has a resistance of about 3 to 5 ohms at room temperature. Typically, the protective coating 20a, 20b and 20c is about 0.0005 to 0.001 inches thick. When aluminium oxide coatings are used, the coating thickness is about 0.002 to 0.005 inches in order to assure gas thightness.

A large length (L) to diameter (D) ratio will produce greater angular sensitivity to airflow in the plane containing the axes of the cylinders 11a, 15b and 11b. Flow away from the plane, as shown by flow angle α, will be able to have its direction sensed by the sensing element pair 11a and 11b through a 360 degree change in angle. Sign sense of direction can be determined by electrical inspection of the resistance value of each sensing elements 11a and 11b when they are compared with each other by appropriate electrical circuitry as illustrated in U.S. Patent No. 3,900,819, and reference is made to said U.S. Patent No. 3,900,819 for a discussion of the operation of the dual sensing elements as a directional fluid flow transducer.

Fig. 3 illustrates the second form 10c of the transducer of Fig. 1, wherein the sensing film 19c is divided into two portions 19c′ and 19c″ so as to be deployed near the ends of the central sensing support element 15c. For example, zones A and A′ are shown to be approximately equal in length and a low resistance portion 19c‴, zone B, provides electrical connection between the ends of portions 19c′ and 19c″ where they lie on the central support element 15c. This unheated zone B, formed by the conductor 19c‴, goes completely around the central sensing support element 15c. The end caps 13c and 14c provide connection means for electrical attachment of the lead wires 17c and 16c to the outboard ends of films 19c′ and 19c″, respectively. The cross section structural detail of the transducer of Fig. 3 is the same as shown in Fig. 2.

Fig. 4 graphically illustrates the manner by which the temperature distribution may be lineally improved along the length of the transducer of Fig. 3, wherein the numeral 22 designates the approximate shape of the temperature distribution of a transducer that has a central element that is not heated. Curves 23a and 23b illustrate the improvement which may be realized by the heating of sensing element sections 19c′ and 19″ of Fig. 3. The ends of the transducer tend to approach ambient temperature by virtue of stem and lead wire conduction heat losses, as well as the lack of heating contribution by the element end cap connections which also serve as heat absorbers or sinks. For ideal spatial or direction response a uniform temperature distribution along the length "L" of the transducer is desired.

Fig. 5 illustrates a bridge within a four arm Wheatstone bridge which may be used to excite the transducer of Figs. 1 and 3. As shown in Fig. 5, resistors 24, 25 and 35 are three arms of the Wheatstone bridge. The fourth arm is formed by resistors 27 and 28, together with sensing elements 11a and 11b which altogether form a bridge within a bridge. Element 15b or 15c, the biasing element of Figs. 1 and 3 respectively, forms part of the fourth arm. By this connection the total resisitance of the series/parallel connection of elements 11a, 11b, and 15b (or 15c) is maintained at a constant value by virtue of the feedback connection provided by amplifier 29 together with current booster amplifier 30 whose output is connected to the Wheatstone bridge at point 31. The bridge error signal is developed across the bridge between points 32 and 33 which are connected to the inverting and non-inverting inputs respectively of amplifier 29. Bridge ground connection is made at point 34. All of the resistors forming the bridge, with the exception of sensing elements 11a and 11b, as well as element 15b (or 15c) should have low temperature coefficients of resistance. The sensing elements must have a value of temperature coefficient of resistance which is non-zero and substantially larger than that of the bridge resistors used as the reference arms. Resistor 35 can be used as a temperature sensor which is used for temperature compensation of the hot film velocity sensing elements 11a, 11b and 15b (or 15c). The anemometric or wind speed output is provided by buffer amplifier 36 which produces a low impedance output 37 which follows the transducer signal which is developed between ground point 34 and point 32. Output 37 is non-linear and follows the approximate fourth root of wind speed, and it also contains a constant DC term which is determined by the zero wind heating condition, and the output also includes turbulence components. An excellent reference which describes the treatment and use of these signals is "Resistance Temperature Transducers" by Virgil A. Sandborn of Colorado State University, 1972, Metrology Press, Fort Collins, Colorado.

For sign sense of direction, amplifier 38 is connected to junction points 39 and 40 at the direction sensing bridge within the Wheatstone bridge, and the sign sense output 41 will change sign, assuming that bridge 11a, 11b, 27 and 28 is statically balanced for zero wind conditions, depending on whether sensing element 11a or 11b is into the wind flow. Output signals 41 and 37 can be combined by analog or digital computer means in order to arrive at a single signal which uniquely produces wind speed times cosine of the incident wind vector.

Fig. 6 graphically illustrates a polar plot of transducer response from the circuit shown in Fig. 5 when looking down on the transducer 10c shown in Fig. 3. Sensing elements 11a and 11b are shown in their geometric relationship to the desired ideal figure eight polar representation of the cosine function 42. It is difficult to construct an ideal sensing element pair, therefore, the measured response is usually somewhat different as shown by curve 43. This can be described approximately as a cosine plus sine function; however, it is not a simple expression. The addition of sensing element 15c with zonal heating, as described by Figs. 3 and 4 tends to bring the curve 43 closer to the ideal cosine function 42, and experience shows that it can be done in a predictable fashion. The total response to wind flow in a direction other than one that lies in the plane of the paper is the same as that to wind flow in the direction that lies in the plane of the paper which forms the same angle $\ominus$ to the axis of the transducer except that there is a separation plane along the vertical 90 degree 270 degree axis. Thus, a three dimensional graph would look like a toroid, with ine polarity output for the right half and the opposite polarity for the left half.

WHAT WE CLAIM IS:—

1. A directional hot film anemometer for measuring fluid flow comprising:

(a) a transducer having a central element closely spaced from and disposed between two outer elements, the three elements being elongate and extending side by side in the direction of elongation,

(b) electrically non-conductive thermal insulating means forming barriers closing the gaps between the central element and the adjacent outer elements,

(c) each of the elements having an elongate electrically insulative body carrying on its outer surface an adherent film of a substance whose electrical resistance varies with temperature, and

(d) each of the elements having means providing electrical connections to its adherent film whereby the film can be heated by the passage of an electrical current.

2. A directional hot film anemometer as claimed in claim 1, which includes

means electrically connecting in series the two outer elements of the transducer,

means electrically connected to the three elements of the transducer and forming a bridge circuit with the two series connected elements in one arm of the bridge and the central element being connected in that same arm in parallel with the two series connected elements,

means connectable to a power source for causing an electrical current to flow to the three elements of the transducer to cause them to be heated above the ambient temperature, and

regulating means connected to the bridge circuit for regulating the electrical current to cause the total resistance of the three elements in the aforesaid bridge arm to be held constant for constant ambient temperature.

3. A directional hot film anemometer as claimed in claim 2, which includes electrical means coupled to the junction of the two series connected elements of the transducer and responsive to the difference in resistance of those elements for obtaining an indication of fluid flow direction.

4. A directional hot film anemometer as claimed in any one of claims 1 to 3, wherein the insulative body of one or more of the elements is hollow.

5. A directional hot film anemometer transducer as claimed in any one of claims 1 to 4, wherein the conductive resistance film of the central element extends along the entire length of the central element.

6. A directional hot film anemometer as claimed in any one of claims 1 to 4, wherein the conductive resistance film on the supporting body of the central element comprises a pair of axially spaced zonal portions which are electrically connected by an intermediate low resistance portion.

7. A directional hot film anemometer transducer as claimed in any one of claims 1 to 4, wherein the conductive resistance film of the central element comprises a plurality of axially spaced zonal portions which are electrically connected.

8. A directional hot film anemometer, which is substantially as hereinbefore described with reference to, and as shown in, Figs. 1, 2 and 5, or Figs. 2, 3 and 5.

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Reference has been directed in pursuance of section 9, subsection (1) of the Patents Act 1949, to Patent No. 1,455,591.

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1579581 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1

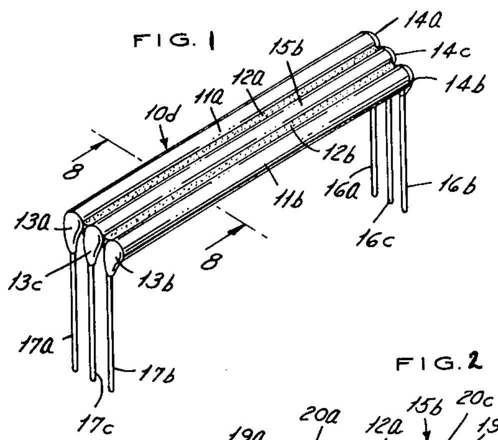


FIG. 2

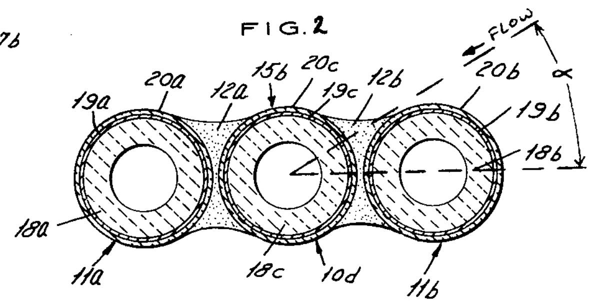
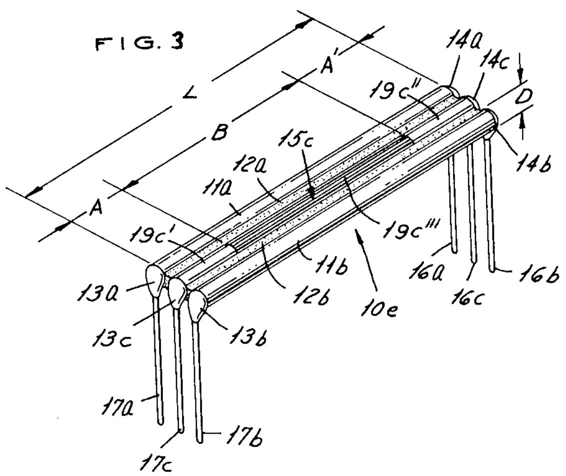


FIG. 3



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2 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 2

FIG. 4

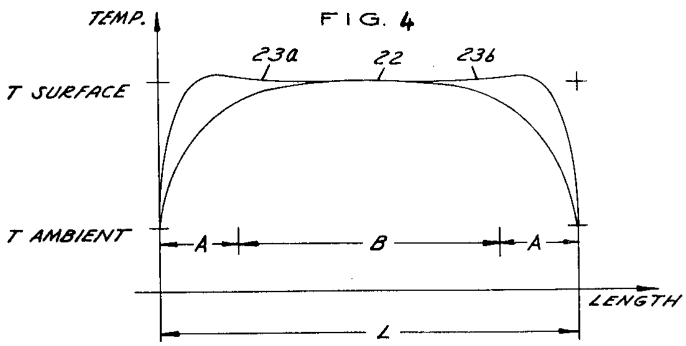

FIG. 5

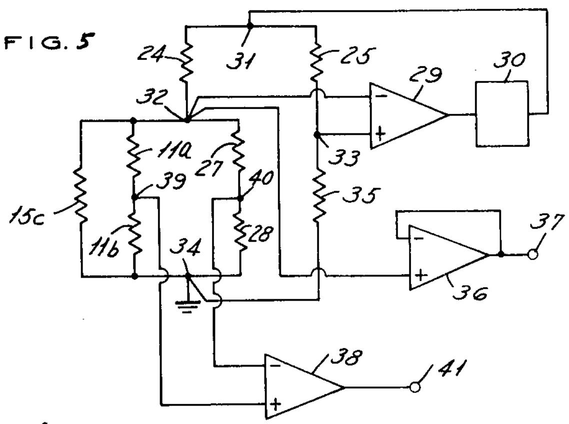

FIG. 6