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A vertical wind measuring instrument

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ABSTRACT. A vertical wind measuring instrument for micro-meteorological studies capable of measuring wind of magnitude upto one metre per second and a maximum frequency of ten cycles per second has been described. The sensitivity of the instrument is 3 cm per sec and the response time is 1·5 sec.

1. Introduction

In connection with investigations on exchange processes in the boundary layer it is necessary to know accurately the turbulent transfer of momentum, sensible heat and water vapour. To determine these fluxes it is also necessary to measure the vertical component of wind so that it can be correlated with the other variables controlling these processes. Accurate information is of primary importance in micrometeorological work.

2. Principle

A number of instruments are available for measuring vertical component of wind using different principles like hot wire, bivane, sonic anemometer and spherical bodies. Propeller type anemometers have also been developed.

After examining the operating principles of all these available instruments it was felt that a light weight spherical sensor in which the dynamic pressure is directly measured appeared to be a better choice for a system designed to measure vertical heat and moisture fluxes. Reed and Lynch (1963) have discussed the advantage of such a sensor. Doe (1963) has already designed an instrument employing spherical sensor for measurement of three components of wind. Although this instrument is an excellent example in design, owing to difficulties of complications in alignment and precise mechanical fabrication it was thought that this instrument can be modified to measure vertical wind only. It was also necessary to select a sensor, output from which could be used for measurement of vertical fluxes directly in conjunction with a bridge type instrument. Moreover, the ratio of horizontal to vertical wind normally encountered is very large and it is difficult to design a system employing same sensor which would have the same sensitivity for these ranges. For measurement of horizontal wind a number of extremely good anemometers are also available. It was therefore thought that utilizing the same principle and the type of sensor a vertical wind instrument can be built.

The present instrument works on the principle of thrust of wind on a spherical body. The sensing element is a spherical shell made of expanded polyesterene foam of 150 mm diameter and 3 mm wall thickness. The transducer consists of a linear voltage differential transformer (LVDT) and wind thrust displaces the core from its normal central position either upwards or downwards. The output from the LVDT is demodulated and fed to a strip chart recorder. A record of the magnitude of wind thrust either up or down is thus obtained.

3. General description

Figs. 1 (a) and 1 (b) are the elevation and plan views of the interior of the instrument. E is a ring of paper-base laminate of diameter 11·5 cm and cross-section of 1 cm by 1 cm. Another sector of an aluminium ring D of diameter 10 cm and cross section 8mm $\times$ 8 mm is fixed to E by means of a bracket slightly displaced from the centre, the planes of each being normal to each other. D carries a rail C also made of aluminium rod of square section 1cm $\times$ 1 cm and is fixed to it by means of two screws. Over this rail moves a slider B which carries the differential transformer A. The transformer can be moved vertically up or down by moving the slider B; it can also be clamped in any position.

Flat grooves are made over the two ends of the rail C to which two flat pieces of beryllium copper springs are fixed and clamped by two plates fitting in the grooves.

The rod G consists of an indigeneous reed known as sarkhandi which is very light, comparatively

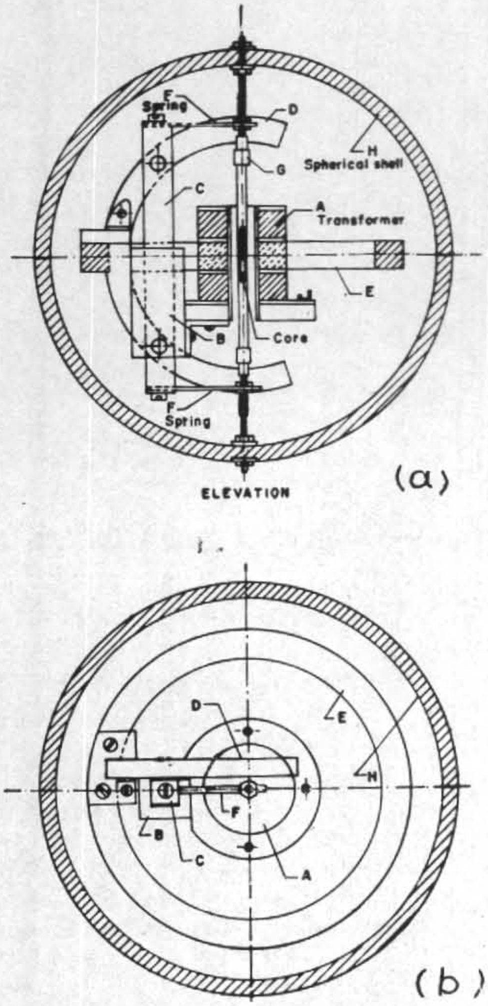

Fig. 1 (a & b)

strong and very smooth. As sarkhandi buckles with weather, it was dipped into transformer winding varnish before putting into the instrument. A slit is made in its centre and two pieces of magnetic laminate of size 3 mm×25 mm are fixed by epoxy rasin glue. To the ends of the rod are fixed two aluminium bushes also with glue; the other end of the bushes are internally threaded into which are inserted two finely threaded brass rods of 1·5 mm diameter.

The threaded portions of the rod G are made to pass through the holes at the end of the flat springs and are clamped by two nuts. Two hemispherical shells H of expanded polyesterene material are placed over these two ends of the rods by one pair of nuts and washers such that their equatorial diameter meet. The sector ring D along with rail C is fixed to the equatorial ring in such a way that the rod G is aligned at the polar axis of the spherical shell.

A rigid aluminium tube is fixed to the ring E and passes through a hole along the joint of the two hemispherical shells.

Thrust by wind on the sphere from any direction displaces the magnetic core rod G up or down. The transformer A is adjusted by sliding up or down in order to obtain no output from it in the normal position when there is no wind.

The primary of the transformer is excited by a 2 Khz oscillator. The output from the secondaries is fed to an operational amplifier, detected by a phase sensitive detector and is recorded on a 0-1 mA strip chart recorder.

The flat springs are made from 2 mm wide and 0·125 mm thick beryllium copper strips; their overall length is 40 mm but effective length for deflection is 27 mm only.

The spherical shell is fabricated from expanded polyestered material; its overall diameter is 15 cm and wall thickness 3 mm. It is made into two halves and are joined at their equator. The total weight of the shell is 6 gm.

4. Design consideration

The drag force on a sphere due to wind is given by—

$$F = \tfrac{1}{2}\,\rho\, C_d\, A\, V^2$$

where, F is drag force

ρ is density of air = .001 gm/cm^3

C_d is drag coefficient of sphere = .4 (assumed)

A is projected area of sphere = 176.7 cm^2

V is wind speed.

For a spring system as described earlier the relation between deflection of the end of the spring and the applied force on the core-rod is given by—

$$d = \frac{4\, l^3}{y\, t\, b^3}\,.\,F$$

where, d is deflection of the end of the spring

l is effective length of the spring 1.35 cm ($2l = 2.7$ cm)

t is thickness of the spring = .0125 cm

b is width of the spring = .125 cm

y is Young's modulus of spring = 19×10^{11} dynes/sq. cm

F is applied force.

With the above values deflection per unit force can be calculated which is equal to 4.11×10^{-4} cm/dyne.

$$\text{The spring constant} = \frac{1}{\text{deflection per unit force}}$$

$$= \frac{1}{4.112 \times 10^{-4}} \text{ dynes/cm}$$

$$= 41.95 \text{ gm/cm}$$

$$= 4.195 \text{ gm/0.1 cm}$$

Calculated value of spring constant $4 \cdot 195$ gm/$0 \cdot 1$ cm agrees well with the experimental value. Deflection of the system is observed by adding weights on the top of the sphere. The experimental results are shown in Fig. 3.

From the above, the relation connecting the deflection of core and wind speed can be derived as —

$$d = \frac{2 l^3 \rho C_d A}{y t l^3} \cdot V^2$$

The relation between deflection of the core and the output voltage from the secondaries of the differential transformer can be expressed when the displacement is small relative to length of the coil as —

$$E_0 = \frac{2.a.E_i}{L} \cdot d$$

$$= K \cdot d$$

where, E_0 = output voltage
E_i = input voltage to the primary
L = inductance of primary
d = deflection of core from a zero level
a = constant
and $K = 2aE_i/L$

The output voltage can therefore be related to the square of the wind speed by the following expression —

$$E_0 = \frac{2Kl^3 \rho C_d A}{y t b^3} \cdot V^2 = K_1 K_2 V^2$$

where, $$K_1 = \frac{2L}{aE}$$

$$K_2 = \frac{2l^3 \rho C_d A}{y t b^3}$$

The output voltage is therefore directly proportional to the square of the wind speed.

The choice of the size of the sphere has been decided by the fact that the drag coefficient should be constant over the operating range of wind speed

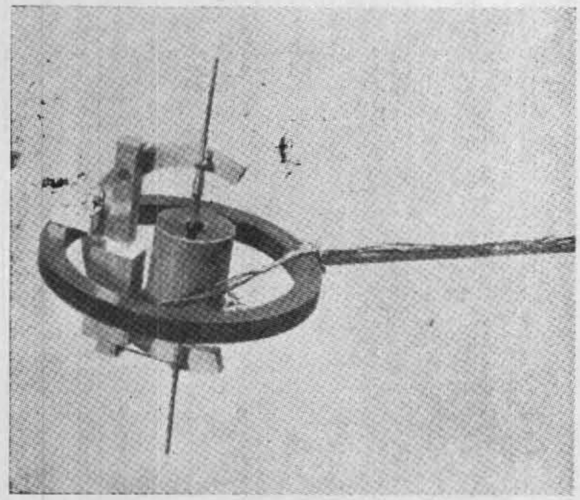

Fig. 2 (a)

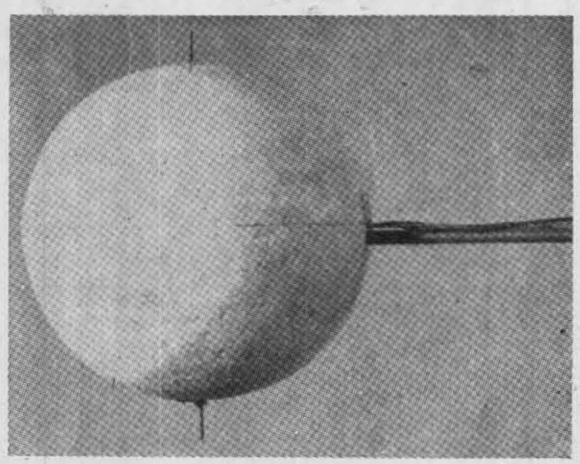

Fig. 2 (b)

Figs. 2(a) and 2(b) show the photographs of the interior mechanism of the instrument and when it is exposed to atmosphere for measurement with the spherical shell.

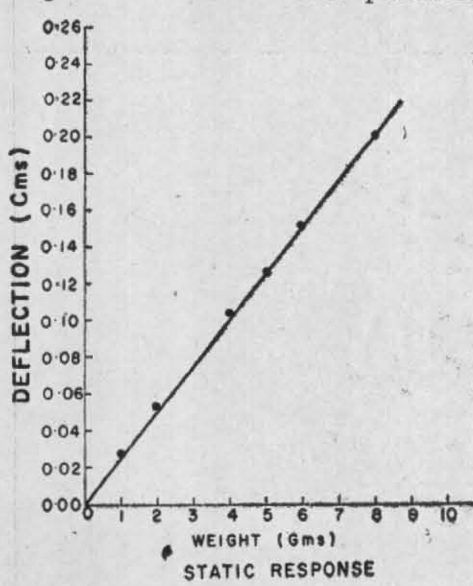

Fig. 3

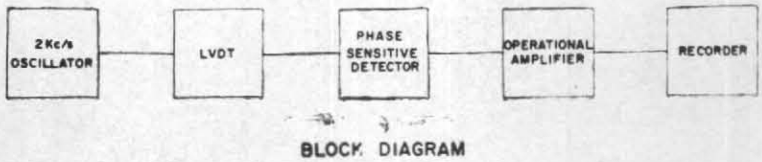

Fig. 4

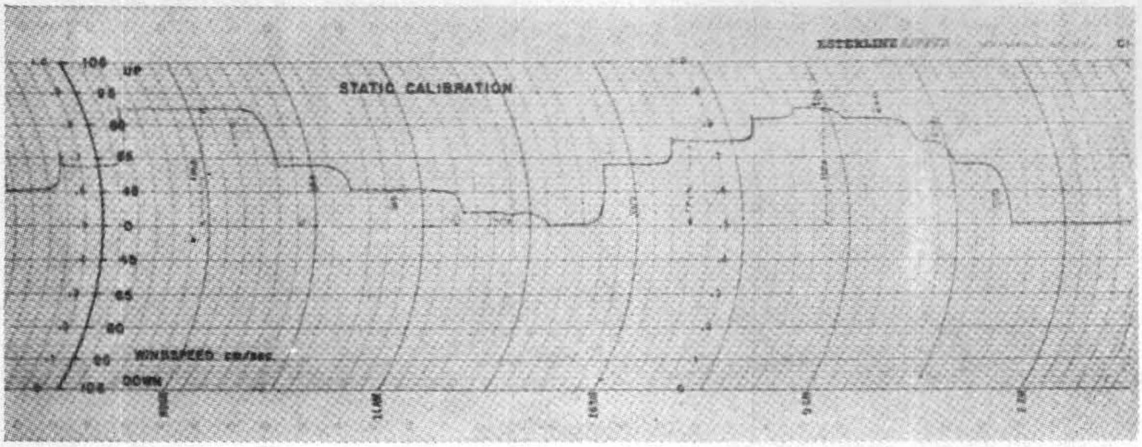

Fig. 5 (a). Final output for static weights (in mg)

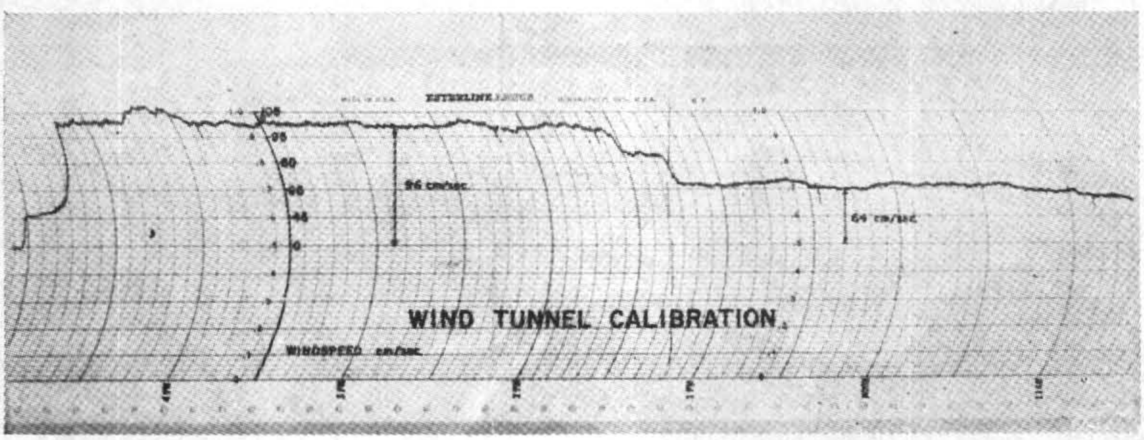

Fig. 5 (b). Wind tunnel calibration

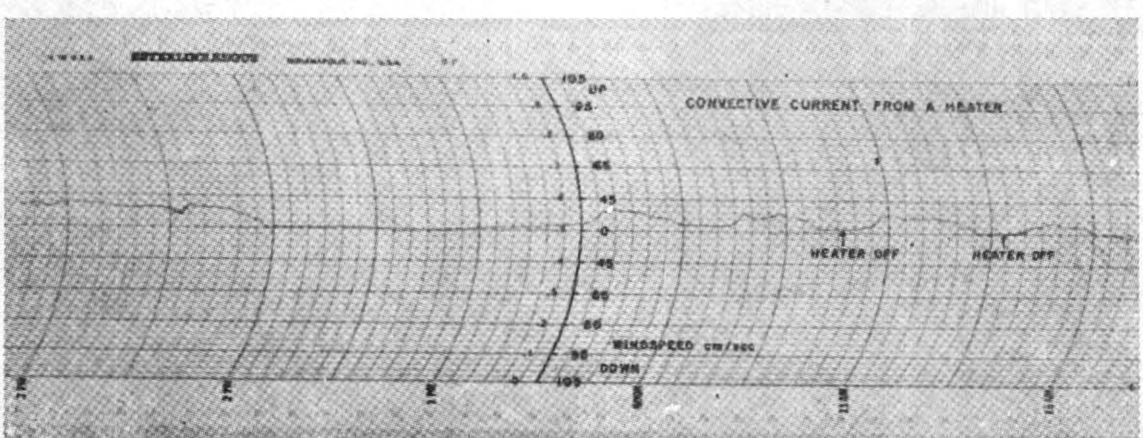

Fig. 6. Record of convection current due to a heater placed below

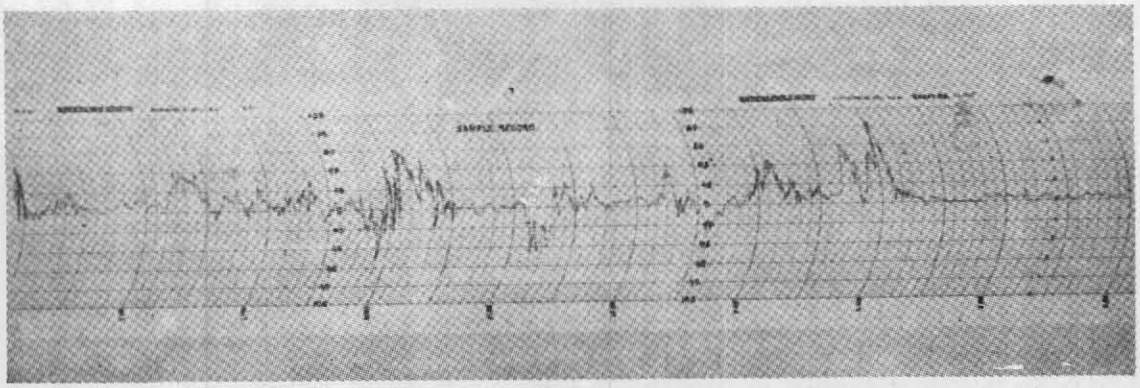

Fig. 7 (a). Sample record obtained on a day with light winds

and that the sphere should provide sufficient dynamic force to displace the core against the force of the flat springs corresponding to the maximum scale reading of the recording systems. The drag coefficient of a sphere is substantially constant over the region of Reynolds number from 10^3 to 10^5. Assuming a value of Reynolds number 2×10^4 over the middle of this region and maximum vertical wind speed of 2 metres per second the size of the sphere is about 17 cm. A sphere of 15 cm diameter has been used for the instrument. This would produce a thrust of order of $1\cdot3$ gm/cm assuming the drag coefficient to be $0\cdot4$ for 2m/s wind speed. The weight of the shell is 6 gm.

Springs

The springs are made from beryllium copper strips and heat treated. Their effective length is $2\cdot70$ cm, width $0\cdot125$ cm and thickness $0\cdot0125$ cm. The Young's modulus constant of the material is 19×10^{11} dynes/sq. cm. For a drag force corresponding to 1 m/sec wind the core would be deflected approximately by 7×10^{-3} cm.

LVDT

The primary is wound with 4000 turns of anamelled copper wire of 44 swg and two secondaries each with 7500 turns of same gauge. When the primary is excited with $1\cdot5$ V at 2 Khz the output at the secondary varies from $\cdot01$V either way for a maximum displacement of core of 7×10^{-3} cm.

5. Electronic circuitry and performance

The block diagram of the electronic circuitry is given in Fig. 4. Most of the units used are conventional and therefore no details of their operation are being given.

A 2 Khz/s Rc oscillator furnishes the existing voltage for the primary of the LVDT which is amplified by a power amplifier and fed through interconnecting cable to the instrument. The output from the secondaries is fed to a phase sensing circuit, then to an operational amplifier, type 6 PC 5 which is able to drive a 0-1 mA chart recorder.

The recorder used is a strip chart one requiring driving voltage of $0\cdot7$ volts from centre to full scale value. The phase sensitive detector and operational amplifier have been so adjusted that this driving voltage is obtained from the system. As far as possible noise, stray pick up, drift and non-linear operation have been avoided. Half scale output corresponds to a maximum wind speed of 1 m/sec; final output in terms of wind speeds for static weights can be seen in Fig. 5 (a). Fig. 5(b) shows wind tunnel calibration with air meter C 4033.

6. Natural frequency, damping and response

Doe (1963), for the results summarised by Priestly has shown that the vertical wind sensors should have a natural frequency of oscillation greater than ten cycles for the results to be of any significance. The natural frequency of the sensors (n) and the moving parts of the transducer can be computed from the relation —

$$n = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$$

where, K = force exerted by the spring per unit displacement

m = moving mass.

The computed value comes to about 4 cycles/sec. A small amount of damping has been used to eliminate residual vibrations. Response time was found by giving a step thrust to the instrument, which is $1\cdot5$ sec.

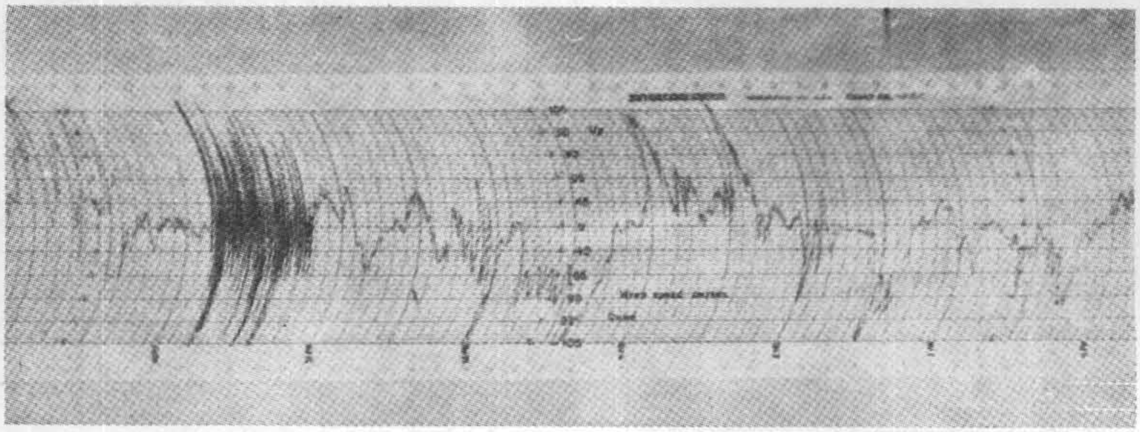

Fig. 7 (b). Sample record obtained on a day with gusty winds

7. Sensitivity

The instrument is capable of recording steady vertical velocity of the order of 3 cm per second. In Fig. 6 it may be seen the record of an updraft from a hot plate when the sensor was placed at a distance of $2\frac{1}{2}$ ft from the heater. A sample record can be seen in Fig. 7.

8. Conclusion

The instrument constructed is capable of recording vertical velocities of the order of 3 cm/sec to 3·6 kmph with frequency even greater than 10 cycles but this is limited by the response of the recording device.

Acknowledgements

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