Presented Fourth Symposium on Meteorological Observations and Instrumentation, Denver, Colo., Apr. 10-14, 1978, AMS. To appear in Prenrint Volume.

BNL-23632

AN INDUCTION-TYPE BIVANE TO MEASURE VERTICAL AND LATERAL WIND VELOCITY FLUCTUATIONS *

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1. INTRODUCTION

Measurements of instantaneous lateral and vertical velocities from towers have several micro-meteorological applications. Studies related to atmospheric diffusion, boundary layer development, sea-breeze phenomenon, wind gust characteristics, siting of nuclear and fossil power plants, etc. require the information regarding the longitudinal and lateral atmospheric turbulence. Several meteorological instruments are available to make such measurements, viz. sonic anemometers, three-dimensional hot-wire and hot-film anemometers and propeller-vane sensors, to mention a few. Each has its own advantages and disadvantages. A sensor that measures wind based on cooling, for example constant temperature hot-wire and hot-film sensors, has the advantage of high frequency response but suffers from the disadvantages of the necessity to face the wind due to its cosine response characteristics, its delicate features and susceptibility to loss of calibration and breakage during prolonged exposure in the atmosphere. Split-film sensors help in sensing the direction of wind with better accuracy, but need correlation of six different outputs which is difficult for continuous long-term measurements. On occasion, when high frequency response (~500 Hz) is a necessity, hot-wire sensors are ideal. Sonic anemometers are more rugged, but the three-dimensional types involve complex electronics requiring constant attention and maintenance. They are certainly well suited for particular experiments in the range of a few hours to a few days in places where background noise is not a problem.

This leaves us with the conventional vane-type sensors for prolonged measurements. They orient themselves with the wind continuously and have second order dynamic response characteristics (MacCready, Jr. and Jex, 1964). Bivanes that measure lateral and vertical wind gusts in terms of deviations from mean positions are available. Vane-propeller-type sensors combine a propeller with the bivane. One of the problems we encountered with these instruments was that the electronic components of the sensors fail after continuous use in the atmosphere for a few days, particularly in a hostile environment consisting of precipitation, salt spray and high winds. There is, of course, always the possibility of mechanical damage to moving parts; hence, the need for a bivane that will be rugged but at the same time have reasonably high frequency response. Annular-type bivanes have been used in the past at Brookhaven National Laboratory (Mazzarella, 1952). The bivane described in this paper is also an annular-type, but several times smaller in size. It has a good frequency response (~2 Hz) and is very rugged. It was in continuous operation for a period of one year on a meteorological tower and maintained its calibration. More recently, for the past six months, it has been used for over-water measurements of atmospheric turbulence at an air-sea interaction buoy anchored 5-km off shore. It was found to perform without mechanical or electronic difficulties over this period of time. Due to its low power consumption and easy adaptation to AC or DC power supply, its use is unlimited for various meteorological applications. This paper describes its basic design features, wind tunnel tests for response characteristics, and comparative field measurements with other sensors.

2. DESIGN FEATURES

On the top of a vertical housing for the electronics is a light-weight vane assembly in the form of a cone supported at its center of gravity. An annular tail is counterbalanced, partly by an adjustable weight at the apex and partly by another adjustable weight near the center of gravity.

As indicated in the line diagram (Figure 1) counterbalancing is carried out by three counterweights. The small wire "trim" counterweight serves to either return the vane to horizontal after the last gust or leave it in the direction of the last gust. Its position along the horizontal rod determines this.

Vertical zero adjustment is accomplished by a setscrew arrangement on the short horizontal chain drum shaft. Vertical DC output is normally plus and minus with zero as horizontal. An operational amplifier changes this to all positive.

Electrical analog of vertical displacement is obtained via a light-weight chain running over a drum and down a hollow shaft to a linear displacement transducer giving a DC output. Azimuth shifts are recorded via a small synchro attached to the vertical hollow shaft. The synchro output is converted to DC sine and cosine for recording. This method eliminates the zero crossing problem. The outputs are combined during data processing to produce absolute directions.

This design represents a one-third reduction in physical size and almost a factor of ten in weight over the previous annular design used at Brookhaven National Laboratory.

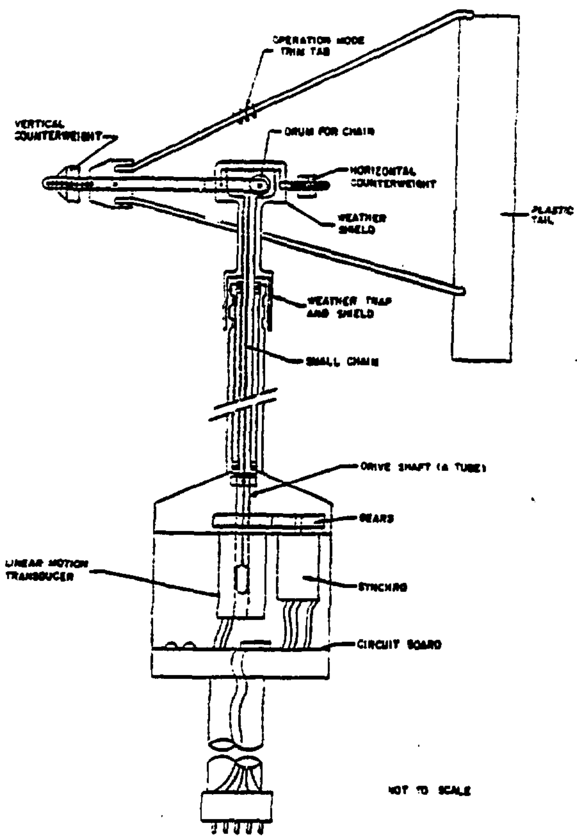

Figure 1. A line diagram of the BNL bivane showing the details of construction.

3. RESPONSE CHARACTERISTICS

The bivane has a second order system response to an angular displacement. This response depends on the input and the first and second derivation of the response. Two parameters commonly used to define the response are the undamped natural frequency ω_n and the ratio of the actual damping to critical damping called damping ratio η. The differential equation for response of the bivane will be of the form

$$\frac{d^2\theta}{dt^2} + 2\,\omega_n\,\eta\,\frac{d\theta}{dt} + \omega_n^2\,\theta = f(t) \qquad (1)$$

where θ is the angular displacement of the vane with respect to a fixed direction and $f(t)$ a time dependent forcing function.

Wind tunnel tests were performed on the bivane at different wind speeds. The method consisted of moving the vane in the vertical plane by a known amount and then releasing it instantaneously to measure its response. The same method was repeated for horizontal angle response. The step response of the bivane for horizontal angle for a mean wind speed of 5 m/sec is shown in Figure 2. An overshoot of 2 deg. is seen before the vane comes to an equilibrium position. Figure 3 shows the step response for

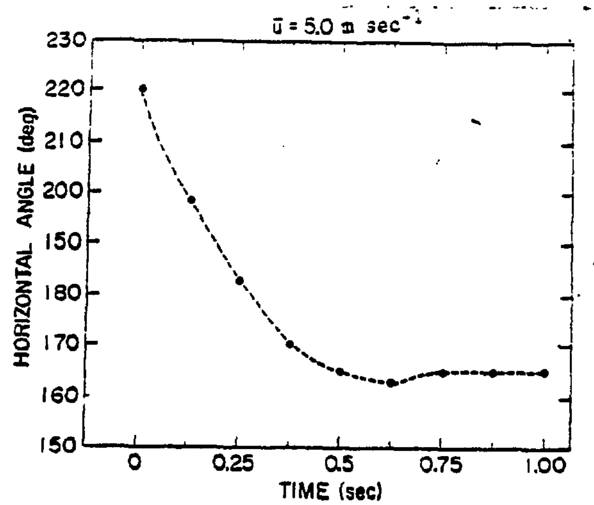

Figure 2. Wind tunnel test for a step change in the horizontal angle. Mean wind speed = 5 m sec^{-1}.

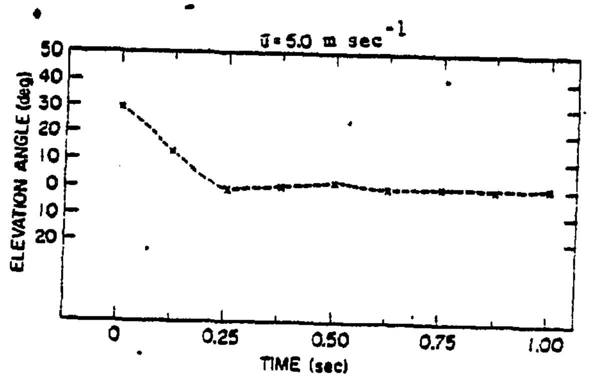

Figure 3. Wind tunnel test for a step change in the elevation angle. Mean wind speed = 5 m sec^{-1}.

the elevation angle for the same wind speed. The overshoot in this case was about 1 degree. From the response curves the parameters, damping ratio η, delay distance D (and delay time T_D = D/U where U is the wind speed) can be computed. The time T_D is usually defined as the value for the vane to move from its initial position to 50 per-cent of the final equilibrium value. The delay distance is computed to be about 0.31 m for horizontal angle. The vane reaches 50 per cent value in less than 1/16 sec for the elevation angle and in about 1/8 sec for the horizontal angle. At lower wind speeds (Figure 4) the overshoot is slightly more and the delay time larger, although the delay distance remains constant.

4. FIELD COMPARISON

A comparison study of different wind sensors was done in the atmospheric surface layer with a 24-m high meteorological tower. A BNL bivane, a vector vane (manufactured by Meteorology Research, Inc.), a metal-clad single hot-wire sensor (manufactured by Thermo Systems, Inc.), and a BNL cup anemometer were compared, as shown in Figure 5. The vector vane used has a frequency response of about 2 Hz (SethuRaman and Brown, 1976)

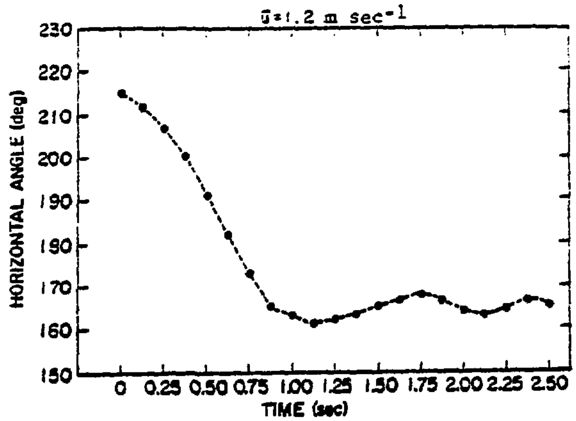

Figure 4. Wind tunnel test for a step change in the horizontal angle. Mean wind speed = 1.2 m sec^{-1}.

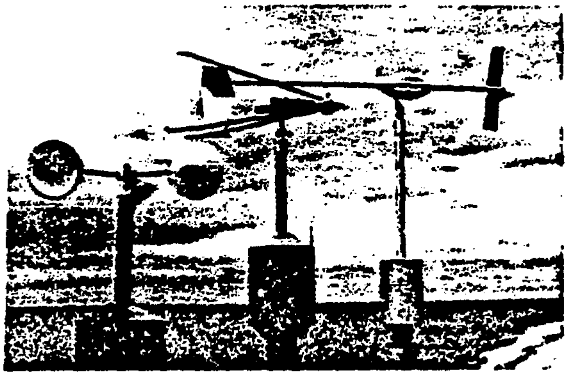

Figure 5. Comparison of measurements made by different instruments at a height of 24 m. The instruments are cup anemometers, BNL bivane, hot-wire and MRI vector vane (from left to right).

the rugged hot-wire about 5 Hz and the cup anemometer about 1 Hz. The horizontal velocities measured by the hot-wire were used in conjunction with the instantaneous horizontal angle and elevation angle outputs to obtain lateral and vertical velocities, respectively. The observations from all instruments were recorded in analog form on magnetic tapes, digitized at 8 per second after passing through low-pass RC filters and analyzed for mean and variance. The standard deviations of the horizontal and elevation angles (σ_θ and σ_φ, respectively) measured by the BNL bivane and the MRI vector vane are given in Table I. The mean wind speed $\bar{u}$ and the standard deviation of the longitudinal velocity fluctuations σ_u is also given as additional information.

Table I. Comparison of Observations

	Hot wire		Bivane*		MRI		VV**	
	$\bar{u}$	σ_u	σ_θ	σ_φ	$\bar{u}$	σ_u	σ_θ	σ_φ
(EST)	(m/sec)		(deg.)		(m/sec)		(deg.)	
1045-1115	7.37	1.26	11.8	3.8	7.21	1.10	8.0	3.2
1145-1215	8.40	1.15	9.3	3.5	8.20	1.03	5.8	2.8

* BNL Bivane; ** Vector Vane

The standard deviation of vertical velocity fluctuations σ_φ measured by both the instruments was about the same although the BNL bivane gave slightly higher values. The difference was larger for the σ_θ (lateral velocity fluctuations) values. This is not totally surprising due to the higher frequency response of the BNL bivane.

5. CONCLUSIONS

The construction of a rugged bivane to measure lateral and vertical velocity fluctuations is presented. Wind tunnel tests indicate a fairly high frequency response in both the directions. Comparison with other conventional meteorological instruments in the field was carried out to determine its accuracy in relation to others. The results were very encouraging.

REFERENCES

MacCready, Jr., P. B. and H. R. Jex (1964), Response characteristics and meteorological utilization of propeller and vane wind sensors, J. Appl. Meteor. 3, 182-193.

Mazzarella, D. A. (1952), An all-weather remote-recording bivane, Bull. Amer. Meteor. Soc. 33, 60-66.

SethuRaman, S. and R. M. Brown (1976), A comparison of measurements made by a hot-film probe, a bivane, and a directional vane in the atmospheric surface layer, J. Appl. Meteor. 15, 138-144.

*Research performed under the auspices of the U.S. Department of Energy under Contract No. EY-76-C-02-0016.