A Sensitive Cup-Type Anemometer[1]

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(Manuscript received 31 May 1966, in revised form 25 April 1967)

ABSTRACT

A sensitive cup-type anemometer was developed which is mechanically and electrically simple. The characteristics include a starting speed of 6 cm sec^{-1}, distance constant (63%) of 90 cm, and a linear response.

1. Introduction

Measurement of wind profiles over areas of limited horizontal extent for the purpose of determining surface characteristics or transport coefficients demands the following requirements of cup-type anemometers:

1) The anemometer, including cup assembly and transmitter, should be physically small, so that several anemometers can be stacked vertically within the boundary layer of the field.

2) It should be sensitive; that is, it should have a low turning force and a quick response to wind speeds.

3) It should have a linear response.

4) It should be mechanically and electronically simple.

The literature contains descriptions of many types of cup assemblies. Patterson (1926) found that the 3-cup anemometer system yields a more uniform torque than 2-or 4-cup systems. Middleton and Spilhaus (1953) also preferred the 3-cup anemometer because of more uniform torque and a greater torque per unit weight. Conical-shaped cups were preferred over hemispherical-type cups because they run slower (Marvin, 1934), and the relation between cup speed and wind speed was more linear (Sheppard, 1940). Cups with rolled edges were more sensitive to variations in wind-stream turbulence than plain cups (Sheppard, 1940). The overrun caused by turbulence is much less with beaded cups than with smooth cups. The variation in size of the bead seems to be of secondary importance in cup performance (Marvin, 1934).

The relation between arm length and cup size has been investigated by several workers. Brazier (Middleton and Spilhaus, 1953) concluded that the relations between cup speed and wind speed will be linear when the arm length (distance from the center of the cup to the axis) is two times the cup radius. This ratio of arm length to cup radius is small compared to most anomometers. Patterson (1926) concluded that the relation would be linear with very short arms; however, the torque would be smaller. Sheppard (1940) found a linear relation between the rate of rotation and wind speed when the arm length is approximately 2.5 times the cup radius. After careful consideration Patterson (1926) and Fergusson (1934) decided the best design includes an arm length 2.5 times the cup radius. This criterion prevails in commercially available anemometers.

Some of the commercially available anemometers meet most of the above requirements. However, the need for a simpler counting system and better response prompted the development of another cup-type anemometer. The design and response characteristics of the anemometer are discussed in the following sections.

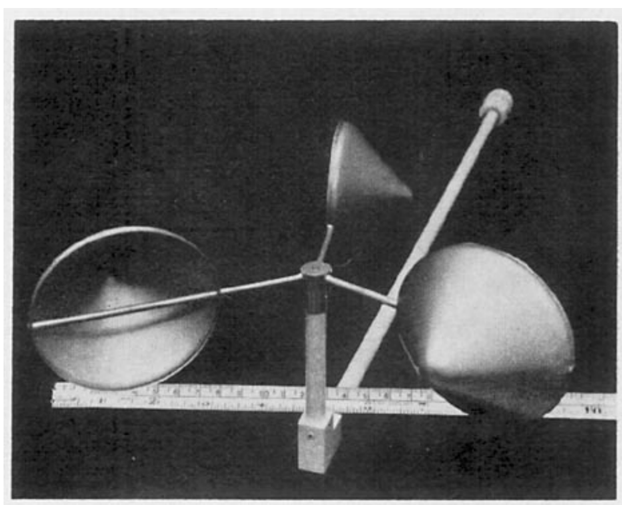

Fig. 1. Sensitive cup-type anemometer with No. 1 cup assembly.

[1] Contribution from the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture. Supported in part by the Atmospheric Science Research Division, U. S. Army Electronic Research and Development Activity, Fort Huachuca, Ariz.

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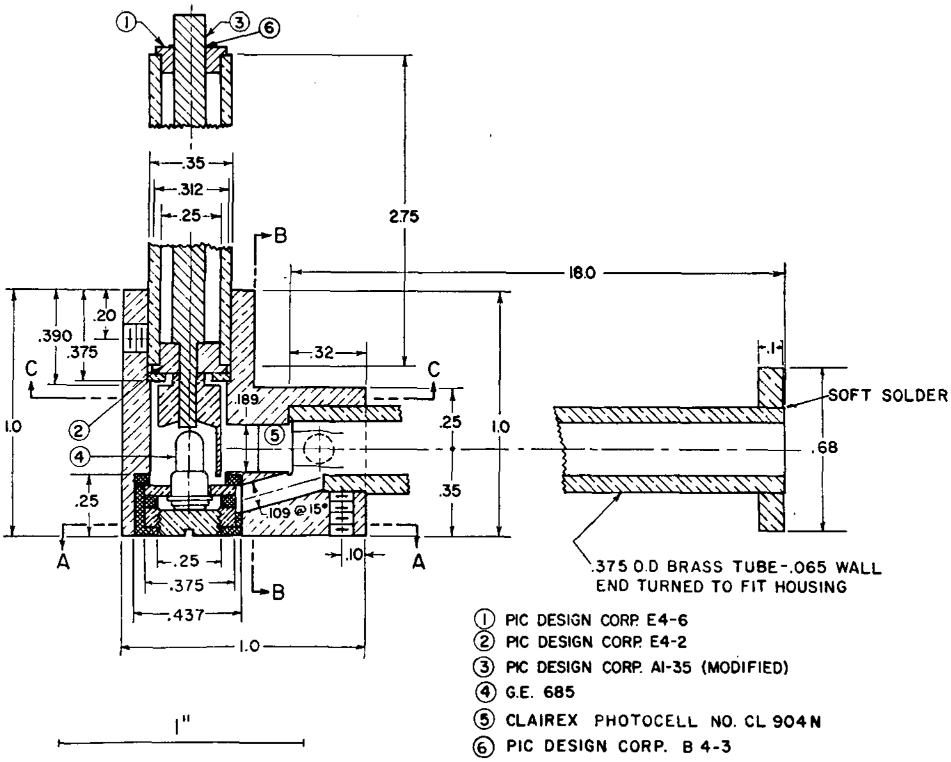

FIG. 2. Sectional view of anemometer transmitter.

2. Design

The anemometer (Fig. 1) was designed to use commercially available components insofar as possible. A two-bearing arrangement (Fig. 2)[3] was used in which the lower bearing acted as a thrust bearing, while both bearings guided the shaft. The complete bearing–light interrupter assembly may be removed for cleaning by loosening two set screws.

The anemometer bearings were operated without oil. Originally, they were degreased with ether; in operation, they were periodically cleaned by submergence in trichlorethylene. A strobe disk with nine patterns, weighing 10.3 gm, was used to test the bearing friction. To be acceptable the shaft must turn as least 600 revolutions, or 128 sec, from the major strobe pattern under fluorescent light to stop.

The cup assembly was constructed from plastic, the cup arms and hub from polystyrene, and the cups from cellulose acetate. The cups were vacuumformed from 15-mil film in a 7.6 cm right-angle cone mold. Heat for the molding process was supplied by a 150-W projector spot lamp mounted approximately 5 cm above the film. The cup assembly was painted with silver paint to prevent ultraviolet deterioration. The cups may also be made from white high-impact polystyrene which does not require painting.

Shaft revolutions and, ultimately, wind speed were recorded on an electromechanical counter actuated through an intermediate relay by interrupting the light on a photoconductive cell in series with the relay (Fig. 3). The light bulb and photocell are located in the trans-

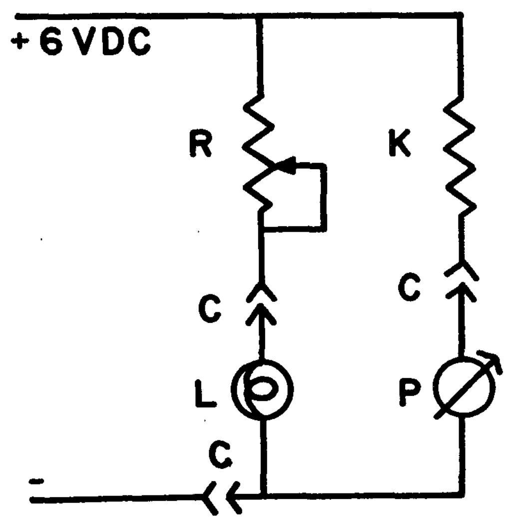

FIG. 3. Anemometer counting circuit. C, connector, 97-3106A-12SL-8445; K, relay, Sigma 4R 1000S-SIL; L, lamp, General Electric 685; P, photocell, Clairex CL904N; R, rheostat, Ohmite 0153 type H.

[3] Complete drawings are available upon request. Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the U. S. Department of Agriculture.

TABLE 1. Characteristics of anemometer cup assemblies.

Characteristic	Cup assembly 1	2	3	4	5
Radius (cm)	3.8	3.6	2.6	2.5	2.8
Arm length (cm)	7.8	7.8	6.5	7.0*	7.0
Assembly weight (gm)	11.1	10.3	11.4	7.0	37.5
Beaded edge	1-mm flange	no	no	no	yes
Distance between lower cup edge and horizontal support (cm)	3.8	3.8	...	7.6*	...
Cup material	molded plastic	molded plastic	molded plastic	molded plastic	aluminum
Specific weight**	32	31	12	20	5

1. With flange: U. S. Water Conservation Laboratory.
2. Without flange: U. S. Conservation Laboratory.
3. Beckman & Whitley, San Carlos, California, Model 170-40.
4. C. W. Thornthwaite Associates, Elmer, N. J.
5. C. F. Casella & Co. Ltd., London, England.

* Measurement obtained from a photograph.

** Surface area of 1 cup×arm length÷cup assembly weight.

mitter (Fig. 2), while the relay and filament voltage-adjusting rheostat are located remotely with the counter. Although the relay K is rated at 6 Vdc (pull-in power, 20 mW), the series arrangement with the photocell allows the relay to be energized but not to become overheated. The relay contacts were used to actuate the counter. The counting circuit may be made to operate on 5–10 Vdc by adjusting the relay and the lamp voltage. Once adjusted, the system will continue to operate with power fluctuations of ± 1 Vdc.

3. Calibration

a. Linearity. The linearity of three types of cups on the same transmitter was investigated in a wind tunnel. Variables included the ratio of arm length to cup radius and the flanged edges. The characteristics of the cup assemblies tested (Nos.1, 2 and 3) along with those of two others, are listed in Table 1.

The results of the wind tunnel tests are shown in Fig. 4, where the points represent an average of two 1-min counting periods, generally agreeing within 1 rpm. The correlation coefficients for the linear regression equations were highly significant. Over the range investigated a linear response was obtained from the three-cup assemblies. The No. 3 assembly, having a larger arm length–cup radius ratio, appeared to rotate faster than the assemblies with smaller ratios. The assembly with flanges rotated faster than the assembly without.

The cup arms on assemblies 1 and 2 started to vibrate at 15 m sec^{-1}. To avoid possible damage at higher wind speeds, 4.76- rather than 3.17-mm plastic rod should be used for the arms.

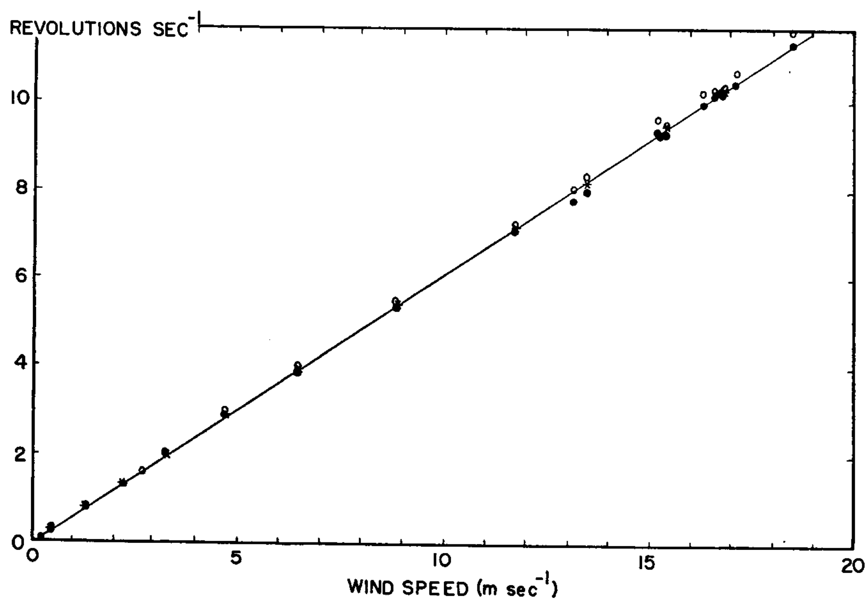

FIG. 4. Calibration results of cup assemblies. No. 1, asterisks, $\hat{Y}=-0.037+0.614X$; No. 2, solid dots, $\hat{Y}=-0.054+0.612X$; No. 3, open circles, $\hat{Y}=-0.044+0.624X$.

A slight nonlinearity is indicated in the calibration curve supplied by the manufacture of assembly 5. The design of cups on assembly 5 is sufficiently different from assemblies 1, 2 and 3 to cause it to turn 22% slower than the others, the design differences being beaded edges and a deeper cylindrical portion.

b. Starting speed and overrun. The starting speed for the No. 1, 2 and 3 cup assemblies was determined by towing the transmitter, mounted on a trolley, with assemblies at a constant speed over a 3-m distance in still air (timed over the center 2 m). Starting speeds of 9, 6 and 9 cm sec^{-1}, respectively, were obtained. The flangeless assembly (No. 2) had a lower starting speed than the flanged assembly (No. 1). The flanges tended to cause the assembly to rotate backward. For similar shape cups the specific weight (Table 1) appears to be a good criterion for determining the starting speed of assemblies with different arm length to cup radius ratios and weights.

The overrun was evaluated by counting revolutions to stop after the anemometer, mounted on a trolley traveling at 2.5 m sec^{-1}, was suddenly stopped. Expressed in centimeters of air, an overrun of 134, 167 and 198 cm was obtained for the No. 1, 2 and 3 assemblies, respectively. This may not be a valid test since the air adjacent to the cups must have been in motion and required time to settle down. In any event, the flanged assembly (No. 1) would have better response to turbulent fluctuation. However, the flangeless design (No. 2) was selected for field use because the lower starting speed was considered more important.

c. Distance constant. The distance constants of assemblies 1, 2, 3 and 5, mounted on the transmitter described, were determined in the tunnel by recording the time required for the assembly to reach 63% of full speed from a stopped position. At 2 m sec^{-1}, the 63% constants were 87, 90, 76 and 168 cm, respectively. Thornthwaite *et al.* (1961) reported an anemometer having a starting speed of 9 cm sec^{-1} and a distance constant of 83 cm evaluated at 3.8 m sec^{-1}. Frenzen (1965) developed a low-inertia anemometer with a distance constant of 70 cm.

d. Stacking. Measurement of wind-speed profiles over areas of limited fetch requires that several anemometers be stacked close together. In the wind tunnel, three anemometers with No. 2 cup assemblies were stacked vertically 30, 25, 20 and 15 cm apart. At 7 m sec^{-1} the presence of the anemometers above and below cause the wind speed indicated by the center anemometer to be 0.3, 0.8, 1.9 and 1.8% high, respectively. These results indicate that the lower portion of wind-speed profiles may be influenced by adjacent anemometers when logarithmically spaced and suggest the use of a dummy anemometer above uniformly spaced anemometers.

e. Cosine response. The cosine response of cup assembly 2 was found to be similar to that illustrated by MacCready (1966), i.e., essentially flat out to an elevation angle of ± 45°, depending on direction of cup rotation and wind, with a rapid drop to zero at 60°.

4. Summary

A sensitive cup-type anemometer was designed to facilitate wind-speed profile measurement over crop surfaces of limited horizontal extent. The design uses commercial parts wherever possible and a minimum of electronic components. It may be quickly dismantled for cleaning. The cup assembly is constructed of plastic and three 7.6-cm right-angle cone cups mounted at a 7.8-cm arm length.

Wind speed is determined by counting revolutions of the cup assembly, by interrupting the light on a photoconductive cell in series with a sensitive relay. The relay contacts are used to actuate an electromechanical counter.

Response characteristics include a starting speed of 6 cm sec^{-1}, a distance constant (63%) of 90 cm, and a linear response over the range tested.

Acknowledgments. Acknowledgment is given the Atmospheric Science Research Laboratory, U. S. Electronic Research and Development Activity, White Sands, N. Mex., and the Department of Atmospheric Sciences, University of Washington, for the use of their wind tunnels.

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