AN IMPROVED DESIGN OF CUP ANEMOMETER

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[*MS. received* 11*th March* 1940]

ABSTRACT. A new design of three-cup anemometer is described possessing the following characteristics: (i) The minimum wind velocity in which the anemometer will function quite satisfactorily, about 0·2 m./sec. (40 ft./min.), is appreciably lower than usual with this type of anemometer, and compares favourably with other sensitive but more troublesome types of anemometer involving moving parts. (ii) The rate of rotation of the cups is related linearly with the wind velocity, and in consequence the indicated mean value of the velocity in a gusty wind is true, apart from the effects of inertia. (iii) The inertia of the moving parts is small so that the anemometer is very responsive to changes in wind velocity and overestimation in a gusty wind is negligibly small. (iv) The anemometer is portable and of relatively small dimensions.

INTRODUCTORY

THE cup anemometer possesses an advantage for many purposes over other types in that its response is independent of wind direction in the plane of the cup circle. This has been offset to some extent in the past by its relative insensitivity in low wind velocities and by the fact that the rate of rotation of the cups was not usually a linear function of the wind velocity. Further, most cup anemometers have possessed rather large inertia which leads to the overestimation of velocity in a gusty wind.

The present paper describes a new design of cup anemometer in which the above-mentioned defects have been largely removed. It is particularly suitable for the measurement of natural winds but may also be used with advantage in some cases in wind tunnels, large ducts etc., particularly if the winds to be measured are light.

Unfortunately the complexity of air motion in the region of rotating cups makes any theoretical treatment of the cup motion almost impossible. Spilhaus* has applied the methods of dimensional analysis to the problem and has shown the importance of certain non-dimensional factors in determining the motion but it is not possible from such treatment to design a cup anemometer of given characteristics nor is the available amount of experimental data sufficient for the purpose. Certain valuable results have, however, been obtained in recent years, namely that a three-cup system may be more sensitive than the older much used four-cup system, that a hemispherical cup is not necessarily the best form and that cups formed with beaded edges are less sensitive to variations in wind stream turbulence than plain cups.

In view of the above, the only practical way to design a cup anemometer with certain desired characteristics is by the method of controlled experiments in a wind tunnel, which has been followed in the present case.

Earlier work on cup anemometers has been much concerned with the so-called "cup factor", i.e. the ratio of the wind velocity to the speed of the cup centres in that wind. A knowledge of the cup factor in any particular case should enable the wind velocity to be deduced immediately from the rate of rotation of the cups; but in the usual instrument, which requires a finite wind velocity to initiate cup motion, this factor will not be a constant and is a function of the wind velocity. In such an instrument the relation between wind velocity and cup speed, or rate of cup rotation, can be written in the form

$$v = v_0 + f(u) \qquad (1)$$

or

$$v = v_0 + f_1(n),$$

where v = wind velocity, v_0 = value of v at which cups just cease to rotate, u = speed of cup centres, n = rate of rotation of cups.

The best for most purposes is an anemometer for which $f(u) = \text{constant} \times u$; in particular if the anemometer is required to indicate directly the run of wind in a given time, the true wind may then be obtained from the indicated value by the addition of a simple constant. The instrument to be described possesses this characteristic; it is now available commercially from Messrs C. F. Casella and Co., Ltd., of London.

DESIGN OF ANEMOMETER

The new design of three-cup system is given to scale in Fig. 1, one only of the three cups being shown. The details of construction were arrived at after a carefully controlled series of wind-tunnel experiments in which the form and size of cups, the length of cup arms and the form of the bearings were all subject to variation. The essential features of the construction are as follows.

Cup form and support (details 9 and 10). The cups, internal diameter 5·16 cm., spun from no. 24 S.W.G. aluminium sheet, are semi-conical in form with beaded edges, of the same relative dimensions as those employed by Brevoort and Joyner† in an investigation of the drag and normal force coefficients of anemometer cups. A larger cup, diameter 7·63 cm., of the same form, was also employed in the wind-tunnel tests and gave slightly greater sensitivity, but it made the instrument rather more cumbersome. Hemispherical cups of the same diameter as that shown in Fig. 1 were also tested, but it was found impossible to obtain a linear relation between wind speed and cup speed with them.

Duralumin arms are fixed to the cups by means of splayed ends riveted to the cups immediately behind the beading. This mounting has proved sufficiently robust and has the merit of smaller weight and moment

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* Spilhaus, A. F., *Massachusetts Inst. Techn., Meteorological Div. Professional Notes, No.* 7.

† Brevoort, M. J. and Joyner, U. T., *N.A.C.A. Tech. Notes*, no. 489 (1934).

of inertia than the more usual form of cup support passing right across the cup face. The cup arms are threaded into the boss (2) and fixed by grub screws (not shown in Fig. 1); they may, therefore, be readily replaced in case of damage.

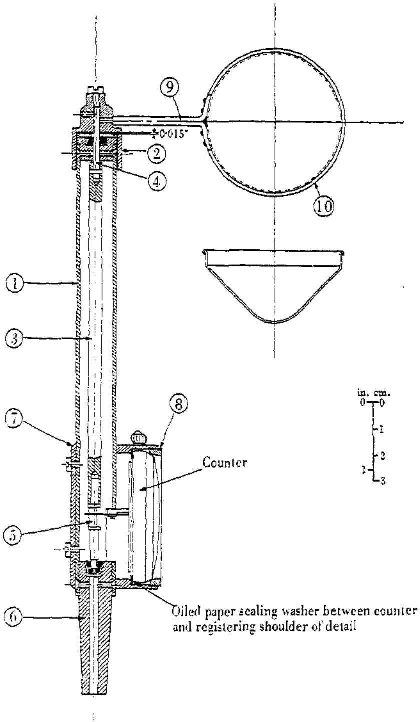

Fig. 1. Sectional assembly of three-cup anemometer (one cup only shown)

Spindle, spindle mounting and housing. For lightness the spindle consists of a duralumin rod (3), into the ends of which steel bearings (4, 5) are riveted. The boss is located on the upper steel spindle by means of a flat on the latter and a grub screw. A screw passing axially through the top of the boss sets the height of the boss with respect to the spindle.

The spindle is mounted on the thrust and journal miniature ball bearings which have recently become available in this country. At an earlier stage of design, jewel bearings, $\frac{1}{8}$ in. diameter, and a jewel end-plate were employed, but they were much inferior, the friction torque of the system with ball bearings being only one-third of that using jewels (68 dyne-cm. compared with 204 dyne-cm.), whilst the ball bearings possess the additional advantage of having very nearly equal static and dynamic friction, so that the minimum wind velocity to which the anemometer will respond is not appreciably greater for a rising than for a falling wind. Further, accurate alignment of the assembly is not so essential with the ball bearings as with jewels.

The spindle is housed in a duralumin tube (1) over the top of which the boss extends downwards with a clearance of about 0·01 in. The journal bearing is thus well protected from rain, dust, etc.

The complete weight of the moving parts of the instrument is less than 50 g.

Cup rotation counter mechanism. The counting mechanism employed constitutes a major feature of the instrument, accounting in part for the considerable sensitivity obtained, and the writer is much indebted to Mr J. E. Brown of the Meteorological Office, London, for suggesting it. This mechanism consists of a Findlay continuous motion stop-watch from which the hair spring and balance are removed. The watch lever is linked to an eccentric (5) on the anemometer spindle by means of a forked rocking lever (Fig. 2), which is mounted on a bracket (Figs. 3, 4) fixed to the back plate of the watch. The rotation of the spindle thereby supplies a trigger action to which the watch mechanism responds under its own energy, that of the coiled main-

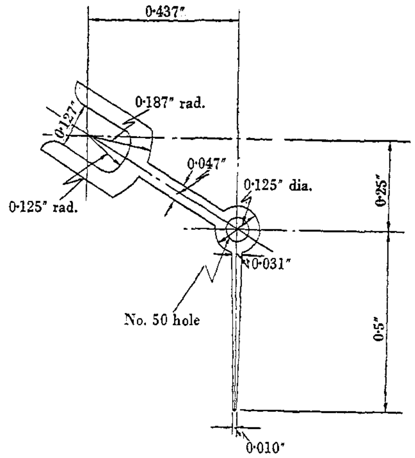

Fig. 2. The rocking lever

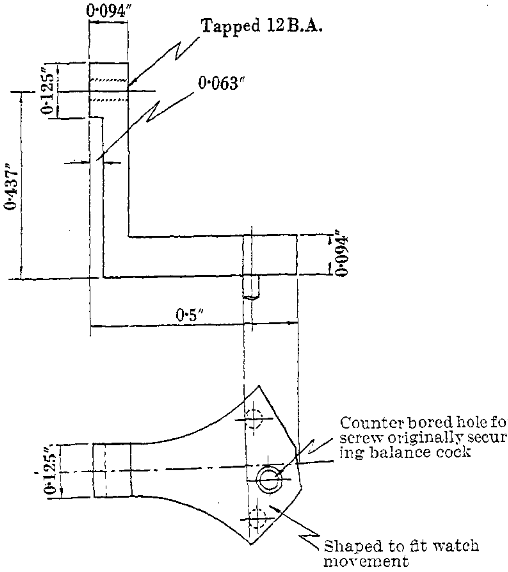

Fig. 3. Bracket for the rocking lever. (The screw hole and dowel pins are so located that, when assembled, the point of the rocking lever engages the lever of the watch movement)

spring.* In addition to the latter merit, the mechanism is thoroughly reliable and relatively cheap for the complexity involved. The counter has a resolving time for consecutive impulses of about 0·01 sec. and is thus competent to integrate the cup rotations in any wind to which the instrument may be suitably exposed.

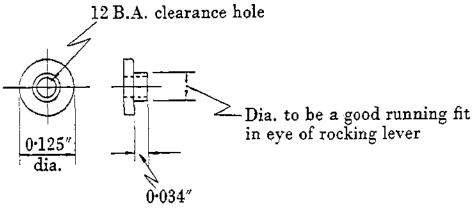

Fig. 4. Rocking lever bearing collar

For convenience in counting, the 0–60 main dial is replaced by a 0–100 dial, giving a scale of 100 between "second" and "minute" hands. A watch dial reading to 30 min. gives, therefore, a range of 0–3000, but one complete oscillation of the watch lever produces 2/3 unit movement on the counter so that the recordable range of cup rotations is 4500.

The "start", "stop" and "set to zero" stud on the counter enables the latter to be put into and out of engagement with the spindle and provides a zero setting device.

The cylindrical counter housing (7) is clearly shown in Fig. 1. The counter is located in the housing by means of a slot to take the winding button and a threaded clamping ring (8). Thus the counter is readily removed in case of damage and a new one may be inserted. The top of the housing is 12·2 cm. (4·8 in.) below the cup arms and 9·4 cm. (3·7 in.) below the lower rim of the cups, which ensures the absence of aerodynamic effects of the counter housing upon the cups.

Anemometer mounting. This is by means of a conical bearing (6). With metal masts this implies the necessity for a machined counterpart but with wooden masts a rigid mounting is readily obtained by using a single appropriately sized bit. Thick bamboo rods may also be used.

THE CALIBRATION CURVE AND PERFORMANCE OF THE ANEMOMETER

A typical wind-tunnel calibration of the anemometer described above is given in Fig. 5 where the co-ordinates are wind velocity, v (m./sec.) and dial count per min., n. The velocity of the cup centres, u, can be deduced from the latter since $u = 0{\cdot}00110\,n$ (m./sec.), the radius of the cup centre motion being 7·0 cm.

The observations given in Fig. 5 lie well on the straight line

$$v = 0{\cdot}19 + 0{\cdot}0325\,n \text{ (m./sec.)}, \qquad (2)$$

or

$$v = 0{\cdot}19 + 2{\cdot}96\,u \text{ (m./sec.)}. \qquad (3)$$

The value of v_0 in equation (1) is thus 0·19 m./sec. from extrapolation of the calibration curve. This is to be compared with a number of experimental determinations of the wind velocity at which the cups just ceased or just began to rotate, the values lying at or about 0·20 m./sec., but the accuracy of the velocity measurement in this region was necessarily very low. Thus the anemometer compares favourably with other types of anemometer with moving parts in its response to low-wind velocities. The fact that it needs no orientation with respect to the wind direction as vane air meters and other anemometers do is an additional advantage, particularly for work in the atmosphere, since a wind vane can be dispensed with.

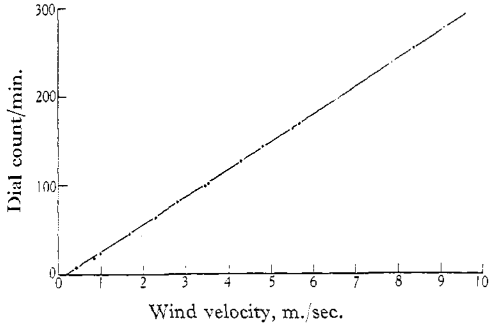

Fig. 5. Typical calibration curve

It is of interest to note that tests made in the wind tunnel with the counter removed gave a calibration curve identical with that for the counter in position for all velocities which allowed of rotation counting by eye. Of six anemometers tested, the variation in the coefficient of n in equation (2) was less than 2 per cent, whilst the minimum velocity for response varied over about 0·1 m./sec. range. Thus for accurate measurement, particularly in low-wind velocities, a particular calibration is required for each instrument.

The calibration curve of Fig. 5 extends only to 9 m./sec. (21 miles/hr.), the upper limit of wind velocity attainable in the wind tunnel. The instrument has, however, been subject to wind velocities in the atmosphere of about 22 m./sec. (50 miles/hr.) and found to be perfectly reliable. Although the weight of the moving parts is small there is no tendency to "chatter" in a turbulent wind.

OVERESTIMATION OF VELOCITY IN A GUSTY WIND

The response of a cup anemometer to a rise in wind velocity is more immediate than to a fall of the same amount and kind, and this results in the overestimation of a gusty wind. No experimental tests on the magnitude of the effect have been carried out with the new instrument but an analysis by Schrenk† enables the amount of overestimation to be computed in a given case.

Schrenk gives a family of curves relating percentage overestimation to a quantity K for various values of the gustiness $\Delta v/v$, Δv being the magnitude of velocity

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[*] Whilst the anemometer was in the testing stage an account by J. L. Tuck appeared in this *Journal* (**13**, p. 366 (1937)) of a similar application of a watch movement to counting. In that case it was employed for counting α-particles and was actuated by the reed of a loud-speaker.

[†] O. Schrenk, *Zeit. techn. Phys.* **10**, p. 57 (1929). See also Kleinschmidt, *Handbuch der Meteorologische Instrumente*, p. 362 (Berlin: Julius Springer (1935)), where, however, the formula for K is given wrongly.

fluctuation, assumed sinusoidal, about the mean velocity, v.

$$K=\frac{0{\cdot}55\rho R^2r^2Tv}{I} \qquad (4)$$

where ρ = air density, R = radius of cup centre circle, r = radius of cups, T = period of velocity fluctuations, I = moment of inertia of moving parts of anemometer, the technical system of units (m., kg., sec.) being employed. The overestimation increases with $\Delta v/v$ and with decrease in K, i.e. with decrease in the period of the fluctuations and with decrease in wind velocity. For the new instrument $R=0{\cdot}07$ m., $r=0{\cdot}025$ m. and $I=6{\cdot}6\times10^{-5}$ kg.m./sec.², and with these values and $\rho=0{\cdot}125$ kg. sec.²/m.⁴, the table has been prepared giving the percentage overestimation of velocity for different values of v, $\Delta v/v$ and T.

Overestimation of wind velocity by new cup anemometer in a gusty wind

v (m./sec.)	2			5			10		
T (sec.)	1	10	60	1	10	60	1	10	60
$\Delta v/v$	0·2	0·4	0·6	0·2	0·4	0·6	0·2	0·4	0·6
Overestimate, per cent of v	1·4	0·1	0·0	0·3	0·0	0·0	0·0	0·0	0·0

It will be noted that a particular gustiness factor has been associated with a given periodicity of wind oscillation, the smaller the periodic time the smaller the ratio, $\Delta v/v$, which has been associated with it. This is consistent with the behaviour of turbulent winds in the atmosphere and the actual values of $\Delta v/v$ which have been associated with given T's are roughly those which are liable to occur in the surface layers of the atmosphere in the absence of stabilizing effects.

The table shows that with the new design of anemometer the overestimation in a natural wind is negligibly small for velocities greater than 2 m./sec. (5 miles/hr.). This is in contrast to the more usual design of cup anemometer of much greater inertia in proportion to its dimensions. With suitable recording apparatus the new anemometer would not, therefore, be inappropriate to the study of the turbulence of natural winds.

ACKNOWLEDGEMENTS

The writer is pleased to acknowledge the very considerable help which he has received from Mr J. E. Brown and Mr W. A. Toms, of the Meteorological Office, London, at various stages of the design and in the construction of the new instrument.

THE MECHANICAL CONSTRUCTION OF A RADIUM BEAM UNIT

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[*MS. received 5th April* 1940]

ABSTRACT. A description is given of the details of construction and the method of operation of the Radium Beam unit which has been installed at the Radium Centre in Sheffield. The bomb is a mass unit capable of carrying a maximum content of 6·2 g. of radium in a light, flexible shuttle. This is transferred pneumatically from the safe to the bomb and vice versa. An automatic signalling gear and clock is incorporated in the apparatus. The bomb may be raised vertically by means of an electric motor, and can rotate round vertical and horizontal axes. A vertical traverse of 3 ft. is possible for the bomb and an overwind mechanism is brought into action in the highest and lowest positions of the bomb head.

INTRODUCTION

In the following paper a description is given of the details of construction and the method of operation of the radium beam unit which has been installed at the Radium Centre in Sheffield. Much of the work is an adaptation of the "bombs" which have been constructed by Sievert* and Grimmett†; and it is from the papers of these workers that many of the general lines of construction have been taken. By simplification of design, however, and by collaboration of the laboratory with the engineers responsible for the construction of the bomb a comparatively inexpensive mechanism has been installed.

The bomb (the head of which is shown in Fig. 1) may be described briefly as a mass unit capable of carrying a maximum content of 6·2 g. of radium in a light, flexible shuttle. This is transferred pneumatically from the safe to the bomb and vice versa. A switchboard indicates by means of signal lights the position of the radium shuttle (*a*) in the radium safe by means of a green light, (*b*) in transit by the showing of a white light and the operation of a buzzer, and (*c*) in the bomb by means of a red light.

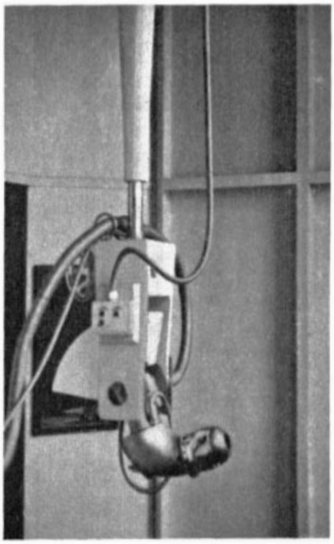

Fig. 1. Radium bomb head

The red light relay starts an electric clock which records automatically the treatment time. The bomb may be raised vertically by means of an electric motor and can rotate round a vertical axis through a worm wheel gearing on the bomb head. Rotation round the hori-

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* R. Sievert, *Acta Radiologica*, **14**, p. 197 (1933).

† L. G. Grimmett, *British J. of Radiology*, Volume X, No. 110, p. 105 (Feb. 1937).