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Analogue simulation of anemometers*

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ABSTRACT. The differential equation for cup and vane anemometers was set up on analogue computers and the responses of the instruments studied for sinusoidal and random types of wind speed variation. The effects of both static and dynamic friction have been taken into accouut. The results show a large exaggeration of mean indicated wind speeds, a large attenuation in the gust amplitudes and a distortion in gust shapes.

1. Introduction

The differential equation representing the response of cup and vane anemometers to wind can be written as:

$$2\pi I\,(dn/dt) + B_1 n + B_0 = Dv^2 - Cnv \qquad (1)$$

where n = speed of rotation, v the wind speed and D, C, I, B_0 and B_1 are constants (Ramachandran 1966).

This equation represents a non-linear physical system. This equation does not lead to a form of solution for n in terms of v, where different expressions for v can be substituted in order to obtain the corresponding expressions for n.

The difficulty in obtaining an analytical solution for the response of an anemometer to different fluctuating patterns of wind speed can be overcome, by the use of an analogue computer. The differential equation is set up on the computer and the input variable, obtained from a function generator, is made to simulate any assumed pattern of wind speed. The output variable would then represent the speed of rotation or, by an appropriate scale, the indicated wind speed, the scale being the same as that obtained during the calibration of the instrument inside the wind tunnel. The constants of the differential equation can be varied at will, either to study the various design parameters or to study the behaviour of different types of actual instruments. Both the input signal and output response can be recorded either on an X Y recorder by repeated simulation, if the input pattern and the conditions can be exactly repoduced at will, or on a two-channel recorder, if the input pattern is a random signal representing the natural wind speed.

The solution represents the true response of anemometers. On the basis of linear interpretation of calibration curves, this response is interpreted as the true wind speed. Now a comparison between the real wind speed (input) and the indicated wind speed (output) reveals the following characteristics —

(*i*) The steady state calibration curve of the anemometer does not remain valid for random fluctuations of wind speed,

(*ii*) The anemometers suppress considerably the gustiness structure,

(*iii*) There is a large exaggeration in the mean indicated wind speed and

(*iv*) The concepts of distance constants and the time constants and the physical meanings usually attached to these concept are not true in natural air.

2. Method used

The following experiments were conducted --

(a) The anemometer was assumed to be frictionless and the wind speed pattern to be either a growing or steady sine wave,

(b) The anemometer was assumed to be frictionless and the wind speed to vary at random and

(c) An actual anemometer with friction was simulated with random wind speed.

3. Results

The results are summarized below.

3.1. *Sine wave response of a frictionless anemometer*

When an anemometer is assumed frictionless, the constants B_0 and B_1 in Eq. (1) become zero, so

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†Dr. Ramachandran passed away on 11 October 1969

that —

$$\frac{dn}{dt} = \frac{D}{2\pi I} v^2 - \frac{C}{2\pi I} nv$$
$$= \frac{1}{L}\left[\frac{D}{C} v^2 - nv\right] \qquad (2)$$

where,

$$L = 2\pi I/C = \text{the distance constant.}$$

If we write —

$$v' = v_{\text{ind}} = (C/D)\, n$$

the indicated wind speed,

$$v' = \frac{1}{L}\left[\int v^2 dt - \int vv'\, dt\right] \qquad (3)$$

Fig. 1 shows the details of simulation of this equation. The voltage obtained from the function generator is applied to a servo-multiplier connected as a squarer. The output of the integrator has a negative sign which is again re-inverted to the positive sign by the adder at its output. The output of the adder is reduced by a coefficient potentiometer to give the indicated response. This output is also applied to the second section of the servo-multiplier whose other input is the same as the output of function generator. The output of the servo-multiplier is intergrated and reinverted to give $+\int vv'\, dt$ and then fed to the adder.

In one series of experiments a sine wave was allowed to grow from a small to a large amplitude by employing a small positive feedback in a sine wave generator. This sine wave was added to a similarly growing exponential wave. The pattern resembles in a crude way the growth of gustiness in the atmosphere. The wave form at the output of the function generator can be expressed as —

$$v_1 = a_1\,[1-\exp(-\alpha t)] + x \sin wt \qquad (4)$$

where,

$$x = a_2 t \quad \text{for} \quad 0 < t < t_1$$
$$x = a_2 t_1 \quad \text{for} \quad t \geqslant t_1$$
$$= \text{constant}$$

The output of the computer-set-up along with the input from the function generator were recorded on an X Y recorder (Pace Variplotter No. 100 D).

The experiment was repeated for various values of distance constant L and for different frequencies. A few photographs of the Variplotter records are shown in Fig. 2 and refer to an anemometer with a distance constant of 16·9 metres. Fig. 2 (b) shows a condition in which the signal amplitude is suddenly reduced from a large initial value to a smaller final value, whereas Fig. 2 (c) refers to a very low frequency sine wave. Figs. 2(d) and 2(e) refer to high frequency fluctuations of sine waves.

Fig. 3(a) refers to a windmill with a distance constant of 100 metres, Fig. 3(b) to a sensitive anemometer with a distance constant of 10 metres and Figs. 3(c) and 3(d) to micrometeorological instruments with distance constants 3 and 2 metres. The following results are evident from these records —

(1) There is a large exaggeration in the indicated mean values of the patterns,

(2) There is a large reduction in the amplitudes of fluctuations and

(3) There is a distortion in the shapes of gusts.

3.2. *Behaviour of frictionless anemometer in random wind speed*

In the second series of experiments the sine function generator was replaced by a noise generator followed by a low pass filter to simulate random wind speed. The frequencies of the resulting signal were in the range 0 to 50 c/s. A typical analogue computer record for a frictionless anemometer with distance constant 5 metres is shown in Fig. 5. This record was obtained on a two-channel Sanborn recorder. The scale factor for the lower curve representing response 3 times that for the upper curve.

3.3. *Behaviour of an actual anemometer with friction in random wind speed*

In the last series of experiments, the cup generator anemometer commonly used at airport meteorological observatories was simulated in th computer. The equation for this instrument can be written in the form —

$$v' = \frac{C}{2\pi I}\int v^2 dt - \frac{C}{2\pi I}\int vv' dt -$$
$$- \frac{B_1}{2\pi I}\int v' dt - \frac{B_0}{2\pi I}\;\frac{C}{D}\int dt \qquad (5)$$

Substituting the numerical values for the instrument —

$$v' = 0{\cdot}55 \int v^2 dt - 0{\cdot}55 \int vv'\, dt -$$
$$- 0{\cdot}1 \int v' dt - 0{\cdot}55 \int dt \qquad (6)$$

The analogue computer set up for this experiment is shown in Fig. 4. The input function was at random as obtained by turning a potentiometer shaft at random manually in the range of bandwidth 0 to 10 c/s. Both the signal input and response were recorded on fast moving Evershed Vignobles double channel recorder. A typical record is shown in the photograph of Fig. 6.

The essential features of the results are the same—

(*i*) A large attenuation in gust structure,

(*ii*) Loss of details of fine structure and

(*iii*) Exaggeration indicated mean wind speed frequently to an extent of 20 per cent or more.

4. Acknowledgements

The sine wave responses were studied at the analogue computer installation at the Atomic Energy Establishment, Trombay. Thanks are due to the Director, Electronics Division of the Establishment and to Shri J. Ranganathan and Shri Murthy who extended the necessary facilities. The random signal experiments were carried out using the analogue computer of the Defence Establishment at Poona, and thanks are due to Dr. K.R. Saha for having made arrangements to obtain these facilities. Thanks are due to the Editor, *Quarterly Journal of Royal Meteorological Society*, for permission to reproduce some of the material from my earlier paper (Ramachandran 1969).

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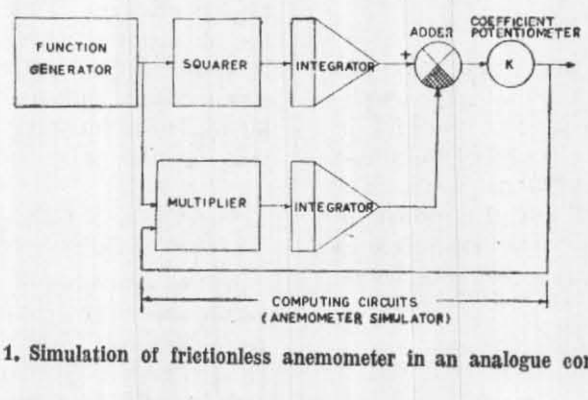

Fig. 1. Simulation of frictionless anemometer in an analogue computer

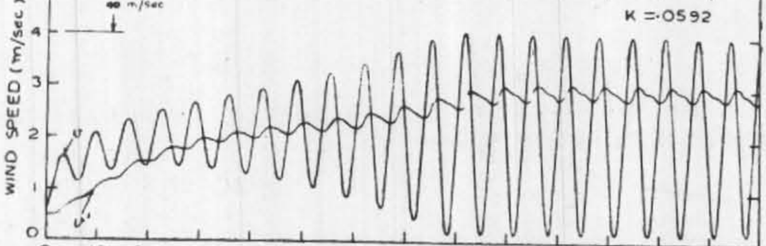

Fig. 2(a). Response of frictionless anemometer (v_1 = 16·9m) to a wind speed function given by Eq. (4)

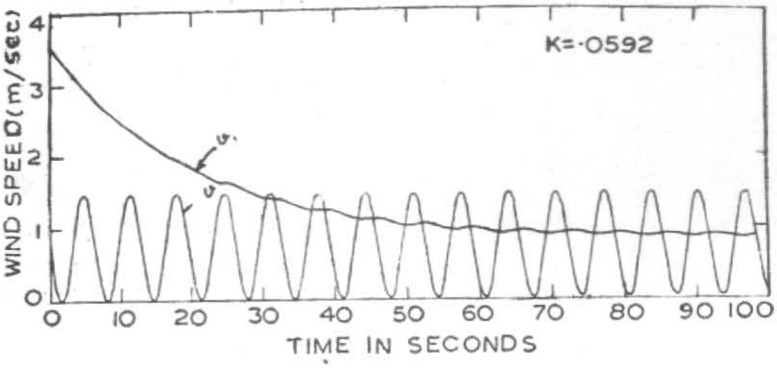

Fig. 2(b). Fall of response of frictionless anemometer (v=16·9m)

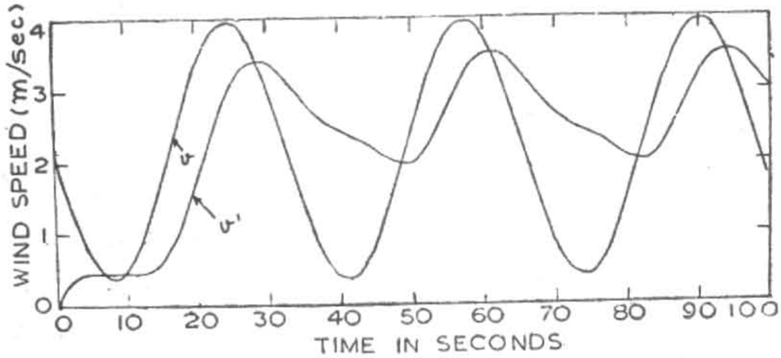

Fig. 2(c). Response of the anemometer to very low frequency

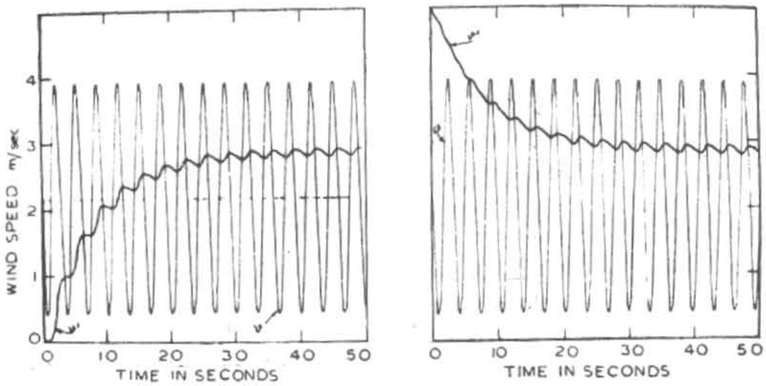

Fig. 2(d) and 2(e). Response of the anemometer to very high frequency sine waves

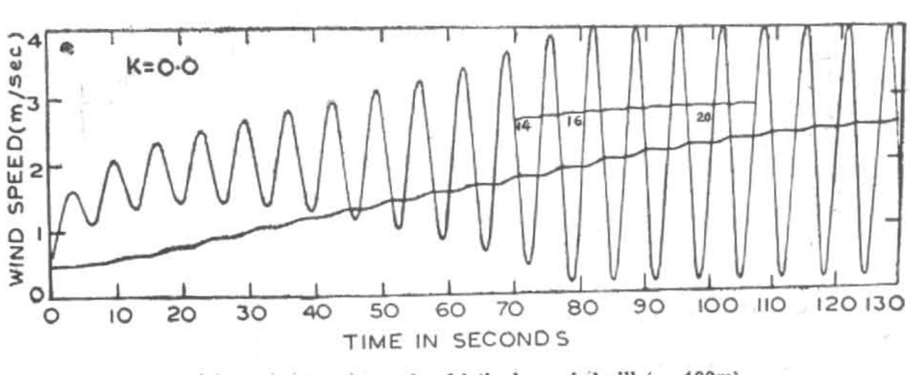

Fig. 3(a). Response of a frictionless windmill (v=100m)

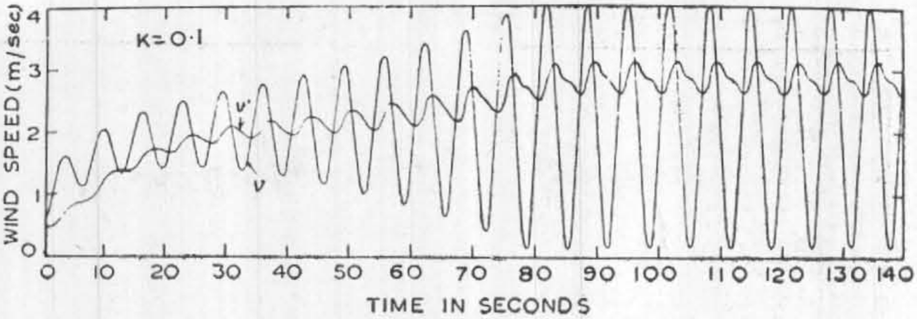

Fig. 3(b)

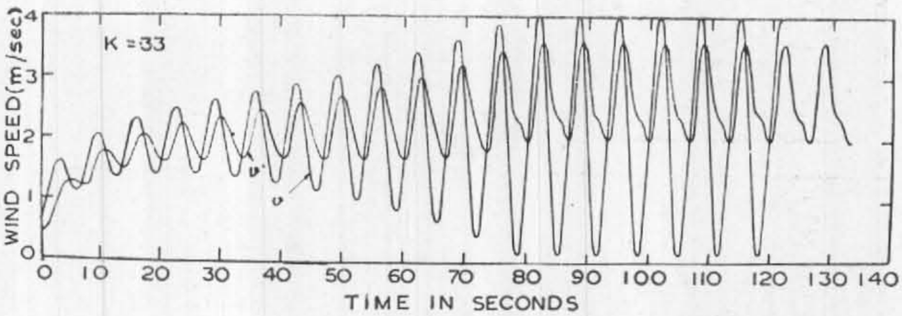

Fig. 3(c)

Figs. 3(b) and 3(c). Response of two frictionless anemometers distance constants 10 and 3 m respectively

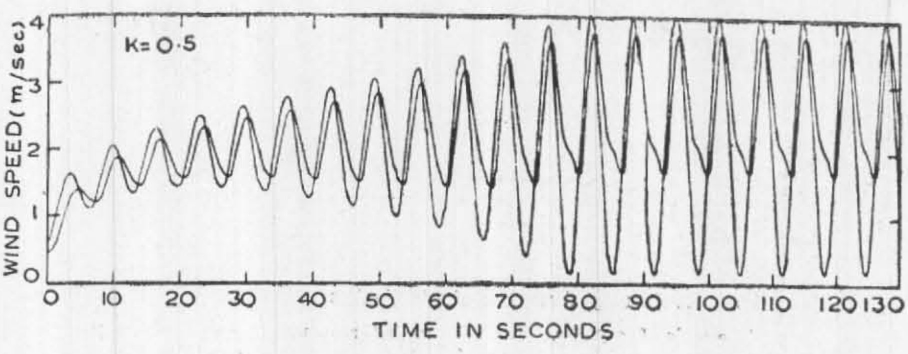

Fig. 3(d). Response of an anemometer with distant constant 2 m

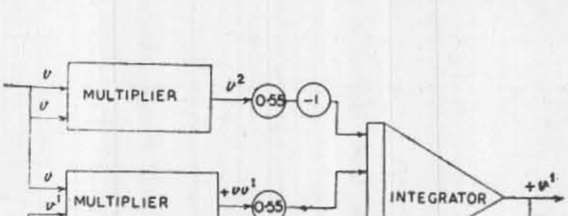

Fig. 4. Simulation of cup generator anemometer in analogue computer

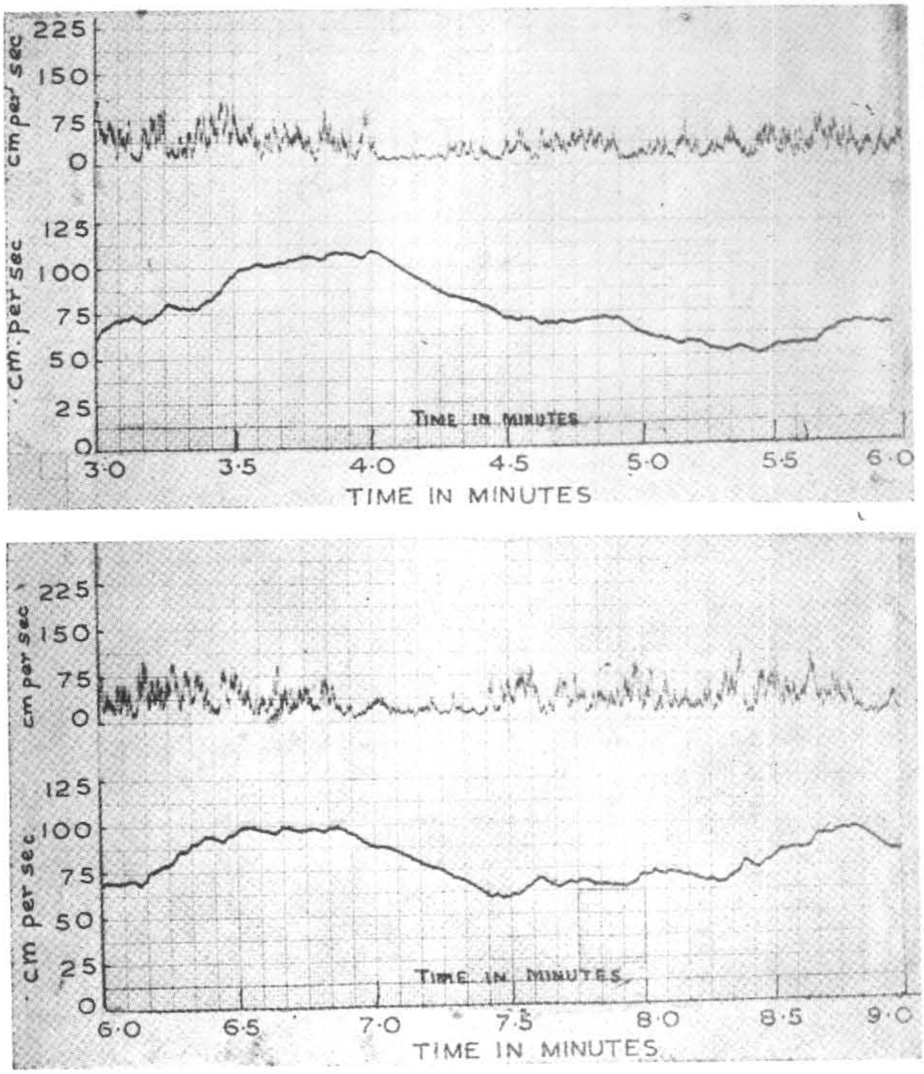

Fig. 5. Random signal response of a frictionless anememeter with $D=5$m

The scale of response curve (bottom) is three times that of signal (top)

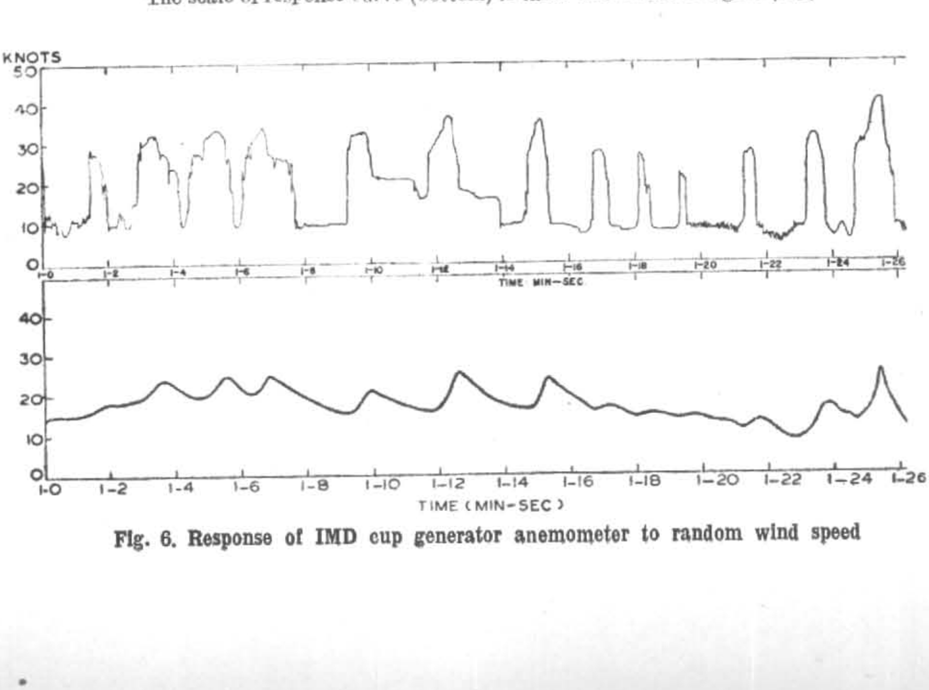

Fig. 6. Response of IMD cup generator anemometer to random wind speed