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AN IMPROVED MECHANICAL MICROANEMOMETER FOR LOW AIR VELOCITIES

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ABSTRACT

At the 21st Micobalance Techniques Conference a mechanical microanemometer has been presented measuring air velocities ranging from 5 to 140 mm/s. It consists of a moving-coil meter with a vane fixed to the pointer. The Lorentz couple exerted on the coil is brought about by an electric current and compensates for the couple from the force acting on the vane due to the air velocity. The present contribution focusses on the improvement of this microanemometer by making use of the equation of motion of the meter. In this way the dynamic properties of the anemometer are taken into account, resulting in the applicability of the microanemometer at frequencies up to approx. 8 Hz.

INTRODUCTION

At the former M.T. conference a microanemometer was presented (ref.2), which was able to measure air velocities as low as a few mm/s. There the force exerted on a vane was measured. This vane was fixed on the far end of the pointer of a moving-coil meter, which is placed in an airflow. As compensation the Lorentz couple was used caused by a current through the coil. The magnitude of this current was adjusted by means of a feedback circuit. This apparatus proved to be a welcome supplement to the commercially available anemometers, of which the detection limit is about 5 cm/s. The suitability of our anemometer in, for example, investigations of the influence of indoor climate on men, is limited by the maximum frequency of fluctuating air velocities, which can be detected. These frequencies are of the order of a few Hz.

In this paper an improved type of anemometer is discussed and in order to obtain a good measure for the air velocity the complete equation of motion of the moving-coil meter is taken into account (ref.1).

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MEASURING DEVICE

In order to be able to measure low air velocities the force exerted on a vane placed in an airflow is measured. There the vane is fixed upon the pointer of a moving-coil meter. The deflection of the balance is measured by means of an optical detection sytem, consisting of two photodiodes, a LED and a small strip of metal. The output voltage V_{reg} of the feedback system adjusts the Lorentz couple until equilibrium position is obtained, so V_{reg} is a good measure for the air velocity. In our device the moving-coil meter is placed inside a sphere, except for the beam with the vane. In Fig. 1 a schematic representation of the anemometer is presented.

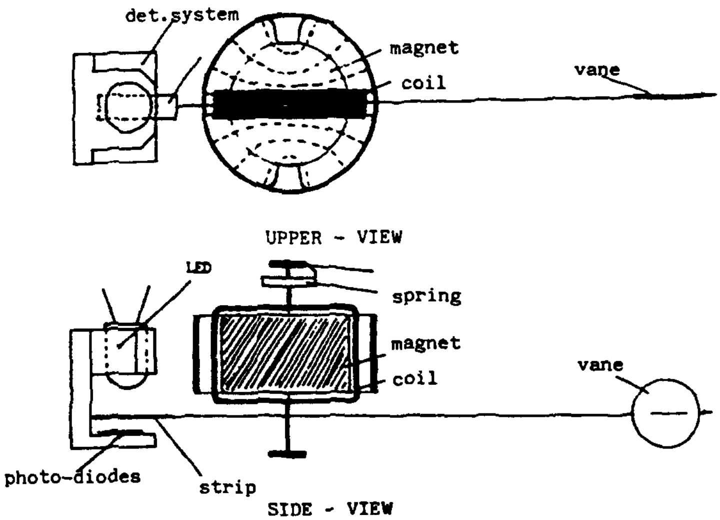

Fig. 1 : Schematic representation of the measuring device top view (a) ; side view (b)

Compared with the former microanemometer (ref.2) a new type of moving-coil meter was chosen with a much smaller magnet and a width of the pointer of 0.4 mm (formerly 0.25 mm). This choice had several consequences

- No second beam is necessary, so our apparatus is much easier to construct.
- The diameter of the surrounding sphere is reduced by approx. one third. The Reynolds number also decreases with the same factor, so instationary phenomena will occur at higher air velocities.

THEORY

A moving-coil meter is usually regarded as a linear second-order system. The equation of motion of the meter can be written as

$$J.\ddot{\alpha}(t) + K.\dot{\alpha}(t) + C.\alpha(t) = F(t).L - G.V_{reg}(t) \qquad 1$$

where $\alpha(t)$ is the angular deflection of the beam,
J the moment of inertia,
K the damping constant,
C the torsion constant,
F(t) the force exerted on the vane,
L the distance between the vane and the axis of rotation,
G the so called sensitivity constant and
$V_{reg}(t)$ is the output voltage of the feedback sytem.

By means of the feedback system the value of $\alpha(t)$ is kept as small as possible by adjusting the value of V_{reg}. When $\ddot{\alpha}(t)$, $\dot{\alpha}(t)$ and $\alpha(t)$ are zero, the following equation yields the relation between F(t) and $V_{reg}(t)$

$$F(t) = G.V_{reg}(t)/L \qquad 2$$

To obtain the frequency respons of the moving-coil system, it will be regarded as shown in Fig. 2. From Fig. 2 it can be seen that

$$\alpha(\omega) = H_1(\omega)\ F(\omega) - H_2(\omega)\ V_{reg}(\omega) \qquad 3$$

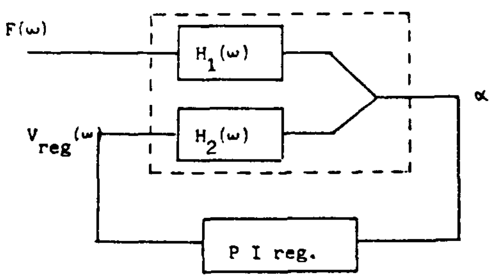

Fig. 2 : Blockdiagram of the moving-coil meter with the feedback system

with

$$V_{reg}(\omega) = R(\omega)\ \alpha(\omega) \qquad 4$$

As our feedback system is a PI regulator, with gain factor P and time constant τ, the transferfunction $S(\omega)$ is given by

$$S(\omega) := \frac{V_{reg}(\omega)}{F(\omega)} \qquad 5$$

becoming

$$S(\omega) = LP \cdot \frac{1 + j\omega\tau}{PG - \omega^2 K\tau + j\omega\tau(PG + C - \omega^2 J)} \qquad 6$$

However in the case of fluctuating air velocities the conditions $\ddot{\alpha}(t) = 0$, $\dot{\alpha}(t) = 0$ and $\alpha(t) = 0$ will not be satisfied constantly, so $V_{reg}(t)$ is not the best measure for $F(t)$. By using eqn. 1 corrections can be made. Assuming a linear relationship between $\alpha(t)$ and the voltage of the photodiodes, $V_d(t)$

$$\alpha(t) = \kappa . V_d(t) \qquad 7$$

a new measure for $F(t)$, $V_{cor}(t)$, can be introduced as

$$V_{cor}(t) = V_{reg}(t) - J' . \ddot{V}_d(t) - K' . \dot{V}_d(t) - C' . V_d(t) \qquad 8$$

where $J' = J.\kappa/G$, $K' = K.\kappa/G$ and $C' = C.\kappa/G$.
From eqns.1 and 8 the relation between $F(t)$ and $V_{cor}(t)$ becomes

$$F(t) = G.V_{cor}(t)/L \qquad 9$$

EXPERIMENTS

First the validity of eqn. 7 was investigated. There metal strips of width ranging from 2.7 mm (the width of one photodiode is 3 mm) to 7.5 mm were compared. In Fig. 3 V_d is plotted as a function of the angle of deflection, α , for different widths of the strip.

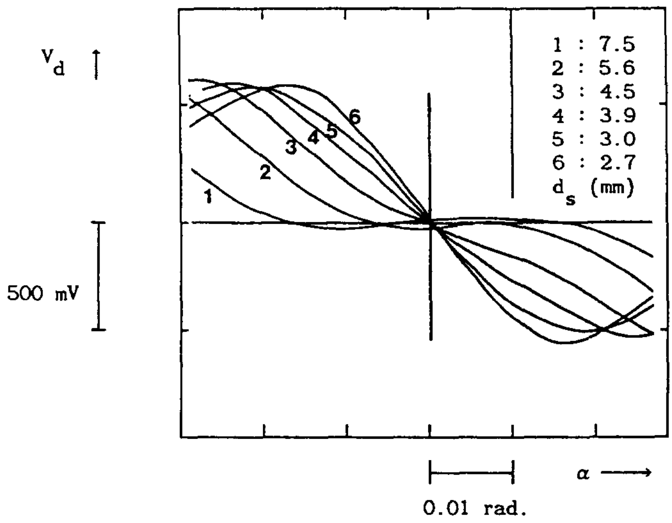

Fig. 3 : The output voltage of the photodiodes, V_d vs. the angle of deflection ,α , for several widths, D, of the strip

It is shown that for widths in the order of the width of one photodiode and small values of α eqn. 7 is valid.

Several preliminary experiments were carried out to determine the constants κ, G, J, K and C:

* The value of κ is determined by a calibration measurement.

An 0.01 Hz alternating current, I_c, was sent through the coil yielding the relation between V_d and I_c. The specifications of the moving-coil meter yield the relation between I_c and α. From these two relations the value of κ is obtained with eqn. 10

$$\kappa = (\partial I_c/\partial V_d.) * (\partial I_c/\partial \alpha)^{-1} \qquad 10$$

* The sensitivity, G can be determined as follows.

The anemometer is placed so that its axis of rotation and the pointer are horizontal. Then several small weights are suspended from the end of the pointer and V_{reg} necessary to compensate for this weight is measured. Using eqn. 2 the value of G can be calculated. A characteristic result is shown in Fig. 4.

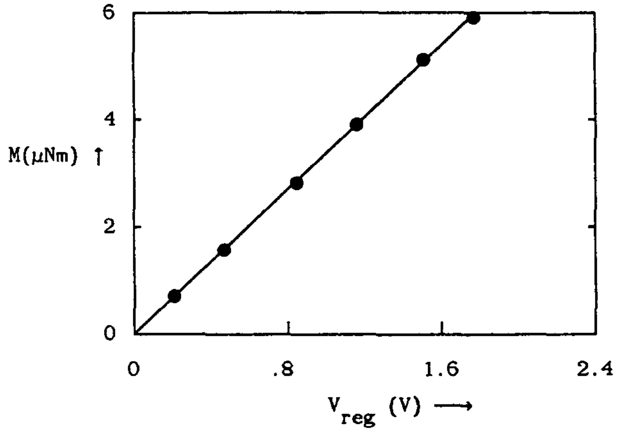

Fig. 4 : Determination of G

* The torsion constant, C, is determined according to an analog procedure without the use of the feedback system. The deflection of the beam is measured as a function of the weight force of the weight pieces.
* The moment of inertia, J, and the damping constant, K, are obtained from a step response (no feedback) and the earlier obtained value of C. There the induction voltage over the coil is measured as a function of time.

With the values of G, J, K and C obtained from the experiments the frequency respons S(f) can be calculated according to eqn. 6.

To measure this frequency response one can exert a known varying force on the vane caused by a varying air velocity. However, in practice it is very difficult to realise an experimental set-up which is able to create known and preferably harmonically varying air velocities. Therefore the following method is applied.

An extra current I_s is superimposed on the current through the coil I_{reg}. This extra current, which is represented by a voltage V_s, will cause a small deflection of the arm, as would a varying force on the vane. The feedback system will react by adjusting $V_{reg}(t)$.

This procedure was followed for several frequencies from 0.25 Hz to 10 Hz. In Fig. 5 V_{reg}/V_s and V_{cor}/V_s are shown while the curved line in Fig. 5 corresponds with the calculated S(f)/S(0).

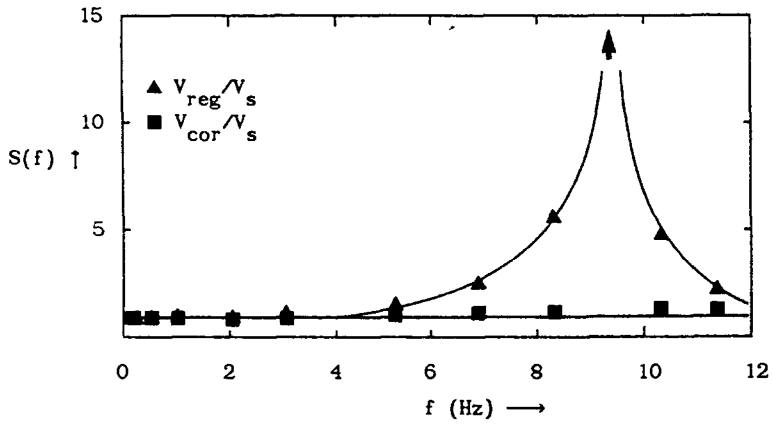

Fig. 5 : The curved line corresponds with eqn. 6 and represents S(f)/S(0). The data show V_{reg}/V_s and V_{cor}/V_s vs. f.

It should be noted here that no measurement was possible at a frequency of 8 Hz, because the response V_{reg} gets unstable at this frequency. At frequencies lower than approx. 3 Hz the difference in V_{cor}/V_s and V_{reg}/V_s is smaller than 10 %. At higher frequencies however $V_{cor}(t)$ proves to be nearly independent of the frequency and is therefore a better measure for the force.

Also from Fig. 5 we see the peak in V_{reg}/V_s occurs at approx. 8 Hz. It is shown that, as was expected, there is an excellent agreement between the calculated S(f)/S(0) and the measurements.

The usefulness of $V_{cor}(t)$ instead of $V_{reg}(t)$ is also demonstrated in Fig. 6. Here the response of our anemometer upon a step function in V_s is shown at two different values of P.

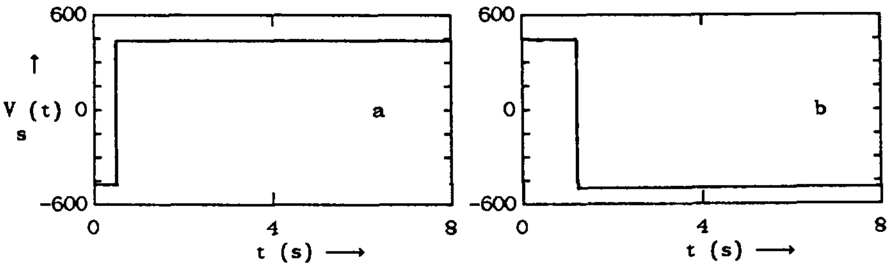

Fig. 6 : $V_s(t)$, $V_{reg}(t)$ and $V_{cor}(t)$ as a function of time when $V_s(t)$ is a step function at P values 1670 (a) and 300 (b)

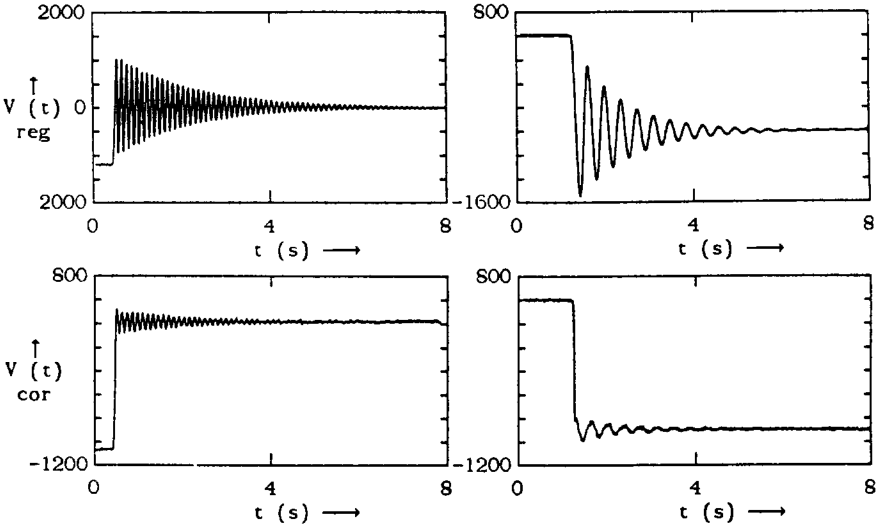

Fig. 6 : For explanation, see other page

The amplitude of the oscillations of $V_{cor}(t)$ is approx. 5 times smaller than in $V_{reg}(t)$. From the comparison of Fig. 6a with Fig. 6b it appears that the gain influences the oscillation frequency: increasing the value of the gain by a factor 5 results in a higher oscillation frequency (approx. factor 2). This is confirmed by an approximation of eqn. 6 which yields as a rough estimation of this frequency

$$f \simeq 1/2\pi \ . \ \sqrt{(PG/J + C/J)} \qquad 11$$

DISCUSSION

It is shown that the width of the strip used in the optical detection system does not have to be very accurate as long as it is of the order of the width of one photodiode (see Fig. 3).

By using the complete equation of motion of the anemometer a better measure for the force can be obtained, which is independent of the frequency of variation up to approx. 8 Hz (see Fig. 5). At frequencies lower than 2 Hz however the use of the complete equation of motion seems rather superfluous.

As a conclusion we can state that the anometer described above is able to measure varying forces at frequencies up to approx 8 Hz. This makes our anemometer suitable for most practical purposes.

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