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USE OF BALANCES IN ANEMOMETRY, PART II

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ABSTRACT

At the 21st Microbalance Techniques Conference a mechanical microanemometer has been presented with a measuring range of 0.5 to 14 cm/s. It consisted of a moving-coil meter with a vane fixed to the pointer of the meter. In the present contribution a variation on that method is presented, where the moment of force, due to the air velocity, acting on the pointer itself is considered. In this study the length of the pointer is varied and mathematical and experimental results are discussed.

INTRODUCTION

At the former Microbalance Techniques Conference (ref. 3) a flow measuring principle is described, based upon the determination of the force exerted on a vane in an air flow. There the vane was placed on the far end of the pointer of a moving-coil meter. This measuring principle resulted in a prototype, which was able to measure air velocities as low as a few mm/s. Based upon the same measuring principle, a new prototype microanemometer is introduced where the force exerted on the pointer itself is measured. In the present paper the new microanemometer together with experimental results will be presented. These experiments will focus on the influence of the length of the pointer on the results.

MEASURING DEVICE

In order to determine air velocities the original pointer of a moving-coil meter is placed in a air flow. This cylindrical hollow beam is max. 67 mm long , has a diameter of 0.4 mm. In Fig. 1 a schematic view of the microanemometer is drawn.

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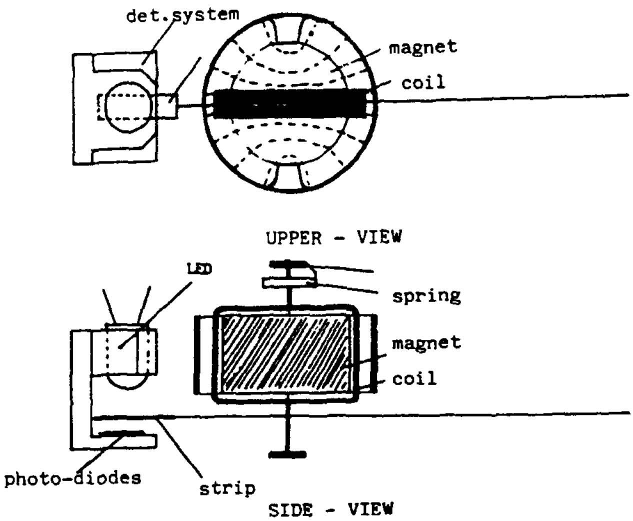

Fig. 1 : Schematic representation of the new microanemometer top view (a) ; side view (b)

At the opposite side of the pointer an optical detection system is placed, consisting of an infrared LED, two photodiodes and a small strip of metal fixed to the pointer. In case of non-zero air velocity a moment of force will be exerted on the pointer, the vertical axis will rotate and the photodiodes will generate an outputcurrent which is led into the feedback system. The output voltage, V_{out}, of the feedback system adjusts the retroactive Lorentz couple to the external moment of force until equilibrium of momentum is achieved. In this way V_{out} is a measure of the air velocity.

The measuring device (except for the pointer) is placed in a hollow aluminium sphere, diameter 5.2 cm, the moving-coil meter being located in such a way that the length of the beam outside of the sphere is as large as possible.

Compared with the former anemometer the restrictive geometrical dimension (the size of the permanent magnet) is essentially reduced. So the size of the surrounding sphere could be reduced by approx. 1/3.

THEORY

The force acting on a cylinder placed in an air flow is a much investigated subject (ref 1, 2, 5). In our case we do not measure the force but the moment of force on the cylindrical pointer.

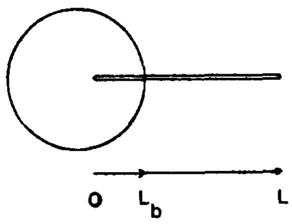

Fig. 2 : Coordinate system, introducing L_b and L

We use, introducing the coordinate system of Fig. 2, for the force per unit length, A(l,v)

$$A(l,v) = 0.5\ \rho\ D\ v^2\ C_d \qquad (1)$$

where ρ is the density of the air,
D the diameter of the cylindrical pointer,
v the velocity of the air and
C_d the so called drag coefficient.

For the moment of force M(L,v) we obtain

$$M(L,v) = \int_{L_b}^{L} A(l,v)\ l\ dl \qquad (2)$$

Assuming that A(l,v) is independent of L leads to

$$M(L,v) = A(v)\ 0.5\ (\ L^2 - L_b^2\ ) \qquad (3)$$

EXPERIMENTS

The new microanemometer was placed inside our calibration unit for low air velocities (ref. 4) and was tested for several air velocities varying from 1 mm/s up to 130 mm/s. After a series of measurements, i.e. a calibration series, the length of the pointer was decreased by approx. 5 mm and a new series was started.

In Fig. 3 M(L,v) is plotted vs. L^2 for several air velocities. From eqn. 3 it follows that A(v) can be obtained from the slope of the curves in Fig. 3. Linear regression is used between M(L,v) and L^2 to fit the measured points to a straight line. The results of this linear regression are presented by the lines drawn in Fig. 3.

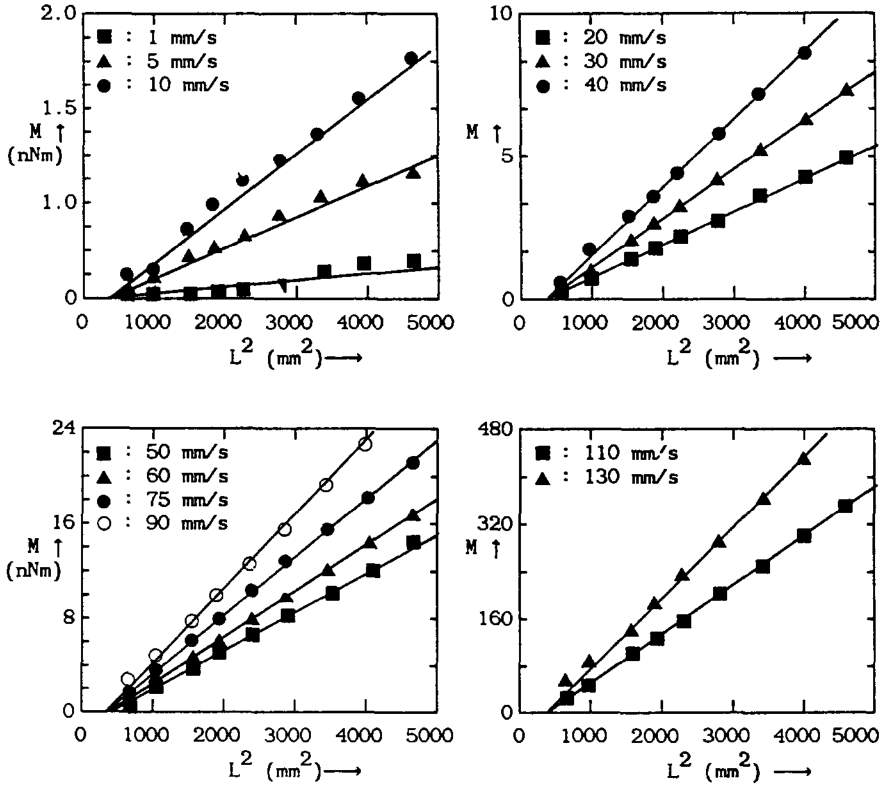

Fig. 3 : $M(L,v)$ vs. L^2 at several air velocities v. The lines drawn correspond with the results of linear regression.

From Fig. 3 one can conclude that for higher air velocities the lines drawn correspond with the experiments within the measurement accuracy. At lower air velocities ($v < 10$ mm/s) and in the vicinity of the sphere discrepancies appear. In general, however, we may say that the assumption that A(v) is constant is valid. The intersection with the L^2 axis yields $L_b^2 = 361 \cdot E{-}6$ mm^2 so $L_b = 19$ mm. This value corresponds well with the actual value of L_b which is 18.9 mm.

In Fig. 4a the values of A(v) obtained from the linear regression are plotted as a function of the air velocity, v and in Fig. 4b the values of A(v)/v vs v are plotted.

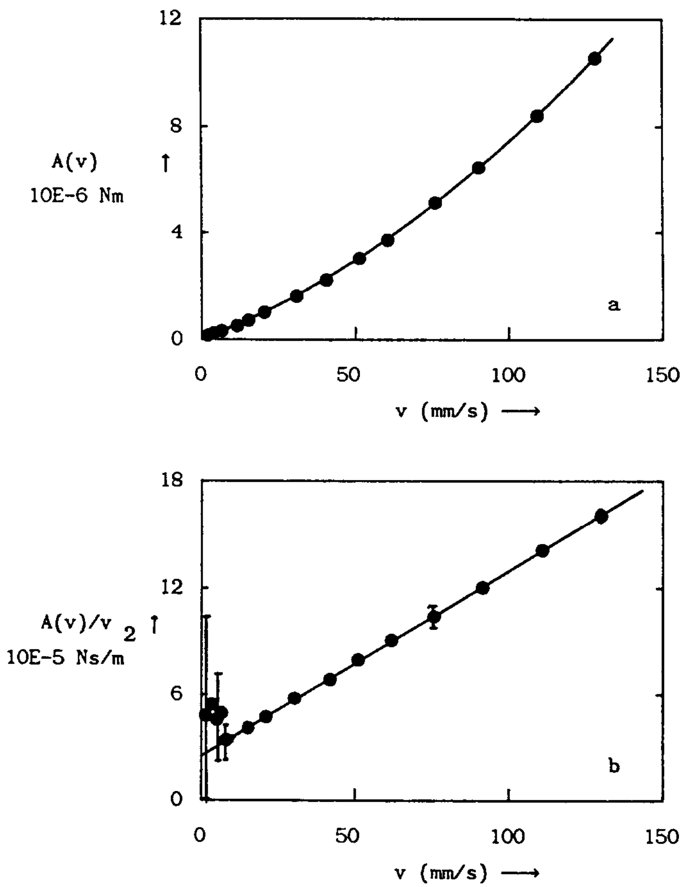

Fig. 4 : Values of A(υ) and A(υ)/υ plotted as a function of the air velocity υ.

In Fig. 4 it is shown that the relation between A(v) and v is quadratic, so

$$A(v) = \alpha v + \beta v^2 \tag{4}$$

This relationship is also drawn in Fig. 4a and the agreement between the measurements and the line drawn is apparent. For air velocities higher than approx. 30 mm/s the second R.H.S. term of eqn. 4 is no longer negligible. This air velocity corresponds with a Reynolds number of approx. 0.5.

DISCUSSION

Because the condition of the drag per unit length being constant is equivalent with the assumption that the flow around the cylinder is quasi-two dimensional, the discrepancy between eqn. 3 and the real experiments is a measure for the influence of the sphere on the air velocity in the vicinity of the sphere. This discrepancy however seems to be rather small (see Fig. 3) and only present at very low air velocities (< 10 mm/s), which may be due to the averaging effect of the pointer.

The drag per unit length has a quadratic dependance upon the air velocity. The Reynolds value, at which the quadratic term may no longer be neglected, is approx. 0.5. This result agrees well with the values given in literature (ref 1, 2, 5).

The length of the pointer, L, can be reduced from 69 to 35 mm. This decrease of L however influences the upper and lowerlimit of air velocities we are able to measure: at smaller L values both limits will increase. In that case a more 'local' determination of the air velocity is obtained.

As a conclusion we may say that the influence of the sphere on the measurement of the air velocity is small so the length of the pointer of the moving coil meter can be chosen, according to the velocity range one is interested in.

REFERENCES

1 G.K.Batchelor : An introduction to Fluid Dynamics, Cambridge university press (1970).
2 J.Happel and H.Brenner : Low Reynolds number hydrodynamics, Noordhoff Int. Publishing Leyden (1973).
3 M.J.F.P.Pluijm, T.H.J.J. van der Hagen, C.H.Massen : Use of balances in anemometry, Thermochimica Acta 103 (1986), pp.69-74.
4 M.J.F.P.Pluijm, G.J.A.Sars, C.H.Massen : Calibration unit for microanemometers at very low air velocities, Appl. Sci. Reserach 4, 10 (1986), pp.227-234.
5 H.Schlichting : Boundary-Layer Theory, Mc.Graw-Hill Book Company (1979).