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A method for the determination of the time constant of low velocity anemometers

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Introduction

Traditionally velocities are recorded in ventilated rooms in order to assess whether the velocities in the occupied zone are so high that they negatively affect the thermal sensation experienced by people. There has been less interest in monitoring the air flow pattern within the room. Instruments on the market are often intended to be used in the field for control of installed ventilation systems. They are therefore designed to resist damage and quite robust types of intruments have been constructed and are in use. Mainly only the mean velocities are recorded and very often the instruments in use have unknown dynamical properties. Recent research has shown that the degree of velocity fluctuations (turbulence intensity) may affect the thermal sensation experienced by people (Fanger & Christensen (1986)). This fact has stimulated renewed interest in monitoring turbulence intensity in ventilated rooms.

Why do we need to know the time-constant?

In order to record fluctuating velocities correctly it is important to know the dynamical response of the instruments because:

- The time constant of the instrument and the integral scale of the fluctuating velocity field in the room determine the measuring time needed to predict the statistical moments of the velocity field (mean velocity, standard deviation etc) within a given accuracy

- The time constant determines the degree of damping of the recorded velocity signal

The rms value of the velocity fluctuations occurring in a ventilated room covers a large range. When expressed as a percentage of the local mean velocity, it is of the order 10% close to the supply air terminal and in the core region of the room it amounts to 20-30%. The energy spectrum of the velocity fluctuations cover a range up to 2 Hz and for mean velocities between 0.10-0.30 m/sek the eulerian integral scale lies between 1 to 0.06 sek, see Sandberg (1987).

Mathematical model of anemometers

The instantaneous heat-loss for an anemometer becomes:

$$mc\frac{dT}{dt} = RI^2(T) - \Phi(u,T) \qquad (1)$$

m = mass of sensor body

c = specific heat

R = resistance

I = current

T = temperature

t = time

u = velocity

Φ = heat loss to the flow and to the support of the sensor

For a hot wire the resistance R at temperature T may be expressed as

$$R = R_{ref}(1 + \beta(T - T_{ref})) \qquad (2)$$

β = temperature coefficient

Where R_{ref} is the resistance at the reference temperature T_{ref}, usually $273^{O}K$.

In the ambient where low velocity transducers are used the errors due to radiation losses are negligible compared to other sources of errors.

The thermal capacity of the sensor body is equal to mc. The lag exhibited by the sensor body when following the fluctuations stems from the circumstance that the flow has to pass the information to the sensor.

Regarding type of control there are two main types of instruments:

Constant current anemometry (CCA)

In this mode the sensor body is heated by a quasi constant electrical current and the resistance of the sensor or the voltage is the electrical variable that is used to record changes in velocities. If we assume that we are in equilibrium and suddenly achieve a change in velocity u' then, after linearization of the equation around the equilibrium state, we obtain a first order differential equation for the corresponding change T' in temperature. This gives us the time constant, M, based on linearization of the equations:

$$M = \frac{cm}{R_{ref}\ \beta I^2}\ \frac{R(T_b) - R(T_a)}{R(T_a)} = \frac{cm}{R_{ref}\ \beta I^2}\alpha \tag{3}$$

$R(T_b)$ = resistance of the sensor at temperature T_b

$R(T_a)$ = resistance of the sensor at room air temperature T_a

α = overheat coefficient

Constant-temperature anemometer (CTA)

In this type the sensor is included in a closed-loop (nowadays often micro processor controlled) control system, which holds the sensor's resistance (and thus its temperature) at a constant value. The output is the electrical power developed in the sensor. The power can be calculated from the voltage (or current) of the sensor. In principle this should mean that we had dT/dt = 0 and the relationship 1 should be purely algebraic and the problem with thermal lag be avoided. However, in practice the derivative dT/dt can only be maintained approximately at zero. Therefore the properties of the feedback loop are the determining factor. Freymuth (1969) has analyzed the differential equation that governs the loop output and the behavior of the system becomes a second order differential equation. Later he has extended the analysis (Freymuth (1977b)) and the CTA is represented as a third order differential equation.

According to Dumas (1988), the time constant for a CTA system can be written as:

$$M_{CTA} = \frac{M}{1 + 2gR(T_a)\alpha} \tag{4}$$

Where M is the time constant for a CCA system and g is a factor depending on the gain of the feedback.

Methods for assessing the time constant

There are several ways of doing this:

1 Develop a mathematical model (nonlinear differential equation) for the instrument and solve the governing equations numerically for different types of velocity fluctuations, e.g. sinusoidal or step changes, see Freymuth (1977a)

2 Linearize the governing equations around an equilibrium state in order to obtain an algebraic expression for the time constant

3 Electronic testing by adding a known disturbance (e.g. square wave or step change) to the heating current or voltage depending on type of instrument.

4 Creating a known velocity fluctuation and recording the response

The expressions (3) and (4) for the time constants have been achieved by applying method 2. Our method belongs to method no. 4 and we produce a low frequency oscillating flow with a non zero mean. Several methods exist that produce a high frequency oscillating flow with a zero mean, see Elger and Adams (1989).

We have chosen the standard deviation response, rather than the usual amplitude response, because it is readily calculated on a computer.

Description of test method

The apparatus is shown in Fig. 1 and Fig. 2.

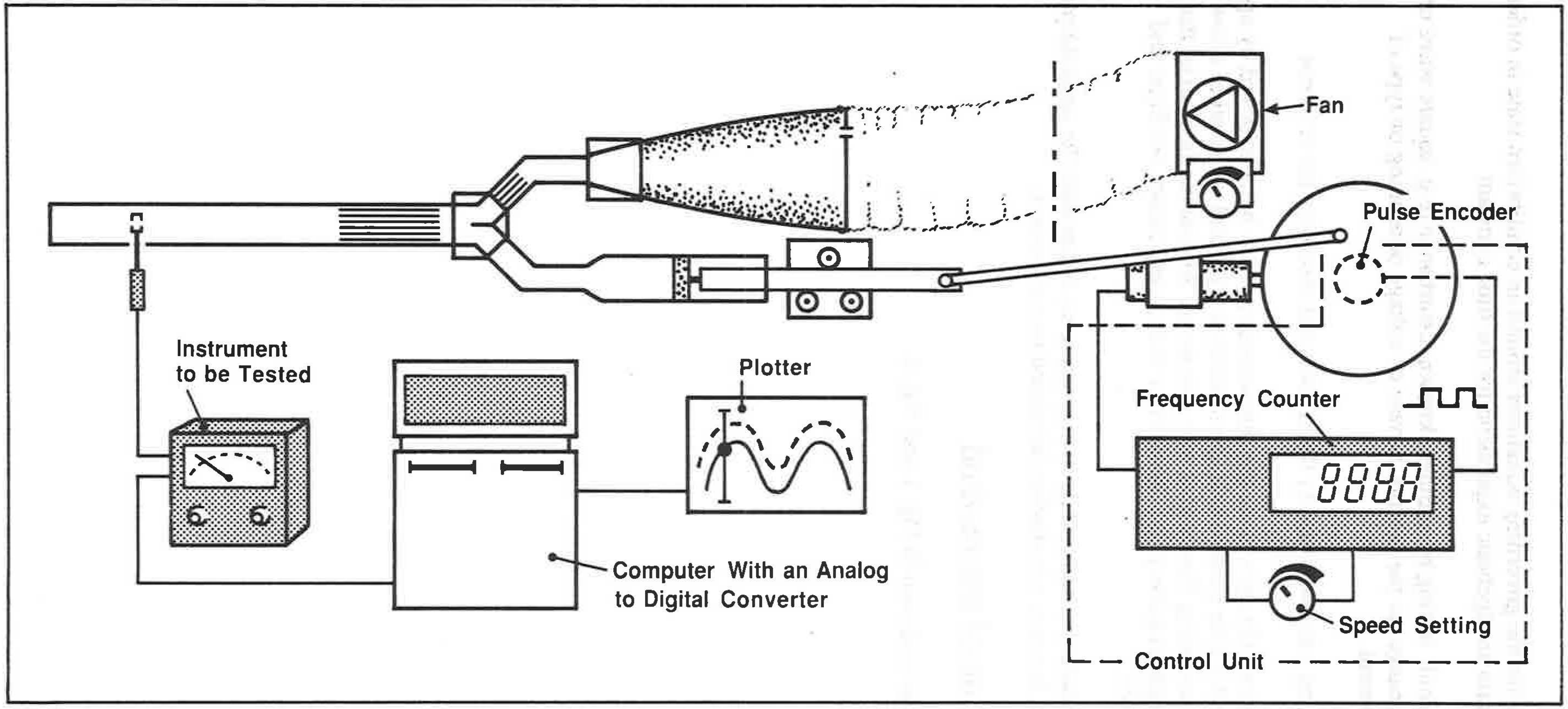

Figure 1. Test rig

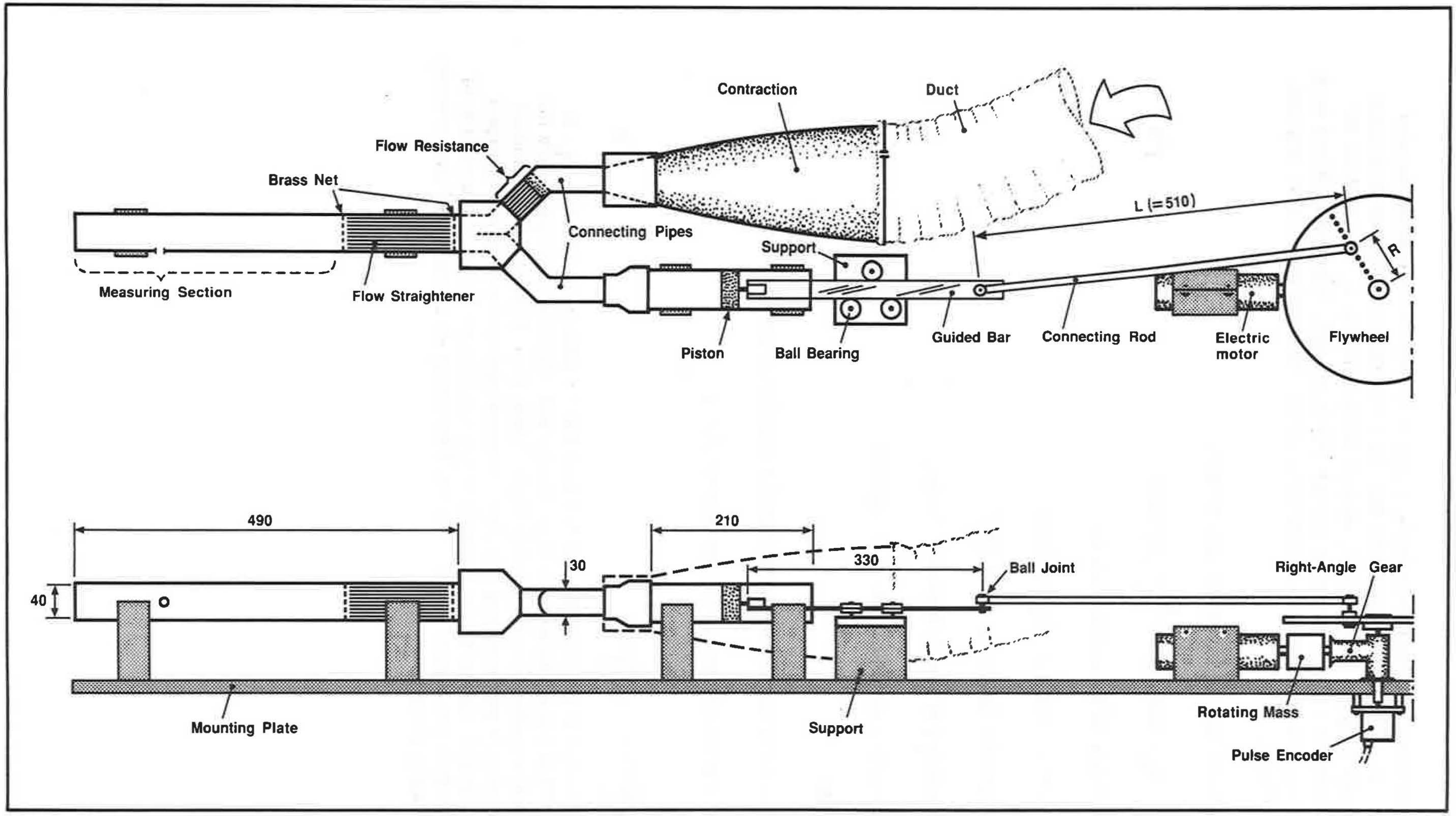

Figure 2. Components of the test rig

The test rig consists of two parts, a *base flow unit* and a *modulating unit.* The base flow unit consists of a fan, duct, contraction and flow resistance. By adjusting the fan speed the desired mean velocity, u_b, is set. With the modulating unit the time varying velocity is created. A piston is driven by a driving unit consisting of an electrical motor, flywheel and connecting rod, see Fig. 2.

The velocity created by the unit becomes

$$u(t) = u_b + R\omega(\sin\omega t + \frac{R}{2L}\sin(2\omega t)) \tag{5}$$

L = length of the connecting bar

R = active radius of the flywheel.

ω = angular frequency ($\omega = 2\pi n$)

n = number of revolutions per second

We see that the amplitude A is equal to:

$$A = R\omega \tag{6}$$

and is subsequently dependent on the angular frequency

The standard deviation for the function (5) is:

$$\sigma = \frac{R\omega}{2}\sqrt{(1 + (\frac{R\omega}{2L})^2)} \tag{7}$$

The tests are accomplished so that first the desired mean velocity, u_b, is set. Then a suitable amplitude,A, is selected. Then for each frequency the effective radius R is selected so that relation (6) is fulfilled. The standard deviation is recorded and the gain is determined by dividing the recorded standard deviation by the theoretical one (7). Figure 3 shows an example of recorded time history of the velocity. The strong damping of the true velocity is clearly shown.

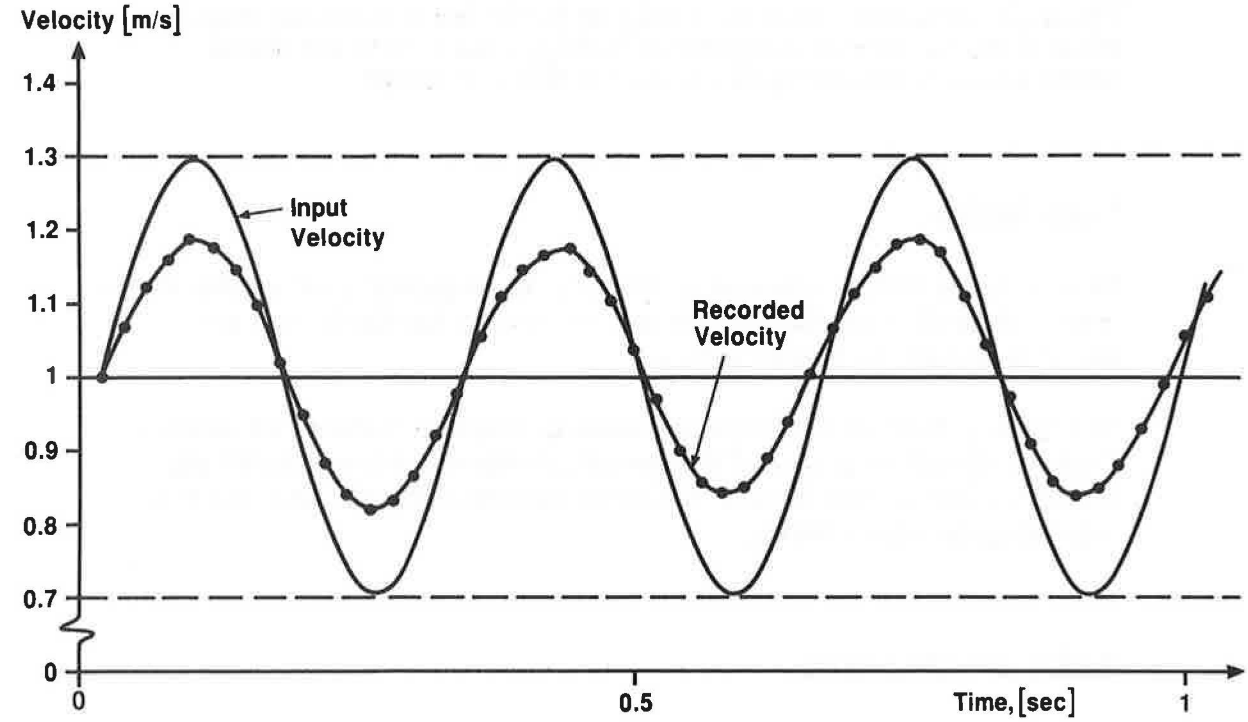

Figure 3 Example of recorded velocity

The *cut-off frequency* is defined as the frequency at which the gain has dropped to $1/\sqrt{2}$.

Figure 4 shows the frequency response of two anemometers. The one denoted "standard" is an anemometer used for control of HVAC systems while the one denoted "fast anemometer" is a type that is used in research.

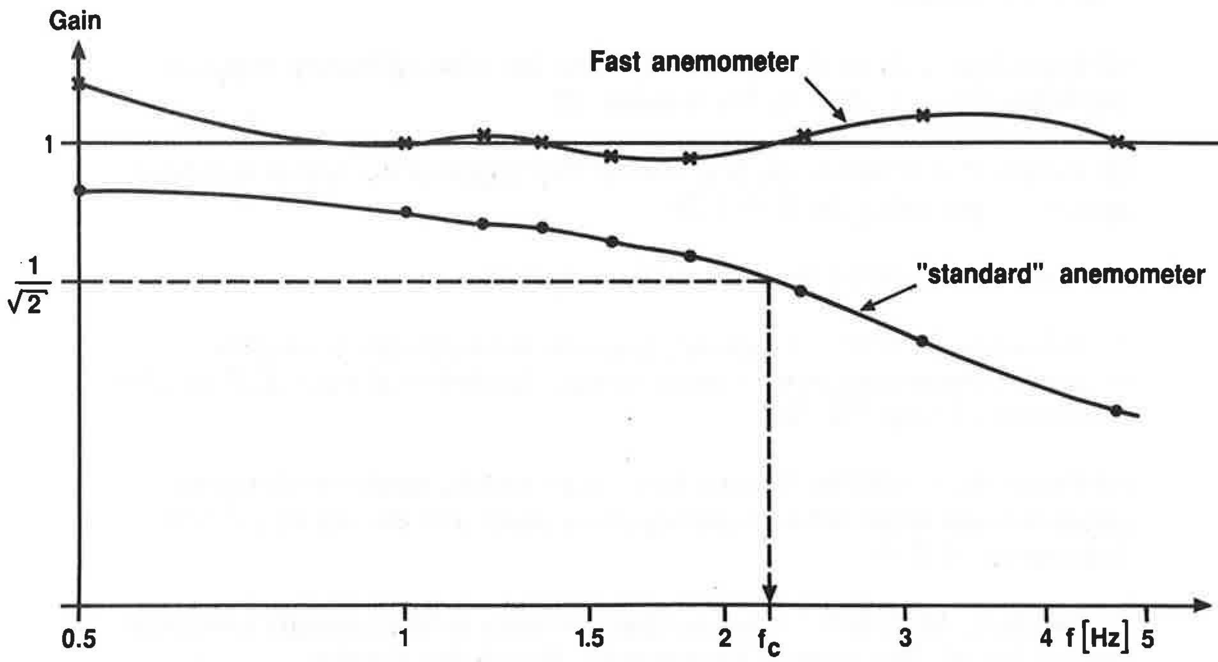

Figure 4 Example of recorded frequency response

The small oscillations in the recorded gain for the fast anemometer may be an effect of the fact that the anemometer is a high order system and due to imperfections in the test rig. Our test rig is only a prototype.

Conclusion

Measurements with an anemometer with greater frequency response than the frequency of the flow oscillation in the test rig showed that the rig well produced the expected reference velocity.

By recording the response to a near sinusoidal reference velocity we obtain a clear and illustrative picture of the dynamical behavior of low velocity anemometers. This method is more illustrative than recording the response to a step change in input velocity.

Acknowledgement

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Summary

A simple dynamic calibration method for anemometers in use for recording velocities in ventilated rooms and for control of air conditioning systems is presented. An apparatus produces a nearly sinusoidal reference velocity field (with mean velocity u_b) of the form:

$$u(t) = u_b + R\omega(\sin\omega t + \frac{R}{2L}\sin(2\omega t))$$

where ω is the angular frequency and $R\omega$ is the frequency dependent amplitude. The quantities R and L are two constants that depend on the dimensions of the apparatus. The standard deviation of the reference velocity is

$$\sigma = \frac{R\omega}{2}\sqrt{(1 + (\frac{R\omega}{2L})^2)}$$

Placement of the velocity transducer into this velocity field provides data for calculating the time constant or cut off frequency. The standard deviation response of the recorded signal, rather than the more common amplitude response, is used in order to calculate the time constant.