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A particle detector for use in ventilation engineering

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SUMMARY

An electronic particle counting device is described, based on a constant-temperature hot-wire anemometer probe. The device has found application in tracing the motions of droplets and measuring their concentration within ventilated areas when subjected to different types of ventilation. In this way the effectiveness of various systems may be determined.

INTRODUCTION

The need to detect and count the numbers of tracer aerosol droplets within a room ventilated by two different methods led to the development of the particle detector described in this paper and is an extension of the apparatus described by Clark, Cox & Lewis (1971).

The basis of the device is a constant-temperature hot-wire anemometer on to which particles from an air stream land. Goldschmidt (1965) showed that by suitable electronic filters the signal associated with the cooling of the wire due to a particle landing on it could be discriminated from the cooling effect due to varying air velocity past the wire.

The present device employs a hot wire anemometer probe enclosed within a nozzle. The electronic circuits are battery-powered and the apparatus is portable when used with a battery-operated electronic counter. Fig. 1 shows a block diagram of the component parts of the detector, and Plate 1 shows the complete apparatus.

THE SAMPLER

Principle of operation

When a particle lands on the heated wire the wire rapidly loses heat to the particle. The voltage output from the wire that is associated with this heat loss is distinguishable from that due to air velocity fluctuations past the wire. The waveforms due to the particle impacts have a very steep slope which reach a sharp peak and then die away quickly. The peak voltage associated with the impact of a 30 μm. diameter particle is about 300 mV. When the particle hits the wire there may also be a 'strain gauge' effect which may change the resistivity of the wire. However, this is assumed to be a small effect since particle impacts have also been detected using a hot film probe where this effect is negligible.

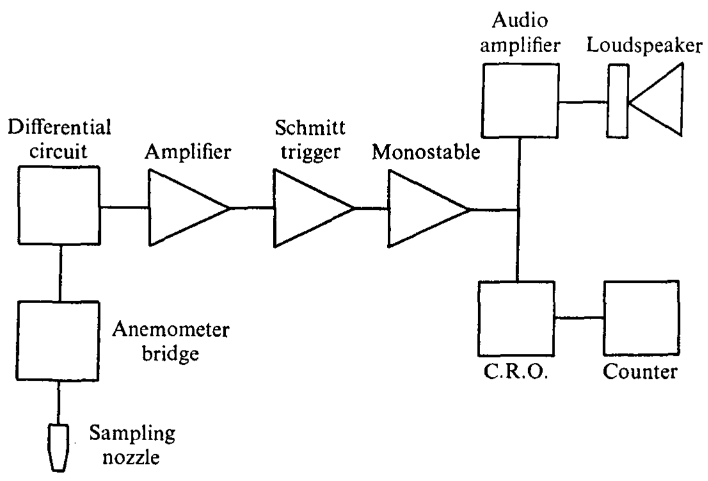

Fig. 1. Block diagram of the sampling apparatus.

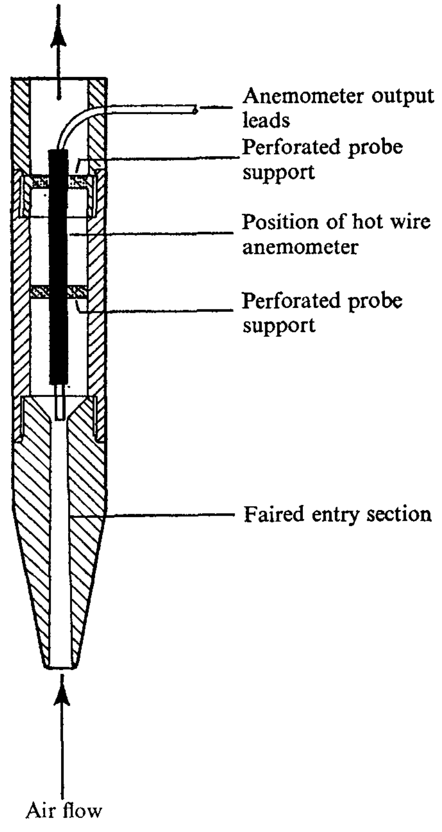

Fig. 2. Section through the sampling nozzle.

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Goldschmidt also showed that the sensitivity of the wire to particle impacts was inversely proportional to the wire diameter and length, and proportional to the temperature coefficient of resistivity of the wire.

Therefore, for large overheat ratios, large air velocities past the wire and low values of wire resistivity, the chances of discriminating particle impacts will increase.

Description of the sampling nozzle

The hot-wire anemometer probe consists of a moulded epoxy-resin body in which are embedded two nichrome wire prongs of 0·025 in diameter. The distance between the prongs is 2 mm. and across the ends of the prongs a 5 μm. diameter tungsten wire is welded. The hot-wire probe is located in a sampling nozzle and a drawing to show the section through the nozzle is shown in Fig. 2.

The nozzle body is made in three sections from aluminium and the probe itself is held centrally in the nozzle body by two probe supports. These supports are perforated to allow the air to pass through the nozzle. The 5 μm. diameter wire on the end of the probe is positioned just at the end of the faired entry section of the nozzle. Flexible plastic tubing is attached to the end of the nozzle and connected to a suction pump. Plate 1 shows the complete assembly together with a battery-operated pump (Micronair Type 3900-10). The output from the hot-wire probe is fed to the anemometer bridge circuit. This is either a DISA 55D05 battery-operated bridge or a DISA 55D01 model which allows the wire to be operated at a maximum overheat ratio of 1·8.

Circuit description

Fig. 3 shows the complete circuit diagram for the sampler. The output from the anemometer bridge is differentiated and then fed to an amplifier. This amplifier output passes to a Schmitt trigger and then to a monostable circuit which provides an output to an electronic counter and a storage oscilloscope. The monostable output is also fed into an audio amplifier coupled to a loudspeaker. Plate 2(*a*) shows separately the output signals from the anemometer probe. The top trace shows the 'spikes' associated with a particle impact on the wire, and on the bottom trace is shown the repetitive signal due to the velocity fluctuations at the wire produced by the reciprocating air-pump. These two signals are superimposed at the anemometer output and the composite signal is fed to the differential circuit and first amplifier, where the signal from the air pump is attenuated to a greater extent than the 'spikes' of the particle impacts.

Plate 2 (*b*, c) illustrates the action of this part of the circuit when sine and square-wave signals are injected into the sampler circuit. These sine and square waves are analogous to the pump and particle signals respectively. Plate 2 (*b*) shows these input sine and square waves which are of similar magnitude, and Plate 2 (*c*) shows, on the same vertical scale, the resultant signal just after the differential circuit and amplifier. It is seen that the differentiation of the square wave produces a signal with no amplitude attenuation whereas the sine wave undergoes an attenuation of about two-thirds the input voltage. It is in this way that the superimposed particle

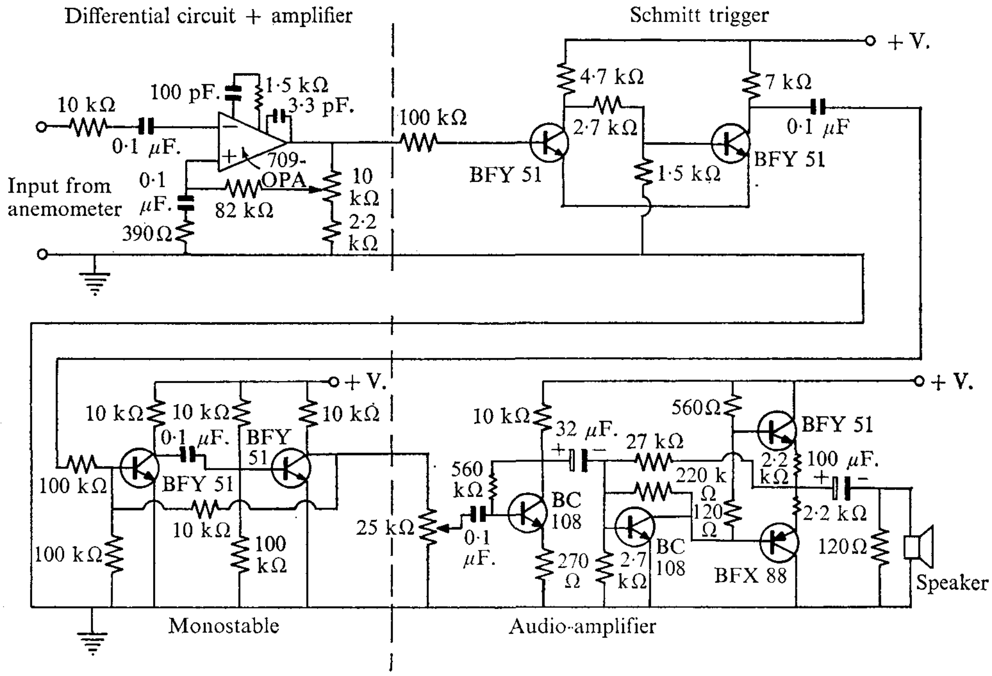

Fig. 3. Circuit diagram of particle sampler.

and pump signals are discriminated with the result that the effect of the particles is enhanced and that of the pump minimized.

These voltage-pulse differences are next fed to the Schmitt trigger. This trigger is adjusted to respond only to pulses of greater amplitude than those associated with the velocity fluctuations. The pulses that pass this trigger, due only to the particle impacts, are fed into the monostable circuit. This produces a constant amplitude voltage output pulse for all amplitudes of the Schmitt trigger output. The electronic counter and storage oscilloscope respond to the monostable output and indicate the number of particle impacts on the wire.

By feeding the monostable circuit into the audio amplifier and loudspeaker a signal is also heard for each particle impact.

Efficiency of the sampler

Experience has shown that the sampler is more sensitive to liquid aerosol droplets than to solid particles. Consequently for tracing the motion of particles in ventilation systems, liquid aerosol droplets up to 30 μm. diameter have been used as the tracer particles. The efficiency of the sampling wire is the ratio of the number of particles that land on the wire to the number of particles, the centres of which would have passed through it if they had moved all the time in straight lines. For purely inertial deposition this efficiency only depends on the particle stop distance. The ratio of this stop distance to a characteristic dimension of the system (i.e. the wire radius) is the Stokes number.

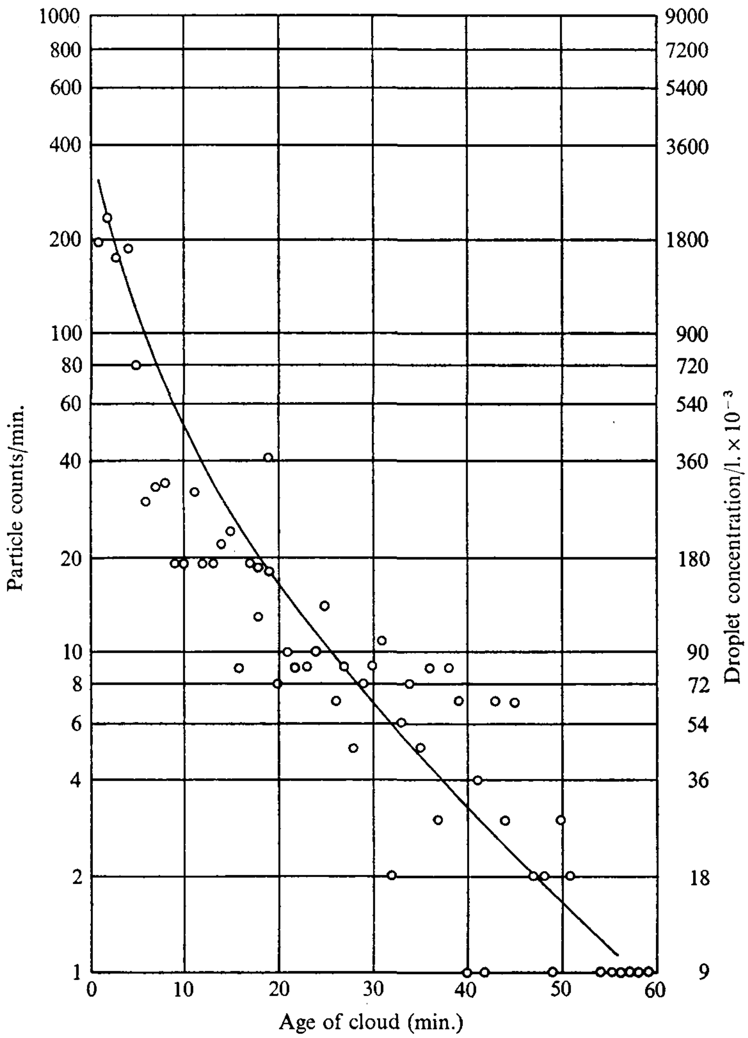

Fig. 4. Decay of a cloud of aerosol droplets in a room during 1 hr.

The collection efficiency for particles landing on a cylinder has been calculated (Fuchs, 1964) and in the case of a 30 μm. diameter particle hitting a 5 μm. diameter wire this efficiency is about 98 %.

The air pump used with this sampler produces an air flow of 1·4 l./min. past the heated wire and the mean air velocity over the wire at the end of the faired entry is about 180 cm./sec.

Use of the sampler

This sampler finds application in air conditioning or heating systems where tracer particles can be introduced into the air stream and their concentrations subsequently sampled. Two illustrations of its use are given here. Fig. 4 shows the decay of a cloud of aerosol droplets due to sedimentation in a room with relatively little air movement. Upwards of 40 min. was required before the particle count returned to that before the aerosol was injected.

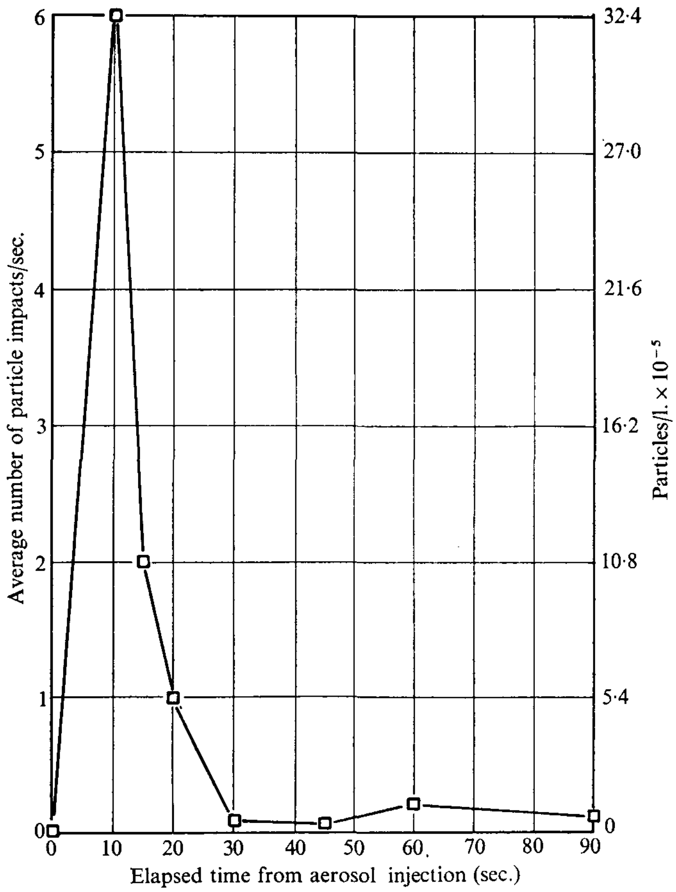

Fig. 5. Tracer droplet concentration levels in the centre of a chamber with a horizontal air flow of 25 cm/sec.

Fig. 5 shows the way in which particle concentration within a horizontal linear (laminar) flow room changed after the injection of tracer particles upstream of the sampling nozzle. The particle count rose steadily for the first 20 sec. and then the rate of counting decreased rapidly as the particles were blown through the room and into the filters.

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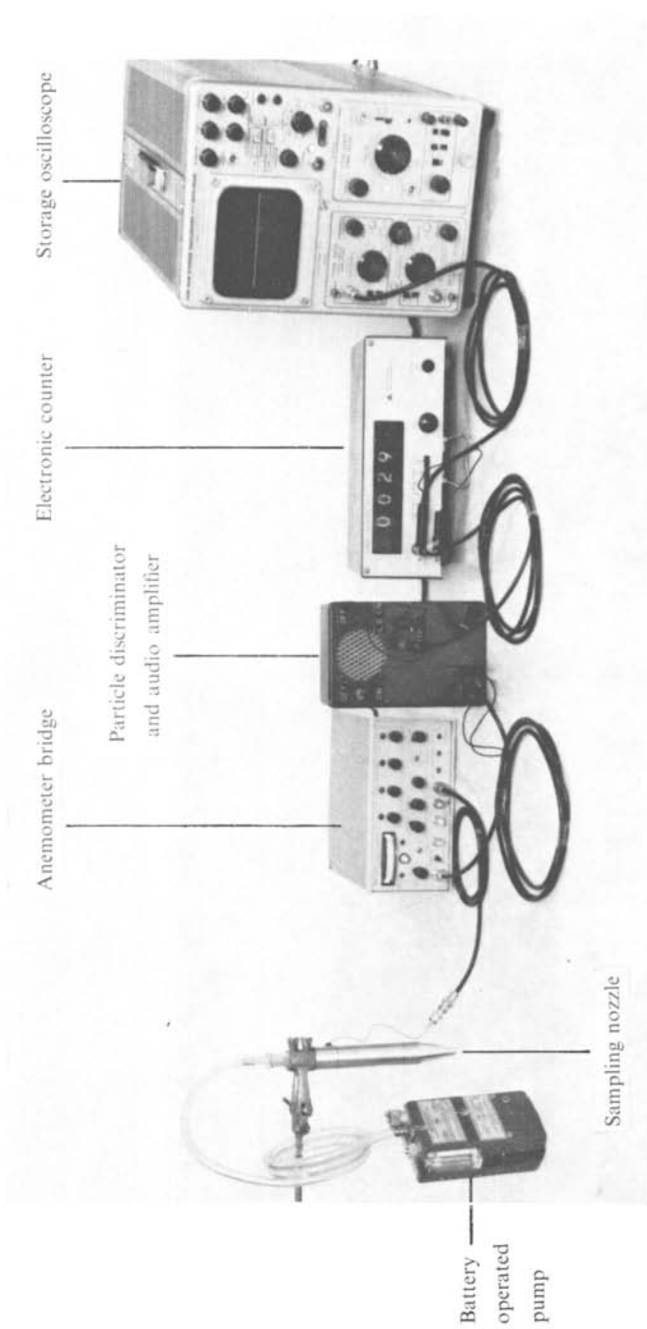

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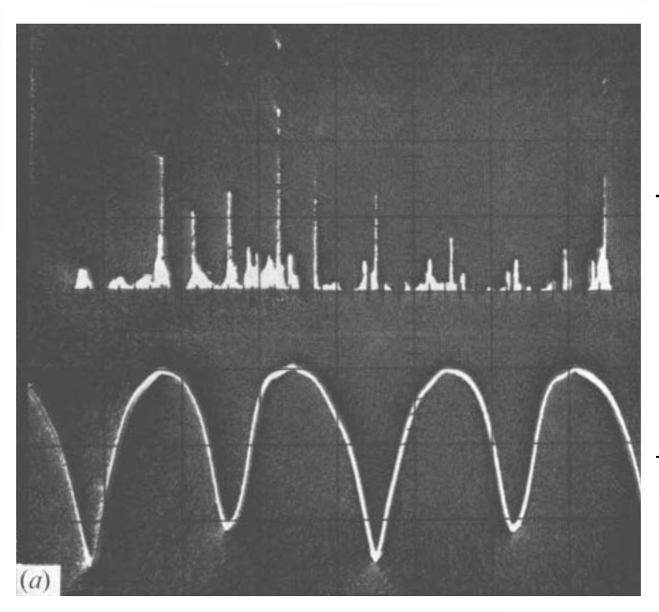

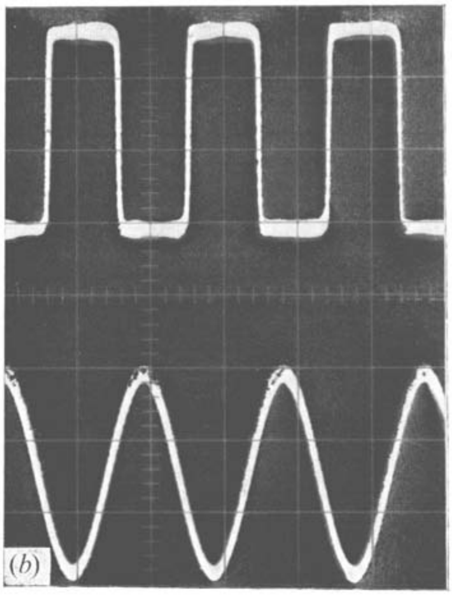

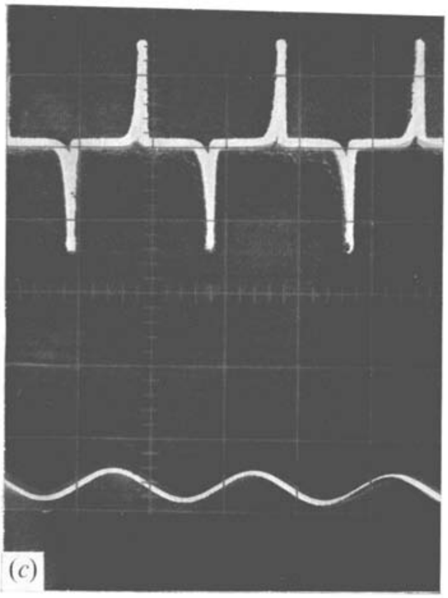

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EXPLANATION OF PLATES

Plate 1

The complete particle detector.

Plate 2

(*a*) Anemometer output signal. Upper line: 'spikes' due to particle impacts. Lower line: signal due to air velocity past the hot-wire probe.

(*b*, *c*) The effect of the differentiator and first amplifier on both square and sine waves. (*b*) Injected square and sine waves of equal magnitude. (*c*) the differentiated signal. The square waves produce sharp peaks of similar magnitude to the injected signal.