the Trimount, and the Emswiler [10, 11]. Calibration of these is impossible, and readings are converted to pressure units by fundamental calculations involving the specific gravity of the fluids used and the design principles involved.

Static Holes and Tubes

For measuring air flow by means of orifices or static tubes the type of openings used for pressure measurement and their location are quite as important as the accuracy of the gage or manometer. Where velocities are low, as in plenum chambers, or where the flow is free of large eddies and parallel to the walls of the conduit, a carefully drilled hole cleared of burrs and at right angles to the stream will give accurate readings [12]. For high accuracy the drilled depth of this hole through the wall should be at least one or preferably two diameters, and four such holes or taps around the periphery of the duct should be provided. Diametrically opposite pairs of taps are connected together, and then such pairs are manifolded together. An alternate method involves the use of the Pitot tube, shown in Fig. 3. This instrument should be pointed up stream, parallel with the air flow.

Where the flow is not axial or parallel to the side walls of the duct a very close approximation of the static pressure and the flow direction can be obtained by a Fechheimer tube [13].

MEASUREMENT OF AIR MOVEMENT

The problem of measuring air movement may be divided into three main parts: air confined in ducts, air circulating in free spaces, and air entering or leaving such space through openings such as grilles. Other gases may be measured by the same methods, but emphasis here is on air measurements [14].

For determining the velocity, and therefore the volume of air flowing in a duct, the Standard Pitot Tube [8] shown in Fig. 3 is probably most often used. When connected as illustrated, this instrument will give readings of both static and velocity pressure directly. From the latter the air velocity may be found from tables, or calculated from the following relation:

$$V = 1096.5 \sqrt{\frac{h_v}{d}} \qquad (3)$$

where

V = velocity, feet per minute.
h_v = velocity pressure, inches of water.
d = density of air, pounds per cubic foot.

Air flow in a duct is seldom uniform. In general the velocity is lowest near the edges or corners, and greatest at or near the center. For this reason a large number of readings should be taken in the manner shown in Fig. 4. In the case of round ducts not less than 20 should be taken along two diameters at centers of equal annular areas. In rectangular ducts the readings should be taken in the center of equal areas over the cross-section of the duct. The number of spaces should not be less than 16 and need not be more than 64. When less than 64 are taken the number of equal spaces should be such that the centers of the areas are not more than 6 in. apart. In determining the average velocity in the duct from

the readings given, the calculated individual velocities or the square roots of the velocity heads must be averaged. It is incorrect to use the average velocity head for this purpose.

To meet special conditions, different sized Pitot tubes which are geometrically similar to the standard tube can be used. Pulsating or disturbed flow will give erroneous results and, if possible, the Pitot tube should be located at least 7½ diameters downstream from a possible disturbance such as that caused by a turn or a criss-cross type of flow straightener should be installed in the duct 1½ diameters ahead of the Pitot tube [8]. Flow straighteners do not equalize flow velocity across a duct. They merely serve to improve the precision of measurements. Equilization can be effected if desirable for measuring purposes by the use of wire netting, perforated plates or cloth screens across the duct.

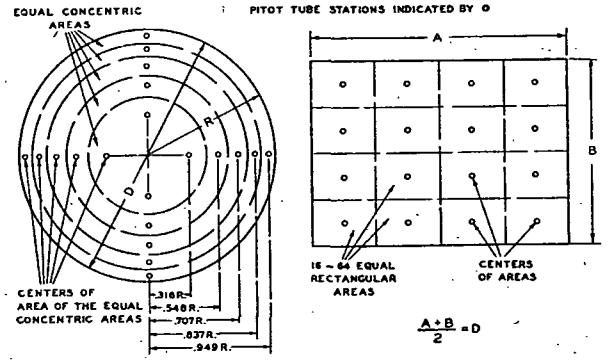

FIG. 4. PITOT TUBE TRAVERSE FOR ROUND AND RECTANGULAR DUCTS

The velocities used in many ducts are too low for measurement by means of pressure gages and it therefore becomes necessary to resort to other types of instruments.

Many forms of Pitot tubes other than the one described have been used and calibrated [15]. A double-ended tube [16], one end pointing down-stream, and one up-stream, is sometimes used for low velocities, but it should be carefully calibrated for accurate results. A special form of this tube design consists of two straight ⅛ in. tubes soldered together, closed at the end, and with a 0.04 in. hole in each tube opposite the line of contact. This tube is useful in exploring velocities on exhaust inlets, such as on hoods placed around grinding wheels.

Application of the Pitot tube is often inconvenient when velocities are low because the resultant velocity pressures become so small that extraordinary means are necessary for measuring them. In addition, velocity surveys of the whole cross-sectional area of a duct are inexpedient when numerous test runs are in prospect. Chiefly for these reasons orifices are favored for much test work. There are two types: the plate orifice and the shaped orifice or nozzle. Plate orifices are simple to construct and convenient to use in that a frame can be made to support them in the duct such that one can be removed and another inserted when it is desirable to use an orifice of a different size. Their disadvantage lies in the fact that a coefficient considerably less than unity must be applied to their indications because of the effect of the vena contracta.