SOME PROPERTIES OF PIN HOLE SOUND PROBES.

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Dvorak[1] observed that a violent wind issued from the mouth of a conical tube placed in front of the open end of a sounding Kundt tube, if the conical tube were of such dimensions as to resonate to the frequency of the sounding tube. He also observed that smoke particles were driven violently from the sounding box of a tuning fork when the fork was strongly stroked; and that in a Kundt tube in which standing waves of sound were maintained there was a steady flow of air out of the tube along the axis and into the tube adjacent to the walls. At the same time Dvorak showed from theoretical reasons that the average pressure at a node could not be zero, except for waves of infinitesimal amplitude, nor could the pressure be zero at an anti-node; hence the steady flow along the axis. Rayleigh and Dvorak made observations along the axis of the tube by probing with an open tube attached to a sensitive manometer. Barus[2] found that if the orifices in the probes were conical and of the right dimensions the pressure phenomena were reversible: i.e., if a salient orifice gave reduced pressure readings on the manometer the re-entrant orifice gave increased pressure readings at the same point along the standing wave. Dvorak observed that the response of the conical hood was best when in resonance and Barus suggests the same thing for the length of the probing tube in his work.

We shall distinguish our conical orifices by designating them salient and re-entrant in the usual sense in which the terms are used in hydrodynamics. The salient orifice normally gave an indication of reduced pressure and the re-entrant orifice gave increased pressure indications.

My first observations on the phenomenon were made with an organ pipe for a source of sound into which a considerable wad of cotton had been introduced about 15 cm. in front of the vibrating jet to damp out any steady flow of air down the pipe. Shellac was used to stick a paper hood over the end of an 8 mm. glass tube about one meter long and a hole was punched in the hood with a common pin (re-entrant orifice). This probe showed an increase in pressure above atmospheric pressure at the node of about 2 mm. of water when the organ pipe (384) was blown vigorously. The depression of pressure was about the same when the hole was made salient. The manner of variation of pressure on the manometer with distance the probe advanced into the tube is shown in figure 1. Similar curves have been secured by Barus.[3] As was to

[1] Weid. Ann. 3, 328 (1878).
[2] Carnegie Inst. Pub. 310, *26* (1921).
[3] Carnegie Inst. Pub. 310, p. 25, *26* (1921).

"Proc. Ind. Acad. Sci., vol. 37, 1927 (1928)."

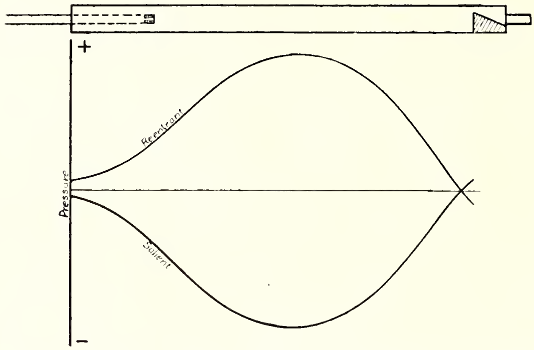

Fig. 1—Variation of pressure on manometer with distance the probe advanced into the tube.

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be expected from theory, the probe showed increased pressure at nodes and apparently zero pressure at anti-nodes, while in the region immediately about the lip of the pipe there was considerable indication of negative pressure difference for the re-entrant vent. Later observations about the lip of an organ pipe shows the pressure conditions in the region to be very unstable, any change of position of objects in the neighborhood or slight changes in the pressure of the source alters the whole pressure topography about the lip without sensibly altering the positions of the nodes in the pipe.

Experiments were made to adapt various displacement bubble gauges for measuring the pressure differences. The general form of such a gauge is shown in figure 2. Two large reservoirs were sealed on to a

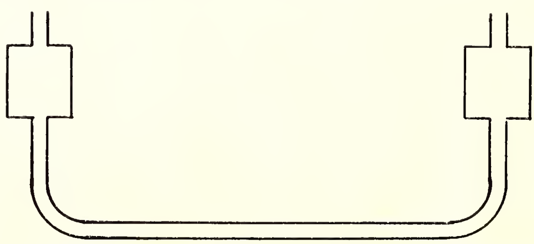

Fig. 2—Displacement bubble gauge for measuring pressure differences.

capillary and a bubble of air about 2.5 cm. long was trapped in the capillary as shown. The displacement of the bubble is proportional to the difference in pressure. The amount of displacement is determined by the amount of liquid exchanged in the reservoirs; i.e., proportional to the area of cross-section of the reservoirs and capillary. In one case this ratio was made 100 to 1, which meant that a change in level of one millimeter of water in the reservoir would produce 100 millimeters displacement of the bubble. Using gasoline for the fluid in the gauge, a displacement of one millimeter of the bubble corresponded to a difference in pressure of 0.46 dynes. The gauge is easily set up and is sufficiently sensitive to show the phenomenon when an organ pipe is blown just above a whisper. The one objection to this type of manometer is its sluggish response, it sometimes requiring as much as ten minutes to come to a full reading. It was at first thought this sluggishness could be partly attributed to the fact that the pressure differences at the orifice were not set up instantly, but later experiments with smoke particles indicated that the pressure differences were practically established with the first oscillation of the sound wave and the time lag of pressure differences at the orifice is really very short indeed. The sluggish behavior of the instrument, then, must be due to the properties of the liquid in the manometer.

Pressure gauges with a stretched membrane were also used successfully to record the pressure differences. The construction of such a gauge is shown in plan in figure 3. D was a sheet of "dental dam"

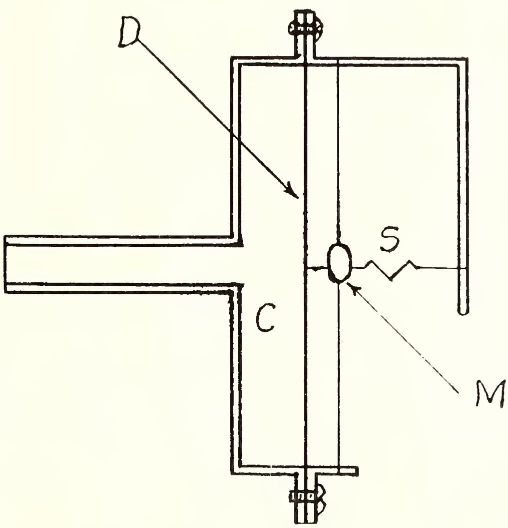

Fig. 3—Plan of pressure gauge with a stretched membrane.

stretched taut over a cavity C about one centimeter deep and five centimeters in diameter. M was a small mirror mounted on a pinion and had one edge attached to the center of the membrane with a silk thread so that it rotated with the inflation and deflation of the gauge. S is the hair spring from a watch to hold the silk thread taut. The deflections were read with a telescope and scale or by observing the spot of light reflected from the mirror. The gauge was very sensitive and quick in its response. An objection to the instrument was that the displaced image of the scale was not distinct. Later experiments with the manometric flame showed this indistinctness of the image to be due to an oscillatory pressure which is superimposed upon the steady pressure trapped by the probe. The steady pressure difference is due to a difference in conductivity in the two directions through the conical orifice. The superimposed oscillatory pressure is not observed on the liquid gauges due to the inertia of the liquids.

The first orifices used to study the phenomenon were made by punching holes in paper hoods cemented to the end of glass rods or by drawing glass tubes to pin-hole orifices. Most of the orifices used were made by drilling holes in small brass plugs with a number 60 drill. A conical orifice was readily made by broaching out this hole with a tapering reamer made by flattening the sides of a phonograph needle or a

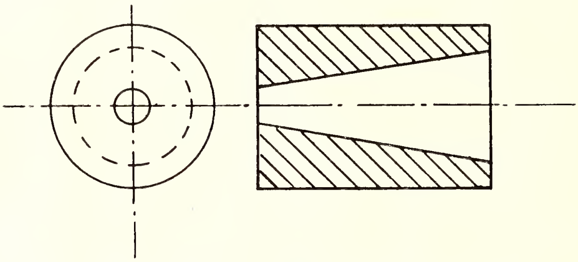

Fig. 4—Plan of the orifice in probing tube.

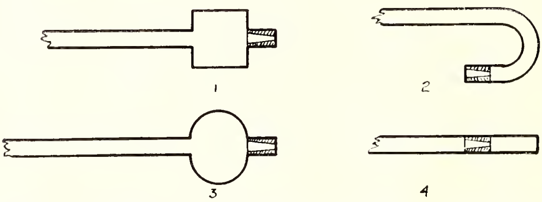

Fig. 5—Shapes of probing tubes examined to determine the influence of shape on the pressure trapped.

short length of small steel rod. Seemingly any hole of the approximate diameter of 0.2 to 0.4 mm. traps energy from standing waves in air; and the amount of energy trapped is but little affected by the character of the edge of the hole, the length of the hole up to about 8 mm. of length, or the angle of the conical orifice for angles less than about 20°. In fact the amount of energy trapped by an orifice that exhibits reversibility seems to depend only on the amount of energy possessed by the wave at the point. Increasing the angle of the orifice to about 30° makes the orifice behave as though it were cylindrical. The plan of an orifice is shown in figure 4. Experiments were performed to test the influence of the region immediately behind the orifice upon the response but no shape or dimension comparable to the orifice seemed to have any effect. A few of the shapes examined are shown in figure 5. A hood over the orifice as shown in figure 5 affected the emission of smoke particles from the orifice but didn't affect the pressure response.

For sources of sound, organ pipes and telephone receivers, or loud speaker units, were used. The organ pipe used most had a frequency of 384 cycles when blown at a pressure of 25 cm. of water. The radio loud speaker unit attached to a Kundt tube is the most convenient method for securing standing waves and the frequency may be varied over wide ranges if the tube is arranged for tuning. The loud speaker unit may be excited by a vacuum tube circuit or a high frequency generator.

Salient Vent. The orifice was placed in the end of the probing tube and advanced along the axis of the Kundt tube in the manner suggested in figure 1. With the end of the probing tube not containing the orifice attached to the manometer the pressure reading was below atmospheric as the orifice approached a nodal point in the Kundt tube. The pressure difference approached zero as the orifice was brought near to an anti-node, but normally did not come to zero reading at the anti-node. If smoke particles were introduced into the probing tube before it was attached to the manometer, the smoke column appeared to be driven back from the orifice about 3 cm. and come to rest. The displacement of the smoke column seemed to take place with the first cycle of the sound wave striking the orifice and no particles were seen to be drawn out into the Kundt tube through the orifice nor were any seen to be driven back into the manometer from the probing tube. The magnitude of the pressure differences and the behavior of the smoke particles was independent of the dimensions of the probing tube. If dust or smoke particles were introduced into the Kundt tube immediately in front of the orifice, they were violently disturbed and the wind seems to have its origin at the probe; i.e., there was a violent wind from the orifice into the Kundt tube. The wind issuing into the Kundt tube was stream-line for more than 10 cm. while the disturbance immediately behind the orifice was turbulent. The violent wind which issued from the vent explains the reduced pressure observed on the manometer. The disturbance both inside and outside the probing tube was greatest when the probe was at a nodal point in the Kundt tube. If the rubber tube connecting the manometer to the probe was disconnected the smoke particles issued slowly from the open end of the probe opposite that containing the orifice. No evidence of standing waves was observed in the probing tube for any frequency of blowing the Kundt tube or for any length or size of the probing tube. If standing waves were set up in the probing tube they were too feeble to disturb the lightest dust particles. When the probe was attached to a Koenig flame the usual serrated image was secured on the revolving mirror showing that pressure trapped by the orifice was not steady. Apparently a difference of pressure was established and super-imposed on this was a lesser oscillatory pressure difference. The same thing was suggested by the blurred image on the diaphragm gauge.

Re-entrant Vent. The salient orifice of the preceding paragraph was removed from the probing tube and reversed to form the re-entrant orifice. Reversing the orifice reversed most of the phenomena observed of the salient orifice. The re-entrant orifice gave increased pressure indications on the manometer where the salient orifice gave reduced pressure readings. If smoke particles were introduced into the probing tube before it was attached to the manometer, with the first start of the standing wave about 4 cm. of the smoke column was jerked violently out of the probe through the orifice into the Kundt tube, but only this initial puff was observed so long as the probe was attached to the manometer. When the probe was not attached to the manometer there appeared to be a steady stream of smoke particles issuing from the orifice into the Kundt tube so long as any smoke remained in the probing tube and the motion was stream line for about 10-15 cm. before the velocity was reduced and the motion became turbulent. While this jet of smoke particles was issuing from the vent a violent disturbance of the smoke particles in the probing tube was noticed just back of the orifice which was always turbulent. A pile of dust particles in the Kundt tube immediately in front of the orifice had a channel blown through it by the jet of air issuing from the vent. Closing the end of the probing tube opposite to that containing the orifice with the finger stopped the flow of smoke particles from the probe, but dust particles in the Kundt tube were still disturbed by a wind that had its origin at the vent. Attaching the probe to the Koenig flame gave the serrated image just as in the case of the salient orifice, and the displaced image on the diaphragm gauge was blurred.

Cylindrical Vent. Probes with cylindrical vents show always an increased pressure difference on the manometer at nodal points in the Kundt tube. They do not exhibit the phenomenon of reversibility. There was a faint wind from the orifice into the Kundt tube when the end not containing the orifice was closed with the finger or attached to the gauge, but smoke particles introduced into the probe were not drawn through the orifice into the Kundt tube by the pressure trapped. The displacement indicated by the diaphragm gauge was for increased pressure difference and the image was blurred. Probes without orifices of any kind responded, in so far as pressure was concerned, in the same manner as cylindrical vents. No wind was observed to be set up from the end of the probe for any condition of blowing the Kundt tube, but dust particles introduced into the probing tube show nodes and loops as in the larger Kundt tube.

In conclusion, the writer wishes to express his appreciation of the interest shown in the problem and the valuable suggestions given by Dr. A. L. Foley, of Indiana University, under whose direction this investigation was undertaken.