A Method of Exciting Vibrations in Plates, Membranes, etc., Based on the Bernoulli Principle

This content has been downloaded from IOPscience. Please scroll down to see the full text.

1921 Proc. Phys. Soc. London 34 104

(<http://iopscience.iop.org/1478-7814/34/1/323>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 129.93.16.3

This content was downloaded on 07/09/2015 at 11:01

Please note that [terms and conditions apply](#).

XV. *A Method of Exciting Vibrations in Plates, Membranes, etc., Based on the Bernoulli Principle.* By PROF. KERR GRANT, *University of Adelaide.*

RECEIVED JANUARY 1, 1922.

(COMMUNICATED BY SIR W. H. BRAGG, F.R.S.)

ABSTRACT.

It is known that a plate placed close to a flanged orifice from which a stream of air or liquid is issuing is attracted towards the orifice. If the plate be mounted as a diaphragm it can be excited to strong vibration by a suitable blast, and a loud sound is produced with high efficiency.

THE apparent attraction which is exerted between two closely juxtaposed surfaces when a stream of air flows between them is well known. Witness, for example, the experiment of lifting a light object, such as a matchbox, by blowing through a pipe, provided with a flange placed in loose contact with the surface of the object.

It occurred to the writer in 1918 that this effect might be applied to maintain vibrations in a plate or diaphragm, since the vibratory motion of the plate or

FIG. 1.

diaphragm could operate as a valve to stop or permit the flow of air, and thus give the variations of pressure necessary to maintain the vibrations. (For brevity any sound-producing appliance based on this principle will be termed a hooter.)

To test this idea a piece of parchment was mounted on a circular wooden ring about 5 in. in diameter and a three-eighths inch brass pipe provided with a flange of brass-plate about 2 in. in diameter, mounted in such a way that the surface of the flange could be adjusted parallel with and in the closest proximity to the parchment diaphragm (Fig. 1). When the pipe was supplied with air from a compressor the parchment was excited to vigorous vibration with the production of a very intense sound, the pitch of which varied with the pressure of the air supplied and the degree of approximation of the flange to the parchment. In general overtones were produced, but by operating at lower pressures and by careful adjustment the diaphragm could be made to vibrate in its fundamental mode.

A pressure of a few pounds to the square inch was found to be sufficient to maintain vibration. In fact, a powerful sound can be obtained by using this appliance as a trumpet.

When a plate of thin sheet-metal was substituted for the parchment somewhat higher pressures were found to be necessary for excitation, the pressure requisite depending, as might be expected, on the stiffness of the plate.

With diaphragms of sheet-metal which are so thick as to function as plates rather than as membranes and yet not thick enough to permit of being accurately machined there is some difficulty in putting on the diaphragm in such a way as to secure a good approximation to a plane. A fairly satisfactory method of doing this is to leave a slight rim on the inner periphery of the supporting ring and then screw down the holding-down ring while the diaphragm is kept hot by a hot metal plate laid upon it. The plate then approximates very nearly to a true plane except for a short distance inwards from its periphery. If it is not expanded during the process of screwing down, the surface takes a hemispherical form. Fig. 2 illustrates the construction of a sheet-metal hooter on the above lines.

A metal hooter was found to operate successfully when the water in the supply main, at a pressure of about 80 lbs. per square inch, was substituted for air as the driving agent. The hooter operated in this case whether it were held in the air or immersed in water.

While the author was engaged during the summer of 1919 at the Research Laboratory of the General Electric Co., Schenectady, N.Y., several hooters were, by the courtesy of the Director, constructed, the largest having a plate of sheet-iron about 1 ft. in diameter and one-eighth inch in thickness. This operated very well on a compressed air supply at a pressure of 80 lbs. per square inch, and could probably be heard under favourable conditions at a distance of one mile. There seems no reason why hooters of very much larger dimensions should not function equally well or better, in which case a sound production of intensity comparable with those of the most powerful sirens or whistles might be expected.

A rough comparison as regards efficiency of sound-production was made between this large hooter and the standard type of compressed-air whistle used on the Schenectady Electric Cars. The sound of this whistle on full air-consumption was appreciably louder than that of the hooter, but since it required for this a 1-inch supply-pipe as against the three-eighths inch on the hooter, it would appear that the latter is very much more efficient.

The efficiency of the hooter as a sound-producer depends in a high degree upon the details of its construction. One condition for good operation is that the

mass of the flanged pipe, together with that of the frame in which it is rigidly supported, should be large compared to that of the vibrating plate or membrane. If this is not so the flange will also vibrate and not only waste energy but interfere with the vibration of the diaphragm.

The amount of air used depends also very largely on the closeness with which the flange can be approximated to the plate—actual contact does not prevent operation—and on the nearness with which exact parallelism of the two surfaces is attained.

The more massive the vibrating plate the better is the adjustment necessary in these respects for satisfactory operation, and for large hooters it is likely that both exact geometrical form and polishing of the juxtaposed surfaces would be desirable.

It is an advantage to vary the surface of the flange from a true plane to a form slightly convex towards the plate and to expand the end of the pipe, as shown in Fig. 3*a*. Probably the space between vibrating plate and flange should vary in sectional area according to the principle of the Venturi-nozzle. If, on the other, the departure from a true plane is in the direction of concavity towards plate or diaphragm (Fig. 3*b*), the operation of the hooter is adversely affected even to the point of failure.

No absolute measurements of the efficiency of the hooter as a sound-producer have yet been made. The comparison with the whistle alluded to above, and the very striking reduction in the quantity of water issuing between flange and plate, which takes place as soon as the latter commences to vibrate, would indicate that this is of a fairly high order.

No attempt at exact mathematical treatment of the energy and force relations involved in the action of this hooter will be made in this paper. Qualitatively the theory of operation is no doubt somewhat as follows: Let the plate be initially at rest with no fluid flowing. The static pressure of the fluid in the supply pipe produces a displacement of the plate or membrane calling into play an opposing force due to elastic resistance or tension, as it may be. Fluid now flows between plate and flange reducing the pressure and permitting return of the plate or membrane up to and beyond its equilibrium position. The flow is thus nearly or completely stopped with consequent rise of pressure up to and beyond the static pressure in the supply system; the plate is then driven back by this pressure and the cycle repeated.

During the first stage work is done by the plate upon the fluid in the supply pipe; during the second, positive work is done by the fluid upon the plate. Since the average pressure is clearly higher during the second stage, the total work done by the fluid on the plate in a cycle is positive.

The production of the sound is due no doubt mainly to the vibrations of the plate or membrane itself, but also in some degree upon the siren-effect of the intermittent outflow of air. This is put in evidence by the fact that the sound is emitted most strongly, at least for some hooters that have been tried, on the side of the nozzle. It might, therefore, be an improvement to modify the construction in such a way as to cause the escaping air to issue in front instead of, as at present, behind the plate.

The frequency of the note depends, of course, mainly on the natural period of the plate or membrane; but this is probably modified in the case of a membrane very considerably, in the first place, by the pressure of the driving fluid,

which will, of course, cause variations of tension in the membrane, and, secondly, by the very heavy damping due to the air-cushion between flange and plate. The presence of this air-cushion probably accounts for the fact that a hooter will vibrate freely even when the flange is actually in contact with the plate or membrane before vibration commences. The damping is sufficient for all hooters yet experimented with to cause instant cessation of the sound when the supply is cut off. An easy method of varying the frequency of a given plate is to load it centrally with different masses tightly screwed or soldered on.

It is probable that frequencies well above the limit of audibility could be obtained, though no hooter has yet been made to test this point. An application to the purposes of submarine signalling suggests itself. For this steel plates comparable with those used in the Fessenden oscillator would be necessary. An auxiliary high pressure water pump with a suitable rapid action control valve would be the only accessories required. The radiation of high frequency waves from an area large compared to the wave length is, as is well known, highly directive in character. In fact, the addition of a horn to the large hooter described above, the frequency of which was certainly below 1,000 d.v. per sec., made very little increase in the amount of sound radiated along the axis of the plate.

I have to thank Mr. A. L. Rogers, mechanic to the Physics Department, for giving the benefit of his skill and experience to the construction of the hooters made and tested here.

DISCUSSION.

Dr. F. L. HOPWOOD remarked that the ingenious device which had been described afforded an instance of the solution of a new problem by the inversion of an old one. It might be advantageous to provide the instrument with a resonator.