# ENGINEERING REPORT

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DIVISION: Research

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SUBJECT:

REPORTED TO Earle L. Ke

TITLE: Relations between Reed and Pipe Resonance Frequencies and the Playing Frequency of a Reed-Pipe Combination

## A B S T R A C T

The present discussion of the frequency relations required for regeneration is restricted to an abstraction which applies to woodwinds with conventional (inward beating) reed systems, and will assume only one of the normal modes of the pipe to play a part in the action.

Summary.

(I) The natural frequency of the isolated reed system must be above the playing frequency if regeneration is to occur.

(II) The resonant frequency of the pipe with the reed replaced by a closed end is higher than the playing frequency.

The present discussion of the frequency relations required for regeneration will be restricted to an abstraction which applies to woodwinds with conventional (inward beating) reed systems, and will assume only one of the normal modes of the pipe to play a part in the action. Nonlinear coupling effects greatly complicate the picture, but do not invalidate the results to be obtained here, so that they will be ignored.

Figure I shows a resonant cavity fitted with a frictionless spring-mounted piston at its bottom end. Let us review the fact that if this piston is driven by a sinusoidal force at a frequency <u>below</u> its own frequency of free vibration (when isolated from the cavity), the piston will move back and forth in such a manner that its displacement is approximately in phase with the driving force. On the other hand, a piston driven above its natural frequency oscillates in such a manner that its displacement is approximately 180° out of phase with the driving force. If we were to somehow set up one or another of the normal modes of vibration of the air in the cavity, the resulting pressure fluctuations on the surface of the piston would drive it back and forth. As pointed out above, the piston would find itself moving outward when the pressure on its inner face is a maximum and inward at the minima of absolute pressure only if the normal mode frequency is lower than the resonant frequency of the spring and piston combination. On the other hand, a normal mode frequency above the piston's own natural frequency would have the piston moving inward at the time of the pressure peaks, etc., etc.

We are now in a position to inquire as to the proper conditions from such a system to sustain its oscillation when supplied with compressed air. Figure 2 shows a similar system provided with a small hole drilled through the sleeve which carries the piston, a hole that is connected with a supply of compressed air. If we arrange to have air admitted into the cavity at the time of a pressure maximum, it turns out that the system can replenish the energy it loses to friction and radiation. This can be seen best with the aid of a diagram like that shown in Figure 3. A piston-controlled valve such as the one we have been discussing is clearly one which sustains oscillation when the piston moves in phase with the pressure variations, and is therefore a system which regenerates only if the isolated piston's natural frequency is higher than that of the sound that is being produced. For emphasis this conclusion (which obviously applies to reed musical instruments) is restated:

> The frequency generated by a reed-pipe combination will always lie below the natural frequency of the isolated reed.

Note: The frequency of an isolated reed depends upon both lip pressure and blowing pressure, and is not the plucked frequency of an isolated reed -- this is because of the aero-elastic effects arising in the air currents over a blown reed. There are a number of subtleties attending this comment which would require an explanation too lengthy for the present report.

Let us now inquire as to the effect of mounting a piston and spring in the bottom of a cavity. Under the conditions of regeneration discussed above, where the piston is being "driven" below resonance by the cavity pressure variations, the piston "gives" a little under the applied pressure and so forms a soft spot in the cavity, thus lowering the natural frequency of the piston and cavity combination below that of the cavity with a blocked piston. In electrical terms, the impedance presented by the piston under these conditions is capacitative, or spring-like, and so acts as an increased volume at the closed end. This second conclusion is of great practical importance, and will therefore be set off to display it more clearly.

> The playing frequency of a reed-pipe combination is determined by the natural frequency of the pipe as perturbed by the elastic impedance of the reed, so that the system plays at a frequency lower than that of a pipe provided with a rigid closure at the reed end.

The simplest glance at the impedance equation of a resonant system shows that raising the natural frequency increases the magnitude of the apparent stiffiness when it is measured below the resonant frequency. This leads to the consequence that raising the frequency of the isolated reed gives rise to a sharpening of the pitch of the reed-pipe system, but only asymptotically toward the natural frequency of the pipe alone. From this we see that the properties (such as uniformity of scale, etc.) of the bore of a woodwind, and of its holes may best be studied in the laboratory by asking the player to play as sharp as possible, so as to give the pipe the most possible control over the frequency, and to minimize the extent to which the player's own ear and habits can affect his results. The proper tuning desired from an instrument can then be determined with the help of an auxiliary set of experiments which show how much flatter than the highest possible pitch a player prefers to play in order to get a good tone and comfortable embouchure.

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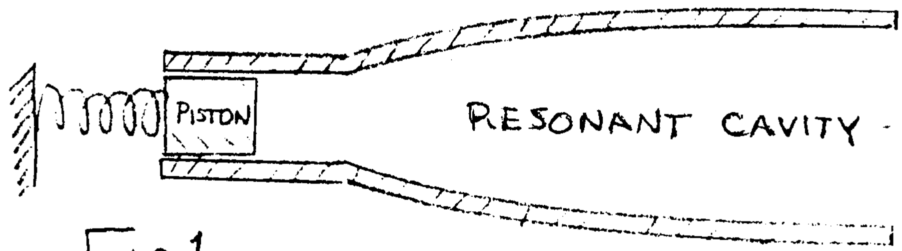


FIG 1

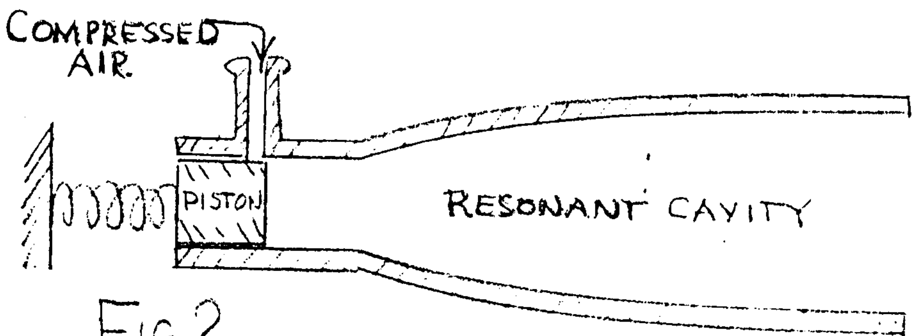


FIG 2

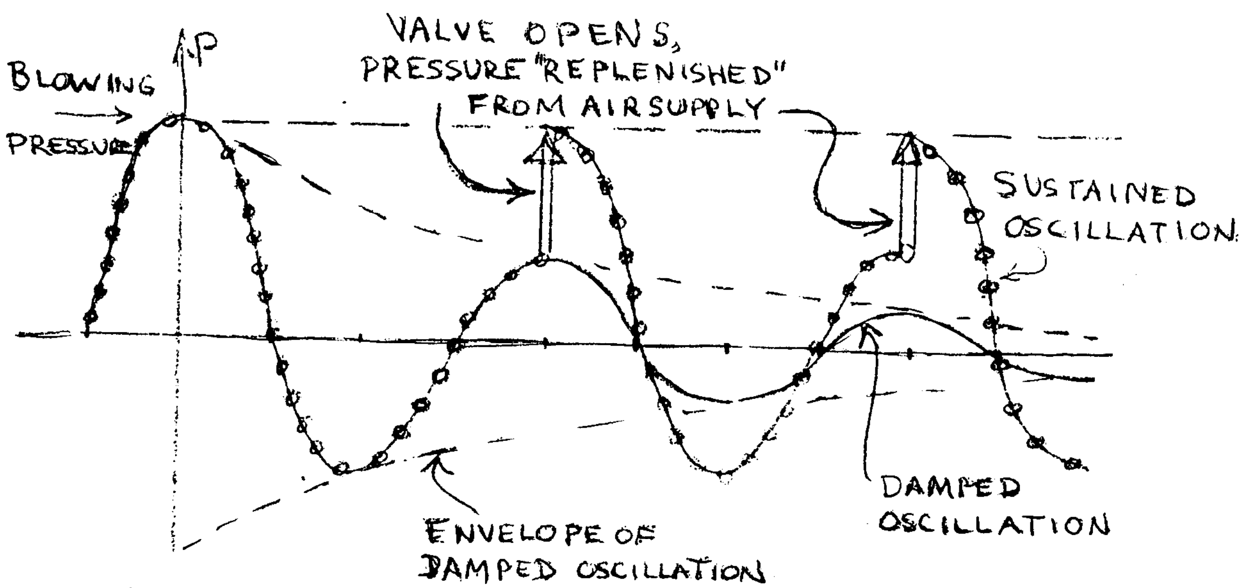


FIG 3.

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