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AN EXPERIMENTAL INVESTIGATION OF NON LINEAR ACOUSTIC DRIVING MECHANISMS IN COMBUSTION CHAMBERS

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INTRODUCTION

Self-sustaining acoustic resonances in combustion chambers are known, in certain cases, to cause significant fatigue with consequent loss of production efficiency and shortened plant life. It is generally accepted that the intense resonances produced can be caused by adverse acoustic coupling between the combustion process and some resonant mode of the furnace chamber or flue. The driving mechanisms essential for initiating and maintaining the acoustic feedback loop, however, are not yet fully understood.

Adams[1], developed previous work by Putnam[2], Baade[3], Cummings[4] and Lawn[5] and proposes a non-linear model of the flame as a parametric amplifier rather than a linear device. This theory implies that the passage through the flame of an acoustic wave consisting of the combination of two or more frequencies can lead to both temperature and pressure perturbations over an extended range of modulation frequencies and under certain conditions of operation, selective acoustic reinforcement may occur. An empiric study of one industrial furnace found that such difference frequencies did exist and introduced a strong energy component into the system at which strong vibration of the plant was observed.

In this paper, a laboratory combustion chamber has been used to model the process involved and the results of a preliminary investigation of the phenomenon are presented.

EXPERIMENTAL PROCEDURE

A laminar, premixed methane-air flame was so situated that it could be exited by a loudspeaker and induce resonant oscillations in a combustion can lowered down over it, see figure 1.

Two separate signal generators were used to provide sinusoidal inputs to the loudspeaker, with the resultant acoustic signal in the combustion can being detected by a 1/2" capacitor microphone situated in the chamber as shown in figure 1.

A single port burner of 2mm diameter held a small conical premixed flame which was stabilized by six small natural gas pilot flames arranged in annular fashion around the burner port. Two alternative copper supply tubes were used for the burner, one of length 0.5 metres was used with a combustion can of resonant frequency 207 Hz and the other, 0.35 metres in length, was used with a combustion can of resonant frequency 250 Hz .

Initial investigations concerned the response of the flame when a single sinusoidal signal fed into the loudspeaker, was swept through a range of frequencies. It was found that for each supply tube, as the frequency increased, the flame front disturbance was seen to reach a maximum at a frequency corresponding to a resonance of the supply system and then gradually decrease. Such maxima were observed at the first three harmonics of the resonant frequency. With the 0.5 metre supply tube, maximum disturbances in the flame front were encountered at 200 Hz, 489 Hz and 800 Hz, and with the 0.35 metre tube at 250 Hz, 628 Hz and 1030 Hz.

The corresponding combustion can was now placed over the 0.5 metre burner tube and the single frequency input swept from 200 Hz to 220 Hz for a primary air/gas ratio of 10 and a total flowrate of 0.66 litres/min. The procedure was repeated for the shorter can and supply tube, for a primary air/gas ratio of 7.5 and a total flowrate of 0.68 litres/min and the input frequency swept from 240 Hz to 260 Hz.

Graphs of gain versus exitation frequency are plotted, where gain is defined as the ratio of the amplitudes of the peak acoustic pressure signal (millivolts) observed with the flame present, to the peak observed in the absence of the flame, see the lower curves in figures 2 and 3.

In a second experiment, two signals of approximately equal amplitude were fed to the loudspeaker and the difference frequency made equal to the resonant frequency of the combustion can used. To avoid either signal directly inducing resonance of the system, the fundamental frequencies of can and burner were avoided. However, to maximise the effect investigated and to ensure a large movement of the flame front, the second harmonic of the given supply system was used as one of the input signals in each case; 489 Hz for the longer combustion can and 628 Hz for the shorter. It can be seen, from figures 2 and 3, that when the difference frequency corresponds to the resonant frequency of the combustion can, a maximum gain is obtained. In each case, the removal of either signal caused the resonance to disappear.

Measurements of the gain for each of the two systems was then examined for variation with primary air/gas ratio (figures 4 and 5) with the single frequency input and the difference frequency being maintained at the resonant frequency of the relevant combustion can. The amplitude of the observed resonance peak was recorded as the gas flow rate was varied from 0.06 litres/min to 0.14 litres/min with the air flow rate remaining constant at 0.6 litres/min.

Readings were also taken to see how flame response varied with amplitude of input signal for various primary air/gas ratios. From figure 6 it can be seen that the responses obtained conform with results obtained elsewhere.

RESULTS

It can be clearly seen from figures 2 and 3, that for both configurations of supply tube and combustion can, the peak value of the gain occurs at the resonant frequency of the combustion chamber used. In the case of the 0.35 metre supply tube, a strong gain was recorded at approximately 244 Hz and 246 Hz, the former relating to the resonances of the supply system and the latter corresponding to the resonant frequency of the combustion chamber. In both cases gain falls as we move away from the resonant frequencies of the chambers, and also in each case, input to the system of the difference frequency produces a greater value of gain than the the single frequency input.

Figures 4 and 5 show the variation of gain with primary air/gas ratio. The maximum gain obtained, in all cases, corresponds to a primary air/gas ratio of around 7.5, which is in close agreement with previous work [6]. For each of the two systems, the greatest gain is achieved with the difference frequency input. An explanation of the difference in the magnitude of the gain recorded in figures 2 and 3 can now be seen. The results for the longer can were obtained with a primary air/gas ratio of 10, which, from figure 4, does not correspond to a situation of maximum gain for the system. The shorter can however, corresponds to a primary air/gas ratio of 7.5,giving higher values of gain.

REFERENCES

[1] Adams.D — The Non-Linear Acoustic Properties of Flames. Proc. I.O.A. Vol 6 Part 1 (1984)

[2] Putnam.A, Brown.D — Combustion Technology - Some Modern Developement. Ch.V. pp 127-162, Academic Press 1984

[3] Baade.P.K — Design Criteria and Models for Preventing Combustion Oscillations. Trans. ASHRAE 84 (1) (1978) 449-465

[4] Cummings.A — Combustion Noise BSE, 1983, Vol. 41

[5] Lawn.C.J — Criteria for Acoustic Pressure Oscillations to be Driven by a Diffusion Flame CEGB (1982) RD/M/1214 N 81

[6] Roberts.J.P — Amplification of an Acoustic Signal by a Laminar, Pre-Mixed, Gaseous Flame Combustion and Flame 33, 79-83 (1978)

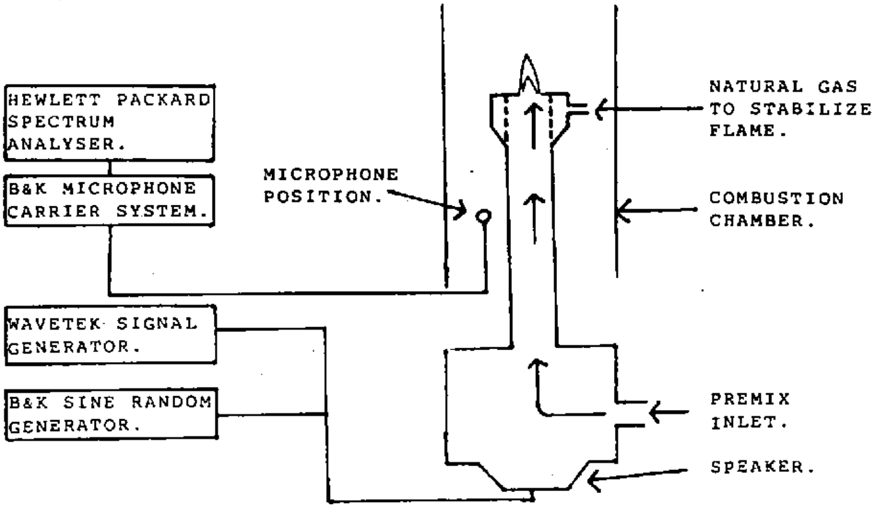

FIGURE 1 : EXPERIMENTAL ARRANGEMENT

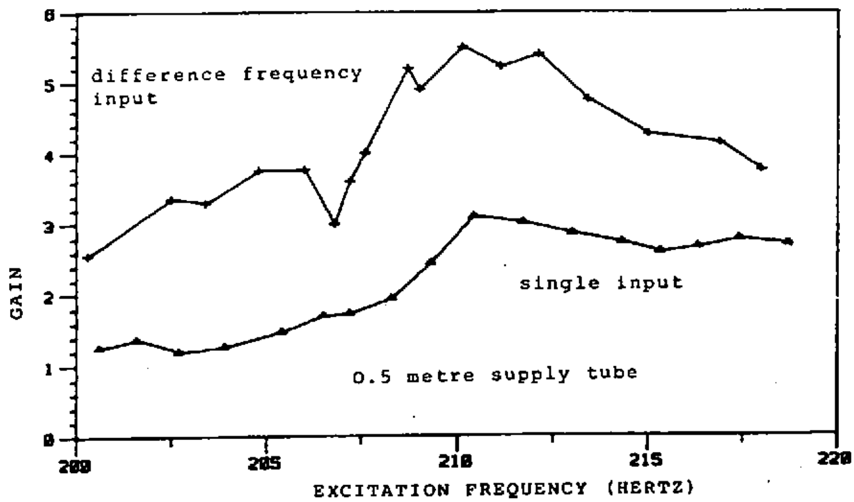

FIGURE 2 : GAIN VERSUS EXCITATION FREQUENCY

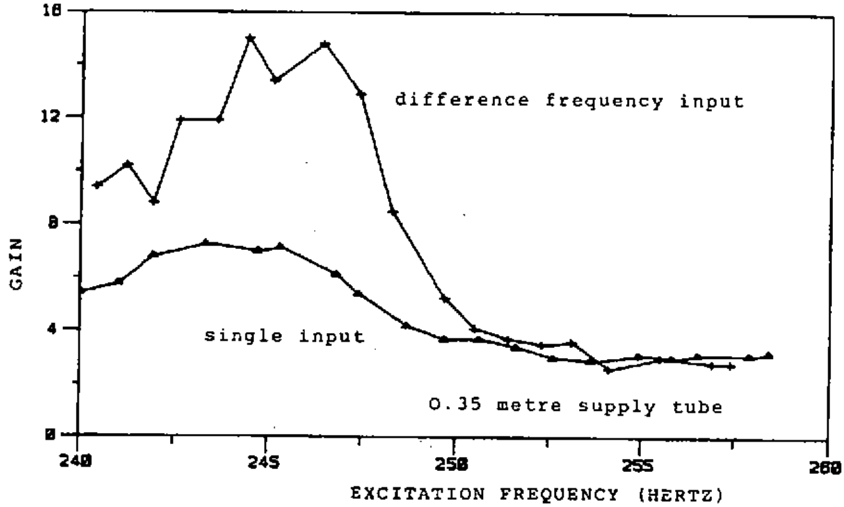

FIGURE 3 : GAIN VERSUS EXCITATION FREQUENCY

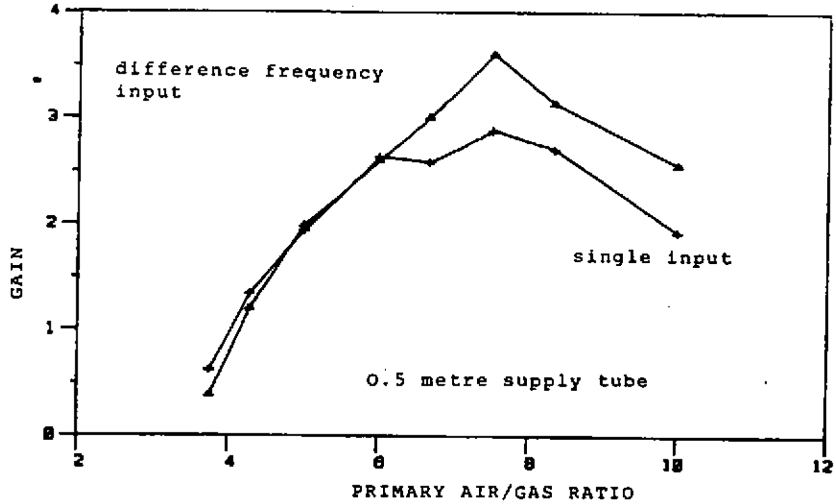

FIGURE 4 : GAIN VERSUS PRIMARY AIR/GAS RATIO

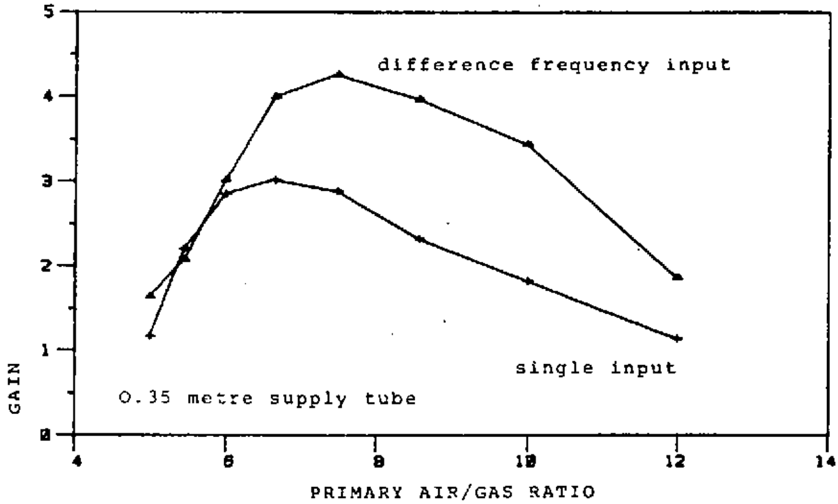

FIGURE 5 : GAIN VERSUS PRIMARY AIR/GAS RATIO

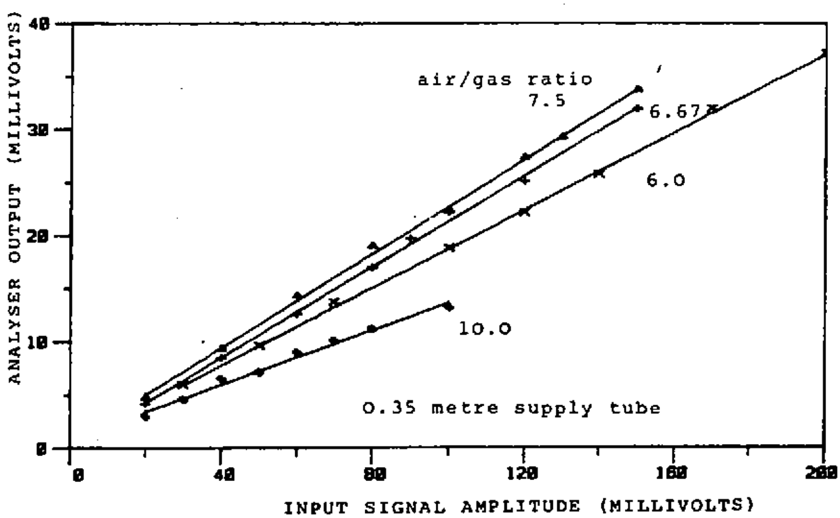

FIGURE 6 : FLAME RESPONSE TO VARIATION OF INPUT SIGNAL AMPLITUDE FOR VARIOUS PRIMARY AIR/GAS RATIOS