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ON THE MEASUREMENT OF CERTAIN ACOUSTIC PARAMETERS OF A COMBUSTION SYSTEM USING A PULSATING ARC SOUND PROBE

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Introduction

In a combustion system adverse acoustic coupling between the flame and resonant modes of the combustion chamber can produce flame instabilities leading to acoustic self-sustaining oscillations. This may cause anything from troublesome noise to resonances so intense that they can lead to mechanical failure. [1]

Although the feedback phenomena causing the instabilities is reasonably well understood it is still difficult to predict with certainty that any particular burner and chamber configuration will not be prone to such oscillations.

This paper reports a stage in the development of a sound probe technique for the controlled excitation of the resonant modes of a combustion system under working conditions, so that the effects of coupling on the combustion process may be obtained directly. The technique involves the use of a pulsating arc discharge as a sound input and a microphone probe for measuring the resulting acoustic pressure.

A simple laboratory model combustion system was constructed and used to test the techniques.

Experimental Arrangement

The model combustion chamberconsisted of a vertical open-ended cylindrical steel tube 800 mm long and diameter 200 mm, with a Meker burner mounted in such a way that it could be positioned along the lower half of the tube's axis (Fig. 1). The burner assembly was made so that when fuelled with methane/air in the ratio 1:10 it would amplify an incident acoustic signal. With the burner placed towards the centre of the tube and fuelled with this mixture ratio self-sustaining oscillations at the fundamental frequency would build up in the system, producing pressure levels in excess of 140 dB inside the chamber.

The arc source was made from two carbon electrodes placed in the luminous region of the laminar flame and powered by 300 V dc and a modulating 50 V ac signal in the frequency range 100 Hz to 10 kHz. Current through the arc and the applied voltage were continuously monitored.

The aim of the experiment was to determine those system parameters which could be taken from measurements made before the onset of self-sustaining oscillations, and from which the conditions for the build up of the resonance could be predicted. A simple electrical analogue of the system is used to achieve this.

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Equivalent Electrical Analogue

It has been shown [2][3] that a pulsating arc can act as a high impedance simple sound source of strength given by

$$Sv = \frac{(\gamma-1)W}{\gamma P_o} \qquad \text{................(1)}$$

The amplifying property of the flame is assumed to be adequately described by only two transfer terms, T_{12} and T_{22}, relating output volume velocity to a) input pressure and b) input volume velocity respectively. (Pressure oscillations of a small source are generally of little significance). Making the further assumption that the internal admittances of the arc source and the flame sources may be neglected we arrive at the simple electrical analogue circuit shown in Fig. 2. Voltage is the analogue of pressure and current the analogue of volume velocity; Y is the effective acoustic admittance of the chamber.

From the circuit it is seen that with flame ampliciation

$$V_f = \frac{I_o + I_v + I_p}{Y} = V_f\left(T_{22} + \frac{T_{12}}{Y}\right) + \frac{I_o}{Y}.$$

With a mixture ratio of 1:7 the flame no longer amplifies and then $T_{12} = T_{22} = 0$, under this condition

$$V_o = \frac{I_o}{Y} \qquad \text{................(2)}$$

so that

$$1 - \frac{V_o}{V_f} = T_{22} + \frac{T_{12}}{Y} \qquad \text{................(3)}$$

The onset of self-sustaining oscillation is taken to be when the loop gain of the system exceeds unity in which case the ratio V_o/V_f will approach zero. (In practice V_f reaches a high steady value limited by absorption and non-linearities in the system).

From equation (3) it is seen that this condition is met at an input admittance of the chamber Y_s related to the transfer terms by

$$Y_s = \frac{T_{12}}{1 - T_{22}} \qquad \text{................(4)}$$

Experimental Results

In order to test this reasoning, measurements of the admittance of the chamber along its axis were obtained using the arc as a known constant volume velocity source and recording the corresponding pressure with the flame in its non-amplifying state (equation 2). The results are plotted in Fig. 3.

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Flame amplification (V_f/V_o) was then measured from the change in S.P.L. when the mixture ratio was altered to give the amplifying conditions. These measurements were taken with the burner in the lower part of the chamber away from the position where self-sustaining oscillations commenced.

A plot of $1 - V_o/V_f$ against the corresponding input impedance ($1/Y$) is shown in Fig. 4. (Equation (2)). From this plot the two transfer terms are given as

$$T_{12} = 0.32 \times 10^{-4}\ m^3\ s^{-1}\ Pa^{-1} \text{ and } T_{22} = -0.22.$$

The substitution of these values into equations (4) results in the prediction that the onset of self-sustaining oscillation will occur when the burner is placed at a position in the chamber where the admittance is $0.26 \times 10^{-4}\ m^3\ s^{-1}\ Pa^{-1}$. Fig. 3 shows that this is 250 mm from the lower opening which is, to within a few mm, just the position found in practice.

Discussion

Considering the simplicity of the model it is somewhat surprising that the prediction should agree so well with observation. It should be pointed out however that the numerical values quoted are based on the validity of equation (1) which has not been tested independently under the conditions described. Values for the transfer terms etc. must therefore remain only tentative at this stage. Predictions arising from the measurements made in the system would appear on the other hand to be entirely self-consistent. Work is continuing to develop the technique for more complicated systems.

References

[1] Ridal B, J. Inst. Fuel (May 1971) 241-247.
[2] Kidin N et al. Acoustics Letters 12:212 (1980).
[3] Medvedev N et al. Combustion and Flame 235 (1982).

Symbols

Sv	–	Source strength (surface area x velocity). $m^3\ s^{-1}$
γ	–	Specific heat ratio.
W	–	Input ac power. W
P_o	–	Ambient pressure. Pa
V_f	–	Equivalent pressure – flame amplifying. Pa
V_o	–	Equivalent pressure – flame not amplifying. Pa
I_o	–	Equivalent arc volume velocity. $m^3\ s^{-1}$
I_p	–	Equivalent flame volume velocity due to pressure input. $m^3\ s^{-1}$
I_v	–	Equivalent flame volume velocity due to velocity input. $m^3\ s^{-1}$
T_{12}	–	Transfer admittance. $m^3\ s^{-1}\ Pa^{-1}$
T_{22}	–	Transfer velocity ratio.
Y	–	Chamber admittance. $m^3\ s^{-1}\ Pa^{-1}$

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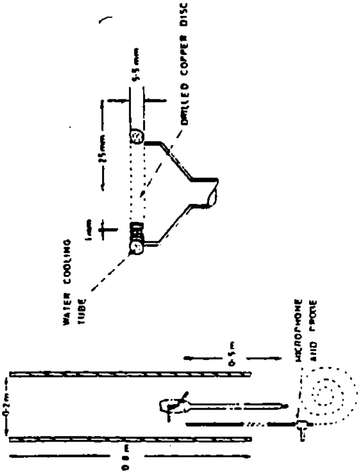

FIG. 1 Burner and chamber

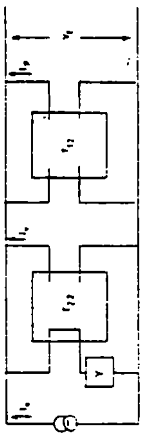

FIG. 2 Electrical analogue

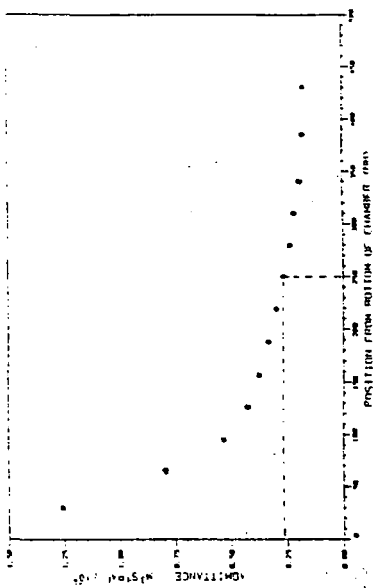

FIG. 3 Chamber admittance at resonance frequency

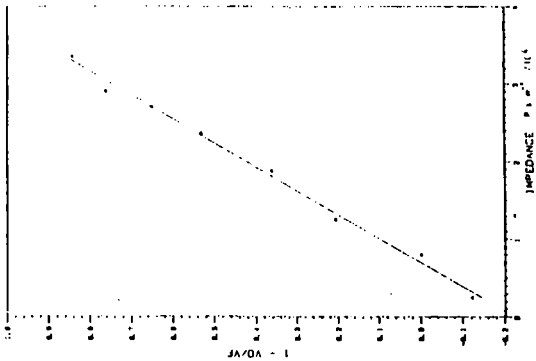

FIG. 4 Fractional Gain vs Impedance