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The Prediction and Measurement of Acoustic Impedance in Fuel Burners

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INTRODUCTION

Combustion oscillations do not occur with great frequency in fuel fired equipment; when they do occur, however, they are often severe enough to cause considerable noise or vibration.

Attempts are therefore being made to obtain a quantitative understanding of combustion oscillations with the ultimate goals of predicting resonance in practical systems, and acquiring better insight into curative measures for oscillations. Initially, predictions of unstable regions of operation are being attempted for simple systems with premixed laminar flames, using a one-dimensional, linearized theory.

In making these predictions, it is necessary to know gas properties on either side of the flame fronts, the acoustic impedance of the burner, the transfer function of the flame (which relates heat release fluctuations to velocity fluctuations in the burner ports) and the acoustic impedance of the combustion chamber.

These last three quantities are being studied separately; considerable effort is involved in obtaining reliable values of each for a particular system. The combustion chamber presents particular difficulty because the gradients of gas properties which are present cause the wave equation to acquire a further six terms, making analytical solutions for the impedance impractical; numerical methods of solution have to be used.

This paper is confined to a description of the prediction and measurement of the acoustic impedance of gas burners.

PREDICTIONS OF IMPEDANCE

The acoustic impedance (defined as acoustic pressure divided by acoustic volume velocity) can readily be calculated for many burner systems in the linear region, using low-frequency ('lumped-constant') or high-frequency (transmission-line) electrical analogues. In the low-frequency (LF) analogues, the system is divided into passive circuit elements, namely acoustic masses, compliances and dissipative elements corresponding to the electrical elements of inductance, capacitance and resistance. A constriction usually behaves as an inductance, a cavity as a capacitance and a dissipative element (viscous loss, radiation loss, etc.) as a resistance.

In the high-frequency (HF) analogues, the requirement, necessary for the low-frequency analogues to be valid, of acoustic wavelength much greater than dimensions of circuit elements no longer applies. Now the acoustical propagation along a pipe must be regarded as analagous to an electrical transmission line; usually a burner system would comprise a combination of transmission lines and lumped-constant elements.

IMPEDANCE OF TWO GAS BURNERS

Figure 1 is a sketch of a tunnel burner, showing the component circuit elements. The LF electrical analogue of this acoustical circuit is shown in Fig. 2. The HF analogue for this burner may be conceived by considering the mixture tubes as transmission lines, using an approximate expression for the impedance at the inner ends of the mixture tubes.

Figure 3 shows a sketch of a 'standing-wave' burner. This is a simple gas burner which is being used in studies of combustion oscillations; to predict its oscillations, it is necessary to know its acoustic impedance. Figure 4 shows the HF electrical analogue of this burner. L_r and R_r are the radiation inductance and resistance at the upstream end of the mixture supply tubes. In this case, it is unnecessary to create an LF analogue since the HF approximation is also valid at low frequencies. This is because all the relevant parts of the system have been included in the HF analogue, whereas this was not the case with the tunnel burner. (To do this would have been exceedingly difficult and certainly not worth the effort involved).

MEASUREMENT OF IMPEDANCE

The acoustic impedance of gas burners is easily measured using a standing-wave tube. The burner is mounted on the end of the tube and the real and imaginary parts of the impedance can be calculated from measurements of four quantities, namely the frequency, the distance from the burner to the first pressure minimum, and the pressure amplitude at a maximum and at the first minimum. Some care is necessary in the measurements, to produce accurate results.

COMPARISON BETWEEN THEORY AND EXPERIMENT

For the tunnel burner, the predicted resistance and reactance follow the same general pattern as the measured values (see Figs. 5 and 6), although the quantitative agreement is not very good in some frequency regions. This is presumably caused by inadequacies in the predictions. The peak in the resistance at about 190 Hz appears in the LF approximation, and the higher-frequency peaks are predicted by the HF approximation. It appears that dissipation is present which is not accounted for in the theory. The LF approximation for the reactance shows a resonance at about 10.5 Hz. This is not, of course, accounted for by the HF approximation, which predicts a reactance which is always positive with decreasing frequency.

The predicted resistance and reactance for the 'standing-wave' burner are in good agreement with the measured values (see Figs. 7 and 8).

CONCLUSIONS

It has been shown possible to make reasonably accurate predictions of the impedance of two gas burners, one experimental and one practical, using electrical analogues. The principal difference between the acoustical and electrical circuits is that electrical resistances are not frequency-dependent, whereas most acoustical resistances are. This would present difficulties with electrical modelling of acoustical systems.

Measurements of the impedance of gas burners with air and gas in the relevant parts of the system would probably be preferable to theoretical predictions, because of the possible failings in the theoretical models and the greater time involved in calculations.

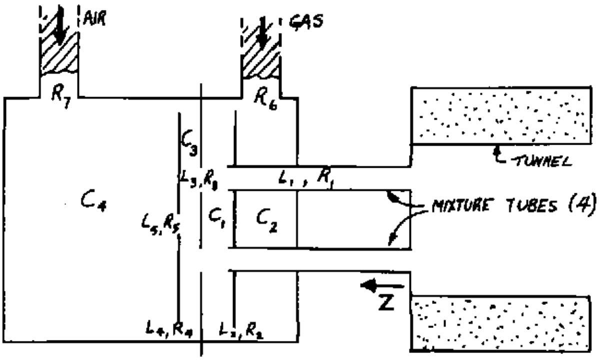

Fig. 1. Sketch of Tunnel Burner

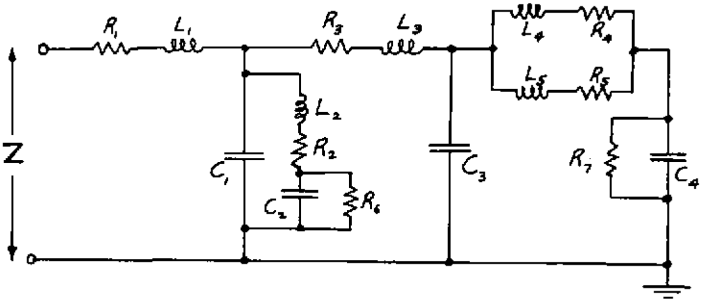

Fig. 2. Low-Frequency Analogue of Tunnel Burner

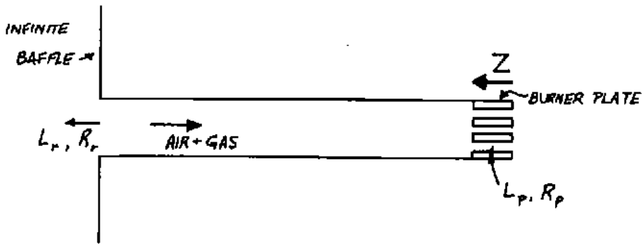

Fig. 3. 'Standing-wave' Burner

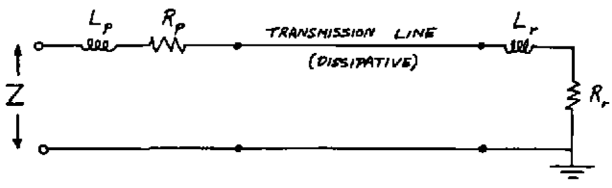

Fig. 4. High-Frequency Analogue of 'Standing-wave' Burner

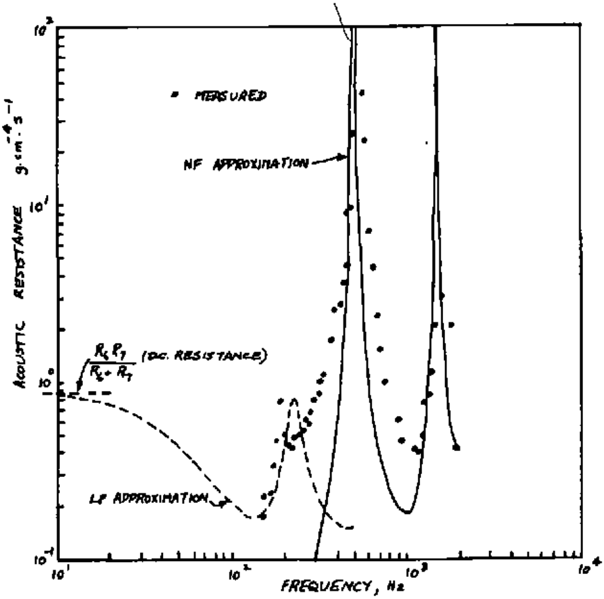

Fig. 5. Resistance of Tunnel Burner

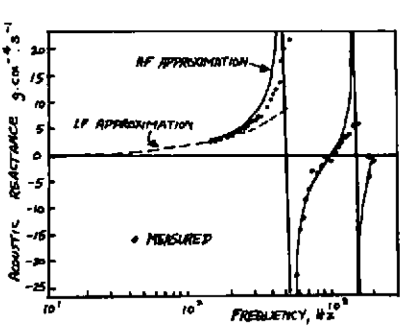

Fig. 6. Reactance of Tunnel Burner

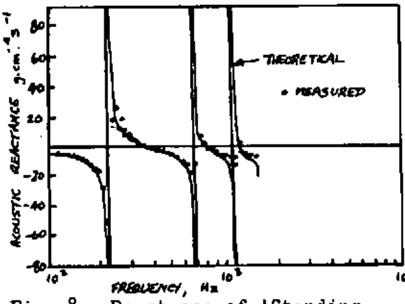

Fig. 8. Reactance of 'Standing-wave' Burner

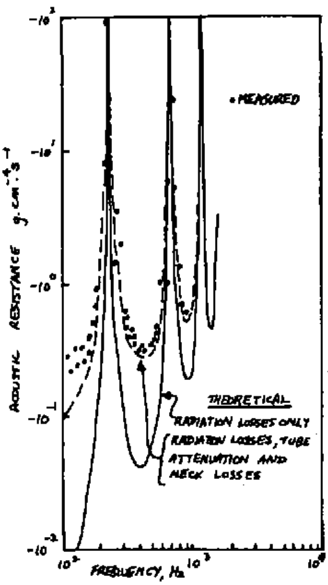

Fig. 7. Resistance of 'Standing-wave' Burner

NOTE: THE COORDINATE SYSTEM FOR FIGURES 7&8 IS NEGATIVE INTO THE BURNER, I.E. NEGATIVE-GOING IN AN UPSTREAM DIRECTION