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THE ACOUSTIC ABSORPTION OF REFRACTORY CERAMIC FIBRE MATERIALS AT OPERATING TEMPERATURES.

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INTRODUCTION

The major cause of self sustaining acoustic oscillations in combustion system is positive feedback between the resonant modes of the chamber and the driving mechanisms of the flame (see references [1] and [2]). This feedback process has been investigated using a modulated dc electric arc discharge to measure the acoustic amplification in the chamber [3]. The onset of self sustaining oscillations was shown to depend on the relationship between the flame transfer function and the acoustic impedance into which the flame, as an acoustic source, feeds. The stability of a given combustion installation which suffers from self sustaining oscillations was shown to be improved by reducing this input impedance by a predetermined amount.

Ceramic fibre materials are frequently used to line furnaces for the purpose of thermal insulation. They also possess a degree of acoustic absorption which can be exploited to improve the stability of combustion system troubled by acoustic resonance. The absorption of such materials is generally temperature dependent so that it is important to be able to determine the relevant absorptive properties at the operating temperatures of the chamber.

This paper describes a technique to measure the input system impedance of a working model combustion chamber terminated by a ceramic fibre sample from which the acoustic absorption coefficient of the sample may be determined. A periodically pulsed electric arc discharge placed inside the flame supplies a volume velocity of known and controllable strength. When the pulse rate of the arc is made equal to the fundamental resonant frequency of the chamber resonance will occur and the resulting acoustic pressure enables the meaurement of the input impedance of the combustion chamber.

EXPERIMENTAL ARRANGEMENT

The apparatus consisted of three parts; the model combustion chamber, the burner arrangement and the sound source (the pulsed arc), see figure 1. The model combustion chamber was a hollow rigid walled cylinder (0.6 m long and 0.2 m in diameter) suspended over the burner by a chain-pulley assembly. This allowed movement of the chamber relative to the burner so that the input impedance could be measured as a function of position. A water cooled multiport burner was employed to support a premixed laminar flame.

Natural gas was used as the fuel gas with an air:fuel mixture ratio of 8:1 at a volume air flow rate of 8 litre/min.

A high voltage blocking oscillator (2.kV) generated a periodic pulsed electric discharge to supply a constant and controllable volume velocity which can be calculated from the electrical input power.

The ceramic fibre samples were made up into 0.2 m diameter discs each with a 5 cm diameter hole drilled through the centre to allow exhaust gases to escape. The sample to be tested was be placed at the upper exit of the chamber, to act as an acoustic termination.

MEASUREMENTS

A microphone probe was positioned adjacent to the flame so that the acoustic pressure in the vicinity of the source could be measured. The resonant acoustic pressure was isolated using a band pass filter coupled to the detecting microphone.

The acoustic pressure, voltage and current were all displayed on a digital storage oscilloscope and then transferred separately to a microcomputer which measured the average peak acoustic pressure corresponding to the fundamental resonant frequency. The Fourier series of the periodic pulse was obtained by numerical means and the components of the electrical input power that corresponds to the fundamental resonant frequency is

$$W_{el} = A\cos(\omega t) + B\sin(\omega t) \qquad (1)$$

The volume velocity (Q) supplied by a modulated dc arc has been shown to be [4]

$$Q = \frac{(\gamma - 1)}{2\gamma P_o} W_{el} \qquad (2)$$

and was assumed to apply to the periodic pulsed arc.

The system input impedance is defined as the ratio (p/Q) of the sound pressure (p) to input volume velocity (Q) of the source (ie the pulsed arc) and has the same axial profile along the length of the chamber as does the sound pressure because (i) the sound pressure and the volume velocity are in phase at resonance (this has been confirmed be true experimentally), and (ii) the amplitude of the volume velocity is kept constant.

The mean temperature of the combustion chamber was estimated from the mean speed of sound as calculated from the resonant frequency and corresponding the wavelength. The measurements of the system input impedance along with the theoretical model given below were used to obtain the absorption coefficient of the sample.

THEORETICAL MODEL

The chamber is assumed to have non absorbing rigid walls, with one end open and the other terminated by the acoustic absorbing material. An analogue to this situation is a tapped electrical transmission line terminated at each end by different loads. One load representing the radiation impedance of the open end and the other the terminating impedance of the sample (see figure 2). In both cases the reactive parts of these loads would determine the resonant wavelength and the resistive components account for the dissipation of sound power.

The normalised combustion chamber input impedance (Zs) is expressed as the parallel combination of the two normalised input impedances on either side of the source (Zx and Zy) and the normalised acoustic impedance of the burner (Zb).

$$\frac{1}{Zs} = \frac{1}{Zx} + \frac{1}{Zy} + \frac{1}{Zb} \qquad (3)$$

Where

$$Zx = \frac{Rr + j\tan kl}{1 + j\,Rr\tan kl} \qquad (4)$$

$$Zy = \frac{RL + j\tan kl}{1 + j\,RL\tan kl} \qquad (5)$$

$$Zb = Rb + j\,Xb \qquad (6)$$

At resonance the input system impedance is purely real since the acoustic pressure and the volume velocity are in phase, and the maximum of which is given by

$$Zs,max = (Rr + RL + Rb/(Rb^2 + Xb^2))^{-1} \qquad (7)$$

Thus the termination resistance can be calculated directly from the maximum measured system input impedance.

The reactance will introduce a phase change between the incident and reflected waves and this change in phase may be calculated from to change in the wavelength and used to evaluate the reactance of the termination. This phase change was shown to be

$$\theta = k(\lambda' - \lambda)/2 \qquad (8)$$

The termination reactance can be expressed as

$$XL = RL \arctan\theta \quad (9)$$

From which both the resistance and the reactance of the termination can be obtained. The acoustic absorption coefficient of the termination is given by [5]

$$\alpha_L = 4RL/((1 + RL)^2 + XL^2) \quad (10)$$

To obtain the actual acoustic absorption coefficient of the sample the effect of the exhaust opening must be allowed for. The actual absorption coefficient for the sample can be determined from the respective areas of the exhaust opening and the termination, and has been found to be

$$\alpha_{cf} = a^2/(a^2 - ae^2) \quad (11)$$

RESULTS AND DISCUSSION

Figures 3 to 6 show the peak acoustic pressure normalised to one watt of electrical input power as measured along the axis of the terminated combustion chamber. In all cases the normalised pressure follows the predicted sine squared trend. The wavelength and the maximum normalised peak acoustic pressure were estimated by fitting the best sine squared curve to the measured data. The acoustic resistance and reactance of the terminations were calculated from these quantities using equations (7), (8) and (9) (see table 1).

Table 1

sample	phase (rad)	Zs	RL	XL	mean temp (K)
kaowool S.D.	$\pi/2$	2.10	0.39	0.39	471
kaowool H.D.	$7\pi/20$	2.56	0.34	0.28	374
durablanket	$\pi/2$	2.41	0.36	0.36	463
end cap	$\pi/2$	2.11	0.42	0.42	485

The acoustic absorption coefficients of the samples were calculated using equation (11) and the results are given in table 2. The correction made for the exhaust showed that this opening had little effect on sample absorption because of the relatively small surface area. For comparison the absorption coefficient for the samples was also measured, at room temperature, using a standing wave tube. The results show a definite tendency for the absorption coefficient to increase with temperature.

Table 2

sample	α_L	corrected coeff. α_{cf}	standing wave tube α_{cf}	% difference
kaowool S.D.	0.75	0.80	0.49	63
kaowool H.D.	0.73	0.78	0.62	26
durablanket	0.73	0.78	0.59	30
end cap	0.77	0.82	0.62	31

CONCLUSION

A technique is described for determining the acoustic impedance of a ceramic fibre sample placed at the exit of an operating combustion chamber from measured data using the theoretical model. The results show that inserting a sample into a combustion chamber causes a reduction in the system input resonant impedance and a change in the wavelength occurs due to phase changes at the surface of the termination.

The acoustic absorption coefficient was calculated from the acoustic impedance of the termination (see table 2). These results when compared with the coefficients measured using a standing wave tube at, room temperature, show that a definite increase in the absorption of the sample occurs with increasing temperature, which is properly due to the effects of small air pockets trapped in the body of the samples.

REFERENCES

1. SALIKIKUDDIN M., ZINN B.
   Adaption of the impedance tube technique for the measurement of combustion process admittance, JSV Vol 68 pp119-132 (1980).
2. MUGRIDGE B.
   Combustion driven oscillations," JSV, Vol 70, No 3, pp437-452 (1980).
3. MEDVEDEV N., VUILLERMOZ M., ROBERTS J.
   An experimental study of sound generated by electrical discharge within a flame," Acoustic Letters, Vol 44, pp337-346 (1982).
4. MACQUISTEN M.A., ROBERTS J.P., VUILLERMOZ M.L.
   Measurement of acoustic stability parameters of combustion systems, Proceedings to IOA, Sollihull (1984).
5. KINSLER L.E., FREY A.R., COPPENS A.B., SANDERS J.V.
   Fundamentals of Acoustics, p203, 3rd Edition, Wiley (1982).

ACOUSTIC ABSORPTION OF CERAMIC FIBRE MATERIALS

LIST OF SYMBOLS

A & B .... the first Fourier components of the electrical input power (W).

a .... radius of the combustion chamber (m).

a .... radius of the exhaust opening (m).

k .... the wavenumber (m).

l .... axial position inside the combustion chamber (m).

Po .... ambient pressure (Pa).

p .... acoustic pressure (Pa).

Q .... volume velocity (m^3/s).

RL .... normalised acoustic resistance of termination.

Rr .... normalised radiation resistance.

Rb .... normalised burner resistance.

Wel .... electrical input power (W).

XL .... normalised acoustic reactance of the termination.

Xr .... normalised radiation reactance.

Xb .... normalised burner reactance.

Zs .... normalised system input impedance.

Zx & Zy ..... normalised input impedances on either side of the flame.

α .... acoustic absorption coefficient.

γ .... specific heat ratio.

θ .... phase (rad).

λ .... wavelength (m).

ω .... angular frequency (rad/s).

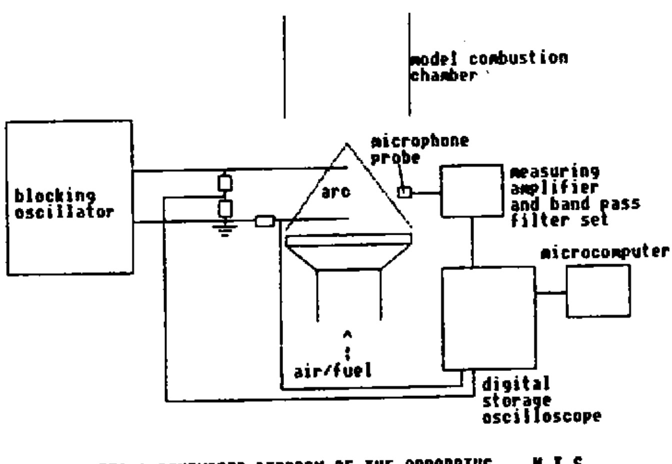

FIG.1 SCHEMATIC DIAGRAM OF THE APPARATUS. N.T.S.

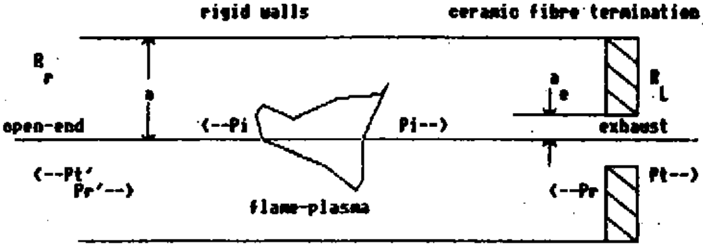

FIG 2. MODEL COMBUSTION CHAMBER.

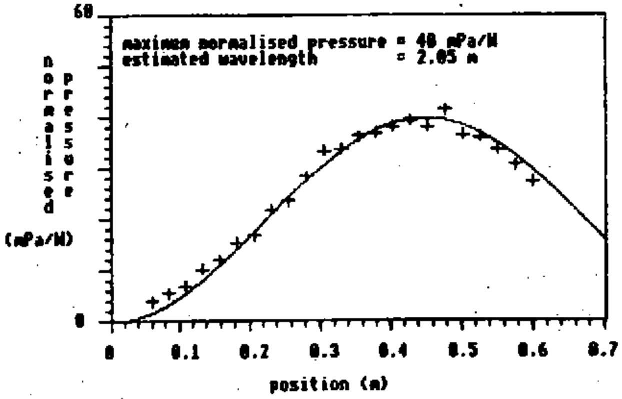

FIG.3 KAOWOOL HEAVY DUTY BLANKET SAMPLE.

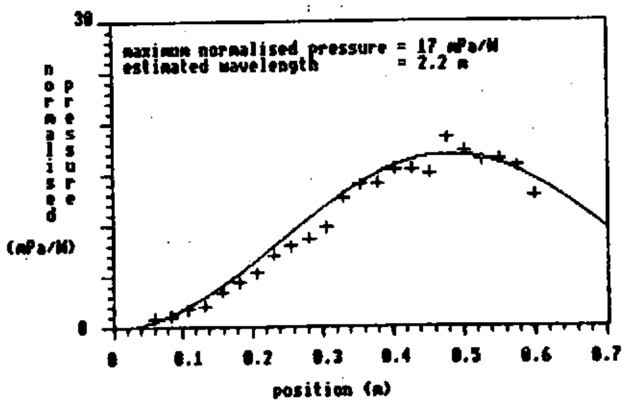

FIG.4 KAOWOOL STANDARD DUTY BLANKET SAMPLE.

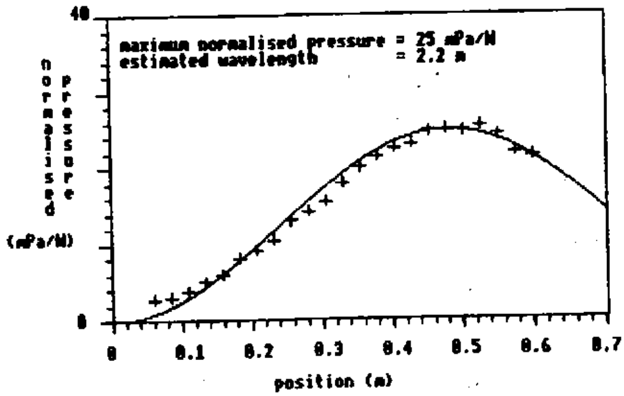

FIG.5 DURABLANKET SAMPLE.

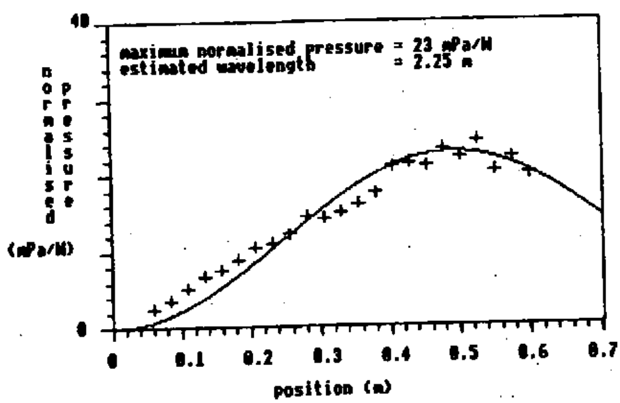

FIG.6 DURABLANKET SAMPLE.