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ACTIVE CONTROL OF COMBUSTION SYSTEM INSTABILITIES.

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1. INTRODUCTION.

1.1 Coupling between the sound generating mechanisms of certain turbulent flames and the acoustic modes of combustions systems has been found to lead to the rapid build up of harmful resonant oscillations within the plant. While there is a reasonable understanding of the interactions involved, their range and complexity are such that it is, as yet, impossible to predict with certainty that any particular installation will not be prone to this type of resonant instability.

1.2 Previous publications by the authors (1,2,3) have described an acoustic probe which may be operated within the flame region of a combustion system and from which the important stability parameters of an installation may be determined. The probe consists of a current discharge maintained between electrodes which is made to pulsate at audi-frequencies and so generate an acoustical signal. The response of the combustion system to this acoustic input can be used to evaluate system performance at, say, the commissioning stage and give prior warning of any tendency to instability. It can also give an indication of the type of remedial measures which would be needed to avoid such instability should there be a tendency for them to occur.

1.3 This paper explores the natural extension of the use of the probe to its operation as an actual control element within an operating system. We show, using an experimental model, that it is possible to use the probe as an active control element capable of inhibiting the build up of these resonant oscillations.

2. EXPERIMENTAL ARRANGEMENT.

2.1 The combustion chamber consisted of a double walled open ended cylindrical chamber 1.5 m long and of internal diameter 200 mm. Cooling water was circulated between the walls, and the whole chamber was mounted in a horizontal position on a moveable trolley. The burner was constructed from 50 mm copper tubing, 1 m in length with the end on which the flame was held seated by turbulent recirculation partially closed by a steel plug to form a narrow annulus through which the premixed fuel gas and air could flow. The burner tube was

fixed to a frame in such a way that by moving the chamber along its axis, the flame could be located at any position along the centre line of the chamber between an open end and the centre.

2.2 The burner was fuelled with a natural gas/air mixture of total flow rate 68 l/min (air/gas ratio 7.5:1) to provide a lifted turbulent flame. A small pilot burner fixed in front of the main burner provided seeding for the arc discharge and acted as one of the electrodes. The second electrode consisted of a steel ring mounted 50 mm in front of the pilot light, see figure 1. The air supply to the pilot flame was passed through a vessel containing a strong solution of potassium hydroxide with a small mains frequency spark discharging over the liquid surface. This provided a good supply of ions for the necessary seeding.

2.3 A d.c. discharge with superimposed audio-frequency modulation was maintained between the electrodes, the power supplied by a suitable high voltage amplifier. This arrangement produced clear sound emission at the modulation frequency which was little affected by the presence or intensity of the main flame.

2.4 The experimental arrangement was completed by a water cooled microphone placed close to the burner, and a low voltage amplifier and phase change circuit connecting the microphone to the high voltage amplifier. This arrangement provided a closed loop control whereby pressure oscillations in the chamber could be detected by the microphone and fed back into the system via the discharge acting as an acoustic transducer, see figure 2.

3. SELF-SUSTAINING OSCILLATIONS.

3.1 A characteristic stability curve of the combustion assembly without the control loop in operation is shown in figure 3. The plot gives the sound pressure levels of the 125 Hz one third octave band which contains the fundamental resonant frequency (measured 0.7 m from the open end of the combustion chamber) with the burner inside the chamber and moved either towards or away from the centre. The plot displays the shape of a typical hysteresis curve, and shows the region of overlap where the system may exist in either the normal low intensity state or the high intensity resonant state depending upon ite recent history and such factors as fuel gas/air ratio and overall flow rates.

3.2 Figure 4 shows the free field frequency spectrum of the turbulent flame which displays the characteristic broad band spectrum of this type of combustion. Peaks in the 4 kHz region were due to causes other than the flame.

4. THE CONTROL LOOP.

4.1 The way in which the control circuit may influence the intensity inside the chamber is illustrated in figure 5. The spectra were measured, as previously, 0.7 m from the open end of the combustion chamber. The two curved show the results of feeding back the control signal first in phase and then out of phase with the resonant signal. For these measurements the burner was located 250 mm inside the chamber when the condition of the system was represented by the lower trace of the stability curve (see figure 3), that is in the non-resonant state. An increase of 9 dB is observed at the fundamental resonant frequency when the control loop is switched from anti-phase to in-phase. When the system is resonant, however, the control circuit has little or no measurable effect on the intensity of the resonance.

4.2 With the control circuit adjusted to provide negative feedback the burner may be inserted closer to the centre of the chamber before self-sustaining oscillations begin. Indeed, as a test, the system was held for an hour in the non-oscillating state with the burner inserted 350 mm into the chamber, that is at a position where resonant oscillations would normally have occurred.

5. CONTROL LOOP PARAMETERS.

5.1 It has been shown (3) that the modulated acts as a constant volume velocity sound source of a strength Q given by

$$Q = \frac{(\ - 1)}{2} \cdot \frac{\ }{P_o}$$

where P_o = atmospheric pressure (Pa)

= specific heat ratio for air

= input electrical a.c. power (W)

5.2 The final acoustic pressure generated by this source would then depend on the source strength and the impedance into which it feeds.

5.3 The control loop may be characterised by the volume velocity produced by the discharge for unit acoustic pressure at the microphone. This quantity, the acoustical transfer admittance Y, was found as follows. With the control loop operating the sound pressure level measured inside the chamber was 126 dB re 20 Pa (an acoustic pressure of 40 Pa). The electrical power to the arc was 150 W, which was about the highest possible for this arrangement before the modulation signal exceeded the d.c. level and caused the discharge to splutter.

5.4 The source strength for this electrical input, derived from the above equation was $2 \times 10^{-4}\ m^3.s^{-1}$, so that Y was of the order of $10^{-5}\ m^3.s^{-1}.Pa^{-1}$.

5.5 The acoustic impedance into which the source feeds will be real at resonance and was measured (see reference 2) as 10^5 $Pa.s.m^{-3}$ so that the acoustical pressure generated by the arc is of the order of 20 Pa. This value is consistent with the observed change in sound pressure level of 9 dB when the feedback loop was changed from in phase to anti phase conditions.

6. DISCUSSION.

6.1 The results reported here form part of a continuing research programme into the use of the pulsating arc discharge in combustion diagnostics and control. It has been shown previously that the feedback loop described here is able to stabilise laminar flame resonant systems easily.

6.2 For widespread use this type of control system must be able to handle turbulent combustion and the present results provide encouragement for continuing with research along the lines reported here. It is believed that the explanations given for the operation of the control loop are close to that which occurs in practice and thus it will be necessary to increase the electrical power by a factor of at least 10 for effective industrial use. Such an increase should be readily achievable.

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Acknowledgements.

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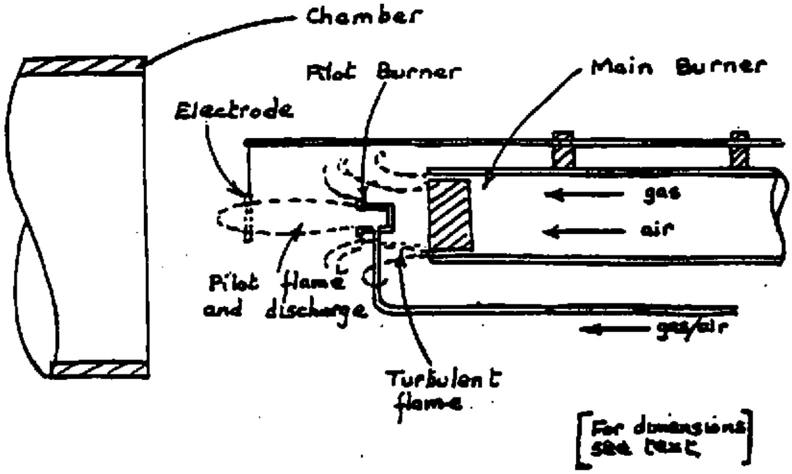

Figure 1. Burner and discharge arrangement.

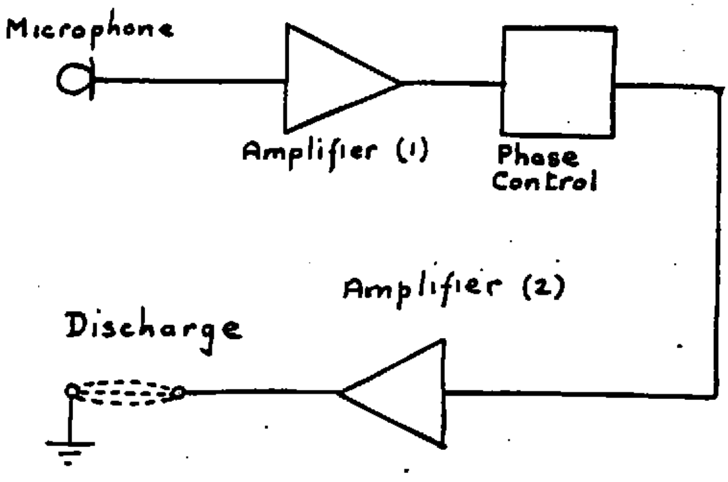

Figure 2. The control loop.

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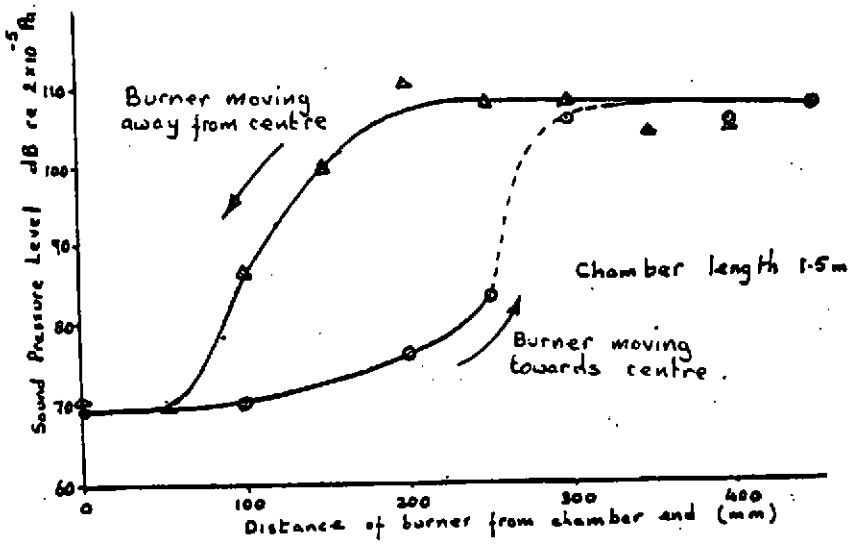

Figure 3. Characteristic stability curve of the combustion assembly.

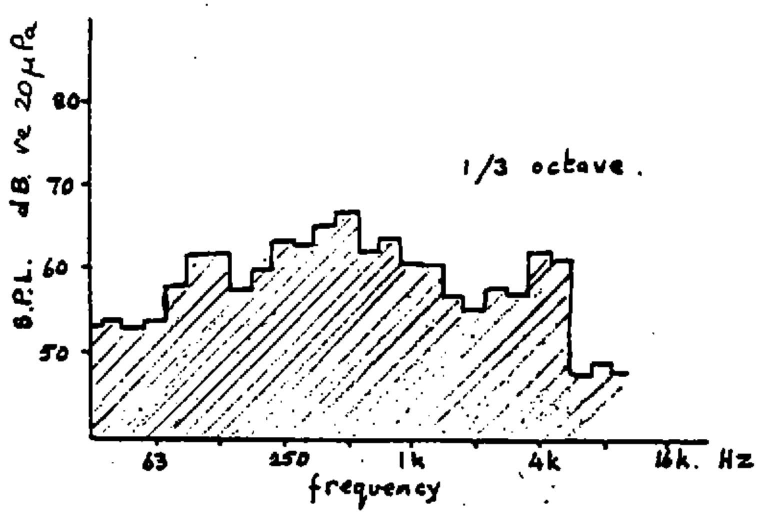

Figure 4. Freefield noise spectrum of flame.

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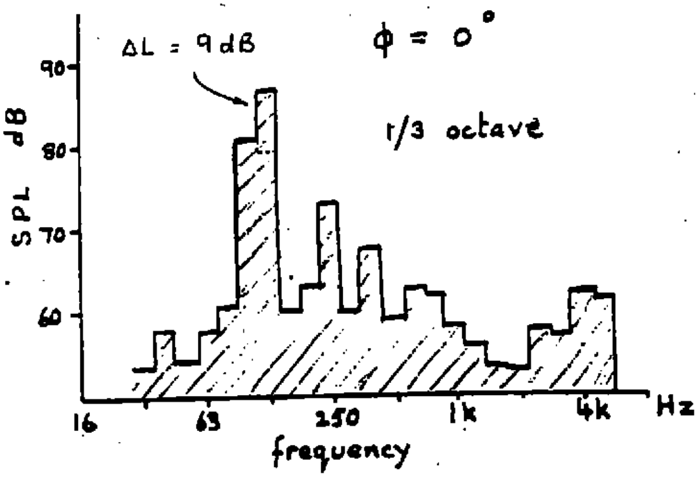
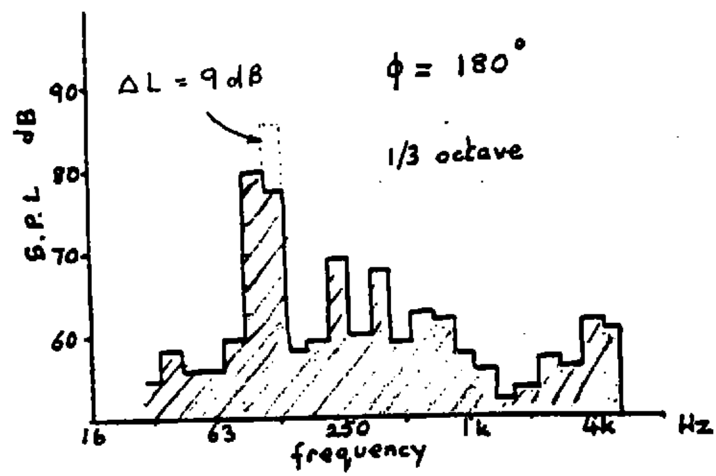
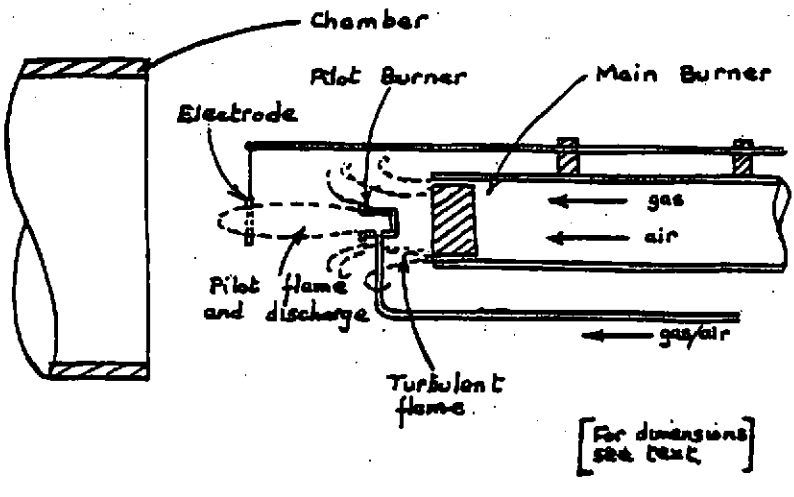


(a)



(b)

Figure 5. Sound spectrum with control loop
a) in phase and b) out of phase.



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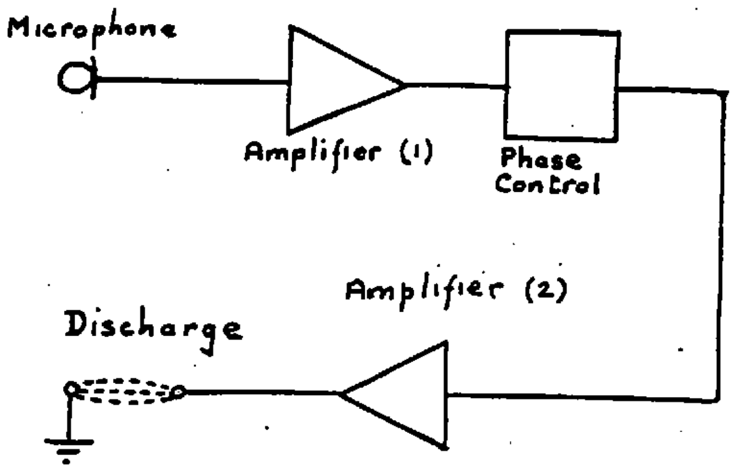

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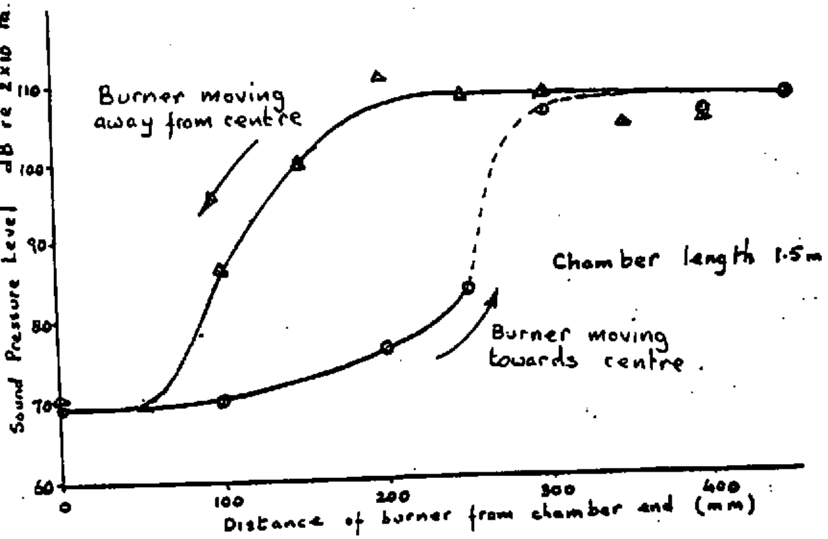

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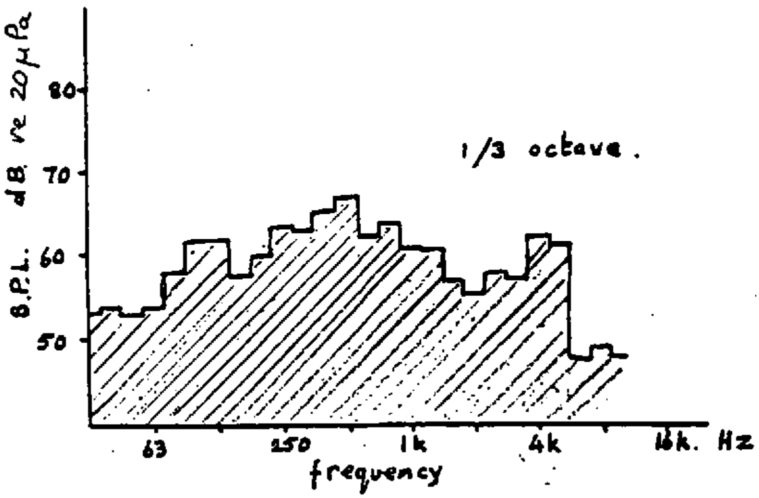

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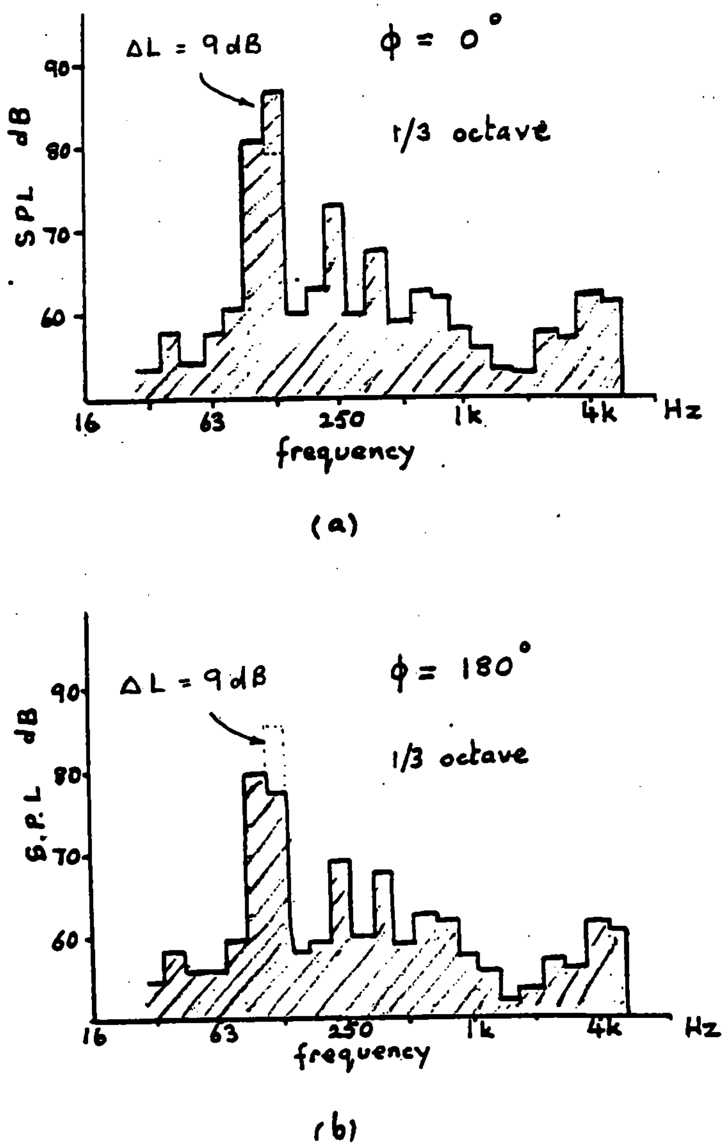

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