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# Combustion Oscillation: Chemical Control Showing Mechanistic Link to Recirculation Zone Purge Time

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## Introduction

Active control mechanisms are being examined for lean premix combustion applications, such as gas turbine generators. Lean premix combustors are susceptible to large combustion oscillations, particularly when driven very lean to achieve low NOx. While past design work has been focussed on understanding the source of the oscillation and modifying the combustor to avoid such oscillations, commercial combustion designers have more recently considered applying new control elements.

As part of the U.S. Department of Energy's *Advanced Gas Turbine Systems Program* (Report To Congress, 1994), the Morgantown Energy Technology Center is investigating various active control techniques. This paper presents results from experiments studying the effect of pilot fuel modulation on combustor oscillation and pollutant emissions for a pilot stabilized dump swirl combustor, typical of gas turbine combustors. The results show that a significant level of attenuation can be achieved in the combustor pressure oscillation (50 to 90 percent) while only moderately affecting pollutant emissions. The control mechanism producing the attenuation is shown to be purely chemical in nature, rather than fluid mechanic. In addition, the frequency region over which control is obtained is shown to be related to the recirculation zone purge time. For this reason, control can be achieved at control frequencies much lower than the frequency of oscillation.

**Experimental Description**

The swirl/pilot stabilized combustor under investigation is shown in Figure 1 oriented vertically with flow in the downward direction. A 24 mm diameter premix nozzle provides a mixture of fuel and air to the combustor. This *annular* premix gas is swirled via 45 degree vanes located 102 mm up from the nozzle exit. A pilot tube with a 13 mm outside diameter and a 10 mm inside diameter is aligned down the axis of the premix nozzle, and supplies a mixture of fuel and air to the pilot flame. An electric igniter rod passes along the center of the pilot tube with a 6.4 mm diameter ceramic tube as insulation. The ceramic tube ends about 25 mm ahead of the igniter rod that is flush with the bottom of the pilot tube. The centering of the igniter is achieved with a 13 mm thick filter material located 83 mm up from the nozzle exit. The combustor has an inside diameter of 76 mm and a straight length of 2.4 m. The product gas exits via a tee section as shown in Figure 1. The portion of the combustor length upstream of the tee is built from 115 mm thick ceramic refractory. Based on first order acoustic relations, the oscillatory modes have been shown to have frequencies of 87, 190, 300, 460, and 600 Hz, Richards et al. (1995). For the data presented here, the 300 Hz mode was present (285 Hz measured).

The experimental data acquired during the tests are flow rates, dynamic pressures at the bottom of the "extension leg" and inside the premix nozzle, centerline temperatures along the axis of the combustor (thermocouples 'A' and 'B'), and gas samples for emission analysis (taken by removing thermocouple 'B').

To excite oscillations in the combustor, a "fuel feed" mechanism is used as described by Putnam (1971) and Richards and Yip (1995). Briefly, the mechanism requires a coupling between the fluid mechanics inside a fuel supply tube and the oscillations occurring inside the combustor. In our test rig, this is achieved through a bypass tube that routs about 10 percent of the annular premix fuel to an injection point located 76 mm up from the nozzle exit.

**Pulse Pilot Control Mechanism Description and Behavior**

As shown in Figure 1, a natural gas fuel solenoid valve is used to modulate the flow of pilot fuel. The maximum frequency at which the solenoid can fully open and close is a little more than 100 Hz. Tests for the effect of pilot fuel modulation on both pressure oscillation and pollutant emissions were performed. As shown in Figure 2, for overall flow rate of about 12 g/s and equivalence ratio of 0.65, the pressure oscillation could be reduced by 76 percent at 12 Hz and a valve opening time of 6.3 ms. Interestingly, the control mechanism works only when the control frequency is below about 30 Hz. The cause for this behavior is explained in the following section.

To determine whether the control achieved by the pilot fuel modulation was due to chemical effects (as caused by the forced variation in pilot gas equivalence ratio), or fluid mechanic effects (as caused by the sudden injection of fuel into the pilot tube), two other tests were performed. For the first test, the pilot fuel and air supplies were divided, with one line fitted with a solenoid valve and the other with a needle valve to control the relative proportion of flow between each line. (See Figure 3.) With this configuration and both valves driven in-phase, experiments could be performed with constant fuel concentration reaching the flame front, but having forced fluid mechanic oscillations inside the pilot tube of the same magnitude as obtained by the pure pilot fuel modulation results described previously. At a control frequency of 12 Hz, the test showed no noticeable pressure attenuation as compared to steady pilot oscillation. Because of this result, it is concluded that fluid mechanic effects are unlikely to be causing the significant attenuation effects shown in the pure pilot fuel modulation tests. Instead, chemical effects are the likely control mechanism.

To verify that chemical effects govern the control mechanism, the fuel needle valve shown in Figure 3 was fully closed and the solenoid valves driven antiphase. With this configuration, experiments could be performed with nearly the same swing in fuel concentration as achieved with the pure pilot modulation tests, but with significantly reduced imposed fluid mechanic oscillations. At a control frequency of 12 Hz, the attenuation was shown to be 80 percent, or very close to the initial pure pilot fuel modulation tests. We conclude that the fundamental control mechanism is chemically related (e.g., the pulses of pilot fuel force a restructuring of the fuel/air mixing, and hence chemistry, inside the pilot zone, which in turn restructures the flame so as to avoid an acoustic/combustion response).

Finally, Figure 4 shows the effect of pulse frequency (using pure pilot fuel modulation) on NOx and CO. Data for an overall equivalence ratio of 0.65 is shown. It is found that the pulse control frequency has very little effect, if any, on pollutants.

**Control Cut-off Frequency Link to Recirculation Zone Purge Time**

The 30 Hz cut-off frequency for our system is shown to be possibly related to the flow in the swirl supported recirculation zone (RZ). First-order estimates of the RZ purge time calculated from the RZ volumetric size and volumetric flow rate of fluid into the RZ show close agreement to the 30 Hz cut-off frequency. To show experimentally that the purge time and cut-off frequency are mechanistically linked, experiments were performed at a single flow rate of annular premix air and fuel (12 g/s), while varying the pilot flow rates of fuel and air proportionally. (No solenoid valves were used on the pilot gas.) Since nearly all pilot gas passes through the RZ, the flow of pilot gas will have a dominant affect on RZ purge time. Moreover, since the premix swirl momentum controls the size of the RZ, the size of the RZ will be approximately constant for these tests. The results from these tests are shown in Figure 5, with the BASE case having a flow rate of 0.39 g/s. For the lower pilot flow rates, there appears to be a direct relationship between cut-off frequency and pilot flow rate as expected from the proposed phenomeno-logical model. However, as the pilot flow rate becomes greater than the base flow, the inverse relationship no longer applies. This discrepancy likely results from the fact that as the pilot flow becomes high, the size of the RZ becomes significantly modified. In summary, these results indicate that when the fuel pulses are separated far enough apart, the RZ has time to purge itself of a pulse of pilot fuel and oscillations are significantly attenuated. Other mechanisms may also explain these results, however, and are currently being examined.

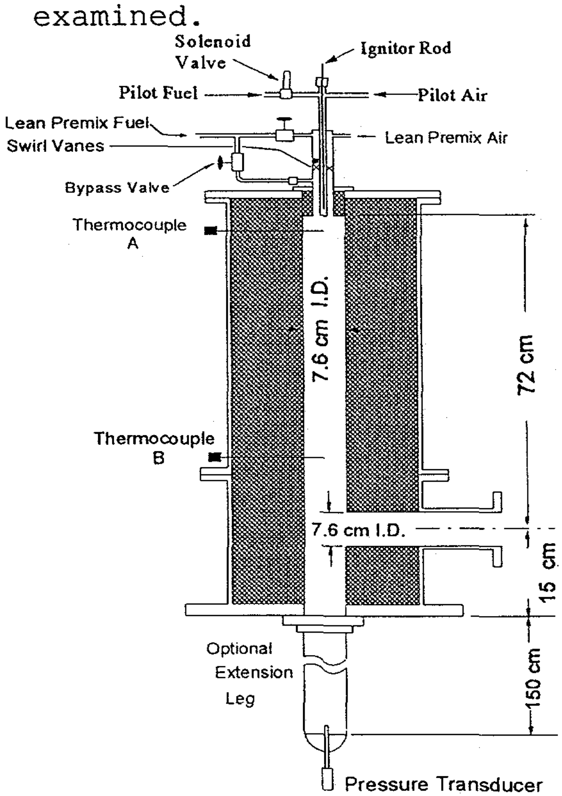


Figure 1. Test Rig

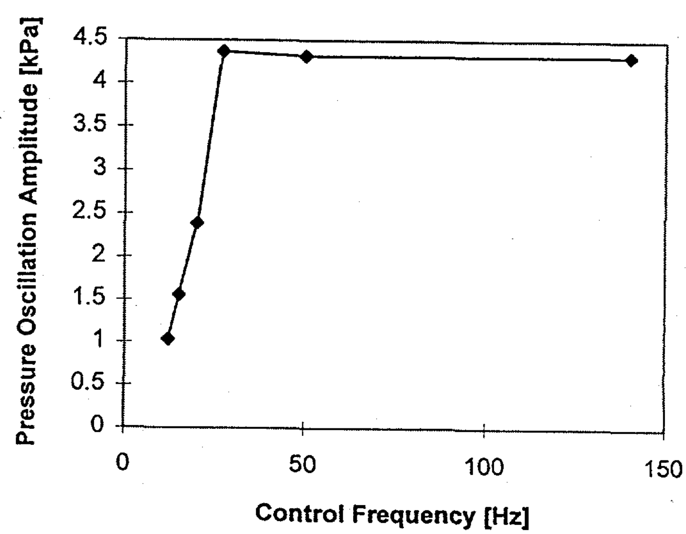


Figure 2. Control Frequency vs. Oscillation Amplitude

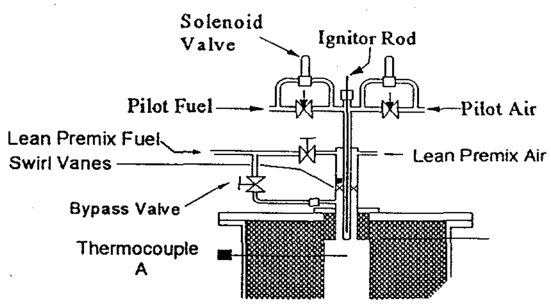


Figure 3. Configuration for Fluid Mechanic Effect Tests

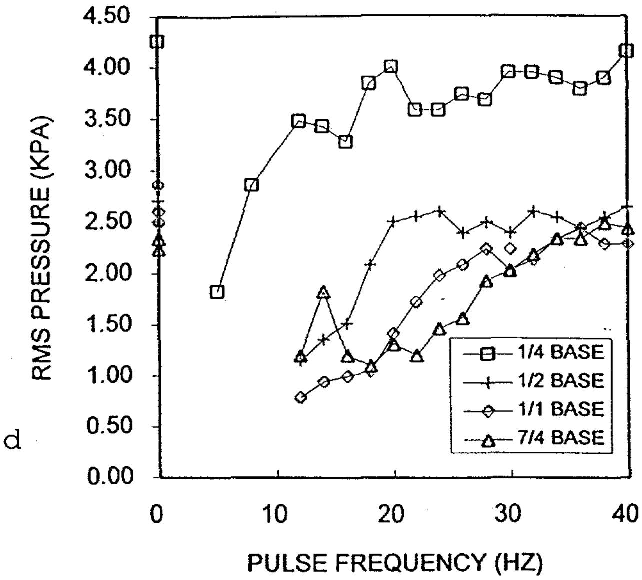


Figure 5. Effect of pilot flow rate on cut-off frequency

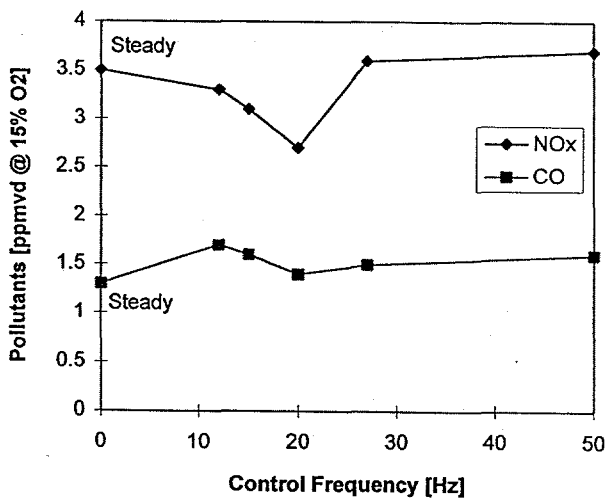


Figure 4. Effect of Control on Pollutants

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## References

Putnam, A.A. (1971), "Combustion Driven Oscillations in Industry", American Elsevier Publishers, New York, NY.

Report to Congress (1994), "Comprehensive Program Plan for Advanced Turbine Systems", DOE/FE-0279-1, U.S. Department of Energy.

Richards, G.A., M.J. Yip, E. Robey, L. Cowell, and D. Rawlins (1995), "Combustion Oscillation Control by Cyclic Fuel Injection", presented at the 1995 ASME Turbo Expo, June 5-8, 1995, Houston, TX.

Richards, G.A. and M.J. Yip (1995), "Oscillating Combustion from a Premix Fuel Nozzle", presented at the Combustion Institute/American Flame Research Committee Meeting, April 23-26, San Antonio, TX.