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Computational Analysis of High Bandwidth Fuel Injection System

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Abstract: Gas turbine exhaust different pollutanats at high temperature, so to reduce level of pollutants lean, premixed combustor designs is used. In these lean, premixed combustor, large amounts of air is premixed with the fuel before its injection into the combustor, which reduces peak temperatures within the combustor and leads to lower NOx emissions.[25]

A number of studies have been conducted to understand the mechanisms of the combustion instabilities and control strategies of combustion oscillations by using active instability control (AIC) [24]. In passive method modifications are done in combustion chamber, in its burners and by increasing acoustic damping via Helmholtz-type resonators or by disturbing the propagation of sound waves via baffles. Combustion instabilities are controlled in passive method with the help a cylindrical extension called a cylindrical burner outlet (CBO), is welded to the burner nozzle. The length of this extension is selected such that prolong the convective time lag by slightly more than one quarter of the period of the oscillation.[21] In active method actuators are used to modulate particular parameter of a combustion system. Under ideal conditions, modulation is performed in such a manner to have the corresponding system variable fluctuate precisely in Counter-phase with the fluctuations constituting the combustion instabilities, thus damping them.

Keywords*: *AIC(active instability control), ACC (Active Combustion Control), CBO(cylindrical burner outlet) ,FRF(Frequency Response Function)

I. INTRODUCTION

Gas turbine exhaust different pollutanats at high temperature, so to reduce level of pollutants lean, premixed combustor designs is used. In these lean, premixed combustor, large amounts of air is premixed with the fuel before its injection into the combustor, which reduces peak temperatures within the combustor and leads to lower NOx emissions.[25]

However, premixed combustors are often susceptible to thermo acoustic combustion instabilities, which can lead to large pressure oscillations in the combustor. These pressure oscillations result in increased noise and decreased durability of jet plane combustor. The goal of using active combustion instability control on a gas turbine engine is to keep pressure oscillations at an acceptable level over a large range of operating conditions i.e. high band width [22]. Combustion instabilities occur in many practical systems such as power plants. It is well known, the control of NOx has become extremely important in many combustion systems, to limit the production of NOx the flame is kept as lean as possible. Which leads to a more unstable flame, with oscillating heat-release that couples with the pressure acoustics of the chamber.To suppress or reduce this phenomenon, two methods are used for eliminating combustion instabilities, are active and passive control systems. A number of studies have been conducted to understand the mechanisms of the combustion instabilities and control strategies of combustion oscillations by using active instability control (AIC) [24]

In passive method modifications are done in combustion chamber, in its burners and by increasing acoustic damping via Helmholtz-type resonators or by disturbing the propagation of sound waves via baffles. Combustion instabilities are controlled in passive method with the help a cylindrical extension called a cylindrical burner outlet (CBO), is welded to the burner nozzle. The length of this extension is selected such that prolong the convective time lag by slightly more than one quarter of the period of the oscillation.[21] In active method actuators are used to modulate particular parameter of a combustion system. Under ideal conditions, modulation is performed in such a manner to have the corresponding system variable fluctuate precisely in Counter-phase with the fluctuations constituting the combustion instabilities, thus damping them.

II. PROBLEM STATEMENT:

To reduce the levels of pollutants created by gas turbine combustors, lean, premixed combustor designs are used. Premixing of air with the fuel before its injection into the combustor greatly reduces peak temperatures within the combustor and leads to lower NOx emissions. Premixed combustors are often susceptible to thermo acoustic combustion instabilities, which can lead to large pressure oscillations in the combustor. These pressure oscillations result in increased noise and decreased durability due to the vibration and flame motion.

This instability limits the operating temperature at the turbine inlet and reduces efficiency and performance. So the air- fuel ratio and flame temperature are optimized throughout the combustor to minimize the production of pollutants. In recent years, Active Combustion Control (ACC) system is used to reduce combustion instabilities in gas turbine. These instabilities can be reduced by modulating fuel flow rate at their frequency. The approach is known as phase shifting control

III. VALIDATION:

In the case of a high bandwidth fuel injection system ,we can use a piston and throttle valve model using METLAB to reduce combustion instabilities in gas turbine.

PISTON-ATOMIZER MODEL RESULT

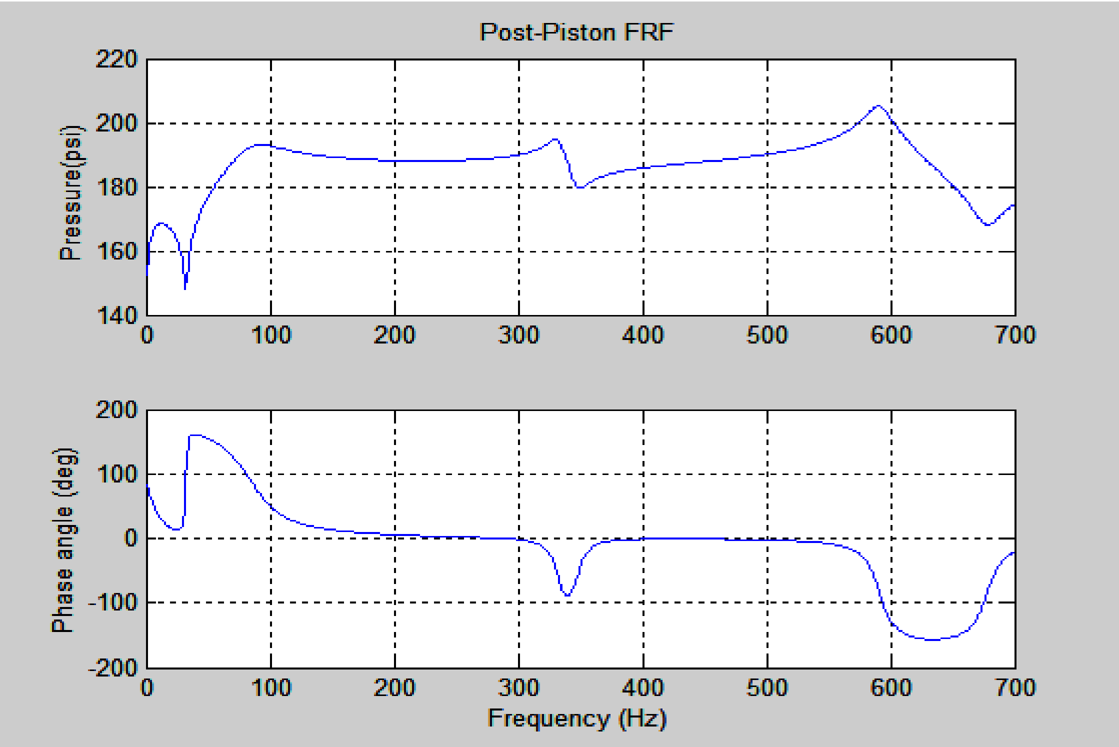

FIGURE 1: Variation in Phase Angle and Pressure w.r.t. Frequency in Post Piston Condition

Frequency(Hz)	Phase(deg)	Pressure(psi)
0	80	160
50	170	175
100	40	200
150	20	190
200	05	185
250	0	190
300	0	190
350	-40	180
400	0	182
450	0	185
500	0	190
550	-5	195
600	-120	200
650	-150	180
700	-20	165

Table 1: Combustion Control Data with post piston condition

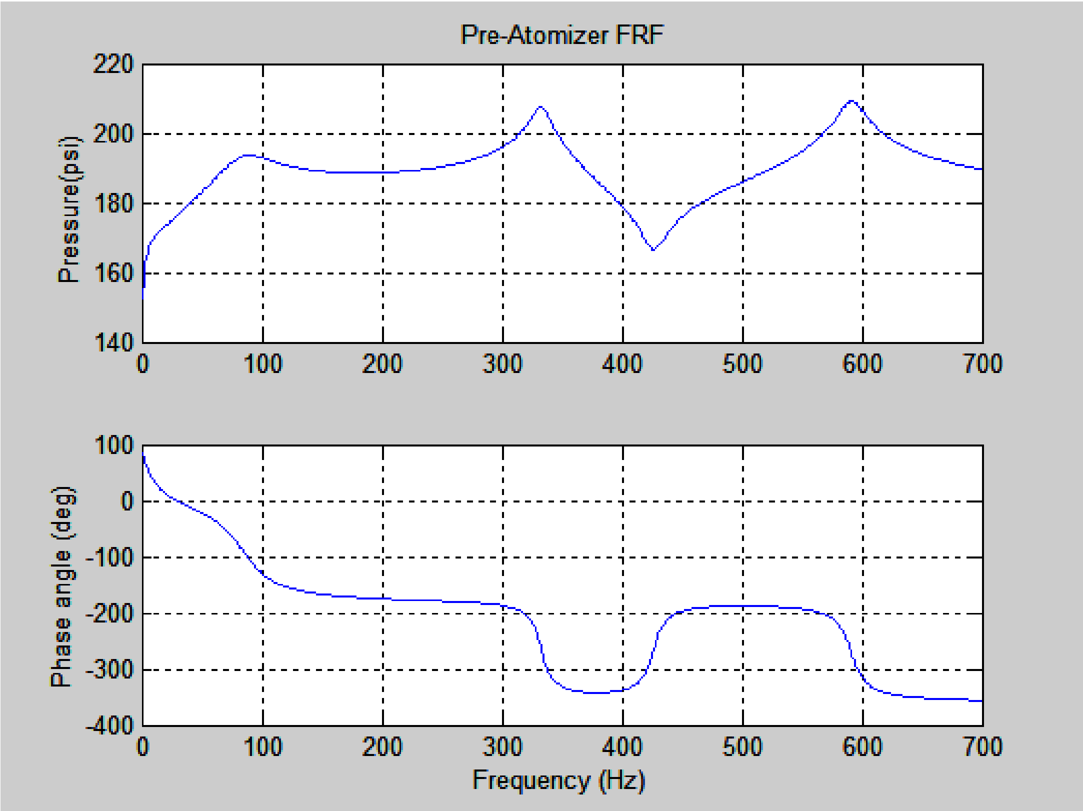

FIGURE 2 Variation in Phase Angle and Pressure w.r.t. Frequency in Pre Atomizer Condition

Frequency(Hz)	Phase(deg)	Pressure(psi)
0	90	160
50	-20	180
100	-110	192
150	-180	190
200	-185	188
250	-190	192
300	-195	195
350	-320	195
400	-340	176
450	-190	172
500	-185	185
550	-195	195
600	-320	205
650	-350	195
700	-360	190

Table 2: Combustion Control Data with pre atomizer condition

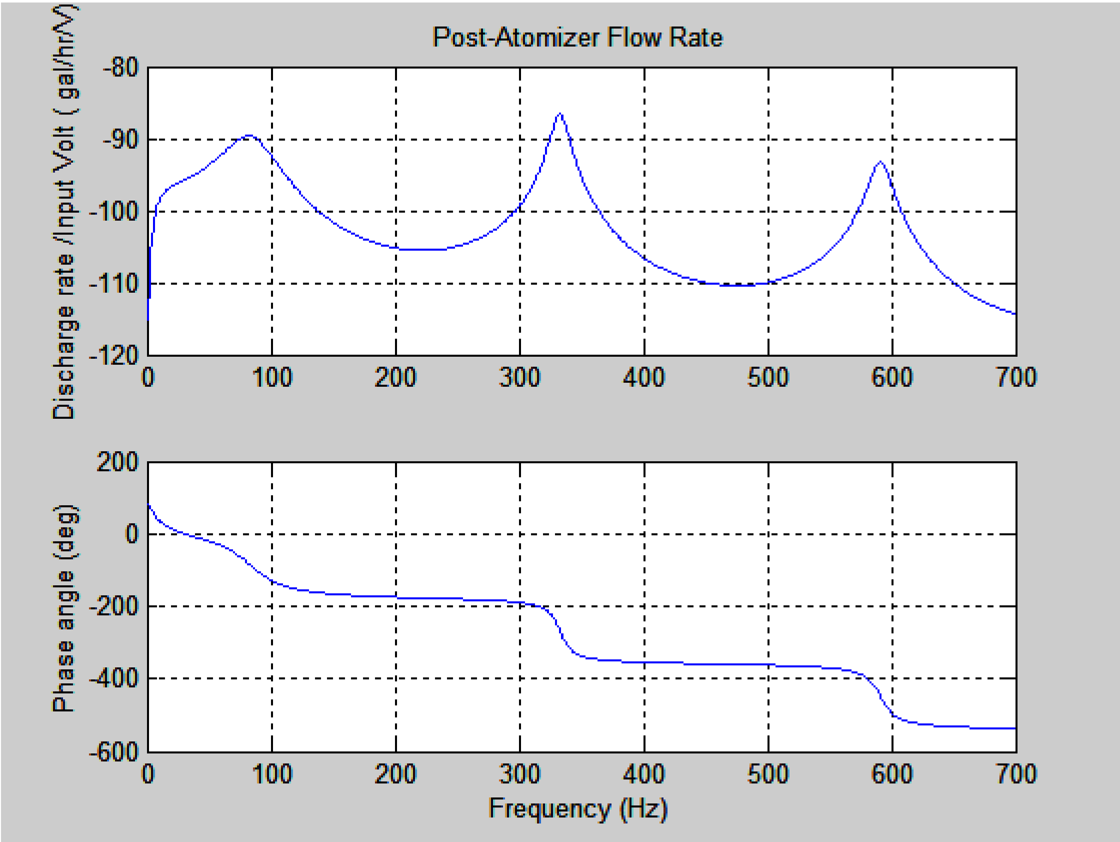

FIGURE 3: Variation in Phase Angle and Flow Condition w.r.t. Frequency in Post Atomizer Condition

Frequency(Hz)	Phase(deg)	Discharge rate/input voltage (gal/hour/volt)
0	60	-105
50	-10	-95
100	-190	-92
150	-190	-102
200	-195	-105
250	-196	-105
300	-198	-100
350	-380	-98
400	-380	-105
450	-380	-110
500	-382	-110
550	-390	-105
600	-500	-98
650	-510	-110
700	-510	-115

Table 3: Combustion Control Data with post atomizer conditions

As shown in figure 1 and 2 maximum pressure intensity (205 psi) with Primary fuel line modulation with the help of piston cylinder unit occur at 590Hz frequency in pre and post piston condition, but it very interesting that in both conditions, when pressure inside in combustion chamber is very high, the equivalence ratio of main flame will change. Although the fuel input in system is sinusoidal, yet the fluctuation of equivalence ratio would not be sinusoidal. It means that it could consists some harmonics, so peak of pressure intensity about 320Hz also occur in both condition.

But if we use a premixed pilot flames generated by the PFI, combustion instabilities can be suppressed and controlled within required bandwidth. However, the improved dynamic stability could reduce NOx emission for a continuous PFI air mass flow rate. In modern gas turbine NOx emissions may also reduce by using combination of methane, hydrogen and air as a working fluid in a combustor.

THROTTLE VALVE-ATOMIZERS MODEL RESULT

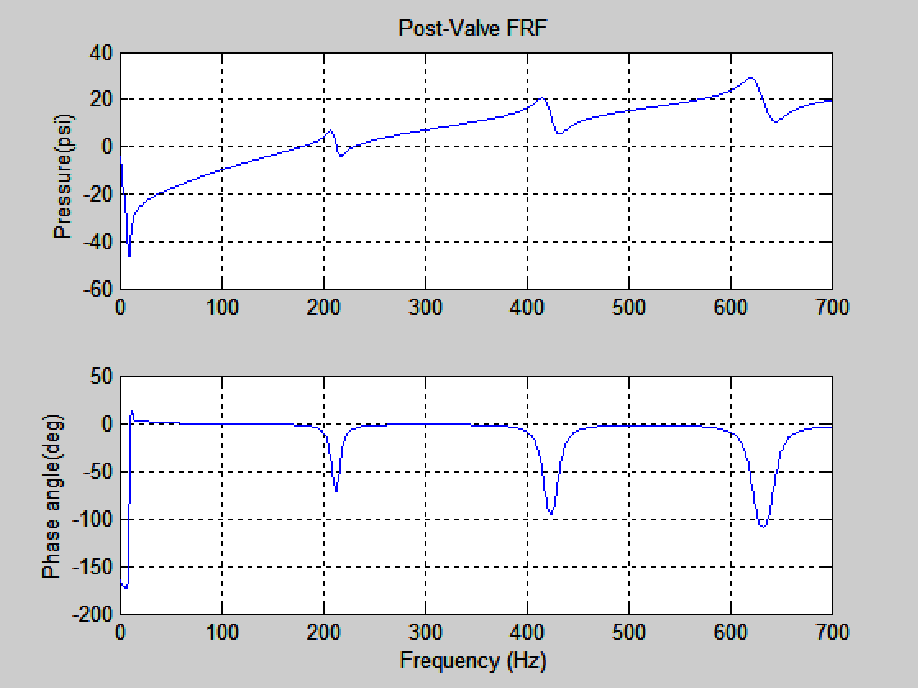

FIGURE 4: Variation in Phase Angle and Pressure w.r.t. Frequency in Post Valve Condition

Frequency(Hz)	Phase(deg)	Pressure(psi)
0	-170	-10
50	0	-20
100	0	-10
150	0	-08
200	-10	04
250	0	04
300	0	08
350	0	10
400	-10	15
450	-10	10
500	0	15
550	0	18
600	-10	22
650	-40	10
700	-10	20

Table 4: Combustion Control Data with Throttle Valve post-Atomizer condition

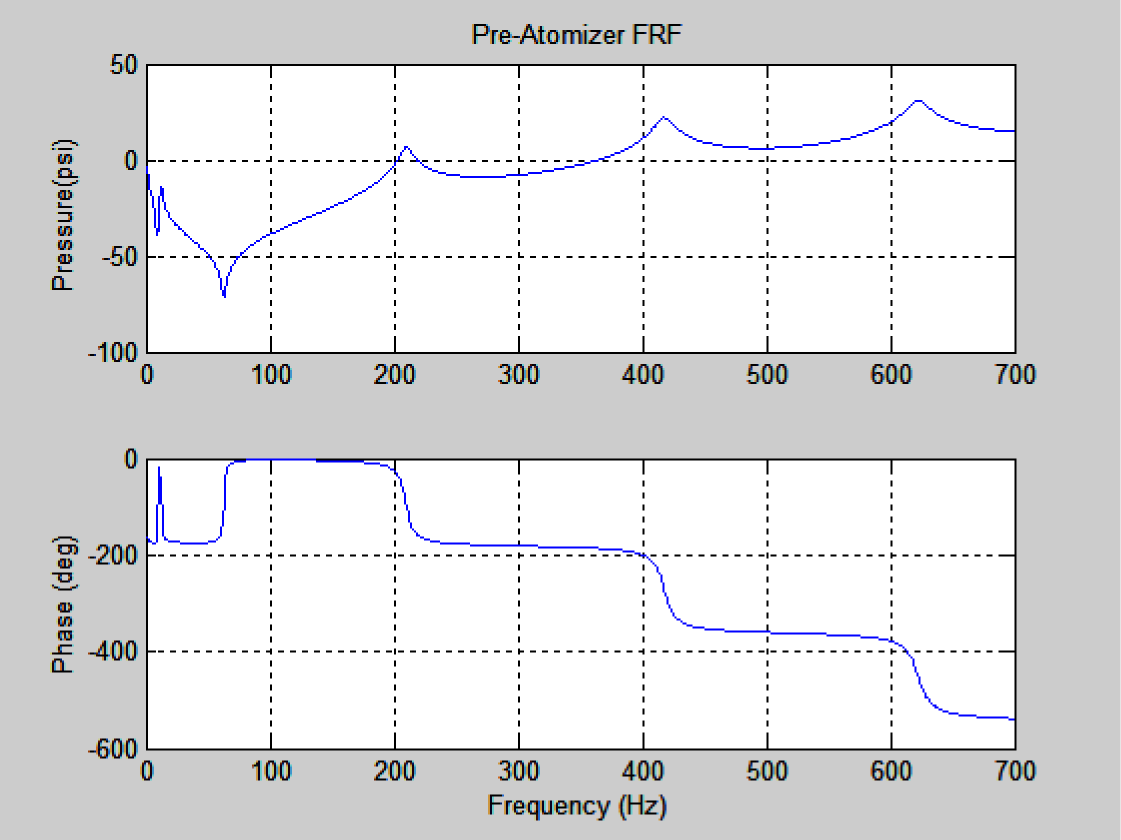

FIGURE 5: Variation in Phase Angle and Pressure w.r.t. Frequency in Post Atomizer Condition

Frequency(Hz)	Phase(deg)	Pressure(psi)
0	-180	-10
50	-180	-50
100	0	-40
150	0	-25
200	-20	0
250	-180	-10
300	-180	-10
350	-190	0
400	-200	10
450	-370	10
500	-380	10
550	-380	15
600	-390	20
650	-500	20
700	-520	20

Table 5: Combustion Control Data with Throttle Valve Pre -Atomizer condition

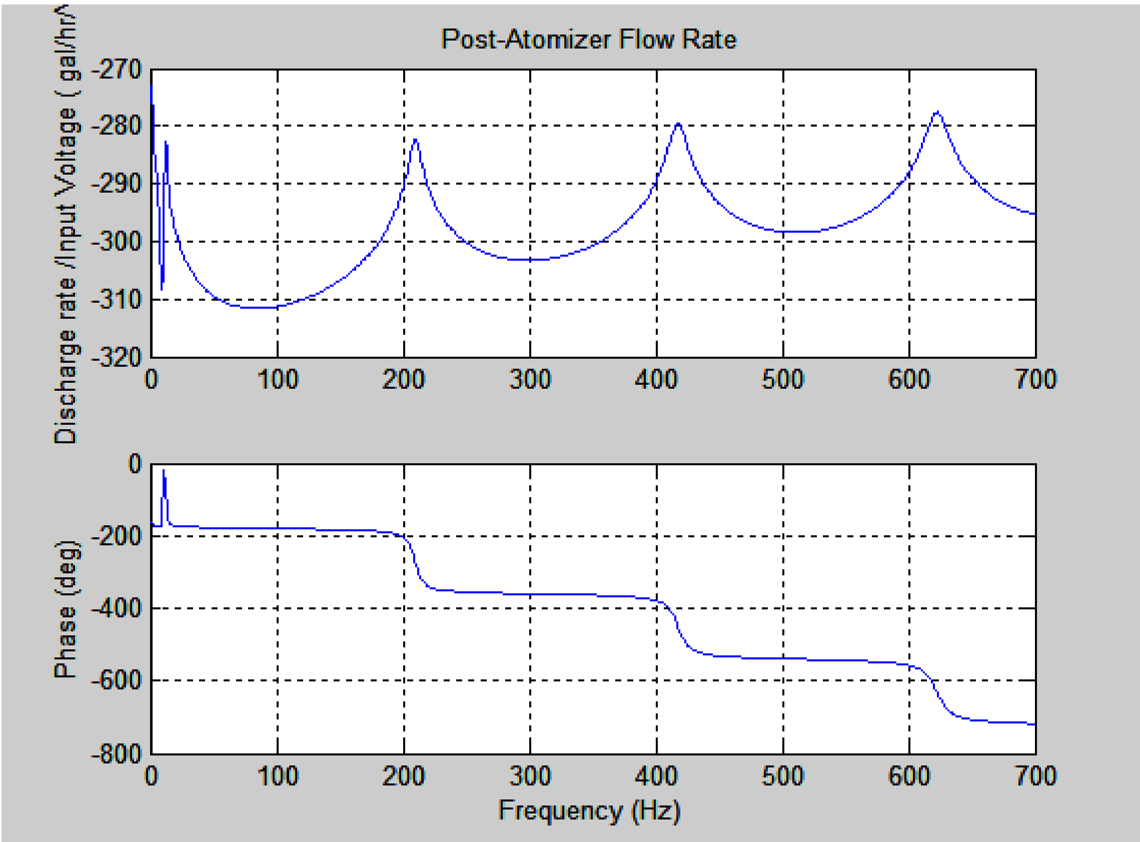

FIGURE 6: Variation in Phase Angle and Flow Rate w.r.t. Frequency in Post Atomizer Condition

Frequency(Hz)	Phase angle (deg)	Discharge velocity/input voltage (gal/hour/volt)
0	-180	-280
50	-180	-310
100	-180	-312
150	-190	-308
200	-200	-290
250	-380	-300
300	-380	-304
350	-390	-300
400	--390	-290
450	-540	-295
500	-540	-298
550	-540	-295
600	-540	-288
650	-700	-290
700	-710	-295

Table 6: Combustion Control Data with post atomizer condition

In the case of secondary line fuel modulation with the help of throttle valve oscillatory combustion is observed in gas turbine, which has many different pressure fluctuation modes over a wide range of high bandwidth fuel injection. In that situation it is very difficult to determine the target peak pressure intensity to eliminate or reduce for NOx emission control. As shown in figure 4 and 5 these peak pressure intensity occurs at the frequency of 210,410 and 640Hz.

NOx emission can also control during secondary fuel modulation by using a lifted flame i.e. injection of fuel in recirculation zone of swirl combustion chamber of gas turbine. In that case due to strong fluid interaction to the main swirl fuel flow occurs near the nozzle throat, lifted flame structure will form. If flame is lifted, the overall flame temperature will also reduce due to mixing of unburned fuel gas and oxidizer, which will reduce combustion chamber noise, pressure fluctuation and NOx emission.

IV. DISCUSSIONS

1. Both active and passive methods are used to control combustion instabilities in gas turbine within required bandwidth, so that NOx and other emission contents may reduced and controlled as per government norms.
2. In active method both piston and throttle valve systems are designed based on maximum modulation level of 40% of mean flow.
3. Piston cylinder unit device utilization is limited by compressibility effect i.e. presence of air content in working fluid will effect on its performance.
4. Throttle valve modulation is limited by hydrodynamic deformation of the valve.
5. Pilot flames may be used in swirl-stabilized combustors to improve the dynamic stability by sustaining the main combustion process at operating points where instabilities are unlikely. These premixed pilot flames are able to suppress instabilities over a wider fuel/air ratio near the lean blowout conditions.
6. In case of gas turbine which is used in jet plane main consideration of design is low frontal area and minimum weight, so the throttle valve design is most suitable design.

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