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EFFECT OF GLOBAL ACCELERATION IN THE ACOUSTIC RESPONSE OF PREMIXED FLAME AND ANALYSIS OF ACOUSTIC INSTABILITY OF COMBUSTION CHAMBER

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Abstract-The aim of this present paper is the experimental analysis of the effect of global acceleration in the response function of premixed flame and acoustic instability of combustion chamber. The global acceleration is an addition term in the Navier- Stokes momentum equation governing the dynamics of heat source. Global acceleration occurs due to acoustic field in the acoustic duct. In this experimental study, the response function is calculated for two cases. In the first case, response function is obtained in the absence of acoustic duct excluding global acceleration term. On the other hand, in the second case, response function is obtained in the presence of acoustic duct including global acceleration term with various flame locations. The response function measured over a range of acoustic excitation of varying amplitude of frequencies. The measurement of response function with and without duct in this experiment due to maximum forcing as $F(\omega) = 0.1105$.The obtained response function behaves similarly to the prediction by linear kinematic theory at low amplitude forcing {$F(\omega) < 0.3$} of acoustic velocity excitation. The phase of response function remains closely to linear at low forcing frequencies, regardless of the forcing amplitude. The air flow rate varies from 5 lpm to 8 lpm and fuel flow rate varies from 0.12 standard liters per minute to 0.3 standard liters per minute this corresponds to a variation of the equivalence (Φ) ratio from 0.65 to 0.9. Four loud speakers are used to excite the flame at a particular frequency range from 150 to 500 Hz.

Keyword- Global acceleration, Acoustic instability, Response function, flame location, premixed flame.

I.INTRODUCTION

This experimental study is the investigation of Effect of Global Acceleration in the Response Function of Premixed Flame and analysis of acoustic instability in combustion chamber. First of all, global acceleration is governing dynamic heat source which occurred due to acoustic field in the acoustic duct. The effect of global acceleration depends on length and diameter of acoustic duct and the amplitude of excitation frequency (forced). Global acceleration is obtained by two methods of solving NS equation. In this experimental study, an asymptote two length scale technique was used. This technique required two length scale. In this experiment two length scale are first length of acoustic duct is 800 mm and second is thickness of flame 1 mm. Response function is defined with two cases. In the first case, the response function is defined as R (ω) =$G(\omega)/F(\omega)$ without using of acoustic duct mean without effect of global acceleration While in the second case, the response function R$'$ (ω) = $G(\omega)/F(\omega)$. when we used acoustic duct that mean occurs effect of global acceleration in the response function. Here we are defined terms as G (ω) = $q'/\bar{q}$and F (ω) =$u'/\bar{u}$. Here q' is the amplitude of fluctuating heat release rate and $\bar{q}$ is the amplitude of mean heat release rate, u' is the amplitude of fluctuating velocity and $\bar{u}$ is the amplitude of mean velocity measured upstream of flame.

In this experimental Analysis of effect global acceleration in the response function, we used four loud speakers to excite the flame at a particular frequency (ω) to obtain response function. The response function is dependent on amplitude of forcing (F) and amplitude of excitation frequency. Due to excitation of flame at particular frequency, then occurs disturbance in the combustion chamber and disturbance increases turbulence in incoming flow. This phenomenon is a changed condition of flow. In this condition, acoustic fluctuating velocity and acoustic fluctuating pressure generating fluctuated heat release rate. Due to fluctuating heat release rate, the acoustic oscillation in the duct generates thermos acoustic instability of premixed flame. The experimentally analysis of flame, which has different characteristics as harmonically forcing of premixed flame and extracting the heat release rate at the forcing frequency, discarding the higher harmonic. The forcing frequency was varied from 150 to 500 Hz with interval 20 Hz. This experimental study is analysis by forcing the flame with harmonic acoustic velocity perturbations and measuring the heat release rate response not only at the forcing frequency but also at higher and lower frequencies due to nonlinear processes. Acoustic waves induced velocity perturbation at the base of flame by excitation of amplitude of frequency. These velocity perturbations travel along the flame, distorts its surface. An experimentally, forced conical premixed flame with acoustic duct is disturbance by propagation velocity and depends on the forcing frequency but it is independent of special location.

Premixed conical flames in convective regime depends on the forcing frequency and the distance from burner exit plane but it is independent of the forcing amplitude. The acoustic response varies with the configuration of the oscillation of premixed flames point out that accurate description of the oscillation flow field. These velocity perturbations are distorted. The flame surface is usually assumed to take the form of as travelling wave exp[i(kx-ωt)], for which streamwise phase speed C is equal to ω/k. The influence by parameter of k on phase and gain (abs Response function) when k is increase than amplitude of phase increase and amplitude of gain decrease because k is dependence on frequency and amplitude of the acoustic perturbation [31].

The two-difference diameter duct were used for the purpose to study the effect of global acceleration and analysis with the small diameter duct is found to have more effect occur impression on large diameter duct. For small diameter duct, more perturbations of flame occurred as compared to large diameter duct. The diameter of acoustic duct is decreases due to the amplitude of fluctuating heat release rate decreases.

II. EXPERIMENTAL SETUP

This experiment is based on geometry of air-fuel mixer, acoustic duct, flow burning pipe and burner. The designed and dimensions of experiment set up is referred [4]. We used LPG gas cylinder for fuel and air compressor for air supply. Fuel pipe one end is connected to fuel cylinder and the other end connected by fuel rotameter. Both Air and Fuel rotameter are working in standard liter per minutes and fuel supply range from 0.1 lpm to 0.3 lpm. Fuel rotameter has two regulators, one is inlet for controlled inlet pressure of fuel and one is outlet for controlled fuel flow rate of fuel. Another fuel pipe is connected in rotameter to air-fuel mixer for fulfil the required fuel supply in combustion chamber. The compressor was used for supply of oxidizer (Air) and its density is 1.13kg/m3 at atmospheric condition. Air pipe one end connected to compressor and another end connected air rotameter and supply controlled by regulators. Air supply volume flow- rate is varies from 5 lpm to 10 lpm. In this experiment, we are doing analysis at lean mixer of air fuel because we are used photomultiplier tube for measuring of heat release rate and it is working on lean mixer of air fuel. The fuel and air are then supplied to a proper air-fuel mixer which have four speakers (4 Ω, 200 W) on four vertical faces for generating acoustic field in the air fuel mixer and the speakers are connected

With amplifier for generating various frequencies. The purpose of burning pipe is to provide flow path of air fuel mixer for burning. This pipe is working as the Bunsen burning tube. The Length of this pipe is 1000 mm, inner diameter 12 mm and thickness 1 mm and made up of brass material. We have selected 12 mm diameter pipe for good result of experiment from out of three different diameters of pipe as like 10 mm, 12 mm and 14 mm. One end of burning pipe is connected to mixing chamber with coupler and another end of pipe is fitted to burner. The burner is used for multiple flame for easily stabilizing of flame. Burner has five holes for multiple flame and these holes same diameters is 3.5 mm. it also made up of brass material. Burning pipe has five holes from top for connecting the micro phones. The distance of holes are 100 mm, 170 mm, 190 mm, 230 mm and 280 mm at varies location from top of burning pipe. These five locations of microphone are used for getting maximum acoustic pressure difference for velocity fluctuation by two holes with microphone technique because in this experiment fluctuation velocity and fluctuating heat release rate are main parameters for response function. Two Acoustic ducts were used as different diameters(114mm,120mm) of same length of 800mm for obtaining the effect of global acceleration in response function of premixed flame. The acoustic ducts are made by borosilicate glass pipes. The two acoustic ducts are used in this experiment for analysis of effect by global acceleration on response function these acoustic ducts has diameter 114 mm, and 120 mm and both ducts is both same length 800 mm and thickness 5 mm. we are also try different diameter of acoustic duct those diameters is lies in between from 100 mm to 130 for testing of sound in this experiment. The ducts do not create sound but generates global acceleration. In this experiment location of flame related to acoustic duct is varied from bottom to top as 1/4, 3/8, 1/2, 5/8 and 3/4 of length of acoustic duct for variation of global acceleration. The PMT is placed on the same vertical level as flame of burner for capturing maximum intensity of flame. The photomultiplier tube (PMT) works on chemiluminescence technique. We have used the chemiluminescence technique for measuring of heat release rate. The PMT and microphones are connected to PC through NI-daq Card.

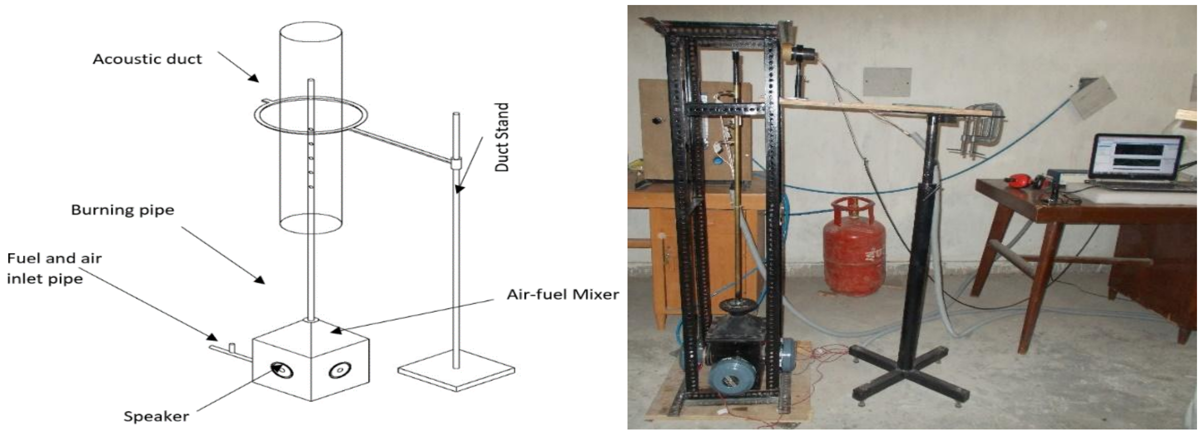

Fig. 1 picture of experimental setup

III. Results

This work is representing the effect of global acceleration in the response function of premixed flame. Excitation frequency and equivalence ratio varied from 150 Hz to 500 Hz and from 0.65 to 0.90corresponding in this study. Frequencies below 150 Hz could not show sinusoidal speaker response at low frequencies condition. Two acoustic ducts were used, there are two types of diameter as 114 mm and 120 mm with same length 800 mm for generating of effect of global acceleration. The flame was excited by forcing range $F_{\omega} = (u'/u)$ = 0.090 to 0.11. Flame excitation range is increasing with varies equivalence ratio from 0.65 to 0.90. We obtained that the change in mean stream flow velocity did not significantly modify the response function of flame within the attempted range. The amplitude of response function of flame is measured in term of $(q'/q)/(u'/u)$. We measured response function for six different values of equivalence ratios 0.65, 0.70, 0.75, 0.80, 0.85, and 0.90 corresponding but here we provide data corresponding to 0.65 and 0.70. The equivalence ratios appeared to have some influence in mean velocity and strong influence of response function of flame. The amplitude of experimentally measured response function of flame is approximately as the theoretically trend reasonably and also show distinctive peaks and troughs. These peaks and troughs in experiment, occurred at all tested equivalence ratios and mean velocities but not shown in the linear theory. This behavior could be the result of several effect such as the spread of time delay. It is respectively similar lag and lead of the experimental phase at higher frequency by roughly the same. However, at medium to higher forcing frequency the phase shows different behavior but the amplitudes of phase are nearly constant with value less than 0.3 of $F(\omega)$. Thus, at low amplitude forcing for this experiment, the phase of response function behaves closely as a linearly increasing lag. This is consistent with linear kinematic theories, however at higher forcing amplitude, the phase of response function is always constant.
In this, comparison the experimental result of referred [3] with our experiment result at $\emptyset$ = 0.80 in figure (2). The comparison the referred experimental and our experiment result, experimental result [3] found peak and tough of amplitude of response function is low because some error not include in result and some boundary condition changes. The peak of response function of referred experimental result is 1.1 and the peak of response function in experimental result is 1.5.

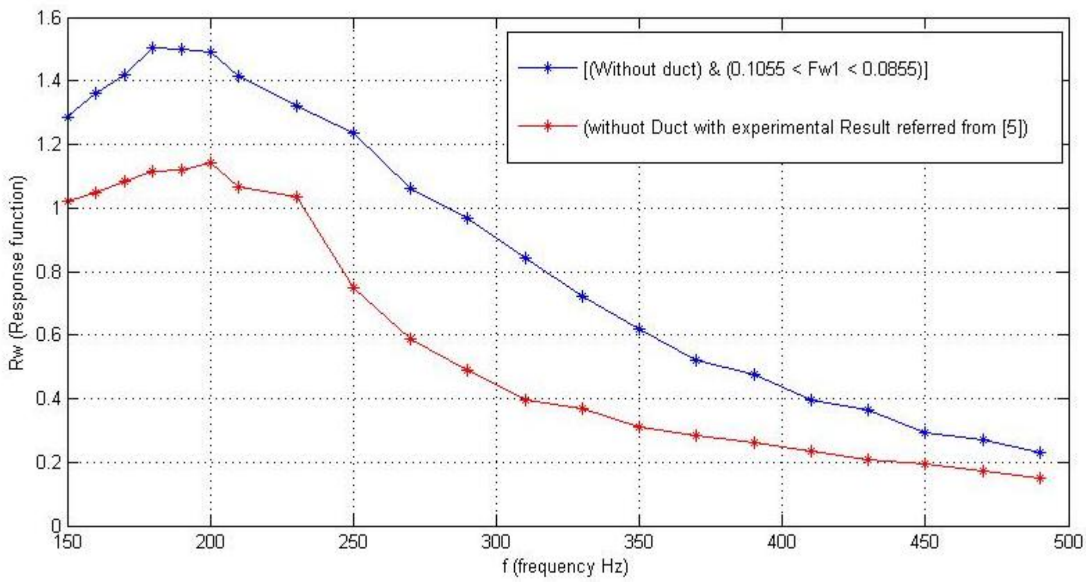

Fig. 2 comparison with Experimental [5] result of response function at constant ϕ = 0.80 and F_{ω}= 0.0955

A. Results with first acoustic duct

Results were obtained with first acoustic duct whose diameter is 114 mm. The effect of global acceleration in response function were measured with acoustic duct and without acoustic duct. These results are measured at various equivalence ratio from 0.65 to 0.90. We measured first result at different location of flame with acoustic duct and fixed equivalence ratios. The experiment was conducted at constant inlet pressures of fuel and air as a 16.46 PSI and temperature of 307K. The results with acoustic duct are shown in the following cases-

1) Case -1

This case represents results at constant equivalence ratio (ϕ=0.65) and constant amplitude of forcing $F\omega(0.0860 \mp 6.4\%)$ of variation. These results shown without duct and five different locations of flame 200 mm, 300 mm, 400 mm, 500mm and 600 mm of 800 length with acoustic duct corresponding. The results are shown in the plot as a *(Fω)* Response function is on Y axis and varies frequencies (f) on X axis in figure (3).

In this figure, we are shown six curves in a plot, response function and varies frequencies 150 to 500 Hz with 20 Hz of intervals. The first curve in plot is without duct that means without effect of global acceleration and it has shown a maximum peak of amplitude response function. The response function is depending on ratio of amplitude of heat release rate to amplitude of mean heat release rate and amplitude of velocity fluctuation

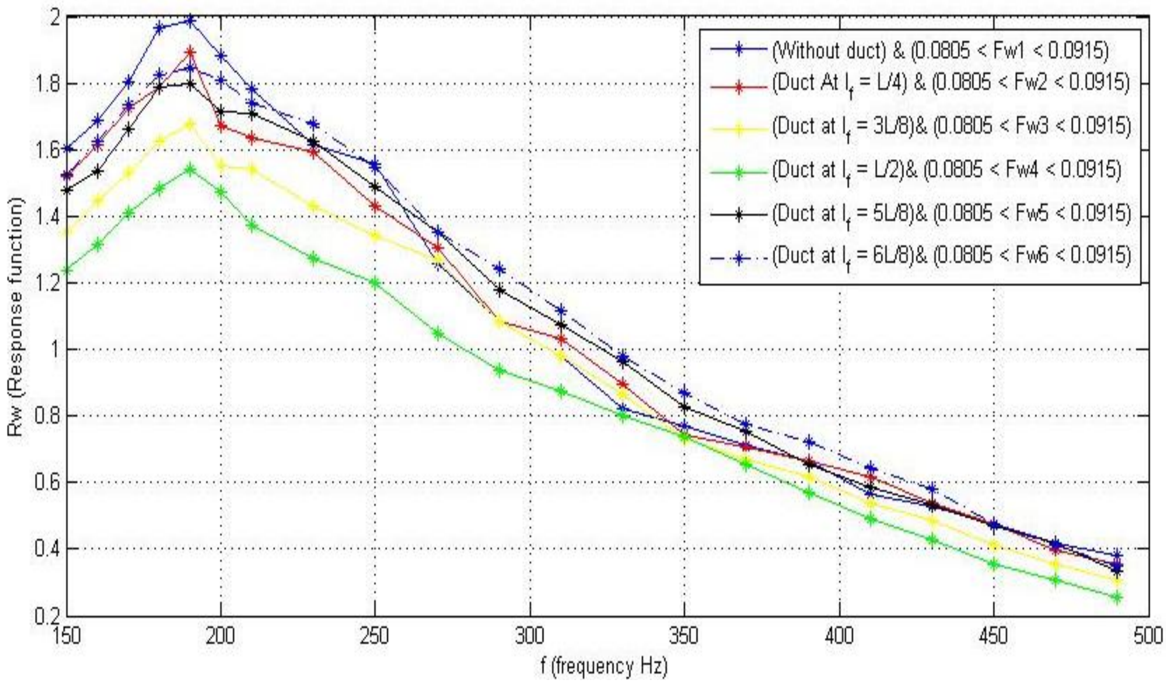

Fig. 3 Variation of response function with frequency at constant ϕ = 0.70 and F_{ω}= 0.0945

to amplitude mean velocity. The amplitude of mean heat release rate and amplitude mean velocity both are constant with constant equivalence ratio. In this case, we are also plots with constant amplitude of fluctuating velocity that means constant forcing amplitude of $F\omega$. The amplitude of response function is depending on amplitude of fluctuation of thermo acoustic heat release rate. The amplitude of heat release rate drastically decreases with increasing of amplitude of frequencies from 250 to till 500 Hz. The effect of global acceleration is increases with decreasing of amplitude of response function and increasing values of amplitude of frequencies. The effect of global acceleration changed with different location of acoustic duct. The maximum effect of global acceleration in response function at location of 400 mm of acoustic duct because of, this location has minimum peak and trough of response function. The minimum effect of global acceleration in response function at 600 mm location of acoustic duct and reason behind of this is the maximum acoustic waves of acoustic duct release in atmosphere and minimum waves are interaction of acoustic zone. Similarly, it is shown that the effect of global acceleration in response function at location 200 mm, 500 mm and 300 mm location of acoustic duct. The effect of global acceleration in the response function is increases with given these locations because peak of the response function decreases within locations.

2) Case – 2

This case represents results at constant equivalence ratio (ϕ=0.70) and constant amplitude of forcing $F\omega(0.0885 \mp 6.8\%)$ of variation. The amplitude of forcing $F\omega$is constant that value is 0.0945 with 10% of variation. These all plots are shown in figure (4). In this figure, all peak of response function deceases as comparison of previous result. The peak of amplitude of response function decreases. Due to amplitude of forcing is greater than first case and amplitude of fluctuating heat release rate is decreases with increasing of equivalence ratio. Amplitude of fluctuating heat release rate is less than first case because equivalence ratio is more than in this case. Results shown at same different location of duct which are mansion in first case. Again, this shown the effect of global acceleration in response function within location of acoustic duct. The effect of global acceleration of response function is maximum at 400 mm location of acoustic duct. The minimum effect of global acceleration on 600 mm location of acoustic duct. The effect of the global acceleration other location of acoustic duct is similar to first the case but it is greater than first case. In this case, the trends of all curve are similar to first case. The maximum effect of global acceleration of response function at region from 250 to 500 Hz. The reason of this is the effect of global acceleration is due to maximum thermo-acoustic instability.

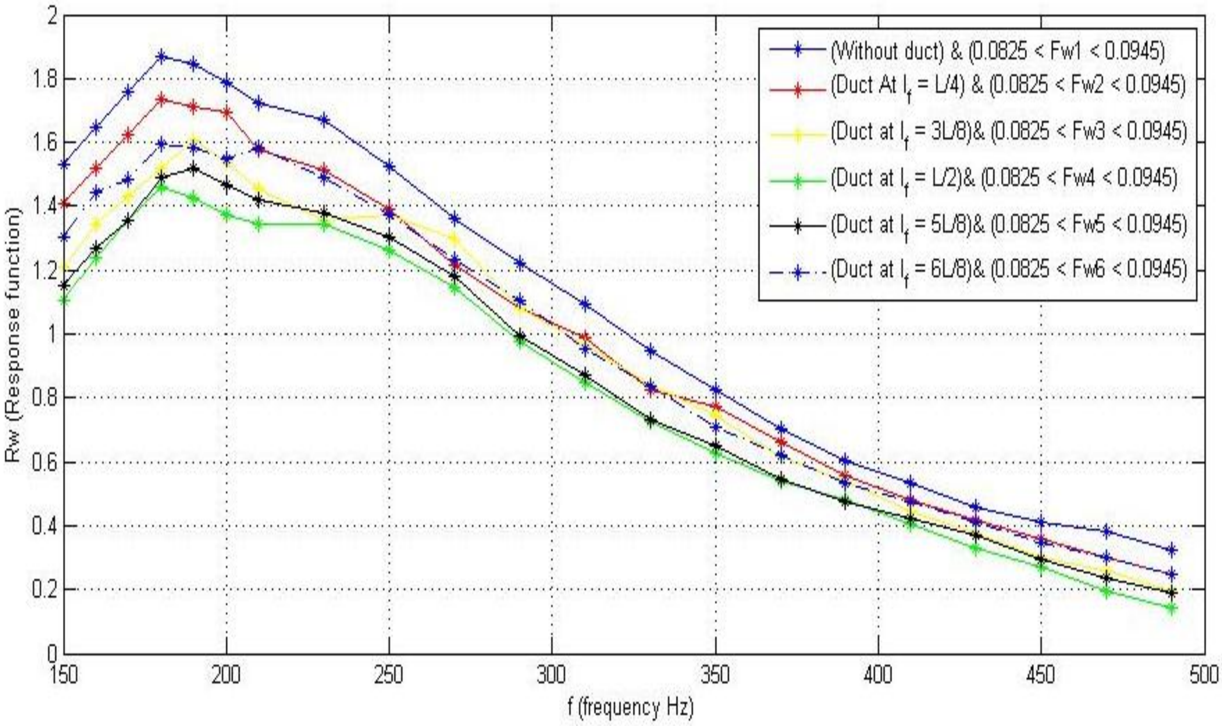

Fig. 4 Variation of response function with frequency at constant ϕ = 0.70 and $F\omega$= 0.0945

B. Results with second acoustic duct

Results are measured with and without acoustic duct. This acoustic duct has diameter 120 mm and length 800 mm. Results are changed with this acoustic duct in comparison with previous acoustic duct. We have kept same boundary conditions in both cases. The results of response function are measured with different flame location of acoustic duct at constant equivalence ratio. Similarly, other results are measured with same set of conditions at varying equivalence ratio from 0.65 to 0.90. The result with this duct are different than previous results. In this case amplitude of fluctuating velocities are low comparison with previous one. The amplitude of fluctuating heat release rate is more than first acoustic duct at varies equivalence ratios. Amplitude of mean velocity and mean heat release rate are constant in both cases. Amplitude of forcing is also low as compared to first duct. These results are measured at excitation frequency from 150 to 500 Hz. Amplitude of excitation frequencies also constant. These results are also got at constant pressures for fuel and air supply and flow temperature 307K.

1) **Case -1**

This case represents results at constant equivalence ratio (ϕ=0.65) and constant amplitude of forcing $F\omega$ (0.0785 ∓3.83%) of variation. These all results are shown in figure (5). The amplitude of response function represents on Y axis and amplitude of frequencies ranging from 150 to 500 Hz in X axis as shown in the figure. The amplitude of mean velocity and mean heat release rate also constant. The results showed different trends in this case as compared to first duct with same equivalence ratio because amplitude of fluctuating heat release rate is increases and amplitude of fluctuating velocity is decreases. The effect of global acceleration in the response function is less than previous case with same equivalence ratios. This change is only due to change diameter of acoustic duct. This is due to increasing diameter of acoustic duct however, decreasing amplitude of velocity fluctuation and increasing amplitude of fluctuating heat release rate. The amplitude of response function is directly proportion to amplitude of fluctuating heat release rate. Due to this reason, the effect of global acceleration is decreases in the response function. Amplitude of response function found maximum without duct condition and minimum amplitude of response function found with duct at 400 mm flame location. The maximum effect of global acceleration in response function with duct at 400 mm flame location. The amplitude of fluctuating of heat release rate is minimum this flame location comparison gets on other flame location with acoustic duct. That is region for maximum effect of global acceleration. The minimum effect of global acceleration found at 600 mm flame location with acoustic duct. Peak and trough of amplitude of response function found maximum in this flame location of this acoustic duct. The amplitude of response function decreases with changing of flame location as 200 mm, 500 and 300 mm with acoustic duct. As well, the effect of global acceleration increases with changing these flame locations of acoustic duct. These results showed same trends as previous results within flame locations of duct. The amplitude of response function is drastically decreasing in ranging of frequencies from 250 to 500 Hz. The effect of global acceleration is maximum in these range of frequencies. The thermo-acoustic instability of flame found maximum in this region.

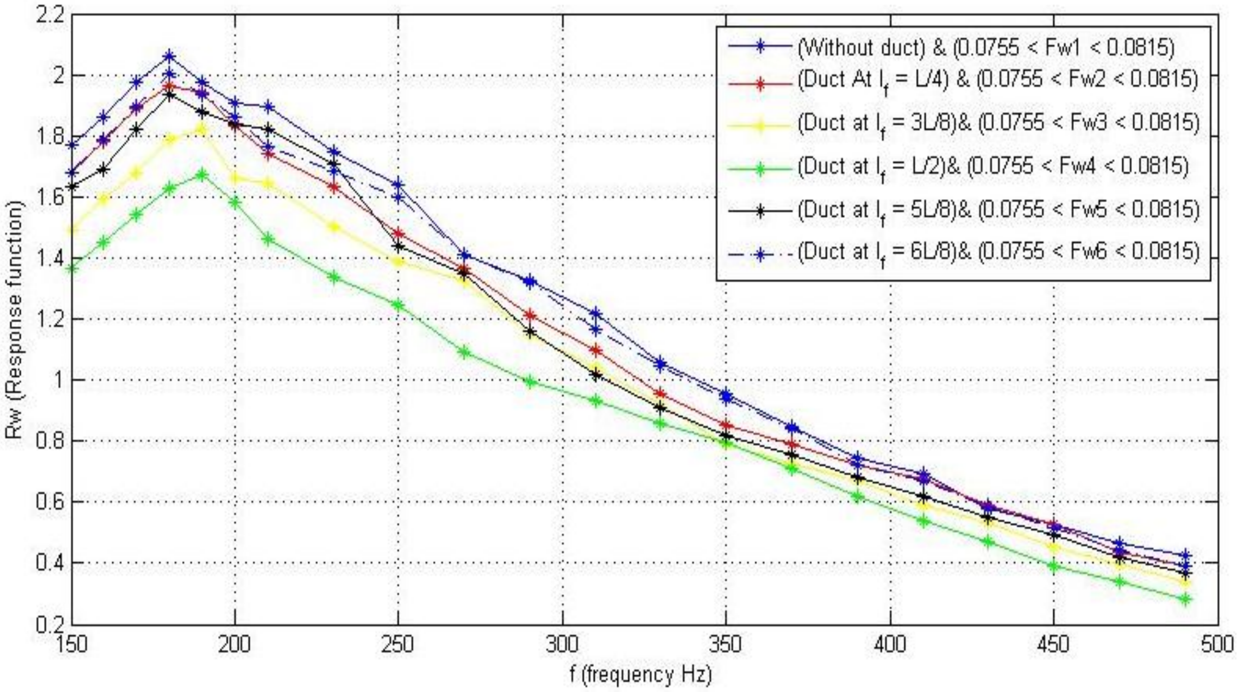

Fig. 5 Variation of response function with frequency at constant ϕ = 0.65 and F_{ω}= 0.0815

2) Case -2

This case represents results at constant equivalence ratio (ϕ=0.70) and constant amplitude of forcing $F\omega$ (0.0810 ∓ 4.32%) of variation. These all results are shown in figure (6). The amplitude of response function represents on Y axis and amplitude of frequencies ranging from 150 to 500 Hz in X axis as shown in the figure. In this case, amplitude of mean heat release rate and mean velocity are constant but both amplitudes are more than previous cases. These amplitudes do not much effect in response function. Main effect in response is due to amplitudes of fluctuating velocity and fluctuating heat release rate. These amplitude of velocity fluctuations found more and amplitude of heat release rate found less than previous cases with all conditions. The effect of global acceleration increases with flame locations. Effect of global acceleration in response function found maximum at 400 mm flame locations with acoustic duct and minimum effect of global acceleration found at 600 mm flame locations with acoustic duct similar to previous cases. The trends of plots also same.

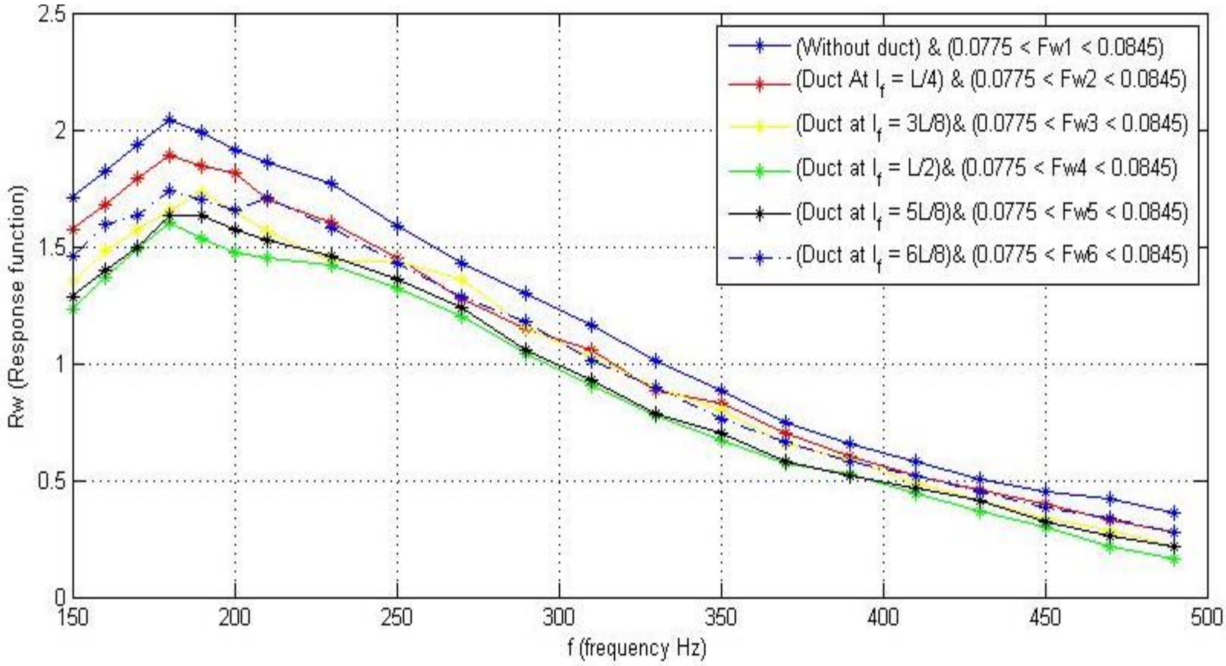

Fig. 1 Variation of response function with frequency at constant ϕ = 0.70 and F_{ω}= 0.0845

IV. CONCLUSION

The effect of global acceleration in response function of premixed conical flame with duct and without duct to excitation was studied experimentally. The amplitude forcing $\{F(\omega)\}$in this study is less than 0.3. That is, it is a studying at low amplitude forcing. We have conducted experiment with different diameter of duct. Small diameter duct creates more fluctuating velocity due to decreasing diameter of duct which increases of amplitude of force. We have studied effect of global acceleration with varies flame location with acoustic duct than maximum effect of global acceleration at flame location one half of acoustic duct. Maximum thermo-acoustic instability of premixed flame with acoustic duct at this location at one half of acoustic duct. In this experiment, we used excitation frequencies varies from 150 to 500 Hz. The effect of global acceleration in of response function is drastically increases with increasing frequencies from 250 to 500. The nonlinearity is increases when excitation frequency reaches more than 500 Hz. The response function is mostly depending on fluctuating heat release rate. Fluctuating heat release rate is continuous decreases with increasing of frequency range. The nonlinearity of the system depends on fluctuating heat release rate. The effect of global acceleration in response function due to effect of fluctuating heat release rate. The effect of global acceleration of response function due to increasing of fluctuating velocity, decreasing of fluctuating heat release rate and excitation amplitude of frequencies.

The phase of response function departed from predicted by linear theory as the excitation amplitude increases. This made the time delay inversely proportional to the forcing frequency in the high amplitude limit. Thus, demonstrating significant conical flame nonlinear over the range of forcing amplitude studied. However, regardless of the excitation amplitude than low frequency response remains similar. In our experiment, frequencies range are in medium than phase of response function is linearly constant within frequency range. The phase of response function is linearly increasing with increase range of frequencies. The effect of forcing on the phase of response function when the amplitude of forcing value is greater than 0.3. The effect of global acceleration in the phase of response function is negligible. If the amplitude will be increasing of fluctuating velocity and amplitude of fluctuating heat release rate will be decreasing. After that, global acceleration will be affected in the phase of response function.

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